SEAWATER DISTILLATION THROUGH SOLAR EVAPORATION

BY

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DECLARATION

I, CHRISTO LE ROUX LOURENS, declare the content of this thesis represent my own unaided work, and has not previously been submitted for academic examination towards any other qualification. Furthermore, it represents my own opinion and not necessarily that of the Cape Peninsula University of Technology.

Signed

30/04/07
Date

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ABSTRACT

An investigation was performed into a new desalination plant operating on the principles of distillation through the utilisation of solar energy only. The need for such a system is due to the high energy requirements of current large scale desalination systems and that, in the future, more and more desalinated water will be required to sustain life in certain areas.

A conceptual design of such a plant was completed and it proved its feasibility by providing an in depth explanation of the principles that govern its operation. A computer model, in the form of a MathCAD program, was developed to simulating this process flow. The accuracy of the program was investigated with the help of a pilot plant. It is shown that such a full scale plant would produce, in the region of Saldanha Bay, a town on the Western Coast of South Africa, 5000m^3 of potable water a day with a solar absorption/evaporation area of 1,87km^2 requiring only 1,75kWh per cubic meter of water produced. Its electrical energy requirements can be provided using solar panels allowing the plant to remain independent of external electrical supplies. This electrical energy requirement is less than 33% of the least energy intensive alternative method, reverse osmosis.

Since the production rate is dependent on the absorption/evaporation area the plant can be scaled to fit the specific production rate required.

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LIST OF SYMBOLS

A	Area (m^2)
c	Vapour concentration (kg/m^3)
C_D	Drag coefficient
c_p	Specific heat capacity at constant pressure (kJ/kgK)
D	Diffusion coefficient (cm^2/s)
E	Solar radiation absorbed (W/m^2)
E_i	Solar incident energy (W/m^2)
f	Friction coefficient
F_{12}	Shape factor between two surfaces
g	Acceleration due to gravity (m/s^2)
Gr	Grashof Number
h	Heat transfer coefficient (W/m^2K) or mass transfer coefficient (m/s)
H	Height (m) or head loss (m)
h_f	Enthalpy of water (J/kg)
h_g	Enthalpy of water vapour (J/kg)
k	Thermal conductivity (W/Mk) or relative roughness
K	Shock loss coefficient
L or l	Length (m)
m	Mass flow rate (kg/s)
M	Molecular weight (kg/mol)
Nu	Nusselt Number
P	Perimeter (m) or production rate (m^3/day)
p	Pressure (Pa - absolute)
Pr	Prandtl Number
Q	Energy transfer (W)
R	Mean hydraulic radius (m)
r	Absolute humidity
Re	Reynolds Number
RH	Relative humidity
R_o	Universal gas constant (8314,41 J/kgK)
S	Slope

S	Salinity
Sc	Schmidt Number
St	Stanton Number
T	Temperature (K)
t	Thickness (m) or temperature (°C)
T_{bbs}	Black body temperature of sky (K)
u	Velocity (m/s)
V	Volume flow rate (m^3/s) or molecular volume
W	Width (m)
x	Distance from leading edge (m)

α	Absorbtivity
Δ	Change
ε	Emissivity
μ	Dynamic viscosity (kg/ms)
ρ	Reflectivity or density (kg/m^3)
σ	Stefan-Boltzmann Constant (5,669x10^{-8} W/m^2K^4)
τ	Transmissivity
υ	Wave factor

Subscripts

a	Air
ag	Surface contact between air and glass
ap	Surface contact between air and condenser pipe
atm	Atmospheric
aw	Surface contact between air and seawater
c	Concrete
ccpa	Convection between condenser pipe and air
ccpw	Convection between condenser pipe and seawater
ccw	Convection between concrete and seawater
cg	Convection between glass and air
co	Convection between outer glass panel and atmosphere
conc	Conduction through concrete
concp	Conduction through condenser pipe

cong	Conduction through air gap between glass panels
cong1	Conduction through outer glass panel
cong2	Conduction through inner glass panel
cp	Condenser pipe
cw	Convection between seawater and air
d	Diameter
da	Dry air
dp	Discharge pipe
e	Evaporator
f	Film
g_1	Outer glass panel
g_2	Inner glass panel
i	Inner surface or Initial
ma	Moist air
mt	Mass transfer
o	Outer surface
rel	Relative
rg	Radiation between glass panels
ro	Radiation from outer glass panel to atmosphere
rw	Radiation between seawater and glass panel
sat	Saturation
sh	Secondary heater
sw	Seawater
T	Total
v	Vapour
x	Evaluate local (at numerical integration section)

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1. INTRODUCTION

1.1 Background

A recent United Nations study shows that nearly half the world's population will experience critical water shortage by 2025 [1]. Areas of South Africa are likely to be among those facing increasingly frequent water shortages. A much debated concern over the world's changing climate adds to the urgency of focusing attention to this potentially crippling threat to South Africa's population and economy. In total the world has 36 million cubic kilometres of fresh water of which only 0,25% is contained in lakes and rivers [2]. The world's ever growing population and industries put more and more pressure on this dwindling supply. In some cases rivers, such as the Colorado in the USA, often do not reach the sea. This is due to either mismanagement or over consumption of their water [3].

The sea is by far the greatest source and store of water. To tackle this looming disaster, more than 15 000 desalination systems are currently in operation, producing potable water in a 120 countries worldwide [4]. This amounts to more than 36 million cubic meter of water a day [6]. The problem with desalination is the high cost of operating a conventional plant. Multi-stage flash, the most common of the large production facilities, requires up to 23,4kWh of electrical power for each cubic meter of potable water produced (see Section 1.3.1.1). For the energy rich countries, such as those in the Middle East, this is not as great a problem as facing developing nations. Large desalination plants require two things the developing world lacks, large start up capital and a lot of electrical or heat energy.

The aim of this project is to find a new desalination plant design requiring significantly less electricity to purify seawater. Conventional large capacity plants operate on high temperature evaporation of seawater to produce potable water, such as Multi-Stage Flash (MSF) (see Section 1.3.1.1), or at high pressure to part fresh water from seawater, such as Reverse Osmosis (see Section 1.3.1.2). Both high temperature and high pressure systems require significant quantities of energy. This is their Achilles tendon and the cause for high cost operation. To drastically reduce energy consumption a new desalination plant should operate at close to atmospheric pressure and at raised temperatures unassisted by electricity or fossil fuels.

1.2 Concept of Envisaged Plant

The proposed plant, like the MSF (Multi-stage Flash), evaporates seawater then, cools down the evaporated moisture to condense it and finally produce pure fresh water. But, unlike the MSF, the evaporation is preformed at temperatures achieved by solar radiation heating, not through electrical heating. The pressure in water circulation is also only sufficient to overcome pipe loses and achieve elevation change. This low pressure and temperature achieved through solar heating could limit the electrical energy required of this new system to a mere 1,75kWh/m^3 of pure water produced.

To further reduce the cost of operation pumps and fans, required for circulating the air and seawater, will be powered using photovoltaic (PV) cells (see Section 1.3.2.1). Although PV cells are expensive they have a long lifespan, require little to no maintenance and are environmentally friendly [5]. Also, the plant will only be in operation when the sun is out, which is the only time power is required, which is the only time the PV cells will generate electricity.

This desalination plant consists of an evaporator, condenser and a secondary water heater.

Seawater is pumped through a condenser and is heated by energy transfer from warm air leaving the evaporator. The seawater is then heated further in a secondary heater before it flows into and through an evaporator. Seawater not evaporated (which has a slightly increased salt concentration) flows back into the sea. Air from the condenser flows into the evaporator where it is heated and it picks up moisture from the seawater. Warm, moist air leaves the evaporator and flows into the condenser, where it is cooled down by cold seawater. During cooling, vapour in the air condenses. Cold air with a reduced absolute humidity leaves the condenser and flows back into the evaporator. Desalinated water flows out at the bottom of the condenser.

A schematic representation of the process is shown in Figure 1. The solid lines with arrows represent the flow of salt water. The dashed lines with arrows represent the flow of air.

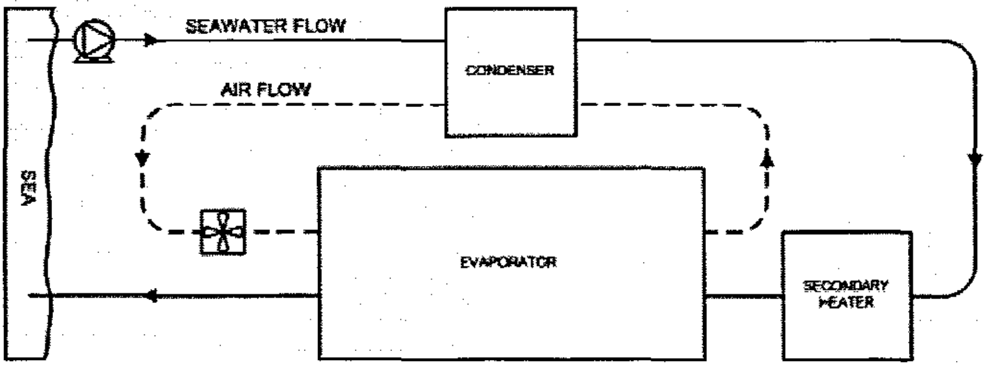


Figure 1: Schematic representation of proposed desalination plant

The reader is referred to Section 1.4 for a complete and in-depth explanation of the desalination process of the envisaged plant. Also, the research presented here was preformed with the sole purpose of investigating the technical feasibility of this specific process and to determine whether or not it merits further research into it economic feasibility and process automation.

This plant is ideal for coastal areas with cold sea currents, high solar radiation and mostly clear skies. Most of South Africa's West Coast falls into this category. In fact most coastal areas with cold sea currents have a low rainfall, predominantly clear skies and can, therefore, benefit. The plant would function best if built at minimum elevation above sea level required to ensure safety and as close to the sea as possible to reduce pipe losses.

Water fit for human consumption would also be fit for livestock and irrigation. Consequently such a plant could assist in extending arable land and increasing food production. The water would be ideal for industrial use as well, since no further purification would be required.

1.3 Literature Review

1.3.1 Existing Desalination Systems

Desalination can be achieved using many different techniques, all of which can be classified into one of the following categories [7]:

1. phase change or thermal processes; and
2. membrane or single phase processes.

In Table 1 below the most common of these are listed.

Table 1: Desalination Processes

Phase-change Processes	Membrane Processes
Multi-stage Flash	Reverse Osmosis
Multi Effect boiling	Reverse Osmosis with Brine Conversion
Solar Stills	Electrodialysis

One of these desalination processes, electrodialysis, specialises in brine purification and is therefore excluded from the literature review [8]. All of them, except solar stills, are traditionally driven by fossil or nuclear energy. In recent years much research was done into developing renewable energy driven desalination processes. Most notable of these are conventional desalination systems driven by electricity produced by renewable energy systems such as wind turbines and photovoltaic cells. Section 1.3.1.5; page 8 discusses these in more detail.

Each system discussed below has inherent design advantages and disadvantages. The same applies to operation and operating principles. An in-depth survey is required to determine which would best serve a specific area or function best. Consequently, this section focuses on basic operation and background, not on advantages and disadvantages. In the light of this electrical requirements are the sole criteria of comparison.

1.3.1.1 Multi-Stage Flash (MSF)

MSF is by far the most common of the large quantity desalination systems in operation. Of the world desalination production it has 60% of the market share and if one looks at the Middle East this figure jumps to 80% [10]. It has been around since the late 1950s, first adopted by the Gulf States. A vast store of experience has been accumulated enabling designers to greatly improve the process, technology, construction and operation of the MSF plant [11]. This is probably what has ensured its survival. Even though this system is tried and trusted, it is the desalination system requiring the biggest amount of energy to produce purified water compared to other large quantity production facilities. Energy consumption can be as high as 23,4kWh/m^3, nearly three times more than an average reverse osmosis plant [12]. It is the great pool of knowledge of MSF systems that had resulted in simple operation, ease of design and adequate solutions to the operation problems. These operation problems, among others, are scale formation, corrosion and fouling. All these factors ensure 37% of all large quantity production facilities, built between 1994 and 2003, were MSF plants in spite of their high energy requirements [10].

MSF systems require low pressure steam for operation. That is why they are normally constructed in conjunction with power plants. The low quality, low pressure steam exiting the turbines can be used to heat brine or seawater [12]. Figure 2; page 6 shows the flow process of a small MSF plant [13]. This particular system has 12 stage, 9 heat recovery and 3 heat rejection stages. Steam enters the brine heater where it condenses. This change in phase supplies the required energy to heat the brine. The optimum brine temperature to start the first stage flash is called the top brine temperature [11]. The heated brine enters the first flash chamber where its pressure and temperature drops slightly causing a small amount of vapour to form. This vapour then condenses around the brine pre-heater pipes to form desalinated water. The remaining brine, which has a slightly higher salt concentration and lower temperature than in the first stage, then flows into the second stage flash chamber and the process is repeated.

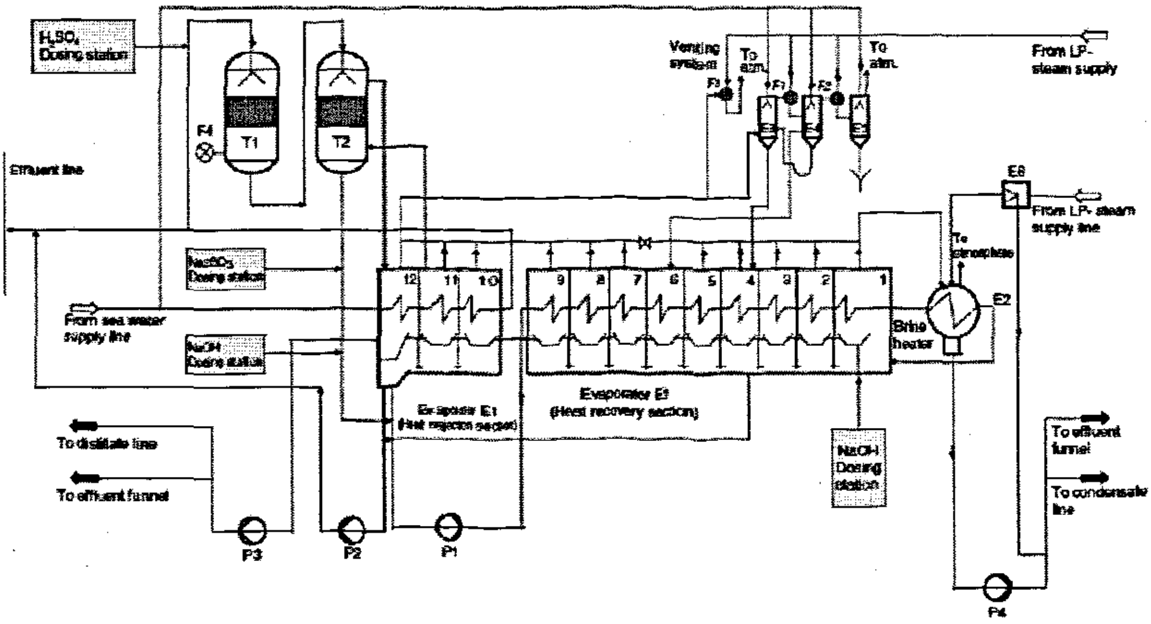


Figure 2: Schematic representation of a MSF plant

1.3.1.2 Reverse Osmosis (RO)

Osmosis is defined as the movement of a substance through a selectively permeable membrane because of a difference in chemical concentration on opposite sides of the membrane. Water is transported through the membrane from the region of high chemical potential to the region of low chemical potential. Reverse osmosis (RO), on the other hand, is when sufficient hydraulic pressure is applied to the region of higher chemical potential to change the direction of naturally occurring osmosis [14]. This means fresh water can literally be squeezed from seawater through a selective permeable membrane. In 1960 Loeb and Sourirajan successfully manufactured a synthetic cellulose acetate membrane opening a new era in seawater purification. This was the beginning of RO desalination [15].

RO generally consists of a pre-treatment, a high pressure pump and RO modules or membranes (see Figure 3; page 7). The RO membranes are sensitive to coagulation and chemical degradation; water is filtered and treated before being pressurised to protect the membranes. Conventional RO membranes do not permit operation at pressures higher than 7MPa. This limits feed water conversion to about 40%. The electrical energy requirement of RO systems is about 5,5kWh/m^3. This is significantly less than required by MSF systems [16],[17].

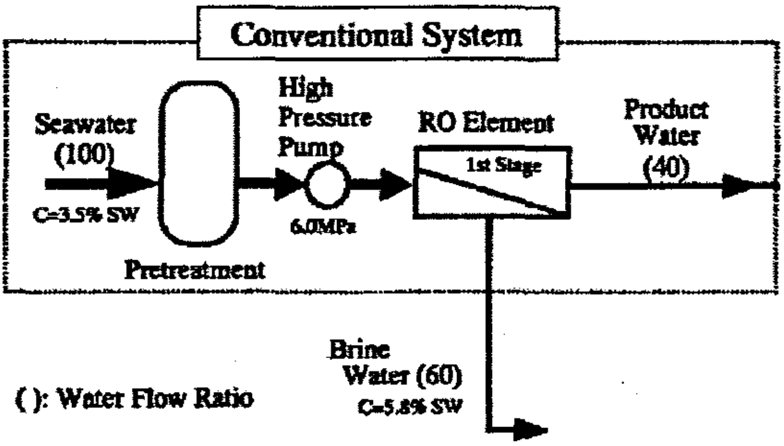


Figure 3: Schematic representation of a conventional RO plant

1.3.1.3 Reverse Osmosis with Brine Conversion System

A new type of reverse osmosis membrane developed allows operation at 9MPa and salt concentration of as high as 5,8%. This development allows the brine water from the conventional RO plant to be purified even more (see Figure 4) [16]. Now it is possible to achieve a 60% feed water recovery; such yields were previously unheard of. Using these high-performance membranes and better anti-biofouling methods, the electrical energy requirements of conventional RO systems have been reduced to 4,6kWh/m^3 [17].

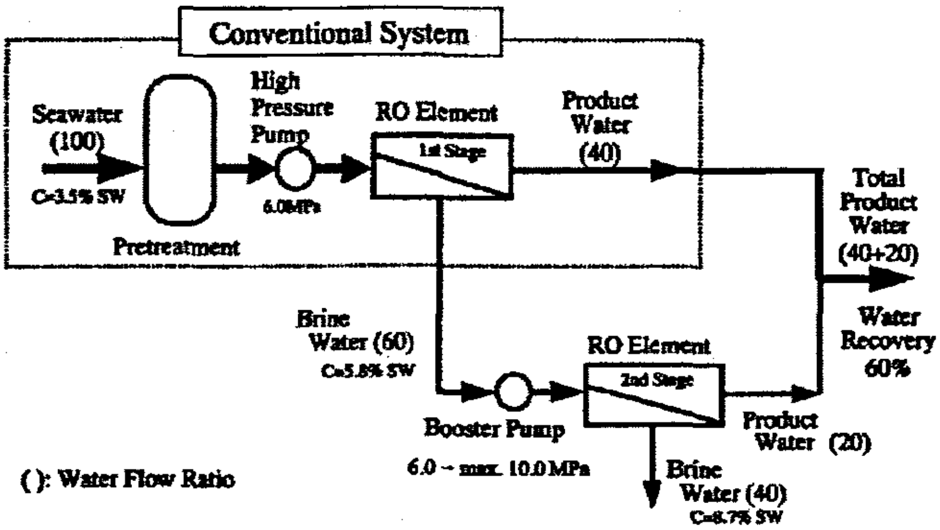


Figure 4: Schematic representation of a RO plant with BCS

1.3.1.4 Multi-effect distillation (MED)

MED has been around a long time. Dating to the middle of the 19th Centaury it is one of the older methods of purifying seawater. Steam flows in a closed circuit through a first evaporator were it is condensed before it flowing back to a boiler (see Figure 5, page 8). The latent energy rejected during phase change evaporates some of the seawater as it flows through a first evaporator. What is left of the seawater flows into the second evaporator where some of it is evaporated by the cooling steam from evaporator 1. As the steam from evaporator 1 cools some condenses to form desalinated water. What is left of evaporator one's steam with that of the newly evaporated steam from evaporator 2 then flows to evaporator 3 and the process repeated [18],[22]. This system requires about 5kWh/m^3 for water produced [22].

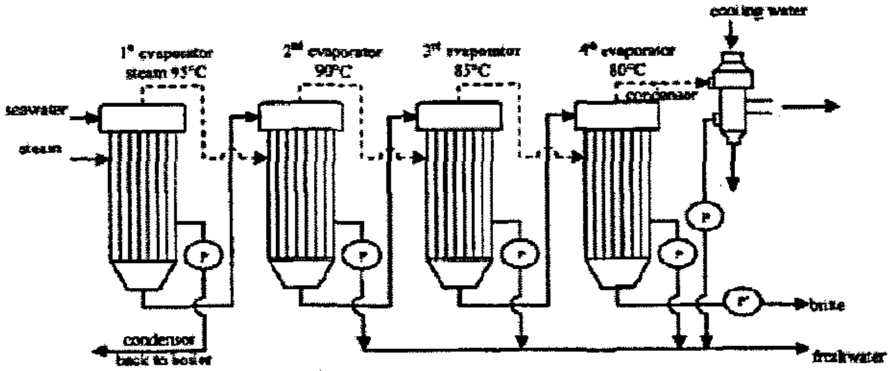


Figure 5: Schematic representation of a MED plant

1.3.1.5 Renewable Energy Powered Desalination Systems

Renewable energy powered desalination systems can be categorised into direct and indirect collection systems.

Direct Collection Systems

Solar stills are the most common of the direct collection systems. Compared to conventional systems solar stills are a simple technology that can be operated by unskilled workers. It also requires very low maintenance making it ideal for poor remote communities were the demand is less than 200 m^3/day [9].

The conventional solar still consists of a basin wherein a constant amount of seawater is covered and enclosed by glass or plastic panels which are inclined at a small angle to the horizontal envelope. The air inside, between the panels and basin is stationary. Solar radiation passes through a glass panel and is trapped by the greenhouse effect and his heats the water which then evaporates. The evaporated water condenses on the inclined glass panels, collects into droplets, runs down the glass into gutters and from here to reservoir tanks. Figure 6 below shows some common solar still designs.

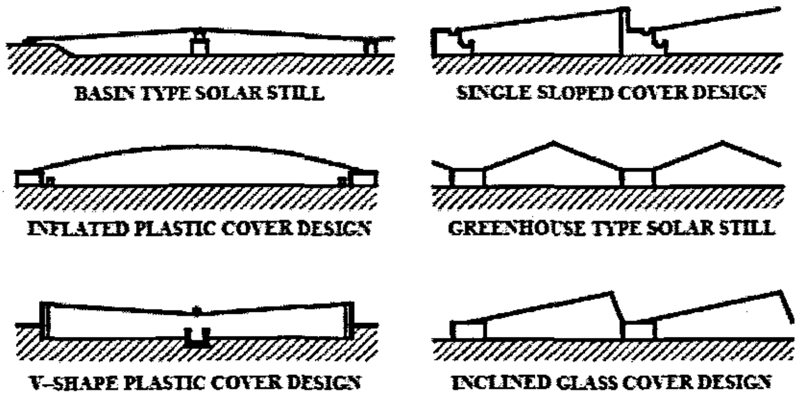


Figure 6: Common solar still designs.

In some cases external equipment is used as an extra thermal energy source. These are then known as active solar stills. The external equipment may be solar collectors or waste energy from industrial plants or boilers [19].

Indirect Collection Systems

Here renewable energy systems (solar collectors, photovoltaic cell wind or water turbines, etc.) produce electricity which then powers conventional desalination systems [19].

At present these systems are evolving through the research and development stage or are implemented in small pilot plants with capacities of from a few cubic meters a day to 100 m^3 a day.

Figure 7 shows that the most popular combination of renewable energy systems and desalination systems is photovoltaic cells and reverse osmosis (RO) [20].

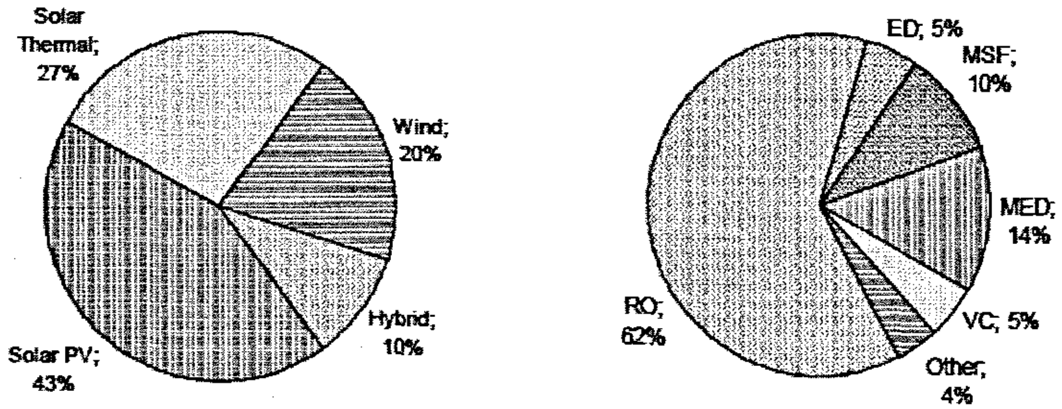


Figure 7: Renewable energy-driven desalination processes and energy sources.

The cost of producing potable water form renewable energy powered desalination systems are still greater than that of systems powered by conventional fossil fuel or nuclear powered systems (see Table 2). This is not due to the cost of generating the electricity but due to capital and maintenance cost of dedicated renewable power generators [21].

Table 2: Cost of RO-plants powered by renewable energy.

Energy source	Power generation costs ($\$MWh^{-1}$)	Energy costs of desalination ($\$m^{-3}$)	Total costs of desalination ($\$m^{-3}$)
Wind			
4 ms^{-1}	108–239	0.65–1.40	1.35–2.10
6 ms^{-1}	45–59	0.27–0.35	0.97–1.05
8 ms^{-1}	27–32	0.16–0.19	0.86–0.89
Solar			
Photovoltaics	342–410	2.05–2.45	2.75–3.15
Solar thermal	185–257	1.10–1.54	1.80–2.23
Tidal	81–104	0.50–0.63	1.19–1.32
Geothermal	54–315	0.32–1.90	1.02–2.58
Conventional power plant	27–45	0.16–0.27	0.75–0.85

1.3.2 Solar Power Generation

There are several different solar power generators on the market and in operation. Some are expensive and still in the research stage, such as the solar chimney. Others, such as solar thermal engines, are expensive and generate power far in excess required by the system under investigation [5]. The only type suited for use with the envisaged system is solar photovoltaics.

1.3.2.1 Photovoltaic Cell (PV)

When exposed to light the material that makes up a PV cell generates a direct electrical current. PV cells have a low efficiency, of the order of 10-20%, and are fairly expensive. What makes it so attractive, however; is its reliability, low maintenance requirement; and durability. It has a service life of at least 25 years. Furthermore, PV cells do not produce noise or emission pollution [5].

Since solar radiation is not constant across the surface of the earth, so the power generated by PV is also not constant, but geographically determined. This varying power production and the fact direct current is produced does not allow a direct connection to most electrical equipment. To overcome this problem batteries are charged by PVs and inverters are used to develop the alternating current required by most electrical equipment.

1.4 Envisaged Plant

Of the three stages in the process flow of this plant, condenser, secondary water heater and evaporator (see Figure 8; page 14), the evaporator was the one that required by far the most design attention. The main reason was its unusual design. Whereas the condenser is a fairly standard shell-and-tube device and the design of the secondary water heater is based on that of the evaporator. The function of both the secondary water heater and the condenser was to achieve the optimum temperatures of the seawater and air at the inlet to the evaporator. The design of both will affect their size, not the mass flow rates through them, since the energy exchange required to achieve their temperature change are fixed but the structure will determine how fast the change will occur. Whether or not the plant would work comes down to whether or not the design of the evaporator can achieve the level of productivity desired. Both the secondary water heater and the condenser were designed with functionality and practicality in mind. Their designs allow for effective operation, even if not the most favourable, in order to keep the programming of their computer models relatively simple. A schematic representation of the plant is shown in Figure 8; page 14.

The condenser would be of the counter flow shell-and-tube type. Cold water, pumped directly from the settling ponds flows into the pipes. The settling ponds are used to separate the bigger suspended particles, such as sand, from the seawater. Warm moist air from the evaporator flows on the outside of the pipes. The cold sea water absorbs heat from the warm moist air, thereby reducing air temperature. This increases its relative humidity to saturation. Further cooling in the condenser causes condensation, thus some of the water vapour in the air turns into pure liquid water. The slope of the condenser is such that it transports the air back down to the inlet level of the evaporator, restarting the process.

The water temperature exiting the condenser will be lower than that of the air. The water is used to heat the air inside the evaporator, which is impossible if the water is colder than the surrounding air. To overcome this problem a secondary water heater is introduced. It is essentially of the same structure as that of the evaporator, consisting of double glass panels with water flowing under them and over a concrete surface. Solar radiation enters though the glass and is absorbed, mostly, by the concrete which heats the water. The water, already heated partially in the condenser, enters the heater at a higher elevation than the evaporator, flowing down through the heater into the evaporator.

The evaporator is a simple structure consisting of a sloped concrete floor covered and enclosed by double-glazed glass. Heated water from the secondary water heater enters the evaporator, runs down the slope of the concrete floor and exits at the bottom, running back into the sea. The air, on the other hand, flows between the glass panels and the water, from the bottom of the slope. Solar radiation enters through the glass panels and is trapped by the "greenhouse effect". Most of this energy is absorbed by the concrete, which in turn heats the water. Energy is transferred from the water to the air by forced convection and by the water being evaporated. Premature condensation or condensation on the inner surface of the innermost glass layer would greatly reduce the solar energy entering the evaporator. The use of double-glazed glass panels increases the surface temperature on the inside of the lower glass panel to prevent condensation. Heat loss back to the atmosphere is also reduces by having two glass panels with an air gap between them.

The remaining seawater returning back to the sea flows through a low pressure turbine to recover some of the initial energy used to elevate the seawater.

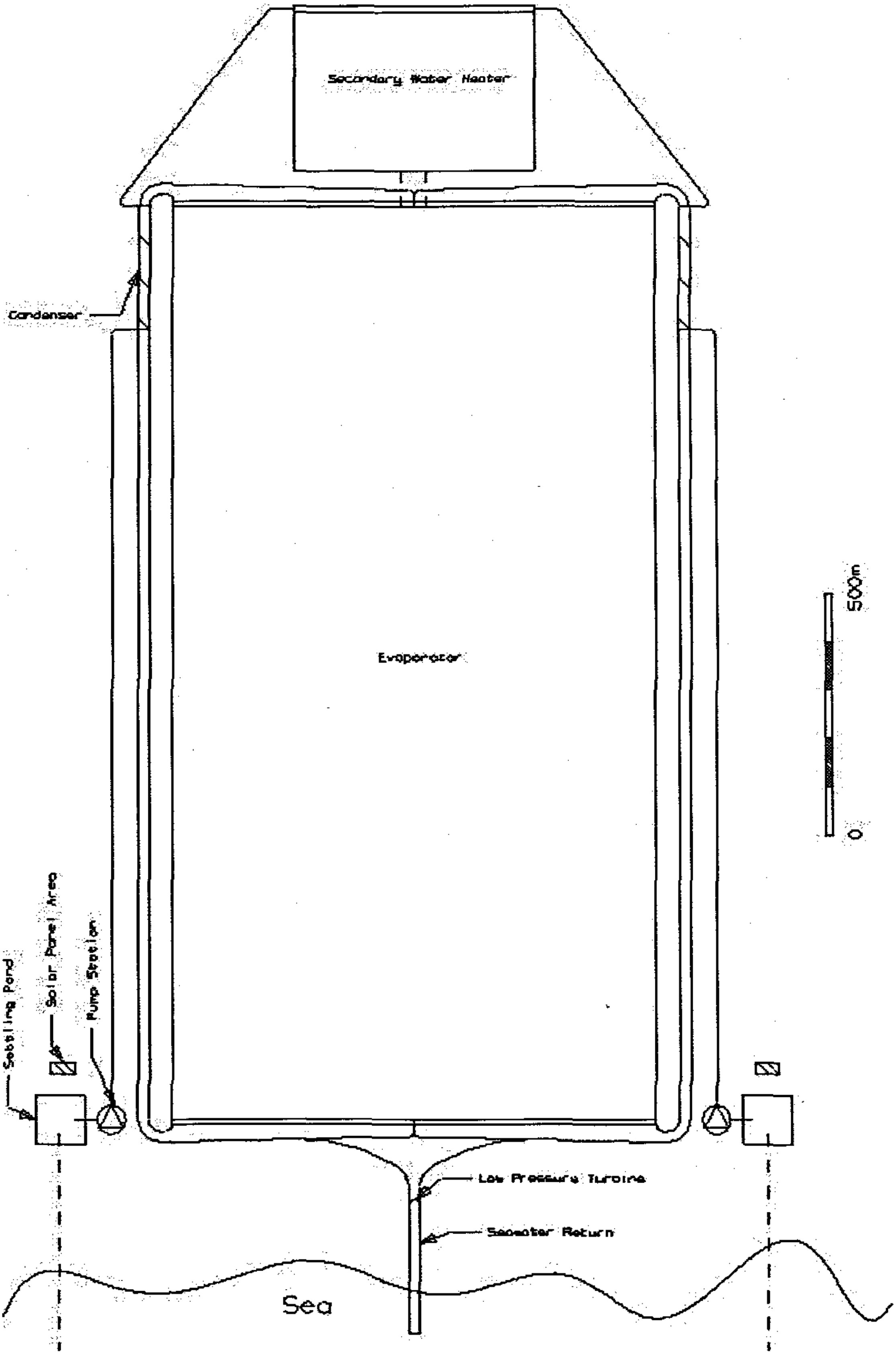


Figure 8: Scaled schematic representation of the envisaged plant

Script Overview

In the next four chapters each of the main process areas of the plant are discussed, namely the evaporator, secondary heater, condenser and fluid transfer systems. Discussion is on the basis of energy gained from solar radiation, its energy transfers, fluid flows and the application of the conservation of mass and energy. A diagram is seen at the top of each page to assist the reader to keep track of where in the text he/she might be, as well as what will follow. Then follows a chapter on fluid properties wherein all those required for the calculation mentioned, described and listed in the proceeding four chapters are presented. This chapter ends off the theoretical section of the thesis.

In Chapter 7 the computer model developed to simulate the desalination plant is presented and discussed. In the following chapter the computer model is described which is used to determine the system requirements of the plant should it be used to supply the quantity of water required by the residential area of a town on the West Coast of South Africa.

The thesis ends with an investigation into the accuracy of the computer modelling, recommendations for future research and conclusions.

Note:

1. *Cross-referencing throughout helps the reader link information and gain a greater understanding.*
2. *The equations relating to energy transfer listed in these chapters can be found in most comprehensive heat transfer books, such as Heat Transfer by Holman [23] whereas the equations pertaining to flow can be found in fluid mechanics books such as Fluid Mechanics by Douglas, Gasiorek and Swaffield [27]. When this is not the case the specific references is given.*

2. EVAPORATOR

Figure 9 shows a schematic representation of the evaporator (seen from the side). The two glass panels trap the air beneath them, while separated by an air gap. The air flows beneath the glass and above the water, as the water flows over the concrete foundation in the opposite direction.

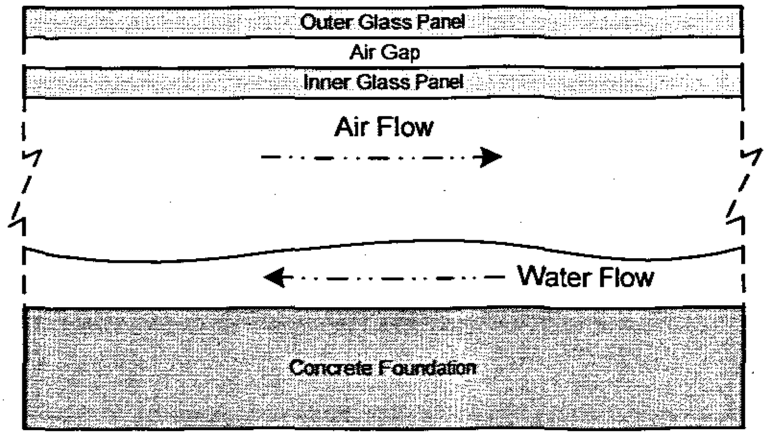


Figure 9: Side view schematic representation of evaporator

2.1 Solar Radiation

As solar radiation strikes the outer surface of outer glass panel (g_1) a fraction of it is reflected back into the atmosphere. Another fraction is absorbed, while a final fraction is transmitted. The magnitudes of these are given by the reflectivity (ρ), absorbtivity (α) and transitivity (τ) of glass respectively (see Figure 10; below). The same happens to the solar radiation reaching the inner glass panel (g_2). A fraction of the radiation reflected of g_2 is reflected back off g_1. Each time radiation is reflected an amount is absorbed by the glass panels and transmitted. The total amount of solar energy absorbed by the panels can be calculated from Figure 10; page 16 as well as the amount to have passed into the evaporator.

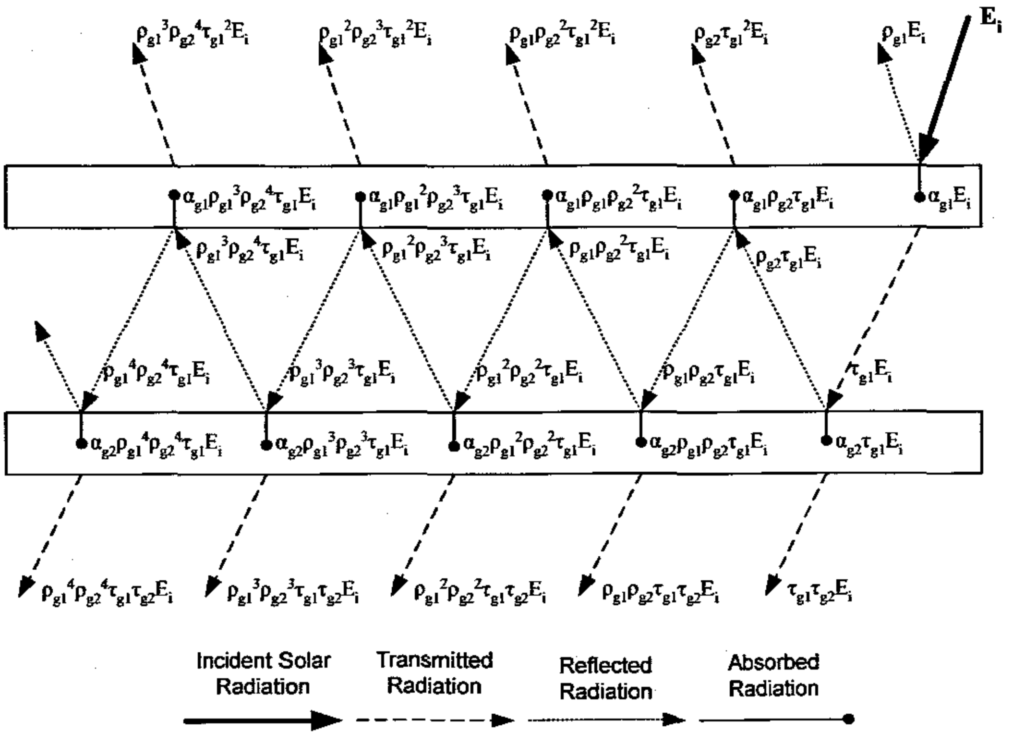


Figure 10: Solar radiation diagram of evaporator's glass panels

2.1.1 Solar Radiation Absorbed by the Outer Glass Panel (W/m^2):

The solar radiation absorbed by the outer glass panel (E_{g1}) consists of the radiation absorbed when the incident energy originally passed through it, as well as a small amount absorbed each time the solar radiation is reflected by it.

$$E_{g1} = \alpha_{g1}E_i + \alpha_{g1}\rho_{g2}\tau_{g1}E_i + \alpha_{g1}\rho_{g1}\rho_{g2}{}^2\tau_{g1}E_i + \alpha_{g1}\rho_{g1}{}^2\rho_{g2}{}^3\tau_{g1}E + \alpha_{g1}\rho_{g1}{}^2\rho_{g2}{}^3\tau_{g1}E + \ldots$$
$$= \alpha_{g1}E_i\left(1 + \rho_{g2}\tau_{g1}\sum_0^n \rho_{g1}{}^n\rho_{g2}{}^n\right)$$

Equation 1

Where: E_i = Solar Incident Radiation (W/m^2)

2.1.2 Solar Radiation Absorbed by Inner Glass Panel (W/m²):

Similarly to the radiation absorbed by the outer glass panel, that of the inner glass panel (E_{g2}) can be determined by adding the small amount of radiation absorbed by it every time the solar radiation gets reflected by it.

$$E_{g2} = \alpha_{g2}\tau_{g1}E_i + \alpha_{g2}\rho_{g1}\rho_{g2}\tau_{g1}E_i + \alpha_{g2}\rho_{g1}^{\ 2}\rho_{g2}^{\ 2}\tau_{g1}E_i + \alpha_{g2}\rho_{g1}^{\ 3}\rho_{g2}^{\ 3}\tau_{g1}E_i + \ldots$$

$$= \alpha_{g2}\tau_{g1}E_i\sum_{0}^{n}\rho_{g1}^{\ n}\rho_{g2}^{\ n}$$

Equation 2

2.1.3 Solar Radiation Entering Evaporator (W/m²):

By adding the radiation transmitted through the inner glass panel each time it reflected the solar radiation, one can calculate the amount of solar radiation entering the evaporator (E_e):

$$E_e = \tau_{g1}\tau_{g2}E_i + \rho_{g1}\rho_{g2}\tau_{g1}\tau_{g2}E_i + \rho_{g1}^{\ 2}\rho_{g2}^{\ 2}\tau_{g1}\tau_{g2}E_i + \rho_{g1}^{\ 3}\rho_{g2}^{\ 3}\tau_{g1}\tau_{g2}E_i + \ldots$$

$$= \tau_{g1}\tau_{g2}E_i\sum_{0}^{n}\rho_{g1}^{\ n}\rho_{g2}^{\ n}$$

Equation 3

The radiation entering the evaporator is absorbed, reflected and transmitted by the air, water and concrete. To simplify this complex calculation it was assumed the radiation entering the evaporator is absorbed by the concrete and the water heated by forced convection from the concrete.

Assumption 1: All solar radiation entering through the glass panels is absorbed solely by the concrete foundation.

Thus:

$$E_c = E_e$$

Equation 4

2.2 Energy Transfer

Figure 11; page 20 shows the energy transfers associated with the evaporator. The concrete foundation is heated as it absorbs solar radiation entering through the glass panels. It in turn heats seawater which then heats air flowing above it. Energy is lost from the air through the glass panels when the air is warmer than the inner surface of the inner glass panel, but gained when the glass surface is warmer than the air.

2.2.1 Conduction Heat transfer from Concrete Foundation to Ground (Q_{cond}):

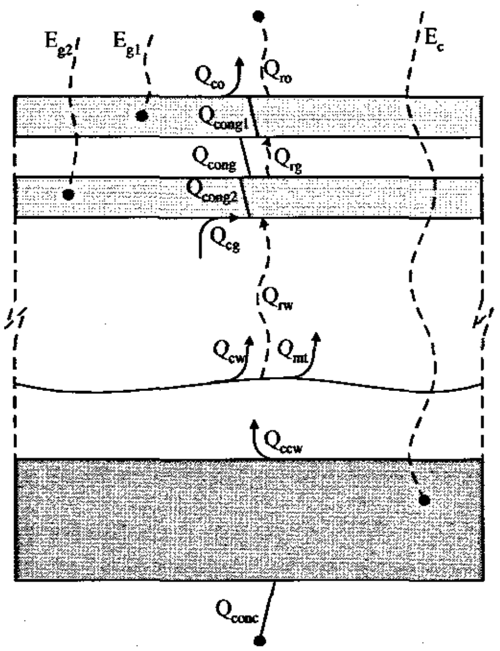
In order to determine energy transfer between the concrete foundation and the ground one need to know the temperature of the ground some distance away from the foundation and the grounds thermal conductivity. Both values were difficult to establish and will vary along the length and width of the foundation. The thermal conductivity of rock and soil are sufficiently low for them to be considered insulators. Therefore, to simplify this problem, the following assumption was made:

Assumption 2: The loss of energy from the concrete to the ground is 5% of the solar radiation absorbed by the foundation.

$$\therefore Q_{conc} = 0{,}05 E_c A$$

Equation 5

Where: A = Contact area between ground and concrete foundation (m^2)



E_c = Solar radiation absorbed by concrete
E_{g1} = Solar radiation absorbed by inner glass panel
E_{g2} = Solar radiation absorbed by outer glass panel
Q_{conc} = Conduction energy lose from concrete to ground
Q_{ccw} = Forced convection from concrete to seawater
Q_{cw} = Forced convection from seawater to air
Q_{mt} = Mass transfer form seawater to air
Q_{rw} = Radiation heat transfer from seawater to inner glass panel
Q_{cg} = Forced convection from air to inner glass
Q_{cong2} = Conduction through inner glass panel
Q_{cong} = Free convection through air gap
Q_{rg} = Thermal radiation from inner to outer glass panel
Q_{co} = Forced convection from outer glass panel to atmosphere
Q_{ro} = Thermal radiation from outer glass panel to atmosphere

Figure 11: Schematic representation of the energy transfers of the evaporator

2.2.2 Forced Convection Heat Transfer between Concrete Foundation and Seawater (Q_{ccw}):

Forced convection is the heat transfer occurring when a fluid flows due to external means over a surface and a temperature difference exists between them. Convection heat transfer equations are generally in the following form (known as Newton's Law of Cooling):

$$Q = hA(T_1 - T_2)$$

Equation 6

Where: Q = Rate of energy transfer between the two mediums (W)
h = Heat transfer coefficient (W/m^{2}K)
T = Temperature of a medium (K)
A = Area in contact between two mediums (m^2)

The heat transfer coefficient is, in general, based on boundary layer theory (which was first introduced by the German scientist Ludwig Prandtl) or determined empirically. In this instance the flow occurs over a flat surface (the concrete) and the heat transfer coefficient is calculated from the equations below. The equation for turbulent flow over a flat surface or flow with Reynolds Number higher than 5x10^5 is based on the Colburn Analogy of fluid friction and heat transfer.

With laminar boundary layer:

$$h_x = \frac{kNu_x}{x} \qquad \text{if} \qquad \mathrm{Re}_x < 5\times10^5$$

Equation 7

Where: $Nu_x = 0{,}322\,\mathrm{Re}_x^{\frac{1}{2}}\,\mathrm{Pr}^{\frac{1}{3}}$

Equation 8

And by: $h_x = \rho c_p u St_x$ if $5\times10^5 < \mathrm{Re}_x < 10^9$

Equation 9

When the Reynolds Number is between 5x10^5 and 10^7 the flow is turbulent and velocity profile that can be approximated by the 7th root law i.e.:

Where: $St_x = \dfrac{0{,}0296\,\mathrm{Re}_x^{-0{,}2}}{\mathrm{Pr}^{\frac{2}{3}}}$ if $5\times10^5 < \mathrm{Re}_x < 10^7$

Equation 10

And with Reynolds Number between 10^7 and 10^9 the velocity profile can be approximated by the logarithmic profile.

$$\text{And: } St_x = \frac{0{,}185(\log \mathrm{Re}_x)^{-2{,}584}}{\mathrm{Pr}^{\frac{2}{3}}} \qquad \text{if} \qquad 10^7 < \mathrm{Re}_x < 10^9$$

Equation 11

$$\text{And: } \mathrm{Re}_x = \frac{\rho u x}{\mu}$$

Equation 12

$$\text{And: } \mathrm{Pr} = \frac{c_p \mu}{k}$$

Equation 13

And: $\mathrm{Nu_x}$ = Local Nusselt Number
$\mathrm{St_x}$ = Local Stanton Number
$\mathrm{Re_x}$ = Local Reynolds Number
Pr = Prandtl Number
h_x = Local heat transfer coefficient (W/m^{2}K)
ρ = Density of energy absorbing medium (kg/m^3)
c_p = Specific heat capacity at constant pressure of energy absorbing medium (kJ/kgK)
u = Free stream velocity of moving medium or relative free stream velocity if both mediums in motion (m/s)
μ = Dynamic viscosity of energy absorbing medium (kg/ms)
k = Thermal conductivity of energy absorbing medium (W/mK)
x = Distance from leading edge of flat surface (m)

Thus, the energy gained by the seawater at any point in the evaporator (from Equation 6; page 21) is:

$$Q_{ccw} = h_{xccw} A (T_c - T_{sw})$$

Equation 14

Where: T_c = Temperature of concrete foundation (K)
T_{sw} = Temperature of seawater (K)
h_{xccw} = Local forced convection heat transfer coefficient between concrete foundation and seawater (W/m^{2}K)

The properties of the energy absorbing medium (in this case the seawater) are calculated at the film temperature (T_f). This temperature is the mathematical average of the temperatures of the two mediums in contact.

$$T_f = \frac{T_1 + T_2}{2}$$

Equation 15

$$\therefore T_{fccw} = \frac{T_c + T_{sw}}{2}$$

Equation 16

Where: T_{fccw} = Film temperature between the concrete foundation and seawater (K)

2.2.3 Forced Convection Heat Transfer Between Seawater and Air (Q_{cw}):

Since the heat transfer here is also by forced convection it is also governed by Equation 6 to Equation 15; page 21:

Thus, the energy gained by the air (from Equation 6; page 21) is:

$$Q_{cw} = h_{xcw} A (T_{sw} - T_a)$$

Equation 17

Where: T_a = Temperature of air (K)
h_{xcw} = Local forced convection heat transfer coefficient between air and seawater (W/m^{2}K)

Also from Equation 15; page 23 the film temperature between air and seawater (T_{fcw}) is:

$$T_{fcw} = \frac{T_{sw} + T_a}{2}$$

Equation 18

2.2.4 Thermal Radiation Heat Transfer between Seawater and Inner Glass Panel (Q_{rw}):

Thermal radiation heat transfer is governed by the equation:

$$Q = \frac{\sigma A_1 \left(T_1^{\,4} - T_2^{\,4}\right)}{\frac{(1-\varepsilon_1)}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{12}} + \frac{(1-\varepsilon_2)}{\varepsilon_2 A_2}}$$

Equation 19

Where: σ = Stefan-Boltzmann Constant (5,669x10^{-8} W/m^{2}K^4)
ε = *Emissivity of the two surfaces respectively*
T = Temperature of the two surfaces respectively (K)
A = Area of the two surfaces respectively
F_{12} = Shape-factor of the two surfaces

If the two surfaces are flat, infinite and parallel their shape-factor is equal to 1. In addition, if their areas are equal, Equation 19 simplifies to:

$$Q = \frac{\sigma A \left(T_1^{\,4} - T_2^{\,4}\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

Equation 20

Because of the evaporator's very large size and design one could assume its surfaces are infinite, flat and parallel. The surface of the seawater, however, will not be flat. This is due to its flow and to the flow of the air over its surface. By personal observation of light breezes blowing over pond surfaces it is estimated that the surface area may increase to 120% or more of its flat surface area. This will be called the wave factor (υ).

Assumption 3: The surface area of the seawater is increase by 20% due the its flow and the flow of air, thus υ = 1,2.

Therefore: $A_1 = \upsilon A_2$

Equation 21

Since all the energy leaving the seawater through radiation reaches the surface of the inner glass panel, the shape-factor remains 1, but Equation 19 simplifies to:

$$Q = \frac{\sigma A_2 \left(T_1^{\,4} - T_2^{\,4}\right)}{\dfrac{1}{\varepsilon_1} + \upsilon\left(\dfrac{1}{\varepsilon_2} - 1\right)}$$

Equation 22

The heat transfer through radiation from the seawater to the inner glass panel can be determined by (from Equation 22):

$$Q_{rw} = \frac{\sigma A_g \left(T_{sw}^{\,4} - T_{g2i}^{\,4}\right)}{\dfrac{1}{\varepsilon_{sw}} + \upsilon\left(\dfrac{1}{\varepsilon_{g2}} - 1\right)}$$

Equation 23

Where: ε_{sw} = Emissivity of the seawater surfaces.
ε_{g2} = Emissivity of the inner glass panel.
T_{g2i} = Temperature of the inner surface of the inner glass panel (K)
A_g = Area of the inner glass panel (m^2)

2.2.5 Mass transfer from seawater to air (Q_{mt}):

The energy entering the air due to the evaporation from the seawater can be determined by the equation:

$$Q_{mt} = m_{mt} h_g$$

Equation 24

Where: $m_{mt} = h_{mt} A\left(c_w - c_a\right)$

Equation 25

And: m_{mt} = Evaporation rate (kg/s)
h_g = Enthalpy of water vapour (J/kg)

h_{mt} = Mass transfer coefficient (m/s)
A = Area of air and seawater in contact (m)
c_w = Vapour concentration at the seawater surface (kg/m^3)
c_a = Vapour concentration in the free stream air (kg/m^3)

When mass transfer and heat transfer occurs simultaneously, as is the case here, a correlation can be drawn between the forced heat transfer coefficient (h_{cw}) and the mass transfer coefficient (h_{mt}):

$$h_{mt} = \frac{h_{cw}}{\rho_a c_p \left(\frac{Sc}{\Pr} \right)^{\frac{2}{3}}}$$

Equation 26

Where: $Sc = \frac{\mu_a}{\rho_a D}$

Equation 27

And: ρ_a = Desity of the air (kg/m^3)
c_p = Specific heat capacity at constant pressure air (kJ/kgK)
Sc = Schmidt Number
Pr = Prandtl Number
μ_a = Dynamic viscosity of air (kg/ms)
D = Diffusion coefficient (m^2/s)

2.2.6 Forced Convection from the Air to Inner Glass Panel (Q_{cg}):

Similar to convection heat transfer Q_{ccw} and Q_{cw}, the forced convection heat transfer from the air to the inner glass panel is also governed by Equation 6 to Equation 15; page 21:

Thus, the energy gained by the inner glass panel (from Equation 6; page 21) is:

$$Q_{cg} = h_{xcg} A (T_a - T_{g2i})$$

Equation 28

Where: h_{xcg} = Local forced convection heat transfer coefficient between air and inner glass panel (W/m^{2}K)

And from Equation 15; page 23 the film temperature between air and inner glass panel (T_{fcw}) is:

$$T_{fcg} = \frac{T_{g2i} + T_a}{2}$$

Equation 29

Where: T_{fcg} = Film temperature between the inner glass panel and air (K)

2.2.7 Conduction Heat Transfer through the Inner Glass Panel (Q_{cong2}):

The conduction heat transfer equation, based on Fourier's Law, is:

$$Q = \frac{kA}{t}(T_1 - T_2)$$

Equation 30

Where: k = Thermal conductivity of the energy transferring material (W/mK)
A = Area of energy transfer (m)
t = Thickness of energy transferring material (m)
T = Surface temperatures of the energy transferring material (K)

Applying this equation to the conduction through the inner glass panel:

$$Q_{cong2} = \frac{k_{g2}A}{t_{g2}}\left(T_{g2i} - T_{g2o}\right)$$

Equation 31

Where: k_{g2} = Thermal conductivity of the inner glass surface (W/mK)
t_{g2} = Thickness of inner glass panel (m)
T_{g2o} = Outer surface temperatures of the inner glass panel (K)

2.2.8 Free Convection Heat Transfer through the Air Gap (Q_{cong}):

When the temperature of the outer surface of the inner glass panel is colder then that of the inner surface of the outer glass panel no free convection will occur. That is due to the fact that the air at the top of the air gap will be warm and less dense that the air at the bottom of the gap. The heated air will remain at the top, while the colder air remains at the bottom thus no convection. In such a case energy transfers occur by conduction and Equation 30 applies.

$$Q_{cong} = \frac{k_a A}{t_{g12}}\left(T_{g2o} - T_{g1i}\right)$$

Equation 32

Where: t_{g12} = Distance between glass panels (m)

T_{g1o} = Inner temperature of the outer glass panel (K)

When the temperature gradient is turned around free convection will occur and an effective thermal conductivity (k_e) for the air can be determined, then again the conduction equation can be used.

$$Q_{cong} = \frac{k_e A}{t_{g12}}\left(T_{g2o} - T_{g1i}\right)$$

Equation 33

Where: $k_e = k_a$ if $Gr\,\Pr < 1700$

Otherwise: $k_e = C\left(Gr\,\Pr\right)^n$

Equation 34

Where: $C = 0{,}059$ and $n = 0{,}4$ if $1700 < Gr\,\Pr < 7000$

$C = 0{,}212$ and $n = \frac{1}{4}$ if $7000 < Gr\,\Pr < 3{,}2 \times 10^5$

$C = 0{,}059$ and $n = \frac{1}{3}$ if $Gr\,\Pr < 3{,}2 \times 10^5$

$$\text{And: } Gr = \frac{g\beta\left(T_{g2i} - T_{g1o}\right)t_{g12}^{\ 3}}{\dfrac{\mu_a}{\rho_a}}$$

Equation 35

$$\text{With: } \beta = \frac{T_{g2o} + T_{g1i}}{2}$$

Equation 36

With: Gr = Grashof Number
g = Acceleration due to gravity (m/s^2)

2.2.9 Thermal Radiation Heat Transfer between Glass Panels (Q_{rg}):

The two surfaces of the glass panels facing each other can be seen as infinite and parallel. They also are flat and equal in size, thus Equation 20; page 24 applies.

$$\therefore Q_{rg} = \frac{\sigma A\left(T_{g2i}^{\ 4} - T_{g1o}^{\ 4}\right)}{\dfrac{1}{\varepsilon_{g1}} + \dfrac{1}{\varepsilon_{g2}} - 1}$$

Equation 37

Where: ε_{g1} = Emmisivity of outer glass panel

2.2.10 Conduction Heat Transfer through Outer Glass Panel (Q_{congl}):

Just as conduction through the inner glass panel the equation for Q_{cong1} is:

$$Q_{cong1} = \frac{k_{g1}A}{t_{g1}}\left(T_{g1i} - T_{g1o}\right)$$

Equation 38

Where: k_{g1} = Thermal conductivity of the outer glass surface (W/mK)
t_{g1} = Thickness of inner glass panel (m)
T_{g1o} = Outer surface temperatures of the inner glass panel (K)

2.2.11 Forced Convection Heat Transfer between the Outer Glass Panel and Atmosphere (Q_{co}):

This desalination plant will be built at the coast where there is usually a wind blowing. This wind will cause forced convection heat transfer from the outer glass panel to the atmosphere. Since the heat transfer here is also by forced convection it is also governed by Equation 6 to Equation 15; page 21:

Thus, the energy loss from the glass panel (from Equation 6; page 21):

$$Q_{co} = h_{xco} A\left(T_{glo} - T_{atm}\right)$$

Equation 39

Where: T_{atm} = Temperature of atmosphere (K)
h_{xco} = Local forced convection heat transfer coefficient on the outside surface of the outer glass panel (W/m^{2}K)

And from Equation 15; page 23 the film temperature between outer glass panel and atmosphere between air and seawater (T_{fco}) is:

$$T_{fco} = \frac{T_{co} + T_{atm}}{2}$$

Equation 40

2.2.12 Thermal Radiation Heat Transfer from the Outer Glass Panel to the Atmosphere (Q_{ro}):

When the thermal radiation heat transfer is from a heated object to the atmosphere a simplified version of Equation 20; page 24 can be utilised:

$$Q_{ro} = \sigma \varepsilon_{gl} A\left(T_{glo}{}^4 - T_{bbs}{}^4\right)$$

Equation 41

Where: T_{bbs} = Black body temperature of sky (K)

When the atmospheric humidity is high, such as it is at coastal areas, the black body temperature of the sky can be assumed to be equal to the ambient temperature [24].

Assumption 4: The black body temperature of the sky is equal to the ambient temperature.

2.3 Fluid Flows

There are different equations describing the flow of fluids inside a conduit, such as ducts, and the flow of liquids in open channels. The air flow inside the evaporator is bordered on all side by either the evaporator itself or the seawater, thus the air flows in a conduit. The seawater on the other hand flows in a channel, since it is bordered on all sides except on top. The following equations can be utilised for the flow of the two fluids.

2.3.1 Seawater Flow:

2.3.1.1 Velocity:

The below is combination of the Darcy-Weisbach and Colebrook-White equations [25].

$$u_{sw} = -(32gRS)^{\frac{1}{2}} \log\left(\frac{k_c}{14{,}8R} + \frac{1{,}255\mu_{sw}}{\rho_{sw}R(32gRS)^{\frac{1}{2}}}\right)$$

Equation 42

Where: $R_{sw} = \frac{A_{sw}}{P_{sw}}$

Equation 43

And: $A_{sw} = H_{sw}W$

Equation 44

And: $P_{sw} = 2H_{sw} + W$

Equation 45

Where: R_{sw} = Mean hydraulic radius of seawater flow (m)
S = Slope of evaporator
k_c = Relative roughness of concrete foundation
A_{sw} = Cross sectional area of flow (m^2)
P_{sw} = Wetted perimeter of flow (m)
H_{sw} = Depth of flow (m)
W = Width of evaporator (m)

2.3.1.2 Flow Rate:

$$V_{sw} = Au_{sw}$$

Equation 46

2.3.1.3 Mass Flow Rate:

$$m_{sw} = V_{sw}\rho_{sw}$$

Equation 47

Where: V_{sw} = Volume flow rate of seawater (m^3/s)
m_{sw} = Mass flow rate of seawater (kg/s)

2.3.2 Air Flow:

2.3.2.1 Velocity:

$$u_a = \frac{V_a}{A}$$

Equation 48

Where: V_a = Volume flow rate of air (m^3/s)

2.3.2.2 Flow Rate:

$$V_a = Au_a$$

Equation 49

2.3.2.3 Mass Flow Rate:

$$m_a = V_a\rho_a$$

Equation 50

Where: m_a = Mass flow rate of air (kg/s)

2.3.2.4 Pressure Loss:

In order to determine the pressure lose from friction the speed at which the air moves over its borders is required. The air's boundary consists of both glass and seawater, but the glass is stationary where as the seawater is in motion. On the sides and top it is bounded by glass and at the bottom it is bounded by seawater. The relative speed between the glass and air is equal to the speed at which the air moves, but the relative speed between the air and the seawater is equal to the speed of the air and seawater combined. In order to determine a velocity which can be substituted into the head loss equations below a relative 'boundary velocity' is determined. This boundary velocity is calculated from boundary periphery ratios as seen in Equation 52 below. Similar to this, the seawater and glass panels also have different relative roughness and a 'relative boundary roughness' must be calculated (see Equation 57 below). Equation 51 is used to determine the head lose due to friction and is know as 'Darcy's Equation' were as the equation for calculating the friction coefficient, Equation 56 is known as the 'Colebrook-White Equation'.

$$H_{fl} = \frac{f_{fl} l u_{arel}^{2}}{2g(4R_a)}$$

Equation 51

With: $u_{arel} = \dfrac{u_a P_{ag} + u_{relasw} P_{aw}}{P_{ag} + P_{aw}}$

Equation 52

Where: $u_{relasw} = u_a + u_{sw}$

Equation 53

And: $P_{ag} = W + 2H_a$

Equation 54

And: $P_{aw} = W$

Equation 55

And: $f_{fl} = \left[-4\log\left(\dfrac{k_{fl}}{3{,}71(4R_a)} + \dfrac{1{,}255}{R_a\sqrt{f_{fl}}} \right) \right]^{-2}$

Equation 56

Where: $$k_{fl} = \frac{k_{sw}P_{aw} + k_g P_{ag}}{P_{ag} + P_{aw}}$$

Equation 57

And: $$R_a = \frac{A_a}{P_a}$$

Equation 58

And: $$A_a = H_a W$$

Equation 59

And: $$P_a = 2(H_a + W)$$

Equation 60

Where: H_{fl} = Head loss due to friction (m)
L = Distance of flow (m)
u_{arel} = Relative boundary velocity (m/s)
R_a = Mean hydraulic radius of air flow (m)
u_{relasw} = Relative velocity between air and seawater (m/s)
P_{ag} = Contact periphery between glass and air (m)
P_{aw} = Contact periphery between seawater and air (m)
H_a = Depth of air flow (m)
f_{fl} = Friction coefficient
k_{fl} = Mean relative roughness of air flow borders

2.4 Mass and Energy Transfer

Since this system is powered by the sun no rapid change occurs. Temperatures and flow rates within the system will change gradually, thus, for any given instant one could assume a steady state operation.

Assumption 5: Steady state exists throughout the system.

Note: In this section the presented equations and assumptions are utilised along with the principles of energy and mass conservation to form a coherent sequence of calculations required to determine the fluid and structure temperatures. To prevent duplication focus will only be on energy and mass transfer and the temperatures associated with them. The reader is referred to Section 2.2 for *the explanation of their calculations. This applies to the corresponding sections in the chapters "Secondary Water Heater" and "Condenser".*

Numerical integration is used to evaluate it entire evaporator. Each section investigated, in turn, is small enough that the property change of the two fluids is so small that Assumption 6 can be made. Here n, an integer, depicts the start of an integration section and n+1 the end of it as well as the start of the next one. n would be zero at the inlet of the evaporator and equal to N at its exit. N is the length of the evaporator divided by the length of an integration section and thus also equal to the number of integration sections. One integration section is shown in Figure 12; page 37.

Assumption 6: The properties of the two fluids remain constant from position n to position n+1.

At n the temperatures of the seawater and the air is known and the solar radiation entering the system can be calculated, it is now possible to calculate the energy and mass transfers for steady state as well as the temperatures associated with them. As soon as the energy transfers to and from the fluids are known one can determine energy change they experienced from n to n+1 and thus the change in temperature, if the following assumptions are made:

Assumption 7: The temperature difference between the two fluids remains constant between position n to position n+1.

Assumption 8: The temperatures of the evaporator; glass panels and concrete, remain constant between position n to position n+1.

Assumption 9: No energy transfer occurs in the glass panels and concrete between numerical integration sections.

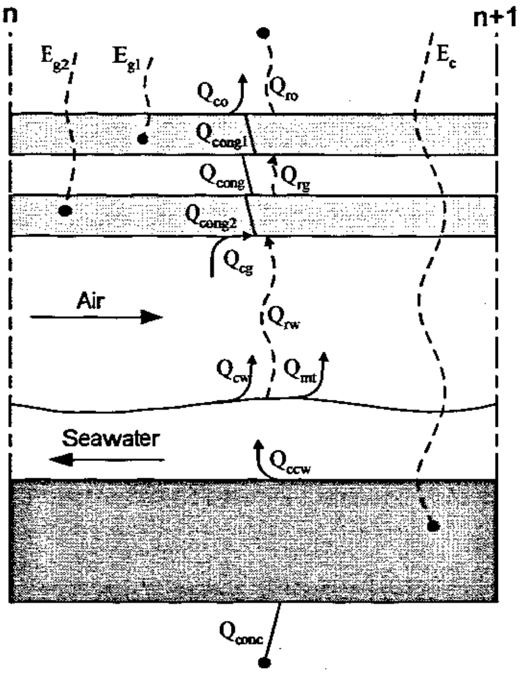


Figure 12: Evaporator energy transfers for numerical integration

2.4.1 Energy Transfers and Temperatures for Steady State

Only the temperatures of the seawater and the air are known. A starting point the outside temperature of the outer glass panel is assumed. By energy balancing the actual temperature of the outer surface of the outer glass panel can be calculated.

1. Assume an outside temperature T_{glo} for the outer glass panel.

2. Determine the energy transfers O_{ro} and Q_{co}:

$$Q_{ro} = \sigma\varepsilon_{g1} A\left(T_{glo}^{\ 4} - T_{bbs}^{\ 4}\right)$$ Equation 41; page 30

$$Q_{co} = h_{xco} A\left(T_{glo} - T_{atm}\right)$$ Equation 39; page 30

3. Since the temperature of the outer glass panel remains constant the energy into and out of it must be equal, thus:

$$Q_{cong} + Q_{rg} + E_{g1}A = Q_{ro} + Q_{co}$$

Equation 61

But the energy conducted and transmitted through the glass panel is equal to the energy entering the inner glass surfaced:

$$Q_{cong1} = Q_{rg} + Q_{cong}$$

Equation 62

$$Q_{cong1} = Q_{ro} + Q_{co} - E_{g1}A$$

Equation 63

From Equation 38; page 29:

$$T_{g1i} = \frac{Q_{cong1} t_{g1}}{k_{g1}A} + T_{g1o}$$

4. Since the temperature of the outer glass panel remains constant the energy into and out of it must be equal, thus:

$$Q_{cong} + Q_{rg} + E_{g1}A = Q_{co} + Q_{ro}$$

$$\therefore Q_{cong} + Q_{rg} = Q_{cong1} - E_{g1}A$$

Equation 64

5. At a certain outer surface temperature the inner glass panel will radiate and conduct, through the air gap, the quantity of energy that would validate Equation 64. This temperature cannot be calculated directly, thus an assumption must be made of its value and its actual value calculated using the following steps:

- Assume an outer surface temperature T_{g2o} of the inner glass panel.
- Calculate the energy transfer Q_{cong}:

$$Q_{cong} = \frac{k_e A}{t_{g12}}\left(T_{g2o} - T_{g1i}\right)$$

Equation 33; page 28

- Calculate what Q_{rg} must be to validate to Equation 64:

$$Q_{rg} = Q_{cong1} - E_{g1}A - Q_{cong}$$

- From Equation 37; page 29, calculate what the outer surface temperature of the inner glass panel must be to radiate this quantity to the outer glass panel. This would be a different temperature $T`_{g2o}$ from the assumed one T_{g2o}.

$$T`_{g2o} = \left[\frac{Q_{rg}\left(\frac{1}{\varepsilon_{g1}} + \frac{1}{\varepsilon_{g2}} - 1 \right)}{\sigma A} + T_{g1o}^{4} \right]^{\frac{1}{4}}$$

Equation 65

- Redefine T_{g2o} as $T`_{g2o}$:

$$T_{g2o} = T`_{g2o}$$

Equation 66

- Redo the steps of #5 until the difference between $T`_{g2o}$ and T_{g2o} is acceptably small, the smaller the difference the more accurate the calculation would be. This would then be the temperature for the outer surface of the inner glass panel that would validate Equation 64; page 38.

6. The amount of energy conducted and transmitted though the inner glass panel is equal to the sum of Q_{cg} and Q_{rw}. As with the outer glass panel, the inner surface temperature of the inner glass panel can be determined from.

$$Q_{cg} + Q_{rw} + E_{g2}A = Q_{cong} + Q_{rg}$$

Equation 67

Where: $Q_{cong2} = Q_{cg} + Q_{rw}$

Equation 68

Thus: $Q_{cong2} = Q_{cong} + Q_{rg} - E_{g2}A$

Equation 69

$$T_{g2i} = \frac{Q_{cong2}t_{g2}}{k_{g2}A} + T_{g2o}$$ Equation 31; page 27

7. There is a curtain net amount of energy available inside the evaporator ΔQ_e to drive the temperature change therein. This amount of energy is equal to the difference of solar radiation entering the inside of the evaporator and leaving it by conduction through the glass panels and concrete.

$$\Delta Q_e = E_e A - Q_{cong2} - Q_{conc}$$

Equation 70

8. Since the temperatures of the evaporator structure are constant, the sum of the energy change of the seawater ΔQ_w and air ΔQ_a will be equal to the available energy ΔQ_e.

$$\Delta Q_e = \Delta Q_w + \Delta Q_a$$

Equation 71

9. For steady state Equation 71 above must be justified. By calculating ΔQ_a one can then calculate ΔQ_{sw} from Equation 71 to use for further calculations of the steady state temperatures.

   - Since the temperature of the air and inner glass panel is known one can calculate Q_{cg} from:

$$Q_{cg} = h_{xcg}A(T_a - T_{g2i})$$ Equation 28; page 26

   - Also, the energy transfer between the seawater and air Q_{cw} from:

$$Q_{cw} = h_{xcw}A(T_{sw} - T_a)$$ Equation 17; page 23

- And Q_{mt}, which is the energy entering the air through mass transfer, from:

$$Q_{mt} = m_{mt} h_g$$

Equation 24; page 25

- The energy change of the air ΔQ_a can now be determined from the difference between its energy gains and loses.

$$\Delta Q_a = Q_{mt} + Q_{cw} - Q_{cg}$$

Equation 72

10. Now the energy change of the seawater can be determined from the energy balance of the evaporator.

$$\Delta Q_{sw} = \Delta Q_e - \Delta Q_a$$

Equation 71; page 40

11. The energy change of the seawater is also equal to the difference between its energy gains and loses.

$$\Delta Q_{sw} = Q_{ccw} - Q_{cw} - Q_{mt} - Q_{rw}$$

Equation 73

12. A new surface temperature of the inner glass panel can now be calculated from:

$$T`_{g2i} = \left[\frac{Q_{rw}\left(\frac{1}{\varepsilon_w} + \upsilon\left(\frac{1}{\varepsilon_{g2}} - 1 \right) \right)}{\sigma A} + T_{sw}^4 \right]^{\frac{1}{4}}$$

Equation 23; page 25

13. As long as T_{g2i} and $T`_{g2i}$ are not equal, or sufficiently close, the outside surface temperature assumed for the outer glass panel is not correct. If $T_{g2i} > T`_{g2i}$ then

the T_{g1o} is too high and vice versa. An updated temperature T_{g1o} can be calculated from:

$$T_{g1o} = T_{g1o} + \left(T`_{g2i} - T_{g2i}\right)$$

Equation 74

14. The new T_{g1o} is closer to the true value and by repeating #1 to #14 the actual energy transfers and temperatures associated therewith can be calculated. With all this done the goal of determining what the energy changes of the two fluids are, is achieved.

2.4.2 Fluid Temperature Change

Now that all the energy transfers associated with steady state have been calculated the temperature change experienced by the fluids from one end of the numerical integration section to the other can be calculated. Note that the fluid energy changes in Section 2.4.1 take the conservation of energy into consideration but now, since there is mass transfer between the seawater and air, mass conservation must also be applied.

2.4.2.1 Seawater:

Energy is gained by the seawater from the concrete (Q_{ccw}) and lost in the form of radiation (Q_{rw}), convection (Q_{cw}) and mass transfer (Q_{mt}). The energy associated with mass transfer is the energy leaving the seawater, but the energy required to liberate a unit mass of water is equal to the difference in enthalpy of water in vapour and liquid form, thus:

$$Q_{fc} = m_{mt}\left(h_g - h_f\right)$$

Equation 75

Where: Q_{fc} = Energy required to liberate vapour (W)
h_g = Enthalpy of water vapour (kJ/kg)
h_f = Enthalpy of water (kJ/kg)

The energy to achieve this comes from the net of the other energy transfers and the temperature change of the seawater that does not experience phase change. Note also that the seawater flows from n+1 to n.

$$\left(Q_{ccw} - Q_{cw} - Q_{rw}\right) + \left(m_{sw_{n+1}} cp_{sw} T_{sw_{n+1}} - m_{sw_n} cp_{sw} T_{sw_n}\right) = Q_{fc}$$

Equation 76

But, from Equation 73; page 41 and Equation 75; page 43:

$$\Delta Q_{sw} + m_{mt} h_f + \left(m_{sw_{n+1}} cp_{sw} T_{sw_{n+1}} - m_{sw_n} cp_{sw} T_{sw_n}\right) = 0$$

Equation 77

$$T_{sw_n} = \frac{m_{mt} h_f + \Delta Q_{sw} + m_{sw_{n+1}} cp_{sw} T_{sw_{n+1}}}{m_{sw_n} cp_{sw}}$$

Air:

The vapour entering the air is warmer than the air itself. Thus, the energy that heats the air comes both from the net energy change between Q_{cw} and Q_{cg} and the cooling down of the vapour. To simplify this calculation it is broken up into two parts, the initial heating or the heating from the difference between Q_{cw} and Q_{cg} and a final heat by the cooling vapour.

Initial Heating:

Note that both the dry air and the original vapour must be heated.

$$Q_{cw} - Q_{cg} = m_{da} cp_{da}\left(T_{ai} - T_{a_n}\right) + m_{da} r_n \left(h_{gi} - h_{g_n}\right)$$

Equation 78

Thus: $$T_{ai} = \frac{Q_{cw} - Q_{cg} - m_{da} r_n \left(h_{gi} - h_{g_n}\right)}{m_{da} cp_{da}} + T_{a_n}$$

Where: m_{da} = Mass flow rate of dry air (kg/s)
T_{ai} = Temperature after initial heating (K)
cp_{da} = Specific heat of dry heat (kJ/kgK)
h_{gi} = Enthalpy of water vapour at T_{ai} (kJ/kg)
h_{gn} = Initial enthalpy of water vapour (kJ/kg)
r_n = Initial absolute humidity

But, since the h_{gi} is derived at temperature T_{ai}, iteration is required to solve T_{ai}.

Final Heating:

Here the heating can be calculated from two fluids mixing where the sum of their initial respective energy is equal to their combined energy after mixing at a new temperature, thus:

$$m_{mt}\left(h_{gsw} - h_{g_{n+1}}\right) + m_{da} cp_{dai} T_{ai} + m_{da} r_i h_{gi} = m_{da} cp_{da_{n+1}} T_{a_{n+1}} + m_{da} r_{n+1} h_{g_{n+1}}$$

Equation 79

Thus: $$T_{a_{n=1}} = \frac{m_{mt}\left(h_{gsw} - h_{g_{n+1}}\right) + m_{da} cp_{dai} T_{ai} + m_{da} r_i h_{gi} - m_{da} r_{n+1} h_{g_{n+1}}}{m_{da} cp_{da_{n+1}}}$$

Where: i = Are properties measured at T_{ai}
n+1 = Properties measured at the exit of numerical integration section (K)

Note again that integration is needed since the equation is used to calculate T_{an+1} while h_{gn+1} is dependent at T_{an+1}.

Now that the exit temperatures of the two fluids are known the same calculation can be applied to the next integration section.

3. SECONDARY WATER HEATER

The structure of the secondary water heater is essentially the same as the evaporator. The only difference is the area between the concrete foundation and the inner glass panel is entirely flooded with water (see Figure 13).

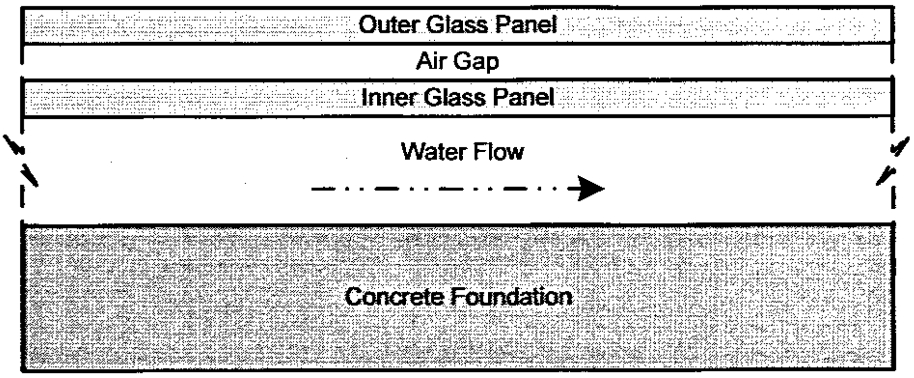


Figure 13: Side view schematic representation of secondary water heater

3.1 Solar Radiation

Since the double glass panel configuration is the same as for the evaporator the radiation absorbed by the outer and inner glass panels can also be determined by Equation 1; page 17 and Equation 2; page 18 respectively.

The total amount of solar radiation entering the heater (E_{sh}) can be determined by Equation 3; page 18 in the form:

$$E_{sh}=\tau_{g1}\tau_{g2}E_i\sum_{0}^{n}\rho_{g1}{}^{n}\rho_{g2}{}^{n}$$

Equation 80

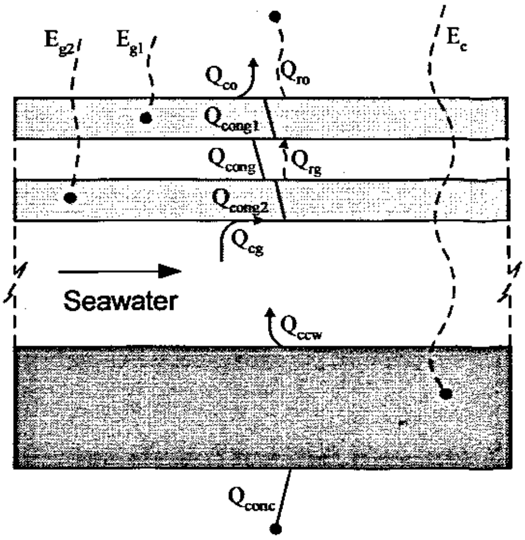
Now, applying Assumption 1; page 18 to the heater to determine the solar radiation absorbed by its foundation (E_c):

$$E_c = E_{sh}$$

Equation 81

3.2 Energy Transfer

Figure 14 shows the energy transfers associated to the secondary water heater. The concrete foundation gets heated as it absorbs the solar radiation entering through the glass panels. It in turn heats the seawater. Energy is lost from the seawater through the glass panels.



E_c = Solar radiation absorbed by concrete

E_{g1} = Solar radiation absorbed by inner glass panel

E_{g2} = Solar radiation absorbed by outer glass panel

Q_{conc} = Conduction energy lose from concrete to ground

Q_{ccw} = Forced convection from concrete to seawater

Q_{cg} = Forced convection from air to inner glass

Q_{cong2} = Conduction through inner glass panel

Q_{cong} = Free convection through air gap

Q_{rg} = Thermal radiation from inner to outer glass panel

Q_{co} = Forced convection from outer glass panel to atmosphere

Q_{ro} = Thermal radiation from outer glass panel to atmosphere

Figure 14: Schematic representation of the energy transfers of the secondary water heater

3.2.1 Conduction Heat transfer form Concrete Foundation to Ground (Q_{conc}):

Equation 6; page 21 is applied to the concrete foundation for exactly the same reasons as for the evaporator, thus, from Equation 16; page 23:

$$Q_{conc} = 0{,}05 E_c A$$

Equation 82

3.2.2 Forced Convection Heat Transfer Between Concrete Foundation and Seawater (Q_{ccw}):

Since the heat transfer is by forced convection Equation 6; page 21 through Equation 16; page 23 applies here too.

3.2.3 Forced Convection Heat Transfer Between Inner Glass Panel and Seawater (Q_{ccw}):

Here too Equation 6; page 21 through Equation 16; page 23 can be applied, but different here than in the evaporator the energy transfer is not between air and glass but between seawater and glass, thus, from Equation 28; page 26:

$$Q_{cg} = h_{xcg} A \left(T_{sw} - T_{g2i}\right)$$

Equation 83

Where: h_{xcg} = Local forced convection heat transfer coefficient between seawater and inner glass panel (W/m^{2}K)

And from Equation 29; page 27:

$$T_{fcg} = \frac{T_{g2i} + T_a}{2}$$

Equation 84

Where: T_{fcg} = Film temperature between the concrete foundation and seawater (K)

3.2.4 The following heat transfer values can be determined using the equations as derived for the evaporator:

Q_{cong2} (Equation 31; page 27),
Q_{cong} (Equation 32; page 28),
Q_{rg} (Equation 37; page 29),
Q_{cong1} (Equation 38; page 29),
Q_{co} (Equation 39; page 30 and Equation 40; page 30),
Q_{ro} (Assumption 4; page 31and Equation 41; page 30)

3.3 Fluid Flow

Here the seawater is bounded on all sides, thus conduit equations apply. Since it is bounded on three sides by concrete and on the other by glass relative boundary roughness must once again by calculated.

3.3.1 Flow Rate:

$$V_{sw} = A_{sw} u_{sw}$$

Equation 85

Where: V_{sw} = Volume flow rate (m^3/s)
A_{sw} = Flow area inside secondary water heater (m^2)
u_{sw} = Flow Speed of seawater (m/s)

3.3.2 Mass Flow Rate:

$$m_{sw} = V_{sw} \rho_{sw}$$

Equation 86

Where: m_{sw} = Mass flow rate of seawater (kg/s)

Pressure Loss:

$$H_{fl} = \frac{f_{fl} l u_{sw}^{\ 2}}{2g(4R_{sw})}$$

Equation 87

And: $$f_{fl} = \left[-4\log\left(\frac{k_{fl}}{3{,}71(4R_{sw})} + \frac{1{,}255}{R_{sw}\sqrt{f_{fl}}}\right)\right]^{-2}$$

Equation 88

Where: $$k_{fl} = \frac{k_g P_{gw} + k_c P_{cw}}{P_{gw} + P_{cw}}$$

Equation 89

With: $P_{gw} = W$

Equation 90

And: $P_{cw} = W + 2H_{sw}$

Equation 91

And: $$R_{sw} = \frac{A_{sw}}{P_{cw}}$$

Equation 92

Where: H_{fl} = Head loss due to friction (m)

L = Distance of flow (m)

R_{sw} = Mean hydraulic radius of seawater flow (m)

P_{gw} = Contact periphery between glass and seawater (m)

P_{cw} = Contact periphery between concrete and seawater (m)

k_{fl} = Mean relative roughness of seawater flow borders

3.4 Applying Mass and Energy Transfer

The heater experiences no mass transfer between fluids and its steady state temperatures and energy transfer can be calculated as follows.

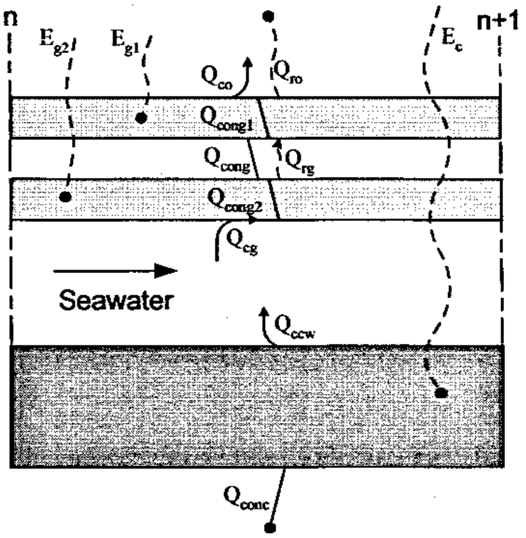


Figure 15: Secondary water heater energy transfer for numerical integration.

3.4.1 Energy Transfers and Temperatures for Steady State

1. Since the glass panel structure of the evaporator and heater are identical #1 to #5 of the heater are exactly the same as for the evaporator.

2. The amount of energy conducted and transmitted though the inner glass panel is equal to the sum of Q_{cg} and Q_{rw} and similarly to the outer glass panel the inner surface temperature of the inner glass panel can be determined from.

$$Q_{cg} + E_{g2}A = Q_{cong} + Q_{rg}$$

Equation 93

Where: $Q_{cong2} = Q_{cg}$

Equation 94

Thus: $Q_{cong2} = Q_{cong} + Q_{rg} - E_{g2}A$

Equation 95

$$T_{g2i} = \frac{Q_{cong2}t_{g2}}{k_{g2}A} + T_{g2o}$$

Equation 31; page 27

3. Just as it was for the evaporator, the amount of energy available is, equal to ΔQ_e where:

$$\Delta Q_e = E_e A - Q_{cong2} - Q_{conc}$$ Equation 70; page 40

4. But here the seawater is the only fluid inside the heater and therefore it alone experiences a temperature change, thus:

$$\Delta Q_e = \Delta Q_w$$

Equation 96

And: $\Delta Q_w = Q_{ccw} - Q_{cg}$

Equation 97

5. Since the temperature of the concrete remains constant its energy balance gives:

$$E_c A - Q_{conc} - Q_{cw} = 0$$

Equation 98

Thus: $Q_{cw} = E_c A - Q_{conc}$

And: $Q_{cg} = Q_{ccw} - \Delta Q_w$ From Equation 97; page 51

6. Now a new temperature T'_{g2i} for the inner surface of the inner glass panel can be determined from:

$$T'_{g2i} = T_{sw} + \frac{Q_{cg}}{h_{cg} A}$$

7. As long as T_{g2i} and T'_{g2i} are not equal, or sufficiently close, the outside surface temperature assumed for the outer glass panel is not correct. If $T_{g2i} > T'_{g2i}$ then the T_{g1o} is too high and vice versa. An updated temperature T_{g1o} can be calculated from:

$$T_{g1o} = T_{g1o} + \left(T'_{g2i} - T_{g2i}\right)$$

Equation 99

8. The new T_{g1o} is closer to the true value and by repeating #1 to #14 the actual energy transfers and temperatures associated therewith can be calculated. With all

this done the goal of determining what the energy changes of the two fluids are, is achieved.

3.4.2 Fluid Temperature Change

Since the mass of the seawater remains constant and its temperature change is known, it is a simple calculation to determine its exit temperature from the section.

$$\Delta Q_{sw} = m_{sw} cp_{sw} \left(T_{sw_{n+1}} - T_{sw_n}\right)$$

Equation 100

Thus: $T_{sw_{n+1}} = \dfrac{\Delta Q_{sw}}{m_{sw} cp_{sw}} + T_{sw_n}$

Now that the exit temperature of the seawater is known the same calculation can be applied to the next integration section.

4. CONDENSER

Figure 16 shows a schematic representation of the condenser. Seawater flows through the condenser piping and the air in the area between the piping in the opposite direction. The seawater is heated as it extracts energy from the warm humid air. As the air cools condensation occurs on the outside of the condenser pipes. The condensate drips down and collects in the desalinated water channel.

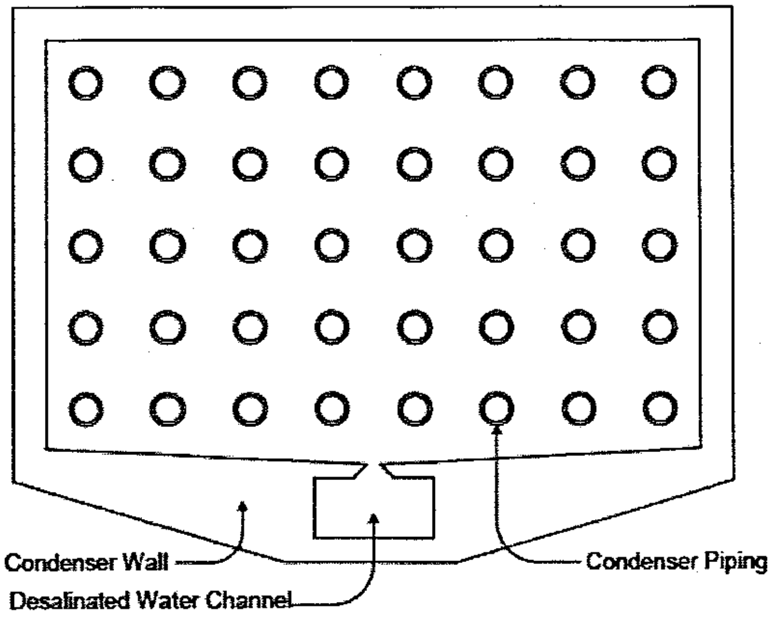
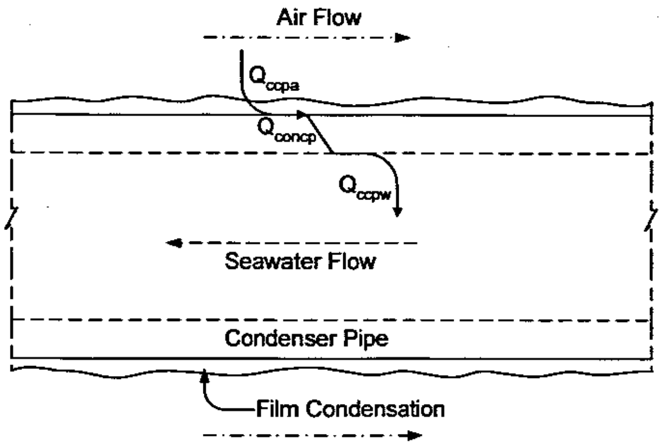


Figure 16: Schematic representation of condenser

4.1 Energy Transfer

As the air flows over the pipes it loses energy to the pipes through the condensate film. This energy is transferred by conduction through the pipe wall to the seawater (see Figure 17; page 54). All the condenser pipes and the flow around them are identical, thus, only one pipe is considered.



Q_{ccw} = Forced convection from pipe wall to seawater
Q_{concp} = Conduction through pipe wall
Q_{ccpa} = Energy transfer from air to pipe wall through condensate

Figure 17: Schematic representation of condenser pipe heat transfer

4.1.1 Convection Heat Transfer from the Air to the Outer Wall of the Condenser Pipe (Q_{ccpa}):

Since this heat transfer is in the form of forced convection the amount of energy transferred from the humid air to the outer surface of the condenser pipe is calculated by Equation 6; page 21:

$$Q_{ccpa} = h_{ccpa} A_{cpo} \left(T_a - T_{cpo} \right)$$

Equation 101

Where: h_{ccpa} = Heat transfer coefficient from the air through the condensation film to condenser pipe (W/m^{2}K)
T_{cpo} = Outside surface temperature condenser pipe (K)
A_{cpo} = Outside area of condenser pipe (m^2)

The heat transfer coefficient for the heat flow through the condensation film, while condensation is taking place is given as (Nusselt's Equation for Condensation Heat Transfer Coefficient) [26]:

$$h_{ccpo} = 0{,}725\left(\frac{k_f \rho_f \left(\rho_f - \rho_v\right) g h_{fgf}}{\mu_f d_{cpo}\left(T_a - T_{cpo}\right)}\right)$$

Equation 102

Where: k_f = Water film thermal conductivity (W/mK)
ρ_f = Density of water film (kg/m^3)
ρ_v = Vapour density in air (kg/m^3)
h_{fgf} = Enthalpy of the vaporization of water (J/kg)
μ_f = Dynamic viscosity of the water film (kg/ms)
d_{cpo} = Outside diameter of condenser pipe (m)

This equation is intended for small temperature differences as is the case with the condenser. This heat transfer coefficient, however, is for one pipe only and when condenser pipes are position below one another the condensate dripping from one pipe onto the next influences the coefficient of the next pipe. In order to determine an average heat transfer coefficient for number of pipes positioned its way the following equation can be utilised:

$$\bar{h}_{ccpo} = h_{ccpo} N^{-\frac{1}{6}}$$

Equation 103

Where: N = Number of pipes in a rows

4.1.2 Conduction through the Condenser Pipe (Q_{concp}):

The conduction heat transfer equation previously mentioned (Equation 30; page 27) can be applied here but, because of the internal and external area differences of the pipe, the conduction area must be calculated using this equation:

$$A = \pi \ln\left(\frac{r_{cpo}}{r_{cpi}}\right) l$$

Equation 104

Where: r_{cpo} = Outside radius of condenser pipe (m)
r_{cpi} = Inside radius of condenser pipe (m)
l = Length along which conduction occurs (m)

Thus:

$$Q_{concp} = \frac{k_{pc} A}{t_{cp}} \left(T_{cpo} - T_{cpi} \right)$$

Equation 105

With: k_{cp} = Thermal conductivity of condenser pipe (W/mK)
t_{cp} = Thickness of condenser pipe wall (m)
T_{cpi} = Inner wall temperature of condenser pipe (K)

4.1.3 Forced Convection between Pipe Wall and the Seawater (Q_{ccpw}):

Since this is forced convection Equation 6; page 21 applies, but the flow occurs on the inside of a pipe, thus:

$$Nu_d = 0{,}023 \operatorname{Re}^{0{,}8} \operatorname{Pr}^{0{,}4}$$

Equation 106

With: $$\operatorname{Re} = \frac{\rho_{sw} u_{sw} d_{cpi}}{\mu_{sw}}$$

Equation 107

Where: d_{cpi} = Inside diameter of condenser pipe (m)
μ_{sw} = Dynamic viscosity of seawater (kg/ms)
ρ_{sw} = Density of seawater (kg/m^3)
u_{sw} = Seawater velocity (m/s)

And: $$Q_{ccpw} = h_{ccpw} A_{cpi} \left(T_{cpi} - T_{sw} \right)$$

Equation 108

Where: $$A_{cpi} = \pi d_{cpi} l$$

Equation 109

Where: d_{cpi} = Inside diameter of condenser pipe (m)
h_{ccpw} = Heat transfer coefficient between pipe wall and seawater (W/m^{2}K)

4.1.4 Fluid Flow

4.1.4.1 Air Flow:

At the inlet and outlet of the condenser is a number of supply and discharge pipes. These pipes are positioned perpendicular to the air flow. This causes a pressure drop. Between the supply and discharge pipes the air flows parallel to the pipes and the pressure loss is from friction. Here the flow is once again in the form of duct flow, but the duct flow equations only apply after the flow has become fully developed. With the typical flow and temperature of the condenser this would occur in approximately 4 meters, and, compared to the length of the condenser (approximately 250m) this is negligible, therefore the following assumption is made.

Assumption 10: The flow in the condenser becomes fully developed fast enough for the under developed region to be ignored.

Flow Rate:

$$V_a = A_{ca} u_a$$

Equation 110

Where: $A_{ca} = WH - N_{cp} A_{cp}$

Equation 111

With: $A_{cp} = \frac{\pi}{4} d_{cpo}{}^2$

Equation 112

Where: V_a = Volume flow rate of air (m^3/s)
A_{ca} = Flow area inside condenser (m^2)
A_{cp} = Cross sectional area of condenser pipe (m^2)
N_{cp} = Number of condenser pipes
W = Inside width of condenser (m)
H = Inside height of condenser (m)
u_a = Flow velocity of air (m/s)

Mass Flow Rate:

$$m_a = V_a \rho_a$$

Equation 113

Where: m_a = Mass flow rate air (kg/s)

Pressure Loss:

Over Condenser Pipe:

Once again here are two different borders to the air flow. One being the condenser pipes and the other the condenser wall and a relative boundary roughness must be calculated. Similar to the evaporator this is done by the periphery ratios of the two borders as can be seen in Equation 116.

$$H_{fl} = \frac{f_{fl} l u_a^2}{2g(4R_a)}$$

Equation 114

With: $$f_{fl} = \left[-4\log\left(\frac{k_{fl}}{3{,}71(4R_a)} + \frac{1{,}255}{R_a\sqrt{f_{fl}}}\right)\right]^{-2}$$

Equation 115

Where: $$k_{fl} = \frac{N_{cp}k_{cp}P_{ap} + k_c P_{acw}}{P_{ap} + P_{acw}}$$

Equation 116

With: $$P_{ap} = \pi d_{cpo}$$

Equation 117

And: $$P_{acw} = 2(W + H)l$$

Equation 118

And: $$R_a = \frac{A_{ca}}{P_{acw} + P_{ap}}$$

Equation 119

Where: k_{fl} = Mean relative roughness of air flow borders

k_{cp} = Relative roughness of condenser pipe

P_{ap} = Contact periphery between air and condenser pipe (m)

P_{acw} = Contact periphery between air and condenser wall (m)

Supply and Discharge Pipes:

Figure 18 demonstrates how the supply and discharge seawater pipes are positioned perpendicular to the air flow. These pipe diameters are reduced and increased, respectively, to ensure the flow speed in them remains constant.

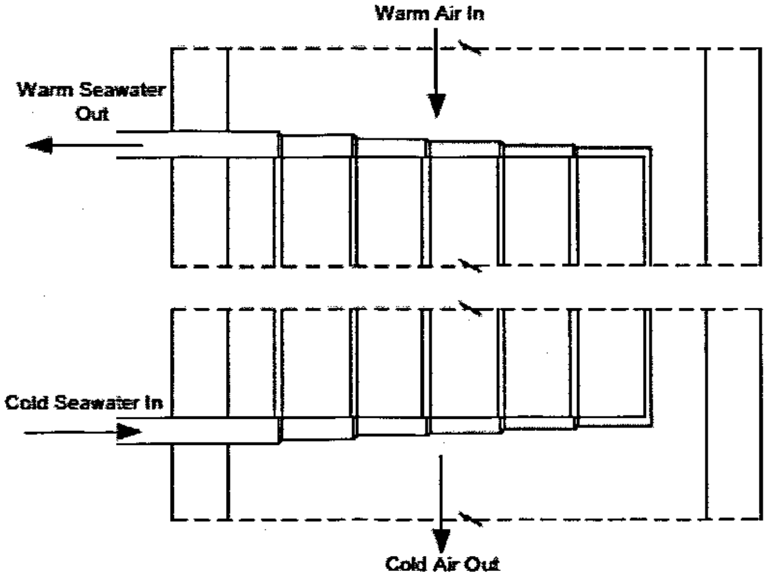


Figure 18: Schematic representation of condenser seen from the above

The pressure loss in the air can be calculated from the flow equations. Note, since the diameter of the supply and discharge pipes decrease an average separation diameter is calculated for the use in these equations. The drag coefficient is determined from tabulated data, and with a flow rate in the condenser as is present, it is close to one. In fact this is approximately true for Reynolds Numbers of between 10^2 and 10^5 [27].

Assumption 11: The drag coefficient remains equal to 1.

$$H_{ld} = \frac{N_{cpr} l d_{avg} C_D u_a^{2}}{2 g A_c}$$

Equation 120

Where: N_{cpr} = Number of pipe rows in condenser

l = Length of supply and effluent pipes protruding into condenser (m)

d_{avg} = Average diameter of supply and effluent pipes (m)

C_D = Drag coefficient

A_c = Condenser area before reaching supply/effluent pipes (m^2)

4.1.4.2 Seawater Flow:

Supply Pipe to Condenser Pipe

Pressure Loss:

This pipe network can be approximated by a parallel pipe system.

Assumption 12: The supply, condenser and discharge pipes form a perfect parallel pipe network.

To calculate the pressure loss from the supply line into the condenser pipe the following equations can be applied to the first tap-off. Here the loss from the larger supply line to the condenser pipe is by a T tap-off, but there is a reduction in diameter of the pipe too.

$$H_{sl} = \frac{\sum K u_{sw}^{2}}{2g}$$

Equation 121

Where: H_{sl} = Head lose due to shock (m)
K = Shock loss coefficient
u_{sw} = Flow velocity inside condenser pipe (m/s)

And: K=1,8 for T tap off

And for reduction:

A_2/A_1	0,1	0,3	0,5	0,7	1,0
K	0,41	0,34	0,24	0,14	0

Condenser Pipe:

Flow Rate:

$$V_{sw} = A_{cpi} u_{sw}$$

Equation 122

Where: A_{cpi} = Flow area inside condenser pipe (m^2)

Mass Flow Rate:

$$m_a = V_a \rho_a$$

Equation 123

Pressure Loss:

$$H_{fl} = \frac{f_{fl} l u_{sw}^{\;2}}{2g(4R_{sw})}$$

Equation 124

Where: $$f_{fl} = \left[-4\log\left(\frac{k_{cp}}{3{,}71(4R_{sw})} + \frac{1{,}255}{R_{sw}\sqrt{f_{fl}}}\right)\right]^{-2}$$

Equation 125

And: $$R_{sw} = \frac{A_{cpi}}{P_{cpi}}$$

Equation 126

Where: P_{cpi} = Internal periphery of condenser pipe (m)

Condenser Pipe to Discharge Pipe:

Similar to the loss that occurs at the transfer from the supply line to the condenser pipe, loss occurs here because of a T-connection, but instead of a sudden reduction, sudden expansion occurs. Equation 121; page 60 can once again be used with the K-values for the T-junction still 1,8 and the K-value for the sudden expansion calculated by the following equation, which is referred to as the 'Borda-Carnot Relationship:

$$K = \left(1 - \frac{A_{cp}}{A_{dp}}\right)^2$$

Equation 127

Where: A_{cp} = Condenser pipe area (m^2)
A_{dp} = Discharge pipe area (m^2)

4.2 Applying Mass and Energy Transfer

Similar to the evaporator and the secondary water heater the energy of the fluids are known at position n (see Figure 15). Numerical integration can once again be used to calculate the change in temperature of the seawater and the air, between n and n+1

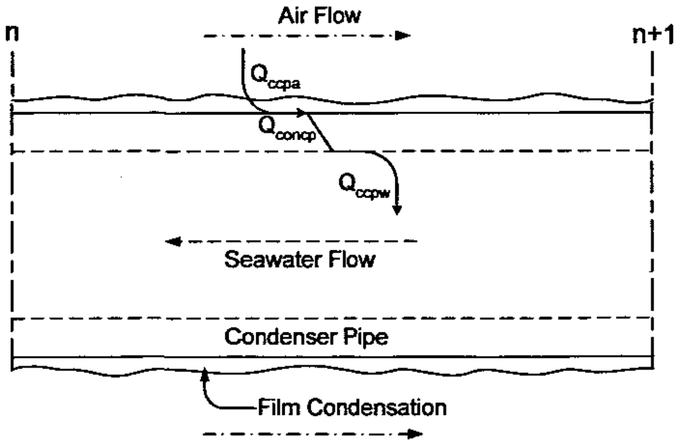


Figure 19: Condenser pipe energy transfer for numerical intergation

4.2.1 Energy Transfers and Temperatures for Steady State

The following steps can be used to calculate the surface temperatures of the condenser pipes as well as the energy changes of the two fluids.

1. Assume an inner surface temperature for the condenser pipe T_{cpi}.
2. Calculate the energy transfer Q_{ccpw} from:

$$Q_{ccpw} = h_{ccpw} A_{cpi} \left(T_{cpi} - T_{sw}\right)$$ Equation 108; page 56

3. The energy conducted through the wall and the energy transferred to the seawater are equal since the temperature of the pipe remains constant.

$$Q_{concp} = Q_{ccpw}$$

Equation 128

4. From the heat conduction equation one can now calculate the temperature of the outer surface of the condenser pipe:

$$T_{cpo} = \frac{Q_{concp} T_{cp}}{k_{pc} A} + T_{cpi}$$ Equation 105; page 56

5. Since the temperature of the pipe's outer surface temperature and the temperature of the air are known the amount of energy transferred from the air to the pipe can be calculated.

$$Q_{ccpa} = h_{ccpa} A_{cpo} \left(T_a - T_{cpo}\right)$$ Equation 101; page 54

6. For steady state Q_{ccpa} and Q_{cwpc} must be equal. If $Q_{ccpa} > Q_{cwpc}$, T_{cpi} must be increased and vice versa.

$$T_{cpi} = T_{cpi} + \left(\frac{Q_{ccpa} - Q_{cwpc}}{1000}\right)$$

The difference between Q_{ccpa} and Q_{cwpc} might be substantial, depending on how accurate the first assumption for T_{cpi} was. A too large difference between these values might cause the iteration values of T_{cpi} to diverge instead of converging and to stop this from happening their difference is divided by a 1000.

7. Steps 1 to 6 must be repeated until Q_{ccpa} and Q_{cwpc} are sufficiently close in magnitude.

4.2.2 Fluid Temperature Change

Once again, as for the evaporator and condenser, it is now possible to determine the temperature changes for the fluids from one end of the numerical integration section to the other since the energy change of both fluids is known. Since no mass transfer exits too or from the seawater, its mass flow rate remains constant. It is a simple calculation of determining its exit temperature. But in the case of the air, its moisture content reduces as more and more moisture condenses onto the condenser pipes, therefore the mass flow rate reduces and a more substantial set of calculations is required.

4.2.2.1 Seawater:

The energy change of the seawater is equal to the amount of energy that is transferred from the condenser pipe wall to the seawater.

$$\Delta Q_{sw} = Q_{ccwp}$$

Equation 129

The equation governing the heat transfer of the seawater is the same as for the secondary heater but in this case the seawater flows from n+1 to n, thus:

$$T_{sw_1} = \frac{\Delta Q_{sw}}{m_{sw} cp_{sw}} + T_{sw_{n+1}}$$

From Equation 100; page 52

4.2.2.2 Air:

The air can experience two different types of cooling.

- Cooling without condensation occurs when the air is still warmer than its saturation temperature, and,
- Cooling with condensation occurs when air is cooled further after saturation.

The energy extracted from the air, and thus its energy change, is equal to the energy transfer from it to the condenser pipe.

$$\Delta Q_a = Q_{ccpa}$$

Equation 130

Cooling without Condensation:

While this cooling occurs no mass transfer takes place and both moisture and air cool.

$$\Delta Q_a = c_{p_a} m_{da}\left(T_{a_{n+1}} - T_{a_n}\right) + m_{da} r_n \left(h_{g_{n+1}} - h_{g_n}\right)$$

Equation 131

$$\text{Thus: } T_{a_{n+1}} = \frac{\Delta Q_a - m_{da} r_n \left(h_{g_{n+1}} - h_{g_n}\right)}{c_{p_a} m_{da}} + T_{a_n}$$

Here iteration will be needed to solve the equation since h_{gn+1} is dependant on T_{an+1}.

Cooling with Condensation:

Mass transfer does occur here along with the cooling of the moisture and the air. The equation can be divided into three sections: Cooling of the dry air, cooling of the moisture that remains in the air after the cooling and phase change of the moisture which condenses from its vapour form to the liquid form. This condensing moisture leaves the system since it drips from the piping into the desalinated water channel.

$$\Delta Q_a = c_{p_a} m_{da}\left(T_{a_{n+1}} - T_{a_n}\right) + m_{da} r_{n+1}\left(h_{g_{n+1}} - h_{g_n}\right) + m_{da}\left(r_n - r_{n+1}\right)\left(h_{f_{n+1}} - h_{g_n}\right)$$

Equation 132

Thus: $$T_{a_{n+1}} = \frac{\Delta Q_a - m_{da} r_{n+1}\left(h_{g_{n+1}} - h_{g_n}\right) - m_{da}\left(r_n - r_{n+1}\right)\left(h_{f_{n+1}} - h_{g_n}\right)}{c_{p_a} m_{da}} + T_{a_n}$$

Here iteration will be needed to solve the equation since h_{gn+1} is dependant on T_{an+1}.

5. FLUID TRANSFER SYSTEMS

Two fluid transfer systems can be distinguished in the plant, one being the duct system that transfers the air from the evaporator to the condenser and back. The other is the pipe system that transfers seawater from the pump station to the condenser and from the condenser to the secondary water heater. From the secondary water heater the seawater flows by gravity to and through the evaporator, thus no calculations are required for the seawater transfer from the secondary water heater to the evaporator.

5.1 Energy Transfers

These two transfer systems, one from the condenser to evaporator and another from the evaporator to the condenser, have no other purpose but to transfer the fluid mediums. They are assumed to be well insulated and thus adiabatic.

Assumption 13: Temperatures of the fluids transported through the transfer systems remain constant.

5.2 Fluid Flow

Both these systems and have pressure losses in the form of either friction loss or shock loss. Their flow properties can by calculated by the equations below.

5.2.1 Flow Rate:

$$V = Au$$

Equation 133

Where: A = Flow area inside duct/pipe (m^2)
V = Flow rate inside duct/pipe (m^3/s)
u = Flow velocity inside duct/pipe (m/s)

5.2.2 Mass Flow Rate:

$$m = V\rho$$

Equation 134

Where: m = Mass flow rate inside duct/pipe (kg/s)
ρ = Density of medium inside duct/pipe (kg/s)

5.2.3 Pressure Loss:

5.2.3.1 Friction Loss:

$$H_{fl} = \frac{f_{fl} l u^2}{2g(4R)}$$

Equation 135

Where: $f_{fl} = \left[-4\log\left(\frac{k}{3{,}71(4R)} + \frac{1{,}255}{R\sqrt{f_{fl}}}\right)\right]^{-2}$

Equation 136

And: $R = \frac{A}{P}$

Equation 137

Where: A = Flow area inside duct/pipe (m^2)
P = Periphery of duct/pipe (m)

5.2.3.2 Shock Loss:

Since the areas of the transfer systems remain uniform, shock loss will occur only when there is a change in the direction of flow, or when the fluid flows through a valve. For both cases the flow equation is applied.

$$H_{sl} = \frac{\sum Ku^2}{2g}$$

Equation 138

Where: H_{sl} = Head lose due to shock (m)
K = Shock loss coefficient

Change in direction occurs in two fashions in these systems, either by a 90° long radius bend or by a 45° bend. The K-value for these changes in direction is 0,6 and 0,4 respectively and the K-valve for a fully opened butterfly valve is 0,2.

In order to determine the total head loss (H_T) from one end of a transfer system the other the sum of the head loss due the friction and shock must be calculated.

$$H_T = H_{fl} + H_{sl}$$

Equation 139

6. FLUID PROPERTIES

As both seawater and air flow through the evaporator their temperatures change and they lose pressure from friction. Furthermore, the seawater's salinity increases as water evaporates and the water evaporated from the seawater increases humidity. All these cause changes in the properties of both the seawater and of the air. The following equations can be used to determine the instantaneous properties of the fluids. Note that although pressure has an effect on the thermal conductivity, viscosity and specific heat capacity of fluids, the effect is small and for calculation purposes it is ignored.

Assumption 14: Change in pressure has no effect on thermal conductivity, viscosity and specific heat capacity of fluids.

6.1 Seawater Properties

6.1.1 Dynamic Viscosity [28]:

$$\log_{10}\left(\frac{\mu_{20}}{\mu}\right)=\left[\frac{t-20}{t+109}\right]\left[A\left(1+a_1S+a_2S^2\right)+B\left(1+b_1S+b_2S^2\right)\left(t-20\right)\right]$$

Equation 140

Where: $\mu_{20}=1{,}002+c_1S+c_2S^2$

Equation 141

And: μ_{20} = Viscosity of solution as 20°C (kg/ms)
μ = Viscosity of seawater (kg/ms)
t = Seawater temperature (°C)
S = Salinity of seawater (g/kg)

With:

A = 1,372 20
a_1 = -0,001 015
a_2 = 0,000 005

B = 0,000 813
b_1 = 0,006 102
b_2 = -0,000 040

c_1 = -0,001 550
c_2 = -0,000 0093

6.1.2 Density [29]:

$$\rho = 10^3 \sum_{i=0}^{2} \sum_{j=0}^{2} b_{ij} T_i \left(\frac{2S-150}{150} \right) T_j \left(\frac{2t-250}{110} \right)$$

Equation 142

With: $T_0(x) = 1$

Equation 143

And: $T_1(x) = x$

Equation 144

And: $T_{r+1}(x) = 2xT_r - T_{r-1}$

Equation 145

Where: $\mathrm{x} = \left(\frac{2S-150}{150} \right)$ or $\left(\frac{2t-250}{110} \right)$

$$\text{And: } b = \begin{pmatrix} 3.972600 & -0{,}084913 & -0{,}005318 \\ 0{,}115079 & 0{,}002695 & 0{,}000682 \\ 0{,}0001109 & -0{,}000330 & -0{,}000011 \end{pmatrix}$$

6.1.3 Thermal Conductivity [31]:

$$\ln k = \ln(k_c + X) + \left(2{,}3 - \frac{G}{T} \right) \left(1 - \frac{T}{T_c + Y} \right)^{0{,}333}$$

Equation 146

With: $X = 0{,}0002S$

Equation 147

And: $Y = 0{,}03S$

Equation 148

And: $G = 343{,}5 + 0{,}37S$

Equation 149

Where: T = Temperature of seawater (K)
T_c = Critical temperature of distilled water = 647 K
k_c = Thermal conductivity of distilled water = 0,240 W/mK

6.1.4 Specific Heat Capacity [32]:

The following equation is documented in the article "Physical Properties of Seawater Solutions: Heat Capacity" but the specific heat capacity it calculates does not correlate to the tabulated data as given in the same text.

$$cp = (a_1 + a_2 S + a_3 S) + (b_1 + b_2 S + b_3 S)T + (c_1 + c_2 S + c_3 S)T^2 + (d_1 + d_2 S + d_3 S)T^3$$

Equation 150

Where:

$a_1 = 5{,}328$ $b_1 = -6{,}913 \times 10^{-3}$ $c_1 = 9{,}6 \times 10^{-6}$ $d_1 = 2{,}5 \times 10^{-9}$

$a_2 = -9{,}76 \times 10^{-2}$ $b_2 = 7{,}351 \times 10^{-4}$ $c_2 = -1{,}927 \times 10^{-6}$ $d_2 = 1{,}666 \times 10^{-9}$

$a_3 = 4{,}04 \times 10^{-4}$ $b_3 = 3{,}15 \times 10^{-6}$ $c_3 = 8{,}23 \times 10^{-9}$ $d_3 = -7{,}125 \times 10^{-12}$

Although the specific heat capacity of seawater changes with variation in concentration and temperature the change is small. There is only a 1,4% increase in the specific heat capacity of seawater, of normal concentration, between a temperature of 0°C and 100°C. The salt concentration increase in this system is less than 5g/kg, which causes only a 0,7% change in specific heat capacity at 20°C.

The specific heat of the seawater is fixed to 4,006kJ/kgK, which is about a value average for this plant.

Assumption 15: The specific heat capacity of the seawater is constant at 4,006 kJ/kgK.

6.2 Air Properties

The air contains moisture and this water vapour content changes its properties. The properties of the dry air's and the vapour are calculated separately and then combined to determine their collective properties. In the case of specific heat capacity, which is a mass dependent property, the combined effect of the air and vapour is determined by calculating the respective specific heat at a given temperature then adding these according to their mass contribution. Similarly their combined thermal conductivity and dynamic viscosity is determined. But instead of using their mass fraction as a basis for their combined property their Mol fraction is used since these properties are independed on mass.

Assumption 16: The combined properties of the air and the moisture it contains can be calculated by adding their respective properties according to their mass contribution in the case of specific heat capacity and by their mol fraction in the case of thermal conductivity and dynamic viscosity.

To set up a temperature dependant equation for determining the thermal conductivity, specific heat and dynamic viscosity respectively, a spreadsheet was created of tabulated data, as documented in Heat Transfer by Holman [23] and Thermodynamic and Transfer Properties of Fluids [30] and a graph was drawn to fit these data points.

6.2.1 Thermal Conductivity:

$$k_{ma} = N_{fv}k_v + N_{fda}k_{da}$$

Equation 151

Where: $k_{da} = 7{,}58\times10^{-8}T + 3{,}479\times10^{-6}$

Equation 152

And:

$$k_v = -3{,}767616\times10^{-14}T^3 + 1{,}247242\times10^{-10}T^2 + 3{,}184034\times10^{-9}T + 7{,}678236\times10^{-6}$$

Equation 153

And: $N_{fv} = \dfrac{N_v}{N_v + N_{da}}$

Equation 154

And: $$N_{fda} = \frac{N_{da}}{N_v + N_{da}}$$

Equation 155

Where: k_{ma} = Thermal conductivity of moist air (kW/mK)
k_{da} = Thermal conductivity of dry air (kW/mK)
k_v = Thermal conductivity of vapour (kW/mK)
N_{fv} = Mole fraction of vapour in air
N_{fda} = Mol fraction of dry air
T = Temperature at which properties is determined (K)
N_v = Mol quantity of water vapour (Mol)
N_{da} = Mol quantity of dry air (Mol)

6.2.2 Dynamic Viscosity:

$$\mu_{ma} = N_{fv}\mu_v + N_{fda}\mu_{da}$$

Equation 156

Where: $$\mu_{da} = 7{,}58 \times 10^{-8} T + 4{,}745 \times 10^{-6}$$

Equation 157

And: $$\mu_v = 1{,}299155 \times 10^{-12} T^2 + 3{,}872699 \times 10^{-8} T - 2{,}390839 \times 10^{-6}$$

Equation 158

Where: μ_{ma} = Dynamic viscosity of moist air (kg/ms)
μ_{da} = Dynamic viscosity of dry air (kg/ms)
μ_v = Dynamic viscosity of water vapour (kg/ms)

6.2.3 Specific Heat Capacity [32]:

$$cp_{ma} = m_{fda}cp_{da} + m_{fv}cp_{fv}$$

Equation 159

Where: $$cp_{da} = 3{,}542857 \times 10^{-7} T^2 - 1{,}626857 \times 10^{-4} T + 1{,}021769$$

Equation 160

And: $cp_v = -5.103046 \times 10^{-10} T^3 + 1{,}252416 \times 10^{-6} T^2 - 3{,}165154 \times 10^{-4} T + 1.861896$

Equation 161

And: $m_{fv} = \dfrac{m_v}{m_v + m_{da}}$

Equation 162

And: $m_{fda} = \dfrac{m_{da}}{m_v + m_{da}}$

Equation 163

Where: cp_{ma} = Specific heat capacity of moist air (kW/mK)
cp_{da} = Specific heat capacity of dry air (kW/mK)
cp_v = Specific heat capacity of water vapour (kW/mK)
m_{fv} = Mass fraction of vapour in air
m_{fda} = Mass fraction of dry air
m_v = Mass flow rate of moisture in air (Mol)
m_{da} = Mass flow rate of dry air (Mol)

6.2.4 Moisture Concentration:

$$c_{ma} = c_{sat} RH$$

Equation 164

Where: $c_{sat} = \dfrac{p_{sat}}{R_w T}$

Equation 165

And: c_{ma} = Moisture concentration of moist air (kg/m^3)
c_{sat} = Moisture concentration of moist air at saturation (kg/m^3)
R_w = Partial pressure of the water vapour (Pa)

6.2.5 Density of Moist Air:

$$\rho_{ma} = \frac{p - p_v}{0,287035T}$$

Equation 166

With: ρ_{ma} = Density of moist air (kg/m3)

6.2.6 Diffusivity of Vapour in Air [23]:

$$D = 435,7 \frac{T^{\frac{3}{2}}}{p\left(V_a^{\frac{1}{3}} + V_w^{\frac{1}{3}}\right)^2} \sqrt{\frac{1}{M_a} + \frac{1}{M_w}}$$

Equation 167

And: D = Diffusivity of vapour in air (cm^2/s)
V_a = Molecular volume of air
V_w = Molecular volume of water
M_a = Molecular mass of air
M_w = Molecular mass of water

6.2.7 Other Properties:

$$m_{ma} = m_{da} + m_v$$

Equation 168

With: $m_v = rm_{da}$

Equation 169

Thus: $m_{ma} = m_{da}(1 + r)$

Equation 170

Where: $r = \dfrac{0,62198 p_v}{p - p_v}$

Equation 171

With: $p_v = p_{sat} RH$

Equation 172

Where: $\ln(p_{sat}) = \frac{C_1}{T} + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 \ln T$

Equation 173

And: m_{ma} = Mass of moist air (kg)
r = Absolute humidity of moist air
p_v = Partial pressure of the water vapour (Pa)
p_{sat} = Saturation pressure (Pa)
RH = Relative Humidity

And:

$C_1 = -5{,}800\,220\,6 \times 10^{3}$
$C_2 = 1{,}391\,499\,3$
$C_3 = -4{,}864\,023\,9 \times 10^{-2}$
$C_4 = 4{,}176\,477\,8 \times 10^{-5}$
$C_5 = -1{,}445\,209\,3 \times 10^{-8}$
$C_6 = 6{,}545\,967\,3$

7. PROGRAMMING

7.1 Program Overview

The reader is referred to the last page of this chapter were a complete program sequence diagram can be found of the computer model developed using MathCad version 11.

The aim of the computer model is a program that will determine the required size of the secondary water heater, condenser and evaporator as well as the required mass flow rates and velocities of both the air and seawater.

The starting point of the program is the production rate of the plant as well as the temperature and humidity ranges of the plant, for these are the factors that will determine the plant size and required mass flow rate of the air. One other required specification is the temperature of the seawater at exit from the condenser as this determines its mass flow rate.

The program calculates:

1. Structural size for evaporator, secondary water heater and condenser
2. Required mass flow rate for seawater and air to achieve desired production rate
3. Thermal property changes of all fluids as they moves trough the system
4. Flow property changes of all fluids as they move through the system
5. Structural and fluid temperatures throughout the system
6. Energy and mass transfers throughout the system
7. Pump and fan power requirements

The continuous recalculation of thermal and flow properties and mass and energy transfers ensures a greater degree of accuracy.

The programme starts at 1 (as seen in Figure 20, below) and works its way through 2, 3 and 4 and finally back to 1. It thus follows the air flow, but runs opposite to the flow of the seawater.

In order to perform the program calculations the folowing boundaries need to be set.

1. Maximum and minimum temperature and humidity of the air
2. Minimum temperature of the seawater
3. Seawater temperature at exit from condenser

These sets of values are required, along with the plant's production rate, to calculate the mass flow rates of the air and water.

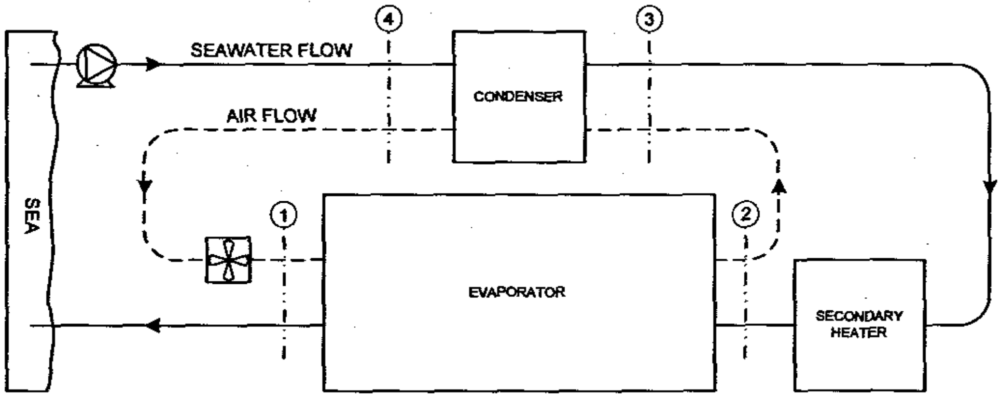


Figure 20: Flow diagram of desalination plant

The temperature and humidity of the air are at their minima at inlet to the evaporator (at 1) and at maxima at outlet (at 2). A specific evaporator size will be required to achieve this preset temperature change, for the bigger the size the more solar energy is absorbed. The preset maximum relative humidity is achieved by calculating the necessary air speed within the evaporator as the air speed is a major contributing factor to evaporation rate. The right air speed will ensure that maximum relative humidity be achieved just before exit form the evaporator, thereby preventing condensate from forming on the inner surface of the innermost glass panel, which would cause a drastic reduction in solar radiation entering the evaporator.

The minimum temperature of the seawater is also at 1. Since this value is known the required temperature of the seawater at inlet to the evaporator that will cause this exit temperature can be calculated.

The air speed inside the evaporator and the size of the evaporator will both contribute to what the temperature of the seawater must be when entering the evaporator. Hence the size of the evaporator, the air flow speed and the inlet temperature of the seawater must be calculated simultaneously.

At 2 the seawater temperature is at its maximum. Now both the seawater temperature at 2 and 3 is known and from the required temperature change the necessary size of the secondary water heater is calculated.

Next, the necessary size of the condenser, to reduce the temperature of the air down to its starting or minimum value, is calculated. From this calculation it is also determined what seawater mass flow rate is required.

The pressure losses of both seawater and air are calculated throughout the system and from this the program finally calculates the power requirements of the pumps and fans.

7.2 Programme Break Down

The program can be broken up into the groups of steps listed below.

1. Define overall constants
2. Evaluate evaporator
3. Evaluate secondary water heater
4. Evaluate condenser
5. Determine power requirements
6. Program output and manual redefinition

Each of these is explained in more detail on the next few pages by breaking them up further. In each case the relevant extracts from the program sequence is provided.

1. Define Overall Constants

a) Set production, ambient, structural, calculation and property constants as well as temperature and humidity ranges.

b) Set miscellaneous structural requirements (Features not calculated by program).

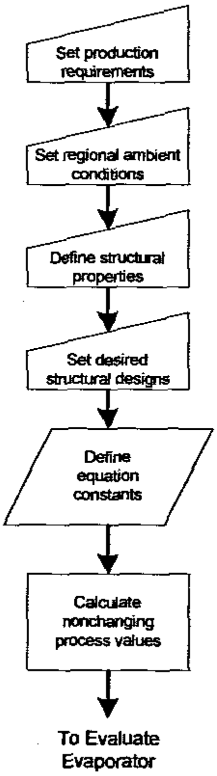


Figure 21: Program sequence extract – Define overall Constants

2. Evaluate Evaporator (Three Nested Loops)

a) Set starting values of main evaporator loop (air speed calculation).

  b) Set starting values of nested evaporator loop (length calculation).

    c) Set starting values of nested evaporator iteration loop (steady state calculations).

d) Calculated nested loop sequence.

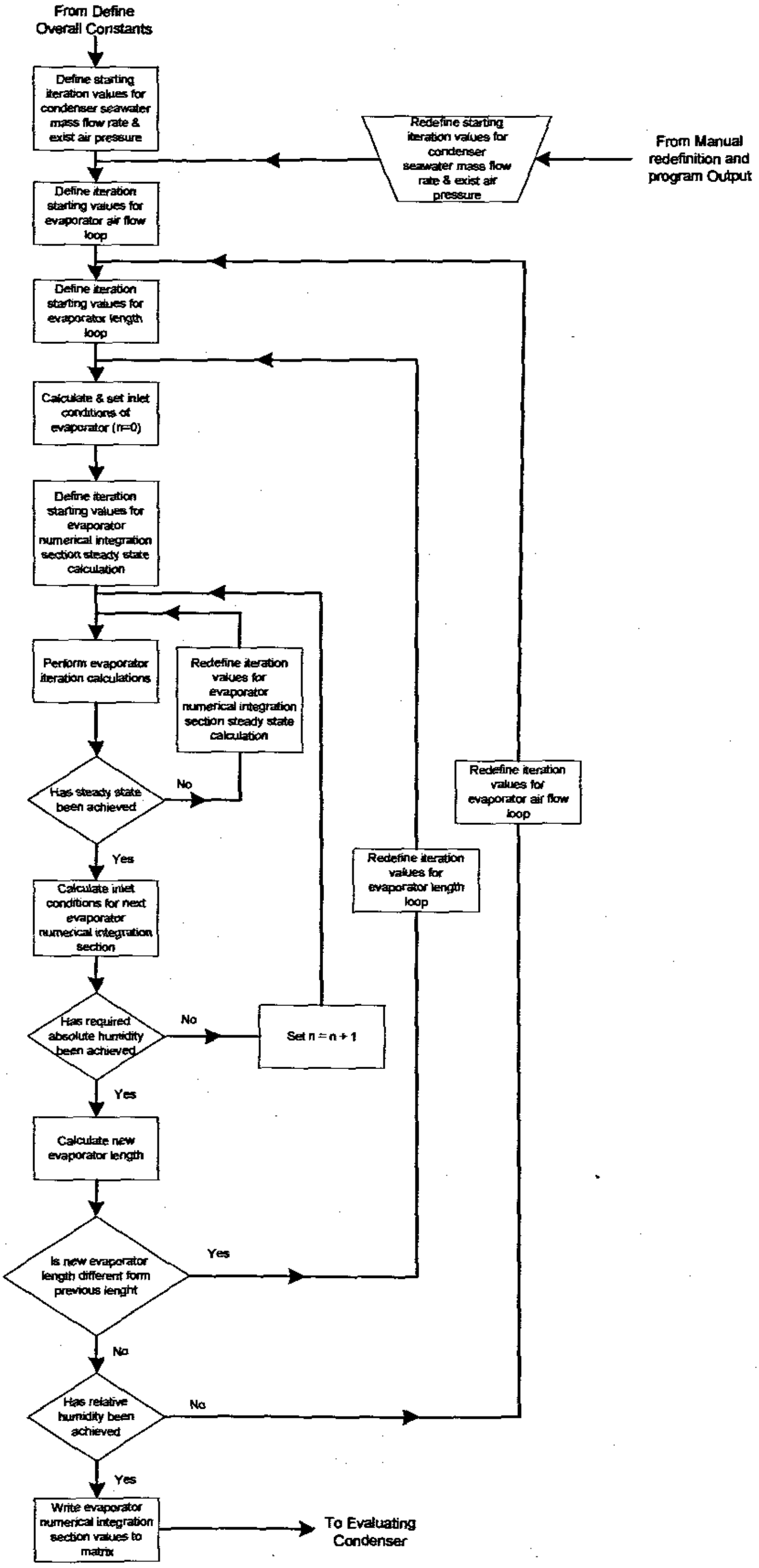


Figure 22: Program sequence extract – Evaluate evaporator

3. Evaluate Secondary Water Heater (Two Nested Loops)

a) Set starting values of main secondary water heater loop (length calculation).

   b) Set starting values of nested secondary water heater iteration loop (steady state calculation).

c) Calculated nested loop sequence.

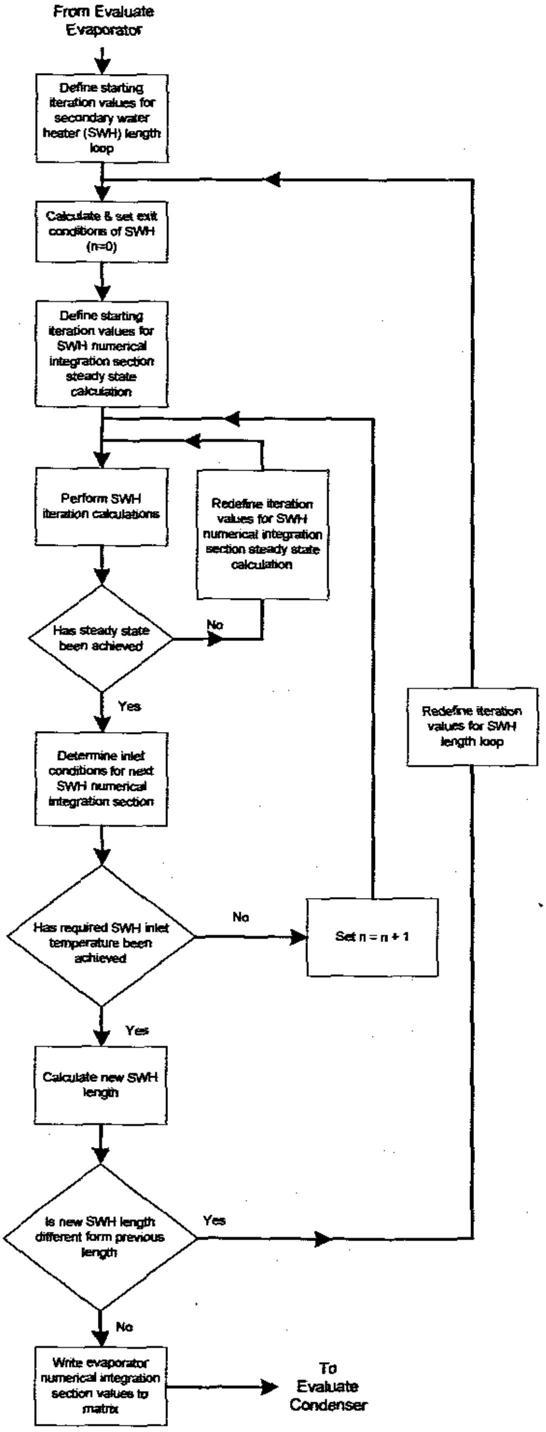


Figure 23: Program sequence extract – Evaluate secondary water heater

4. Evaluate Condenser (3 Nested Loops)

a) Set starting values of main condenser loop (seawater mass flow rate calculation).

b) Set starting values of nested condenser loop (length calculation).

c) Set starting values of nested condenser iteration loop (steady state calculations).

d) Calculated nested loop sequence.

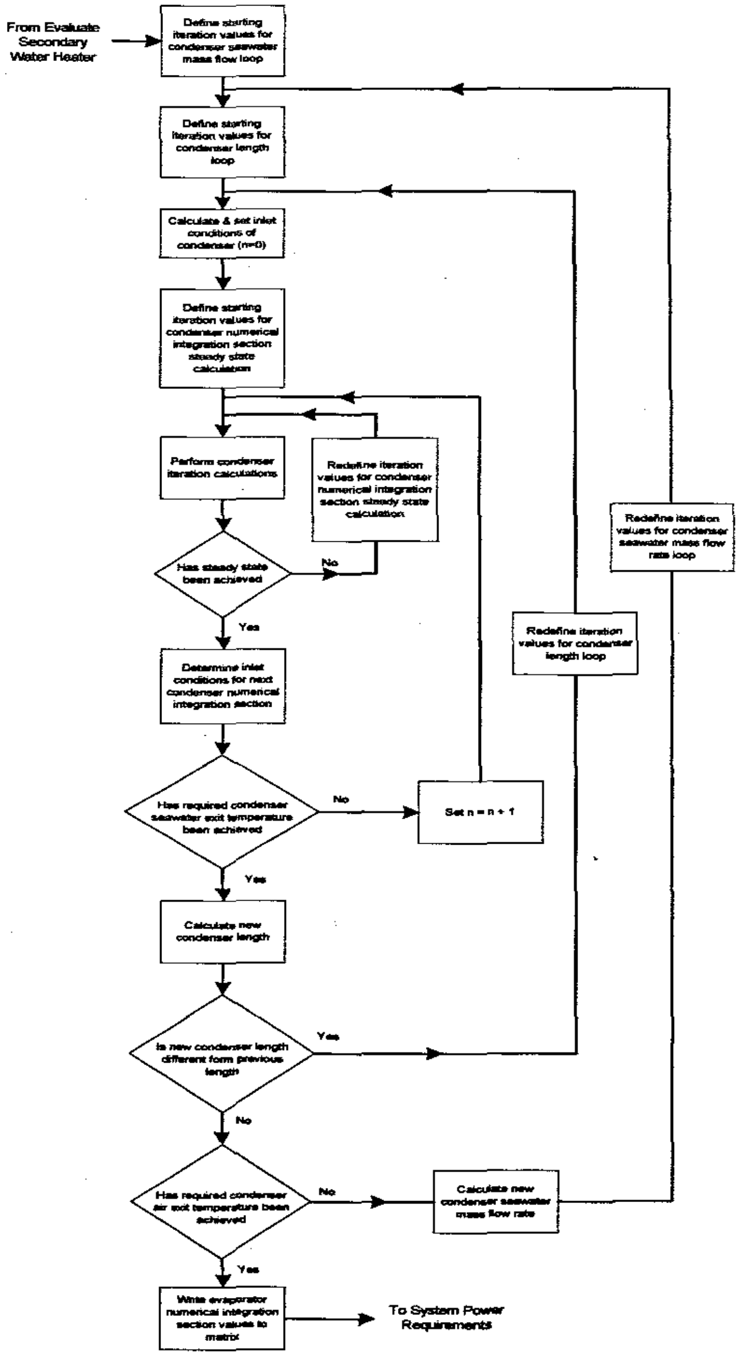


Figure 24: Program sequence extract – Evaluate condenser

5. System Power Requirements

From the seawater and air pressure losses calculate the power requirements of the pumps and fans.

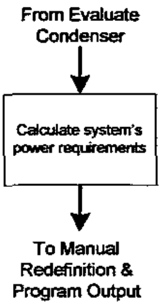


Figure 25: Program sequence extract – system power requirements

6. Manual Redefinition & Program Output

a) Manually redefine starting values of main evaporator loop and re-perform #2 to #6 until desired overall accuracy achieved

b) Write program outputs to a matrix and display it.

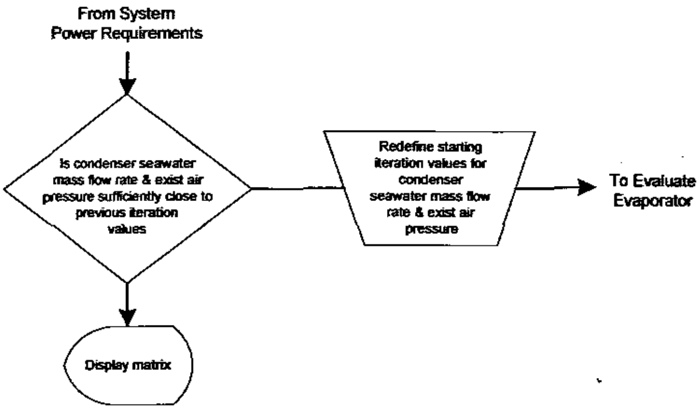


Figure 26: Program sequence extract – manual redefinition and program output

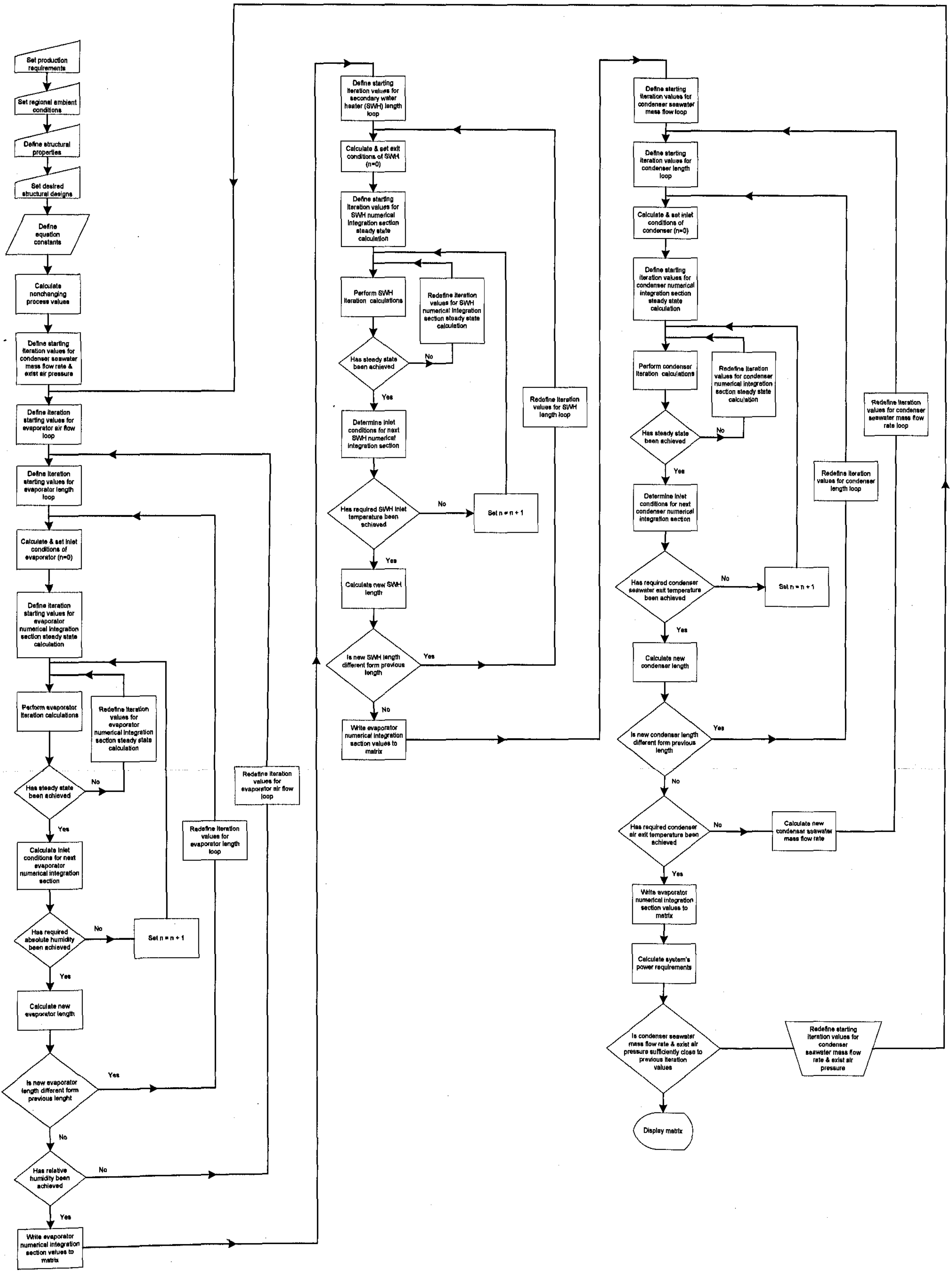


Figure 27: Program Sequence Diagram

8. CASE STUDY

8.1 Location

As mentioned in Section 1.2 this plant is ideal for coastal areas with cold sea currents, high solar radiation and mostly clear skies. Saldanha Bay, on the Western Coast of South Africa, is a typical example. It has, in its mid summer month of January, a maximum solar radiation of a little more than 1000 W/m^2 and an average of 800 W/m^2 for an 8 hour period from 9am until 5pm [34]. Its average ambient condition, for the same period, is 25°C, relative humidity of 10% and an onshore wind of 30 km/h. Its coastal seawater temperature is around 14°C.

In January Saldanha Bay's residential area requires 5000 m^3 of potable water a day. This is for all types of use by domestic consumers but excludes all industrial and commercial areas of the town In this particular scenario the plant is required to produce the required 5 000 m^3 of water in an 8 hour operation day. This would constitute, at average, a production rate of 173,6kg/s. Assuming the production rate to be proportional to incident solar radiation, the maximum production rate of the plant would need to be 217 kg/s.

Assumption 17: Production rate is proportional to incident solar radiation.

The miscellaneous structural requirements, such as glass panel thickness, width, number of condenser pipes, ect, of the evaporator, secondary water heater and condenser, as mentioned in section 7.2, are listed, where it is defined in the program listing in Appendix A.

8.2 Program Output

The following structural sizes, mass flow rates and electrical power are required, as determined by the program, in order to achieve this maximum production rate.

Evaporator Size:	1,871 km^2
Secondary Water Heater Size:	0,15 km^2
Condenser Length:	230m
Mass Flow Rate of Air:	1532 kg/s (dry air)
With Temperature Range:	15 °C at 100% RH to 60 °C at 98% RH
Mass Flow Rate of Seawater:	3164 kg/s
With Temperature Range:	14 to 65,5 °C
Fan Power Requirement:	1,08 MW
Pump Power Requirement:	286 kW
Electrical Power Consumption at Maximum Production:	1,75 kWh/m^3

In all, the program calculates a great deal of data concerning the design of the system and the Table 1 below contains the most important of these.

Note: As was mentioned in Section 1.4 the condenser can be improved, making its design more compact and cost effective but the seawater flow rate required to cool the air down will remain the same.

The size of the evaporator and secondary water heater is dependent on the thickness of the glass panels. The thicker the panel the less heat is lost through them to the atmosphere and, therefore, a smaller solar absorption area is required. In this scenario 50 mm thick glass panels were used, as they are good heat insulators, they are also very rigid therefore requiring less structural support than thinner glass.

Table 3: Program Output for Saldanha Bay System Design

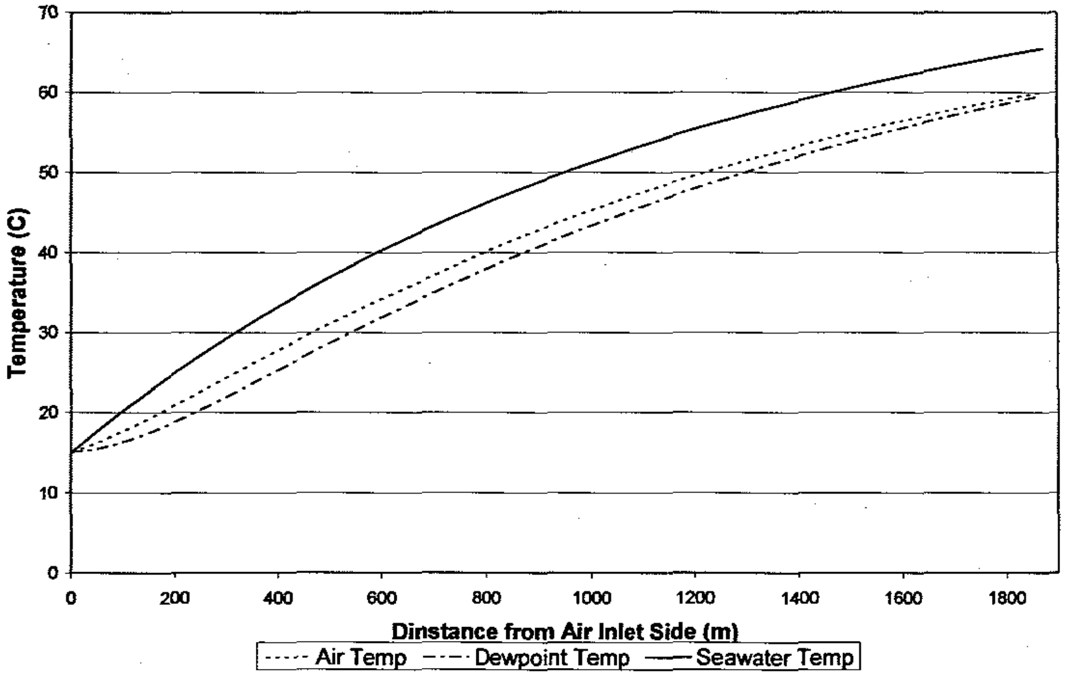
System Specifications		
Air	Temperature Range	15 - 60°C
	Relative Humidity Range	100% - 98%
	Pressure Change Over Fans	99,17 - 100 kPa
	Mass Flow Rate (Dry Air)	1531,8 kg/s
	% Recovery from Low Pressure Turbine	70 %
Seawater	Temperature Range	14 - 65,5°C
	Pressure Change Over Pumps	101,33 - 160,69 kPa
	Mass Flow Rate	3282,1 kg/s
	Salinity Change	30,2 - 32,8 g/kg
Evaporator		
	Length	1872m
	Width	1000m
	Inner Height	228 mm
	Slope	0,001
	Glass Panel Thickness	50 mm
	Air Gap Between Panels	10 mm
	Air Velocity at Inlet	6,1 m/s
	Seawater Velocity at Inlet	0,19 m/s
	Air Pressure Change (Inlet to Exit)	100 - 99,23 kPa
Secondary Water Heater		
	Length	311 m
	Width	500 m
	Inner Height	26 mm
	Slope	0,001
	Glass Panel Thickness	50 mm
	Air Gap Between Panels	10 mm
	Seawater Velocity at Inlet	0,25 m/s
	Seawater Pressure Change (Inlet to Exit)	105 - 101,33 kPa
Condensers		
	Length	249 m
	Inner Width	21,6 m
	Inner Height	8,65 m
	Number of Pipe Columns	50
	Number of Pipe Rows	20
	Distance Between Pipes	368 mm
	Pipe Diameter	65 mm
	Pipe Wall Thickness	1,5 mm
	Velocity of Air at Inlet	5 m/s
	Seawater Pipe Velocity	0,54 m/s
	Air Pressure Change (Inlet to Exit)	99,18 - 99,19 Pa
	Seawater Pressure Change (Inlet to Exit)	151,54 - 117,82 Pa

8.3 Output Graphs

A few of the more important graphs of the program output follow and a brief description of each is provided.

8.3.1 Temperature Change inside Evaporator

The graph below depicts the temperature change through the evaporator.



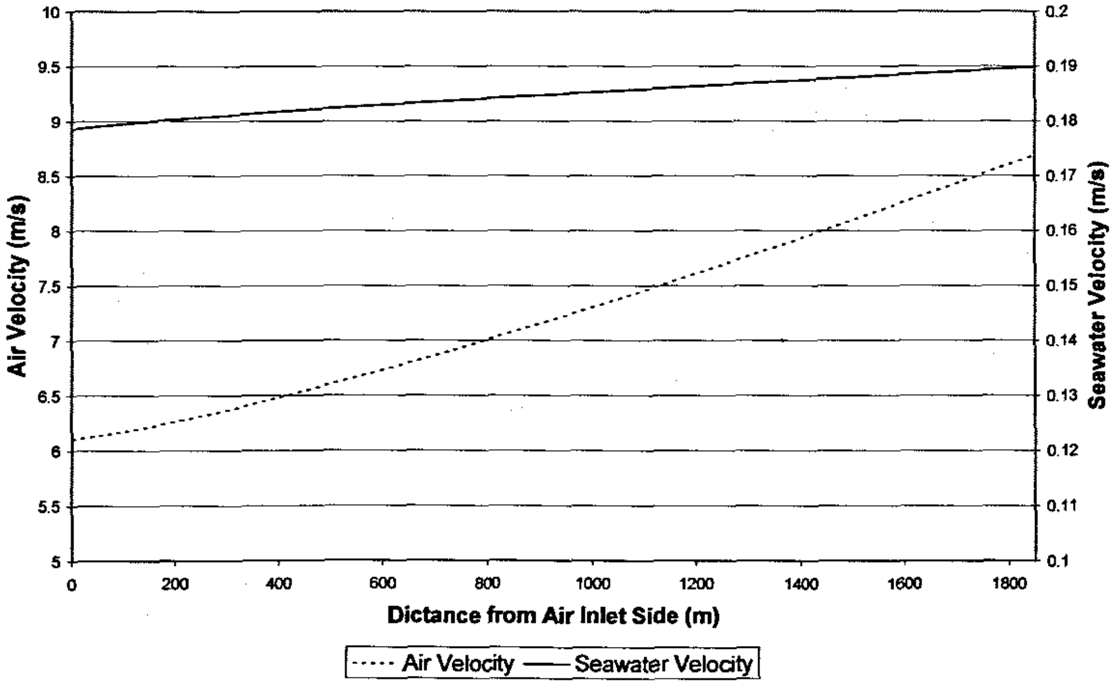
Graph 1: Temperature Change inside Evaporator

Initially the temperature of the seawater and air are almost the same and therefore there is a small change in the temperature of the air as it moves up the length of the evaporator. This rate of change increases as the temperature difference between air and seawater increases. As the air and seawater temperatures increases the temperature of the glass panels increases causing a greater energy loss back to the atmosphere. This is why the rate of temperature change of the air and seawater decreases, since less energy is available to cause temperature change. This loss of energy is helped by the increasing air velocity through the evaporator (see Section 8.3.2, page 91).

The third temperature line represents the dewpoint temperature of the air. Initially the two temperatures of the air and its dewpoint temperature are equal since the air is saturated when it enters the evaporator (relative humidity of 100%). One design requirement of the evaporator is that no condensation must form on the inner surface of its inner glass panel, since this would reduce the amount of solar radiation entering the system. As long as the dewpoint temperature line is below that of the air temperature line this would not happen. The average relative humidity of the air is approximately 92%. Except for the air inlet to the evaporator the highest relative humidity of the air will be at exit from the evaporator and is where the two lines are again close to one another for here the relative humidity is 98%.

8.3.2 Flow Velocities through the Evaporator

The graph below depicts the velocity change of both the air and water as it moves through the evaporator.



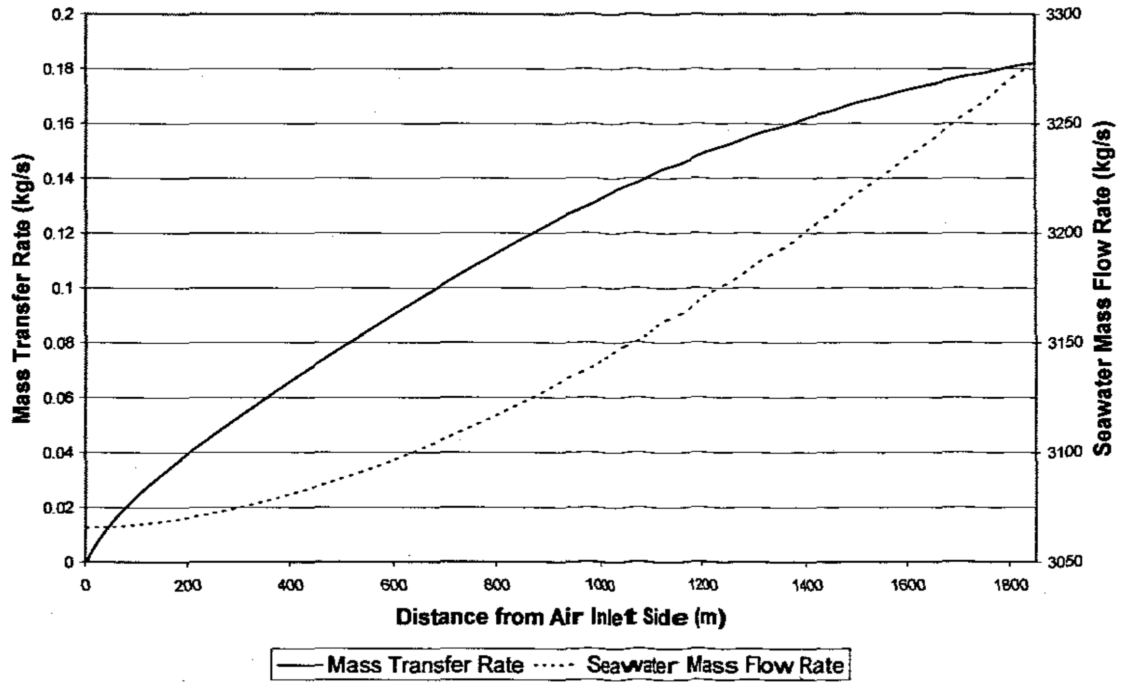
Graph 2: Flow velocities through evaporator.

As the temperature of the air increases its density decreases, thus its volume increases. The effect hereof is that the velocity at which the air travels through the evaporator increases.

The seawater velocity, on the other hand, decreases as it moves through the evaporator, in the opposite direction than that of the air, since its mass flow rate decreases as it evaporates.

8.3.3 Mass Transfer from and Mass Flow Rate of Seawater

The graph below depicts both the rate of mass transfer from (evaporation) and the mass flow rate of the seawater as it moves through the evaporator.

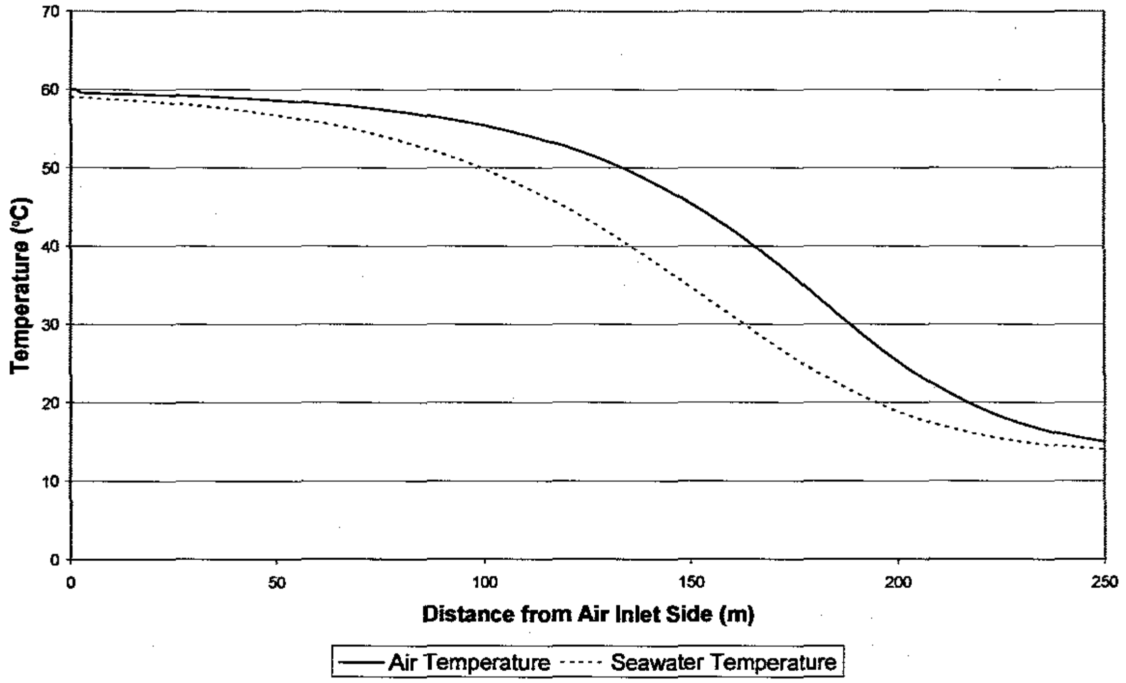


Graph 3: Mass transfer rate from and mass flow rate of seawater through the evaporator.

Mass transfer is dependent on the concentration difference between the mediums, which in turn are dependant on the medium's temperatures. Also mass transfer is dependent on the relative velocity between the two mediums. Initially there is very little difference in the temperature of the air and seawater. This gradually changes and with the increase in velocity of the air (see Section 8.3.2, page 91) the mass transfer rate from the seawater to the air increases. As the rate of change of the temperature of the seawater and air decreases and the humidity of the air increases the rate of change of the mass transfer also decreases.

8.3.4 Temperature Change through Condenser

The graph below depicts the temperature change of both the seawater and the air as they move through the condenser.

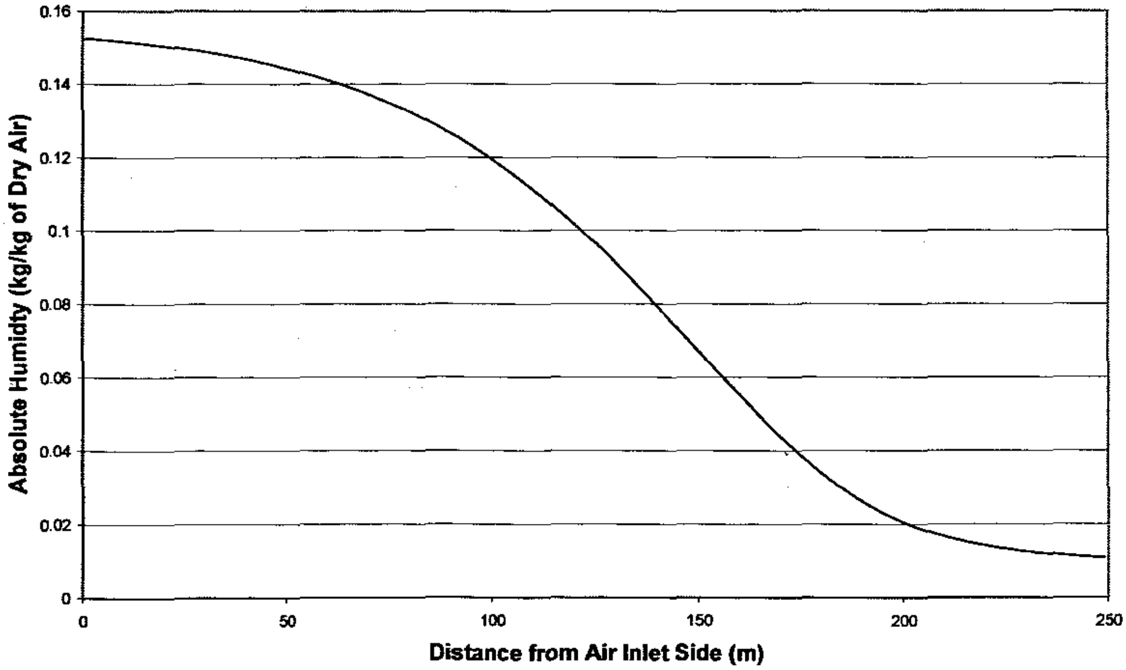


Graph 4: Temperature change through condenser

The air and seawater flow in opposite directions. Where the air enters and the seawater leaves the condenser the difference between their temperatures is small (about 1°C). This small difference results in little energy transfer. Initially the temperature change of the air is less than that of the seawater since the mass flow rate of the air is more than double that of the seawater and it contains a lot of moisture (approximately 153 g of moisture per kilogram of dry air). As the temperature of the air decreases, more of the moisture it contains condenses. Hence, because of a much larger specific heat of water than dry air, less energy needs to be extracted from the air to effect a similar temperature change. The effect of this is that the rate of temperature change of the air increases, not just because of a greater temperature difference between the two fluids but also because the moisture content of the air decreases. The closer the air gets to the outlet of the condenser the smaller the temperature difference between the air and seawater and thus the smaller the rate of change in the temperature of the air.

8.3.5 Absolute Humidity through Condenser

The rate of mass transfer from the air (condensation) is greatly dependent on the temperature difference between the air and on the pipe's surface temperature and thus on the temperature of the seawater inside the pipe. Thus, as the temperature difference increases so does the condensation rate and accordingly the rate of change of the humidity of the air. The absolute humidity of the air at exit from the condenser is not zero since the air still contains a little moisture, about 11g/kg of dry air.



Graph 5: Absolute humidity through condenser

8.4 Cost Evaluation

There are two possible applications for this particular plant, should it be privately owned. One would be to sell the water to a municipality who, in turn, could sell it for industrial, commercial or residential use. Another would be to bottle the water and sell it as an alternative to bottled spring water and as a supplement to the municipal supply. A marketing slogan could be "purer than rainwater" or "not even mother nature could make it this good". Should the national market be saturated the international market could be accessed.

The major difference between these two scenarios is the selling price. Currently the Saldanha Municipality buys water from the West Coast District Board's purifying plant at Withoogte at R2,53/m^3 and sells it for residential use at approximately R5,54/m^3 whereas Spar, a grocery chain store in South Africa, sells five litres of spring water at R20 a bottle which is equivalent to R 4000/m^3 [35].

Table 2, below, shows a much approximated cost estimation of the Saldanha Bay Desalination System. Since the energy cost of the plant would be zero, and it has few moving parts its maintenance cost should be low, therefore the required selling price per unit of water is determined by taking into consideration a capital expenditure recovery period of 20 years into consideration.

In order to simplify the calculation it is assumed the cost of building the evaporator is 80% of the entire cost of building the desalination plant for the evaporator is the largest and most complex of the structures.

Assumption 18: The evaporator carries 80% of the total cost of building the desalination plant.

Saldanha has an average solar radiation during the year of about 610W/m^2. According to Assumption 17; page 87 production rate of the plant is directly proportional to the incident solar radiation, thus the average daily production rate of the plant can be calculated as follows [34]:

$$P_{avg} = P_{\max} \times \frac{I_{avg}}{I_{\max}}$$

Equation 174

Where: P_{avg} = Average production rate (m^3/day)
P_{max} = Maximum production achieved during summer (5000m^3/day)
I_{avg} = Average incident solar energy (800W/m^2)
I_{max} = Maximum average daily incident solar energy (610W/m^2)

This calculates to about 3800m^3/day.

Table 4: Cost Estimation of Saldanha Desalination Plant

Evaporator Area (m^2)	1871000	
	Cost/m^2	
Steel	R 150.00	R 280,650,000
Glass	R 250.00	R 467,750,000
Foundation	R 100.00	R 187,100,000
Cost of Evaporator		**R 935,500,000**

Evaporator Cost Fraction of Total System Cost	80%
Total Cost Estimated Cost	R 1,169,375,000

Initial Capital Expenditure Recovery Period (yrs)	20
Average daily production (m^3/day)	3800
Required Selling Price per Cubic Meter	**R 33.70**
Required Selling Price per Liter	**R 0.03**

Looking at these values it is abundantly clear building this plant with the aim at selling the water it produces to a municipality is not economically sound. In order to recover initial capital expenditure in twenty years the desalinated water would have to be sold at R33,70/m^3. This is more than 6 times the value Saldanha Bay residents pay for water. On the other hand, should a national and/or international desalinated bottle water market sufficiently large exist able to absorb 3800 m^3 of water a day the plant would repay its initial capital investment in less than 12 months. This includes a bottling and distribution cost of half the production cost. Thereafter all the revenue generated, less that spent on maintenance, bottling, advertising, remuneration and distribution, becomes profit.

These are "ballpark" figures at best, thus an in depth investigation into techno-economic feasibility of the system is required for both municipal use as well as for application to the bottled market. The bottled market will dictate the production requirements of such a plant and this will impart on its feasibility.

Recommendation 1: Perform an indepth investigation into the techno-economic feasibility of this plant for municipal use.

Recommendation 2: Investigate whether or not a bottled water market exists that will justify building a plant, scale to fit market. This will have to include the marketability of the water.

9. MODELLING

9.1 Goal of Modelling

In order to verify if the computer modelling of the desalination system is accurate a pilot plant was built; although not a working model. It consisted only of the evaporator section, the heart of the plant. Since the secondary water heater works on much the same principles as the evaporator and the condenser is of the conventional shell-and-tube type, this focus was given only to the evaporator.

At inlet and outlet of the pilot plant a number of fluid properties were measured. The inlet data was then entered into the pilot plant program and its output compared to measurements taken at exit from the pilot plant evaporator.

Fresh water was used for these tests as it was easily come by, was less corrosive and did not have a salinity needing to be maintained.

9.2 Pilot Plant Description

The evaporator consisted of an 18m long and 1.8m wide solar absorption area, consisting of thin metal plates, with glass panels above them. The inner height of the evaporator (the distance between the glass panels and absorption area) is approximately 185mm. The evaporator rested on a metal frame structure. Between the metal frame structure and the evaporator was layer of wood (serving as a solid flat base) and a layer of Styrofoam (serving as heat insulation). On the sides the evaporator consisted of more thin plate covered by styrofoam.

On either end of the evaporator was a rectangular metal tank that serves a number of functions. Since there was no secondary water heater the water is artificially heated by means of heating elements in both tanks and the water was circulated from the water exit side back to the inlet side using a pump. The temperature inside the tanks was controlled by a temperature probe and controller. The tanks also ensured an evenly distributed flow onto and off of the absorption area.

They water ran down a slight slope while the air was sucked out of the evaporator by means of a fan.

The pump had a bypass system allowing the throttling of the water flow, whereas the fan is connected to a variable speed drive.

On either end there was a relative humidity sensor, a hot wire anemometer measuring air temperature and velocity and a temperature probe measuring water temperature. A flow meter inside the circulation pipeline measured water flow rate and a solar radiation sensor inside measured the solar incident radiation entering the evaporator.

A complete equipment specification list is included in Appendix D.

9.3 Test Procedure

All the measuring instruments, the two relative humidity sensors, two anemometers, to temperature probes and flow meter are connected to a computer that does real-time simultaneous data logging every five seconds.

The tests were preformed over a number of days in the following sequence. Five different water flow rate and four different fan velocity settings were selected. On test day one the first water flow rate setting and the first fan velocity settings was used. The test was preformed for half an hour after which the second fan velocity setting was used, the test preformed, and then the third and fourth fan velocity setting was used and each time test repeated. On the second day the second water flow rate set and the same set of test perform. This was repeated for five days, each day with a single water flow rate setting and four fan velocity settings.

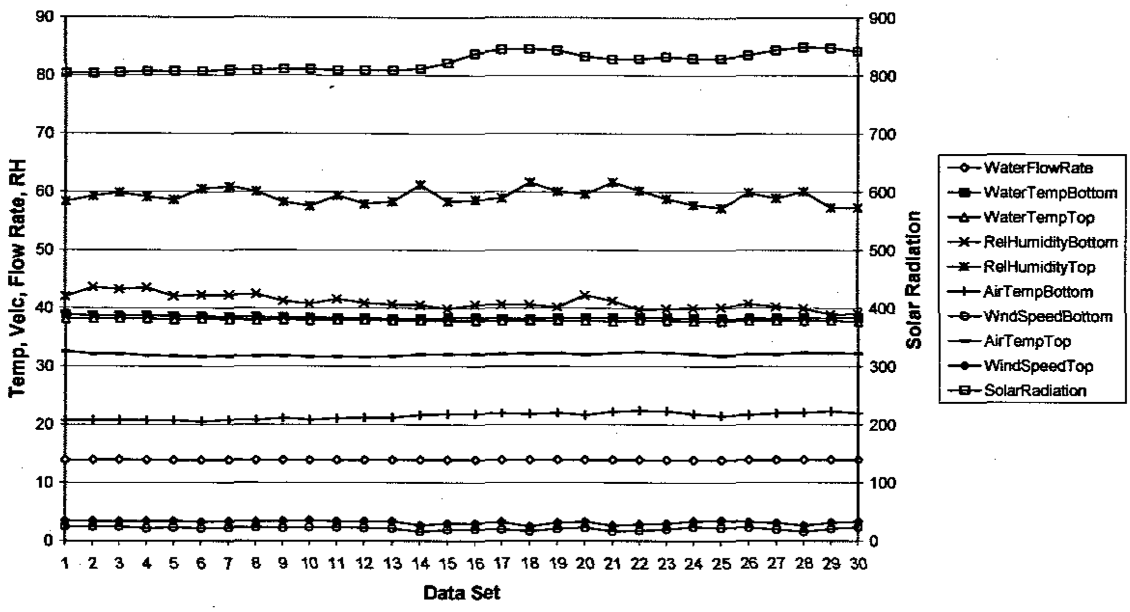
No testing was performed on windy days to limit the effect it will have on the energy lost through the structure of the evaporator.

Table 5: Test Scheduling.

Test Day	Pump Setting	Fan Setting
Day 1	1	1
		2
		3
		4
Day 2	2	1
		2
		3
		4
Day 3	3	1
		2
		3
		4
Day 4	4	1
		2
		3
		4
Day 5	5	1
		2
		3
		4

9.4 Data Analysis

The graph below is a typical example of the sets of data collected by each of the testes mentioned. In the half hour of testing in each of the tests about 300 data sets were collected, each set having the inlet and outlet temperature of both the air and water, the inlet and outlet velocity and relative humidity of the air, the flow rate of the water and the solar radiation all at the same point in time. In order to reduce the amount of data points in this particular graph the average of 10 consecutive points were calculated and plotted.



Graph 6: Data point plot of water flow rate setting 1 and fan speed setting 1.

The change in air temperature and humidity is highly dependent on the flow velocity of the air inside the evaporator since the energy and mass transfer from the water to the air is dependent on the flow velocity. Each time a new fan speed was set (thus a new test started) the system found a new equilibrium (new equilibrium reached in approximately 3 minutes). The higher the fan speed, the lower were the equilibrium temperatures of both air and water, since the mass flow rate of the air increased.

9.5 Modelling Program

A program was prepared especially for the pilot plant. It operated on exactly the same principles as that of the main program. The only difference between the two is the modelling unit contained the evaporator part only. To further specialise, the pilot plant program the structural dimensions and properties unique to the pilot plant were defined and implemented.

Since the program operated on the same principle as the evaporator part of the main program an explanation and breakdown of it was not provided. However, the pilot plant program listing is included in Appendix C.

The flow properties, relative humidity, flow velocity and water and air temperatures, at air inlet to the evaporator was fed into the program which then calculate all the flow properties at air exit to the evaporator and displayed the most important. The evaluation of the program could now be preformed by comparing the actual data at exit to that calculated by the pilot plant program.

9.6 Program Evaluation

Each of the following flow properties was evaluated by comparing actual data at outlet from the evaporator to that calculated by the pilot plant program:

1. Air temperature at exit from evaporator
2. Seawater at inlet to evaporator (same side as air inlet)
3. Relative humidity at exit from evaporator

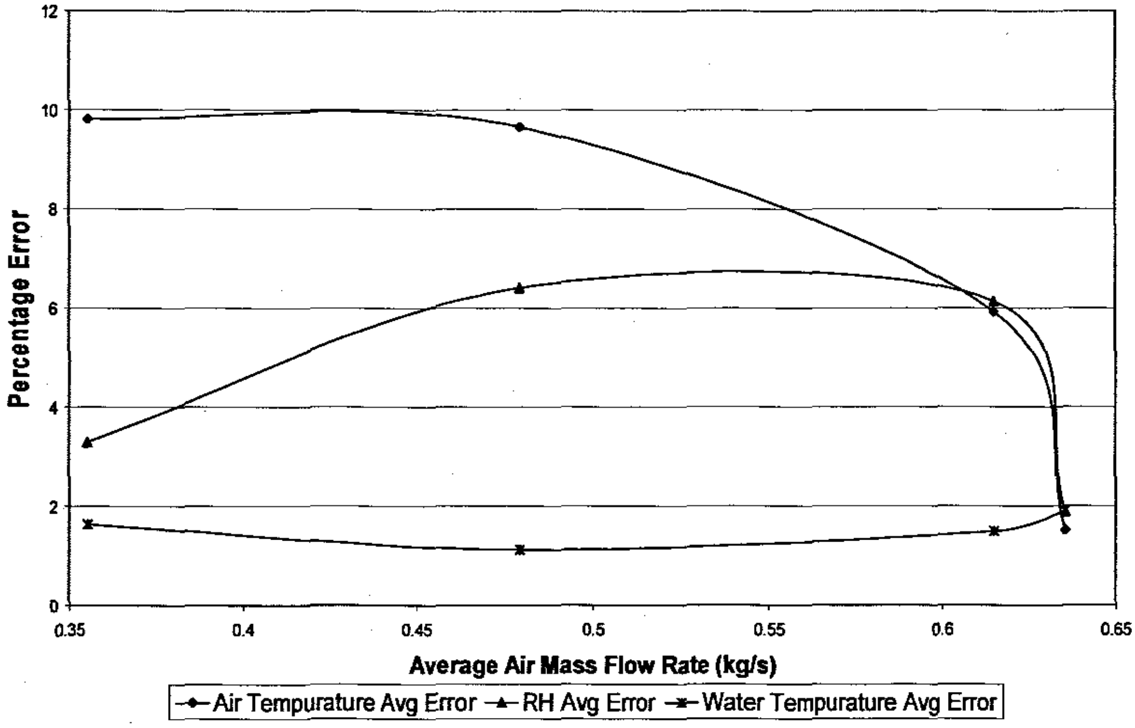
In order to calculate an average discrepancy between the calculated and actual data the following equation was employed.

$$\%_{inaccurate} = \frac{\sum_{1}^{i=D} \left| \frac{Actual_i - Calculated_i}{Actual_i} \right|}{D} \times 100$$

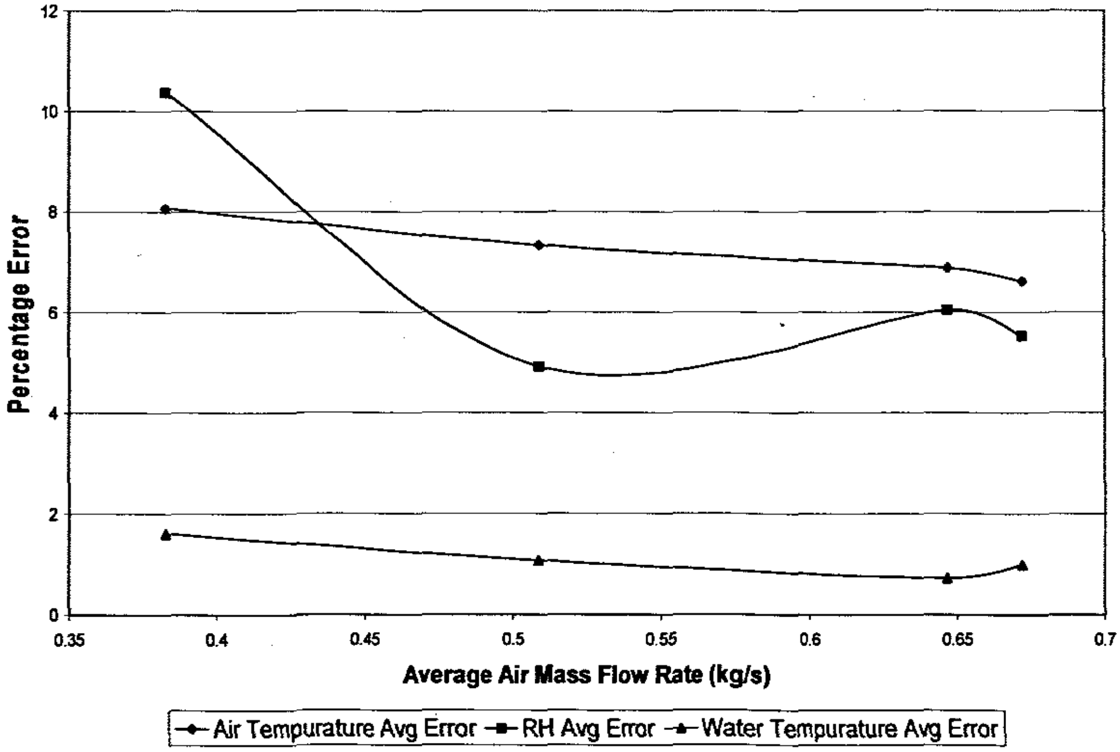
Equation 175

Where: D = Number of data sets in each test
Actual = Actual measured flow properties at exit to evaporator
Calculated = Calculated flow properties at exit to evaporator

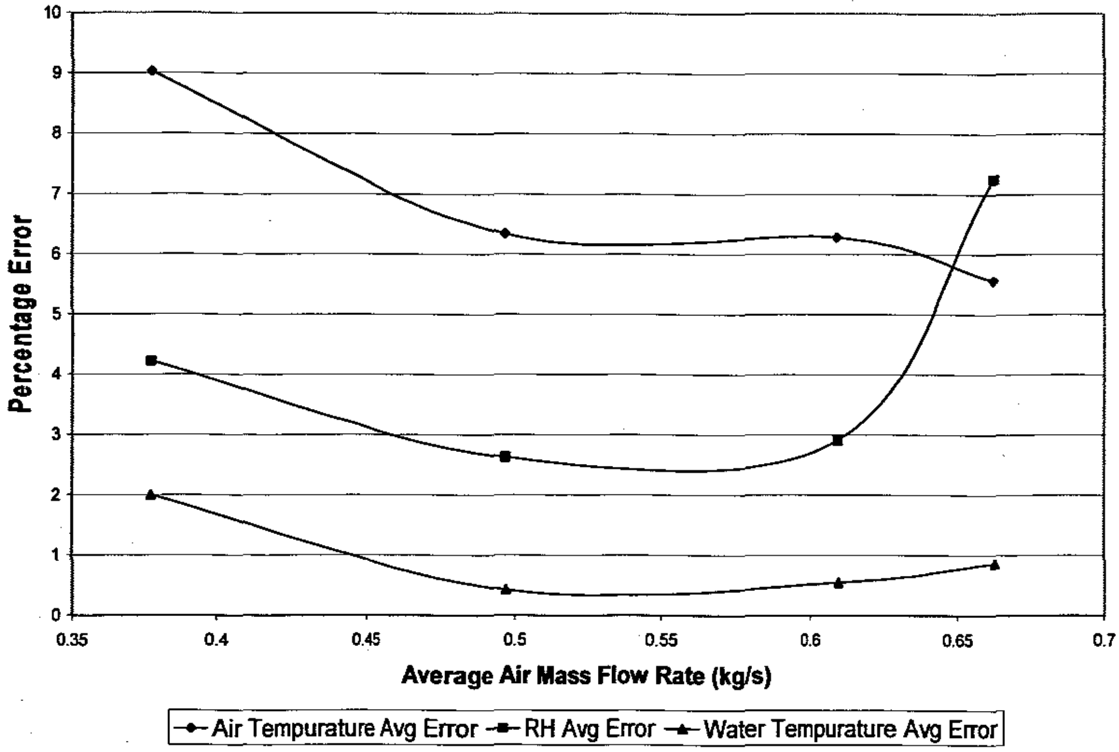
Graphs 7 - 11 depict the percentage discrepancy between the actual air temperature, water temperature and relative humidity as measured during testing and that calculated by the pilot plant program. The discrepancies were calculated using Equation 175.



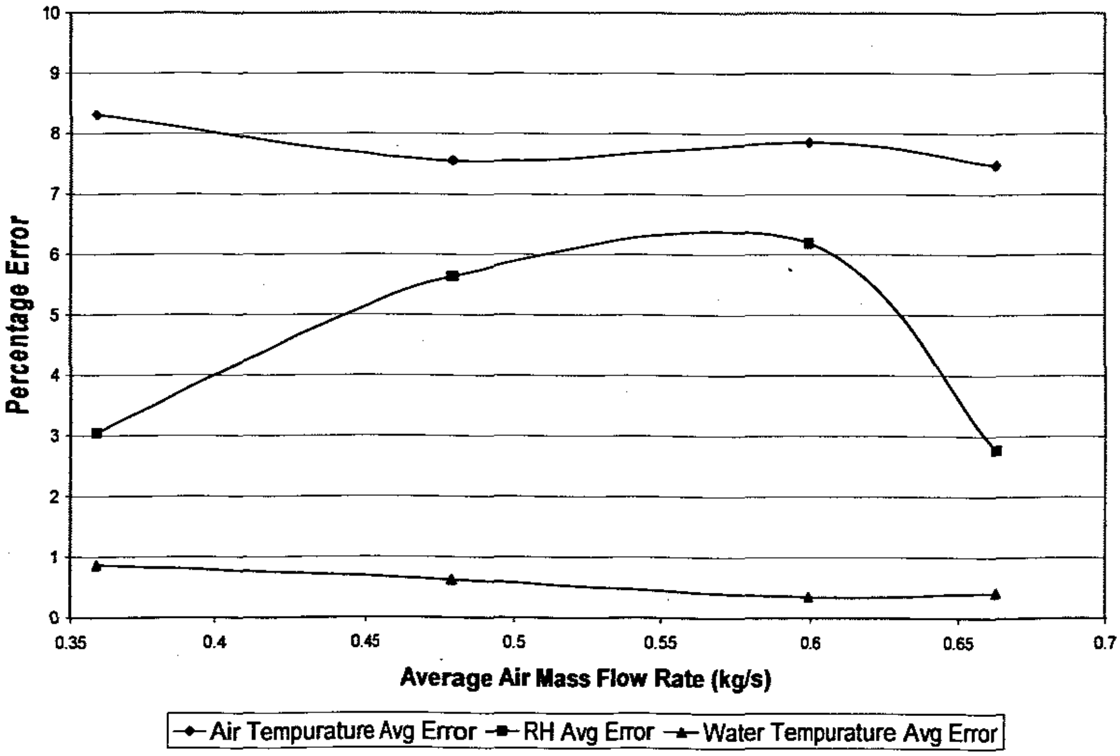
Graph 7: Error graph of test 1– Average percentage error verses air mass flow rate (average mass flow rate of water 2,45kg/s)



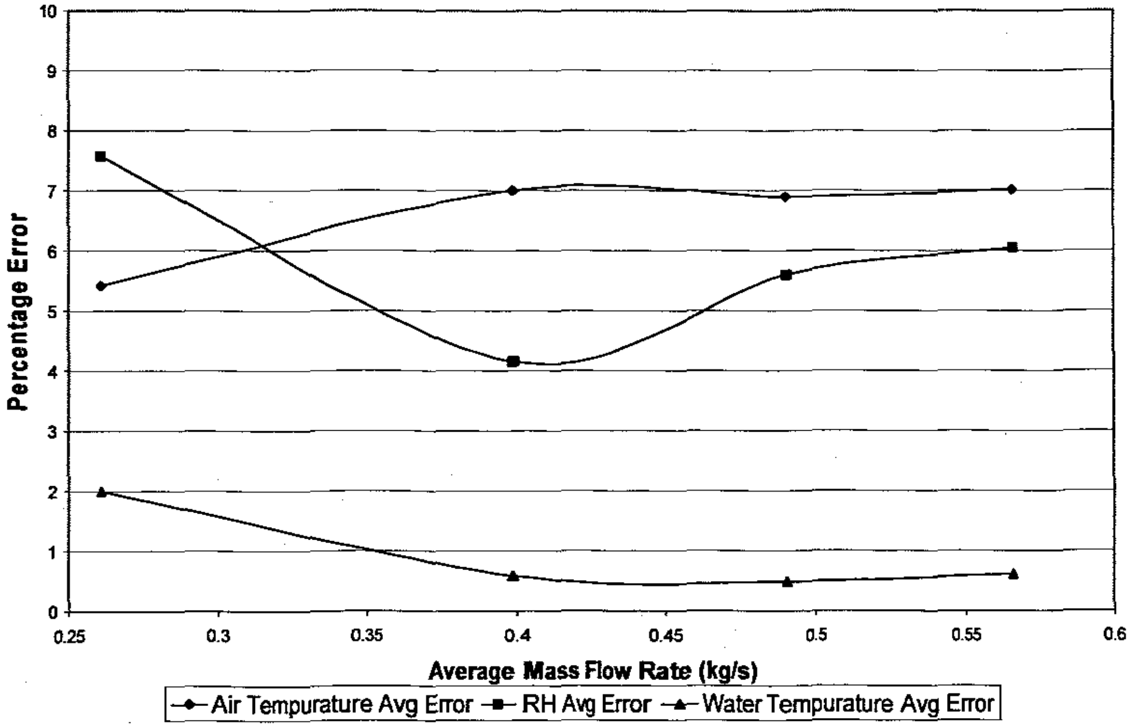
Graph 8: Error graph of test 2 – Average percentage error verses air mass flow rate (average mass flow rate of water 3,2kg/s)



Graph 9: Error graph of test 3 – Average percentage error verses air mass flow rate (average mass flow rate of water 4,19kg/s)



Graph 10: Error graph of test 4 – Average percentage error verses air mass flow rate (average mass flow rate of water 4,89kg/s)



Graph 11: Error graph of test 5 – Average percentage error verses air mass flow rate (average mass flow rate of water 5,36kg/s)

In all the program evaluations the water temperature accuracy was within 98% and in some cases more than 99% accurate. The air temperature and relative humidity on the other hand was less accurate, within 89%, although their percentage errors fluctuated within this 11% of discrepancy.

There seemed to be no apparent relation between the discrepancies; there are three major categories of possible reasons for the discrepancy. One was the inaccuracy of the test equipment, another errors from the structural design and assumption regarding the pilot plant. Finally, the inaccuracy of, or the application of empirical equations, where they are not best suited. Each of these is discussed briefly below.

9.6.1 Accuracy of Measuring Equipment

The PT 100 temperature sensors and the Akron magnetic flow sensors used to measure the temperature of flow rate of the water are known for their accuracy, whereas the hot-wire anemometer and humidity sensor are not so accurate. Both have a claimed accuracy of only 5%. This problem is easily solved buying more reliable and better test equipment, but these are exceedingly expensive and hard to find.

All the measuring instruments were connected to a computer in order to be able to log their readings simultaneously. Because of the length of the pilot plant, 18m, this data had to be transferred over a significant distance via data cables. Although these data cables had twisted pair and woven screening the data was still subjected to sewer noise from nearby high power machinery. This may have affected the data.

9.6.2 Structural Design and Assumption Error

In order to simplify the problem of simulating the pilot plant using a computer model some assumption were made. The biggest are that there was no energy loss through the sides and bottom, or through the metal structure of the pilot pant. However, energy loss through the glass panels was taken into consideration. Part of the structure, painted black, was lit by sunlight and accordingly absorbed energy, but the largest part of the structure was shaded and thus energy lost through it.

9.6.3 Error due to Empirical Equations

Although empirical equations are fairly accurate they are not perfect. These equations were developed under strict experimental procedures. The equations are often suited for those conditions only. Due to the lack of alternative equations some empirical equations, such as the mass transfer equation, had to be implemented where it was not best suited. This particular equation was developed form flat plate boundary layer analogy but waves form on the water from airflow. Furthermore the Reynolds Number used in this equation was suited best when only one fluid was in motion. But here, both the air and water were in motion. The same applied to heat transfer equations for the heat transfer between the water and air.

The structure of the evaporator also had an effect on these equations. Flat plant boundary layer analogy was also used to derive the equations to calculate the heat transfer between air and the glass panels. Although the glass panels are flat they are supported, from below, using mild steel tubing. These tubings causes obstructions in the flow of the air and changed its flow patterns from that of a flat plate.

It is believed errors caused by empirical equations and their unsuitable applications were the major cause for the inaccuracies between measured values and the calculated ones.

Recommendation 3: **Investigate the flow of the to fluids inside the evaporator, condenser and secondary water heater in order to produce more accurate empirical equations to calculate mass transfers, heat transfers and pressure losses.**

10. CONCLUSIONS

10.1 The plant is technically feasible (Chapters 2 to 8). This was proven by developing a computer model that employed the essential mass and energy transfer equations and the principles of mass and energy conservation.

10.2 The computer model of plant simulates its performance accurately (Chapter 9). This was proven by building a pilot of the evaporator and performing test thereon. It was found that the computer model is accurate to within 10%. Thus when used together in this application the error in the heat and mass transfer equations is less than 10%.

10.3 It was found, using the computer model, that the plant would require 1,75 kWh/m^3 of potable water produced. This is up to 13,4 times less electrical energy than the Multi-stage Flash system requires and 3,1 times less than conventional reverse osmosis systems, proving that the plant under investigation requires significantly less electrical power than the two systems currently dominating the market (Chapter 8). Thus, when considering energy costs, low temperature evaporation is better than high temperature evaporation.

10.4 Production rate of this plant is proportionate to the size of the evaporator. Thus, the plant can be sized to fit the specific demand of region it supplies potable water too.

10.5 This low power requirement and the fact that the plant would be in operation only during daytime ensures its electricity needs can be provided using photovoltaic cells. Although these are expensive they require remarkably little maintenance and are extremely durable. Also, recent technological advances in the field will result in more efficient PV's being commercially available in the near future [36].

10.6 The capital investment required to build this plant is, however, very high. It is believed, with the current cost of municipal water, the plant capital cost would make it unsuitable to provide water for domestic and industrial or commercial use (Chapter 8). The capital cost of the plant could however be reduced significantly by using more cost effective materials (see Recommendations).

11. RECOMMENDATIONS

11.1 Technical Recommendation

- Investigate the flow of the fluids inside the evaporator, condenser and secondary water heater in order to produce more accurate empirical equations to calculate mass transfers, heat transfers and pressure losses (Recommendation 3, page 107). This will greatly improve the accuracy of the computer model. It will also simplify the process of developing an accurate automated control system for the plant.

11.2 Economic Recommendations

- Perform an in depth investigation into the techno-economic feasibility of this plant for bulk water supply use (Recommendation 1, page 97). This would show whether or not this specific plant design and process justifies further research into the operation and development of a fully operational desalination plant operating on the principle discussed within this document.

- High quality water can be bottled and marketed. The advantage; bottled water can be sold to consumers at a profit margin as much as a 1000 times higher that the same water could be sold for municipal reticulation. Thus, investigate whether or not a bottled water market exists that will justify building a plant, scaled to fit the market (Recommendation 2, page 97). This will have to include the marketability of the water. 3

- The hiogh purity water could be used in beverage production, eg: niche market beer. Investigate if such a market exsits.

- The seawater exiting the evaporator has an increased salt concentration. This water would normally flow back into the sea. Investigate the possibility of using it as feedstock for the production of salt (NaCl) for domestic and industrial use.

11.3 Design Recommendation

- Clear, durable, though plastic could be an alternative to using double glazed glass. This could greatly reduce the capital cost of the plant, but will have a significant effect on the size of the evaporator and secondary heater. Investigate the effect hereof on the evaporator and secondary heater structural design and size. Then re-evaluate the economic feasibility of the plant.

- The base or floor of the evaporator and secondary water heater would not be large load carrying structures. Investigate alternative materials to concrete, such as bitchimen, to reduce the capital cost of plant.

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APPENDIX A

Computer Model

Program Listing

(Font scaled to fit one page width)

General Information:

Duration of Daily Operation: $\underset{\sim}{day} := 8 \cdot hr$

Average Rate of Water Production Required: $m_{wavg} := 5 \cdot 10^6 kg \cdot day^{-1}$

Maximum Solar Radiation: $E_{max} := 1000 \cdot W \cdot m^{-2}$ (approximate)

Average Solar Radiation: $E_{avg} := 800 \cdot W \cdot m^{-2}$ (approximate) ***NOTE: Average Solar Radiation calculated over a span of 8 hours.***

Maximum Rate of Prodaction: $m_{wmax} := m_{wavg} \cdot \frac{E_{max}}{E_{avg}}$

NOTE: Maximum production calculated by the increase in solar radiation from average to maximum.

Ambient pressure: $p_{atm} := 101325 Pa$

Density of seawater at 25degs: $\rho_{sw25} := 1027 kg \cdot m^3$

Density of water at 25deg: $\rho_{w25} := 995.512 kg \cdot m^3$

Wave Factor: $\upsilon := 1.2$

Elavation of Inlet Above Sealevel: $z_{sl} := 10m$

% Recovery of Seawater Exit Head: $\eta_{wts} := 70\%$

Accuracy of Loops: $\underset{\sim}{\Omega} := 0.000005$ or $A := 0.01\%$

Water Properties:

Emisivity: $\varepsilon_w := 0.96$

Concrete Properties (Painted Black):

Emisivity: $\varepsilon_c := 0.8$

Absorbtivity: $\alpha_c := 0.9$

Density: $\rho_c := 0.1$

Roughness: $k_c := 550 \cdot 10^{-6} m$

Condesor Pipe Properties:

Roughness: $k_{cp} := 100 \cdot 10^{-6} m$

Conductivity: $kc_{cp} := 54 W \cdot m^{-1} \cdot K^{-1}$

Ambient Conditions:

Relative Humidity: $RH_{amb} := 10\%$

Temperature: $T_{amb} := 298K$

Black Body Temperature of the Sky: $T_{bbsky} := T_{amb}$

Wind Speed: $u_{so} := 8.333333 \cdot m \cdot s^{-1}$ (On shore)

Constants:

Air Property Constants:

Saturation Pressure

$C_1 := -5.8002206 \cdot 10^3$

$C_2 := 1.3914993$

$C_3 := -4.8640239 \cdot 10^{-2}$

$C_4 := 4.1764768 \cdot 10^{-5}$

$C_5 := -1.4452093 \cdot 10^{-8}$

$C_6 := 6.5459673$

Dewpoint Temperature

$C_7 := 6.54$

$C_8 := 14.526$

$C_9 := 0.7389$

$C_{10} := 0.09486$

$C_{11} := 0.4569$

Seawater Property Constants:

Conductivity

$T_{swcrit} := 647K$

$k_{swcrit} := 240 \cdot 10^{-3} \cdot W \cdot m^{-1} \cdot K^{-1}$

Density

$$b := \begin{pmatrix} \frac{3.972600}{4} & \frac{-0.084913}{2} & \frac{-0.005318}{2} \\ \frac{0.115079}{2} & 0.002695 & 0.000682 \\ \frac{0.000109}{2} & -0.000330 & -0.000011 \end{pmatrix}$$

Viscosity

$A_v := 1.37220$

$a_{1v} := -0.001015$

$a_{2v} := 0.000005$

$B_v := 0.000813$

$b_{1v} := 0.006102$

$b_{2v} := -0.000040$

$c_{1v} := 0.001550$

$c_{2v} := 0.0000093$

Genaral Constants:

Stefan-Boltzman Constant: $\sigma := 5.669 \cdot 10^{-8} \cdot W \cdot m^{-2} \cdot K^{-4}$

Universal Gas Constant: $R_o := 8314.41 \cdot J \cdot kg^{-1} \cdot K^{-1}$

	Water:	**Air:**
Specific Heat Capacity at Constant Pressure	$cp_w := 4187 \cdot J \cdot kg^{-1} \cdot K^{-1}$	$cp_a := 1005 \cdot J \cdot kg^{-1} \cdot K^{-1}$
Molecular Weight	$M_w := 18$	$M_a := 28.96$
Molecular Volume	$V_w := 18.8$	$V_a := 29$
Gas Constants	$R_w := \frac{R_o}{M_w}$	$R_a := \frac{R_o}{M_a}$

Evaporator:

Glass Panels

	Outer Panel / Panel 1:	**Inner Panel / Panel 2:**
Reflectivity:	$\rho_{g1} := 0.125$	$\rho_{g2} := 0.125$
Transmetivity:	$\tau_{g1} := 0.85$	$\tau_{g2} := 0.85$
Absorbtiviy:	$\alpha_{g1} := 0.025$	$\alpha_{g2} := 0.025$
Emisivity:	$\varepsilon_{g1} := 0.95$	$\varepsilon_{g2} := 0.95$
Conductivity:	$k_{g1} := 1.25 \cdot W \cdot m^{-1} \cdot K^{-1}$	$k_{g2} := 1.25 \cdot W \cdot m^{-1} \cdot K^{-1}$
Thickness:	$t_{g1} := 0.01m$	$t_{g2} := 0.01m$

Distance between pannels: $t_{g1'2} := 0.01m$

Roughness: $k_{rg} := 10 \cdot 10^{-9} \cdot m$

Required/Wanted Inlet & Outlet Conditions:

	Evaporator Inlet:	**Evaporator Exit:**
Air Temperature:	$T_{aei} := 288.15K$	$T_{aex} := 333.15K$
Air Relative Humidity:	RH_{ai} to be determined	$RH_{ex} := 98\%$
Seawater Temperature:	$T_{swei} := 288.15K$	T_{swx} to be determined
Pressure:	$p_{aei} := 100000Pa$	p_{aex} to be determined
Salinaty of Seawater:	Z_{ei} to be determined	Z_{ex} to be determined

Design:

Slope: $\underset{\sim}{S} := 0.001$

Width: $W_e := 1000m$

Solar Radiation Calculation

Reflected by Both Glass Panel to Atmosphere: $E_{atm} := \rho_{g1} \cdot E_{max} + \rho_{g2} \cdot \tau_{g1}^{2} \cdot E_{max} \cdot \sum_{\iota=0}^{10} \left(\rho_{g1}^{\iota} \cdot \rho_{g2}^{\iota}\right)$

Transmitted by Outer Glass Panel: $E_{gin_1} := \tau_{g1} \cdot E_{max}$

Absorped by Outer Glass Panel: $E_{g1} := \alpha_{g1} \cdot E_{max} + \alpha_{g1} \cdot \rho_{g2} \cdot E_{gin_1} \cdot \sum_{\iota=0}^{10} \left(\rho_{g1}^{\iota} \cdot \rho_{g2}^{\iota}\right)$

Transmitted by Inner Glass Panel: $E_e := \tau_{g2} \cdot E_{gin_1} \cdot \sum_{\iota=0}^{10} \left(\rho_{g1}^{\iota} \cdot \rho_{g2}^{\iota}\right)$

Absorped by Inner Glass Panel: $E_{g2} := \alpha_{g2} \cdot E_{gin_1} \cdot \sum_{\iota=0}^{10} \left(\rho_{g1}^{\iota} \cdot \rho_{g2}^{\iota}\right)$

Pre-Heater

Design:

Width: $W_p := 500m$

Slope: $S_p := 0.001$

Velocity of Seawater at Exit: $u_{swpx} := 0.25m \cdot s^{-1}$

Solar Radiation Entering: $E_p := E_e$

NOTE: All other design specs the same as for evaporator

Fluid Transfer

Shock Losses:

Long radius bend: $K_{lr} := 0.6$

45 Deg bend: $K_{45} := 0.4$

Valve: $K_v := 0.2$

Seawater Transfer Pipe Inner Diameter: $d_{tsw} := 0.2m$

NOTE: Diementions of aAir transfer duct the same as condenser

Condenser:

2 INDENTICAL CONDENSORS

Number of pipe per condensor: $N_{cp} := 1000$

Number of pipes rows: $N_{cpr} := 20$

Number of columns: $N_{cpc} := \frac{N_{cp}}{N_{cpr}}$

Flow speed of air at condensor inlet: $u_{aci} := 5m \cdot s^{-1}$

<u>Pipe Dimensions:</u>

Outer Diameter: $d_{cpo} := 0.065m$

Inner Diameter: $d_{cpi} := 0.062m$

Wall Thickness: $t_{cp} := \frac{d_{cpo} - d_{cpi}}{2}$

Inner Cross-sectional Area: $A_{cpo} := \frac{\pi \cdot d_{cpo}^{\,2}}{4}$

Outer Cross-sectional Area: $A_{cpi} := \frac{\pi \cdot d_{cpi}^{\,2}}{4}$

Inner Periphery: $P_{cpi} := \pi \cdot d_{cpi}$

Outer Periphery: $P_{cpo} := \pi \cdot d_{cpo}$

Salinaty of Seawater at inlet: $Z := \frac{1000\left(\rho_{sw25} - \rho_{w25}\right)}{\rho_{sw25}}$

<u>Required/Wanted Inlet & Outlet Conditions:</u>

	<u>Condensor Inlet:</u>	**<u>Condensor Exit:</u>**
Air Temperature:	$T_{acx} := 288.15K$	$T_{aci} := 333.15K$
Air Relative Humidity:	$RH_{cx} := 100\%$	$RH_{ci} := 98\%$
Seawater Temperature:	$T_{swcx} := 287.15K$	$T_{swci} := 332.15K$

```
M := | EVAP ← | $Y \leftarrow 0$
     |        | $p_{acxEst_0} \leftarrow 99179.980381018 \cdot Pa$
     |        | $m_{swcEst_0} \leftarrow 3281.039744616 \cdot kg \cdot s^{-1}$
     |        | $U_e \leftarrow 0$
     |        | $p_{acx} \leftarrow p_{acxEst_Y}$
     |        | $u_{aciHigh_0} \leftarrow 9 \cdot m \cdot s^{-1}$
     |        | $u_{aciLow_0} \leftarrow 0 \cdot m \cdot s^{-1}$
     |        | $LoopStop_{Ue} \leftarrow 1$
     |        | while $LoopStop_{Ue} > 10 \cdot \Lambda$
     |        |     | $u_{aei} \leftarrow \frac{u_{aeiHigh_{U_e}} + u_{aeiLow_{U_e}}}{2}$
     |        |     | $E \leftarrow 0$
     |        |     | $L_{e_0} \leftarrow 4000 \cdot m$
     |        |     | $T_{swexEst_0} \leftarrow T_{swci} + 10 \cdot K$
     |        |     | $p_{aexEst_0} \leftarrow 99500 \cdot Pa$
     |        |     | $\Delta x \leftarrow 1 \cdot m$
     |        |     | $LoopStop_E \leftarrow 1000 \cdot m$
     |        |     | while $LoopStop_E > 0 \cdot m$
     |        |     |     | $N \leftarrow \frac{L_{e_E}}{\Delta x}$
     |        |     |     | $T_{aex} \leftarrow T_{aex}$
     |        |     |     | $RH_{ex} \leftarrow RH_{ex}$
     |        |     |     | $u_{ae_0} \leftarrow u_{aei}$
     |        |     |     | $T_{swex} \leftarrow T_{swexEst_E}$
     |        |     |     | $Z_{ex} \leftarrow Z$
     |        |     |     | $p_{aex} \leftarrow p_{aexEst_E}$
     |        |     |     | $z_{e_0} \leftarrow 0 \cdot m$
```

```
$T_{g1o_0} \leftarrow T_{amb}$
$T_{g1i_0} \leftarrow T_{amb}$
$T_{g2o_0} \leftarrow T_{amb}$
$T_{g2i_0} \leftarrow T_{amb}$
$m_{mt_0} \leftarrow 0 \cdot kg \cdot s^{-1}$
$T_{ae_0} \leftarrow T_{aei}$
$T_{swe_0} \leftarrow T_{swei}$
$p_{ae_0} \leftarrow p_{aei}$
$m_{da} \leftarrow$
    $r_{ex} \leftarrow$
        $C \leftarrow \frac{C_1}{\left(\frac{T_{aex}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{aex}}{K}\right) + C_4 \cdot \left(\frac{T_{aex}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{aex}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{aex}}{K}\right)$
        $p_{vex} \leftarrow$
            $p_{sex} \leftarrow \left(e^C\right) \cdot Pa$
            $p_{sex} \cdot RH_{ex}$
        $\frac{0.62198 \cdot p_{vex}}{p_{aex} - p_{vex}}$
    $r_{e_0} \leftarrow$
        $C \leftarrow \frac{C_1}{\left(\frac{T_{acx}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{acx}}{K}\right) + C_4 \cdot \left(\frac{T_{acx}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{acx}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{acx}}{K}\right)$
        $p_{vcx} \leftarrow$
            $p_{scx} \leftarrow \left(e^C\right) \cdot Pa$
            $p_{scx} \cdot RH_{cx}$
        $\frac{0.62198 \cdot p_{vcx}}{p_{acx} - p_{vcx}}$
    $\frac{m_{wmax}}{r_{ex} - r_{e_0}}$
$RH_{e_0} \leftarrow$
    $p_{vei} \leftarrow \frac{r_{e_0} \cdot p_{ae_0}}{0.62198 + r_{e_0}}$
```

```
    $p_{sei} \leftarrow$
        $C \leftarrow \frac{C_1}{\left(\frac{T_{ae_0}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{ae_0}}{K}\right) + C_4 \cdot \left(\frac{T_{ae_0}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{ae_0}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{ae_0}}{K}\right)$
        $\left(e^C\right) \cdot Pa$
    $\frac{p_{vei}}{p_{sei}}$
$\Delta Q_{ae_0} \leftarrow 0 \cdot W$
$\Delta Q_{swe_0} \leftarrow 0 \cdot W$
$Q_{e_0} \leftarrow 0 \cdot W$
$Re_0 \leftarrow 0$
$m_{swex} \leftarrow m_{swcEst_Y}$
$T_{dp_0} \leftarrow$
    $\omega \leftarrow \ln\left(\frac{p_{vei}}{1000 \cdot Pa}\right)$
    $\left[C_7 + C_8 \cdot \omega + C_9 \cdot \omega^2 + C_{10} \cdot \omega^3 + C_{11} \cdot \left(\frac{p_{vei}}{1000 \cdot Pa}\right)^{0.1984} + 273.15\right] \cdot K$
$Z_{e_0} \leftarrow$
    $m_{se} \leftarrow \frac{Z_{ex} \cdot m_{swex}}{1000}$
    $m_{swe_0} \leftarrow m_{swex} - m_{wmax}$
    $\frac{1000 \cdot m_{se}}{m_{swe_0}}$
$H_{swe_0} \leftarrow$
    $q \leftarrow 0$
    $H_{swLoop_0} \leftarrow 0.005 \cdot m$
    $\mu_{swei} \leftarrow$
        $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z_{e_0} + c_{2v} \cdot \left(Z_{e_0}\right)^2$
        $\chi \leftarrow$
            $T_{sweC} \leftarrow \frac{T_{swe_0} - 273.15 \cdot K}{K}$
            $\chi_1 \leftarrow A_v \cdot \left[1 + a_{1v} \cdot Z_{e_0} + a_{2v} \cdot \left(Z_{e_0}\right)^2\right]$
            $\chi_2 \leftarrow B_v \cdot \left[1 + b_{1v} \cdot Z_{e_0} + b_{2v} \cdot \left(Z_{e_0}\right)^2\right]$
            $\left(\frac{T_{sweC} - 20}{T_{sweC} + 109}\right) \cdot \left[\chi_1 + \chi_2 \cdot \left(T_{sweC} - 20\right)\right]$
```

```
                $\frac{\mu_{20}}{10^{\chi}} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
        $\rho_{swei} \leftarrow$ for $\iota \in 0..2$
            $x_{\iota} \leftarrow \frac{2 \cdot Z_{e_0} - 150}{150}$
            $T_{\iota_0} \leftarrow 1$
            $T_{\iota_1} \leftarrow x_{\iota}$
            $T_{\iota_2} \leftarrow 2 \cdot x_{\iota}^2 - 1$
            for $\varepsilon \in 0..2$
                $x_{\varepsilon} \leftarrow \left(\frac{2 \cdot T_{sweC} - 250}{110}\right)$
                $T_{\varepsilon_0} \leftarrow 1$
                $T_{\varepsilon_1} \leftarrow x_{\varepsilon}$
                $T_{\varepsilon_2} \leftarrow 2 \cdot x_{\varepsilon}^2 - 1$
            $10^3 \cdot kg \cdot m^{-3} \cdot \sum_{\iota=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\iota,\varepsilon} \cdot T_{\varepsilon_{\varepsilon}} \cdot T_{\iota_{\iota}}\right)$
        $V_{swei} \leftarrow \frac{m_{swe_0}}{\rho_{swei}}$
        LoopStop $\leftarrow 1$
        while LoopStop $> \Lambda \wedge q < 100$
            $R \leftarrow \frac{W_e \cdot H_{swLoop_q}}{W_e + 2 \cdot H_{swLoop_q}}$
            $u_{swe_0} \leftarrow -(32 \cdot g \cdot R \cdot S)^{\frac{1}{2}} \cdot \left[\log\left[\frac{k_c}{14.8 \cdot R} + \frac{1.255 \cdot \mu_{swei}}{\rho_{swei} \cdot R \cdot (32 \cdot g \cdot R \cdot S)^{\frac{1}{2}}}\right]\right]$
            $H'_{swLoop_q} \leftarrow \frac{V_{swei}}{u_{swe_0} \cdot W_e}$
            $H_{swLoop_{(q+1)}} \leftarrow H'_{swLoop_q}$
```

```
            $q \leftarrow q + 1$
            LoopStop $\leftarrow \left|\frac{H_{swLoop_q} - H_{swLoop_{q-1}}}{H_{swLoop_q}}\right|$
        $H_{swLoop_q}$
    $H_e \leftarrow$
        $H_{ae_0} \leftarrow$
            $\rho_{wae_0} \leftarrow$
                $p_{vex} \leftarrow$
                    $C \leftarrow \frac{C_1}{\left(\frac{T_{ae_0}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{ae_0}}{K}\right) + C_4 \cdot \left(\frac{T_{ae_0}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{ae_0}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{ae_0}}{K}\right)$
                    $p_{sei} \leftarrow \left(e^{C}\right) \cdot Pa$
                    $p_{sei} \cdot RH_{e_0}$
                $v_{aei} \leftarrow \frac{0.287035 \cdot T_{ae_0}}{p_{ae_0} - p_{vei}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
                $\frac{1 + r_{e_0}}{v_{aei}}$
            $V_{ei} \leftarrow \frac{m_{da} \cdot \left(1 + r_{e_0}\right)}{\rho_{wae_0}}$
            $A_{ei} \leftarrow \frac{V_{ei}}{u_{ae_0}}$
            $\frac{A_{ei}}{W_e}$
        $H_{ae_0} + H_{swe_0}$
    $n \leftarrow 0$
    while $n < N$
        $x_i \leftarrow (n + 0.5) \cdot \Delta x$
        $x_x \leftarrow L_{e_E} - x_i$
        $T_{glo_{n+1}} \leftarrow$
            $i \leftarrow 0$
            $T_{gloLoop_0} \leftarrow T_{glo_n}$
            $LoopStop_i \leftarrow 1$
            while $LoopStop_i > \Lambda \wedge i < 200$
```

```
$Q_{ro} \leftarrow \sigma\cdot\Delta x\cdot\varepsilon_{g1}\cdot W_e\left[T_{bbsky}^{\,4}-\left(T_{g1oLoop_i}\right)^4\right]$
$Q_{co} \leftarrow$
    $hx_{co} \leftarrow$
        $T_{fco} \leftarrow \frac{T_{g1oLoop_i}+T_{amb}}{2}$
        $\rho_{fco} \leftarrow$
            $p_{vfco} \leftarrow$
                $C \leftarrow \frac{C_1}{\left(\frac{T_{fco}}{K}\right)}+C_2+C_3\cdot\left(\frac{T_{fco}}{K}\right)+C_4\cdot\left(\frac{T_{fco}}{K}\right)^2+C_5\cdot\left(\frac{T_{fco}}{K}\right)^3+C_6\cdot\ln\left(\frac{T_{fco}}{K}\right)$
                $p_{sfco} \leftarrow \left(e^{C}\right)\cdot Pa$
                $RH_{amb}\cdot p_{sfco}$
            $v_{afco} \leftarrow \frac{0.287035\cdot T_{fco}}{p_{atm}-p_{vfco}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
            $r_{fco} \leftarrow \frac{0.62198\cdot p_{vfco}}{p_{atm}-p_{vfco}}$
            $\frac{1+r_{fco}}{v_{afco}}$
        $k_{fco} \leftarrow$
            $k_{vfco} \leftarrow \left[3.767616\cdot10^{-14}\cdot\left(\frac{T_{fco}}{K}\right)^3+1.247242\cdot10^{-10}\cdot\left(\frac{T_{fco}}{K}\right)^2+3.184034\cdot10^{-9}\cdot\left(\frac{T_{fco}}{K}\right)+7.678236\cdot10^{-6}\right]\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
            $k_{afco} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fco}}{K}+3.479\cdot10^{-6}\right)\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
            $Nratio_{vfco} \leftarrow \frac{r_{fco}\cdot1\cdot kg}{M_w}$
            $Nratio_{afco} \leftarrow \frac{1\cdot kg}{M_a}$
            $\left(\frac{Nratio_{vfco}}{Nratio_{vfco}+Nratio_{afco}}\right)\cdot k_{vfco}+\left(\frac{Nratio_{afco}}{Nratio_{vfco}+Nratio_{afco}}\right)\cdot k_{afco}$
        $\mu_{fco} \leftarrow$
            $\mu_{vfco} \leftarrow \left[1.299155\cdot10^{-12}\cdot\left(\frac{T_{fco}}{K}\right)^2+3.872699\cdot10^{-8}\cdot\left(\frac{T_{fco}}{K}\right)-2.390839\cdot10^{-6}\right]\cdot kg\cdot m^{-1}\cdot s^{-1}$
            $\mu_{afco} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fco}}{K}+4.745\cdot10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
            $\left(\frac{Nratio_{vfco}}{Nratio_{vfco}+Nratio_{afco}}\right)\cdot\mu_{vfco}+\left(\frac{Nratio_{afco}}{Nratio_{vfco}+Nratio_{afco}}\right)\cdot\mu_{afco}$
```

```
        $cp_{fco} \leftarrow$
            $cp_{vfco} \leftarrow \left[-5.103046\cdot10^{-10}\cdot\left(\frac{T_{fco}}{K}\right)^3+1.252416\cdot10^{-6}\left(\frac{T_{fco}}{K}\right)^2-3.165154\cdot10^{-4}\left(\frac{T_{fco}}{K}\right)+1.861896\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
            $cp_{afco} \leftarrow \left[3.542857\cdot10^{-7}\cdot\left(\frac{T_{fco}}{K}\right)^2-1.626857\cdot10^{-4}\cdot\frac{T_{fco}}{K}+1.021769\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
            $mratio_{vfco} \leftarrow r_{fco}\cdot1\cdot kg$
            $\left(\frac{mratio_{vfco}}{1\cdot kg+mratio_{vfco}}\right)\cdot cp_{vfco}+\left(\frac{1\cdot kg}{1\cdot kg+mratio_{vfco}}\right)\cdot cp_{afco}$
        $Pr_{fco} \leftarrow \frac{cp_{fco}\cdot\mu_{fco}}{k_{fco}}$
        $Re_{xao} \leftarrow \frac{\rho_{fco}\cdot u_{ao}\cdot x_i}{\mu_{fco}}$
        $Nux_{co} \leftarrow$
            $0.332\cdot Pr_{fco}^{\frac{1}{3}}\cdot Re_{xao}^{\frac{1}{2}}$ if $Re_{xao} < 0$
            $0.0296\cdot Pr_{fco}^{\frac{1}{3}}\cdot Re_{xao}^{\frac{4}{5}}$ if $0 \le Re_{xao} \le 10^7$
            $0.185\cdot Pr_{fco}^{\frac{1}{3}}\cdot Re_{xao}\cdot\left(\log\left(Re_{xao}\right)\right)^{-2.584}$ otherwise
        $Nux_{co}\cdot\frac{k_{fco}}{x_i}$
    $hx_{co}\cdot\Delta x\cdot W_e\cdot\left(T_{amb}-T_{g1oLoop_i}\right)$
$Q_{cong1} \leftarrow -Q_{ro}-Q_{co}-E_{g1}\cdot W_e\cdot\Delta x$
$T_{g1i_{n+1}} \leftarrow \frac{Q_{cong1}}{\frac{k_{g1}}{t_{g1}}\cdot\Delta x\cdot W_e}+T_{g1oLoop_i}$
$T_{g2o_{n+1}} \leftarrow$
    $j \leftarrow 0$
    $T_{g2oLoop_0} \leftarrow$
        $\frac{T_{ae_n}+T_{g1i_{n+1}}}{2}$ if $n = 0$
        $T_{g2o_n}$ otherwise
    $T_{ag12} \leftarrow \frac{T_{g2oLoop_j}+T_{g1i_{n+1}}}{2}$
    $LoopStop_i \leftarrow 1$
```

```
while $\text{LoopStop}_j > \Lambda \wedge j < 200$
    $Q_{\text{cong}} \leftarrow$
        $\rho_{\text{ag1'2}} \leftarrow$
            $p_{\text{vag1'2}} \leftarrow$
                $C \leftarrow \frac{C_1}{\left(\frac{T_{\text{ag1'2}}}{K}\right)} + C_2 + C_3\left(\frac{T_{\text{ag1'2}}}{K}\right) + C_4\left(\frac{T_{\text{ag1'2}}}{K}\right)^2 + C_5\left(\frac{T_{\text{ag1'2}}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{\text{ag1'2}}}{K}\right)$
                $p_{\text{sag1'2}} \leftarrow \left(e^C\right) \cdot Pa$
                $RH_{\text{amb}} \cdot p_{\text{sag1'2}}$
            $v_{\text{aag1'2}} \leftarrow \frac{0.287035 \cdot T_{\text{ag1'2}}}{p_{\text{ac}_n} - p_{\text{vag1'2}}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
            $r_{\text{ag1'2}} \leftarrow \frac{0.62198 \cdot p_{\text{vag1'2}}}{p_{\text{atm}} - p_{\text{vag1'2}}}$
            $\frac{1 + r_{\text{ag1'2}}}{v_{\text{aag1'2}}}$
        $k_{\text{ag1'2}} \leftarrow$
            $k_{\text{vag1'2}} \leftarrow \left[3.767616 \cdot 10^{-14} \cdot \left(\frac{T_{\text{ag1'2}}}{K}\right)^3 + 1.247242 \cdot 10^{-10} \left(\frac{T_{\text{ag1'2}}}{K}\right)^2 + 3.184034 \cdot 10^{-9} \cdot \left(\frac{T_{\text{ag1'2}}}{K}\right) + 7.678236 \cdot 10^{-6}\right] \cdot 10^3 \cdot W \cdot m^{-1} \cdot K^{-1}$
            $k_{\text{aag1'2}} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{\text{ag1'2}}}{K} + 3.479 \cdot 10^{-6}\right) \cdot 10^3 \cdot W \cdot m^{-1} \cdot K^{-1}$
            $\text{Nratio}_{\text{vag1'2}} \leftarrow \frac{r_{\text{ag1'2}} \cdot 1 \cdot kg}{M_w}$
            $\text{Nratio}_{\text{aag1'2}} \leftarrow \frac{1 \cdot kg}{M_a}$
            $\left(\frac{\text{Nratio}_{\text{vag1'2}}}{\text{Nratio}_{\text{vag1'2}} + \text{Nratio}_{\text{aag1'2}}}\right) \cdot k_{\text{vag1'2}} + \left(\frac{\text{Nratio}_{\text{aag1'2}}}{\text{Nratio}_{\text{vag1'2}} + \text{Nratio}_{\text{aag1'2}}}\right) \cdot k_{\text{aag1'2}}$
        $\mu_{\text{ag1'2}} \leftarrow$
            $\mu_{\text{vag1'2}} \leftarrow \left[1.299155 \cdot 10^{-12} \cdot \left(\frac{T_{\text{ag1'2}}}{K}\right)^2 + 3.872699 \cdot 10^{-8} \cdot \left(\frac{T_{\text{ag1'2}}}{K}\right) - 2.390839 \cdot 10^{-6}\right] \cdot kg \cdot m^{-1} \cdot s^{-1}$
            $\mu_{\text{aag1'2}} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{\text{ag1'2}}}{K} + 4.745 \cdot 10^{-6}\right) \cdot kg \cdot m^{-1} \cdot s^{-1}$
            $\left(\frac{\text{Nratio}_{\text{vag1'2}}}{\text{Nratio}_{\text{vag1'2}} + \text{Nratio}_{\text{aag1'2}}}\right) \cdot \mu_{\text{vag1'2}} + \left(\frac{\text{Nratio}_{\text{aag1'2}}}{\text{Nratio}_{\text{vag1'2}} + \text{Nratio}_{\text{aag1'2}}}\right) \cdot \mu_{\text{aag1'2}}$
        $cp_{\text{ag1'2}} \leftarrow$
            $cp_{\text{vag1'2}} \leftarrow \left[-5.103046 \cdot 10^{-10} \left(\frac{T_{\text{ag1'2}}}{K}\right)^3 + 1.252416 \cdot 10^{-6} \left(\frac{T_{\text{ag1'2}}}{K}\right)^2 - 3.165154 \cdot 10^{-4} \left(\frac{T_{\text{ag1'2}}}{K}\right) + 1.861896\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
```

```
            $cp_{\text{aag1'2}} \leftarrow \left[3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{\text{ag1'2}}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{\text{ag1'2}}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $\text{mratio}_{\text{vag1'2}} \leftarrow r_{\text{ag1'2}} \cdot 1 \cdot kg$
            $\left(\frac{\text{mratio}_{\text{vag1'2}}}{1 \cdot kg + \text{mratio}_{\text{vag1'2}}}\right) \cdot cp_{\text{vag1'2}} + \left(\frac{1 \cdot kg}{1 \cdot kg + \text{mratio}_{\text{vag1'2}}}\right) \cdot cp_{\text{aag1'2}}$
        $Pr_{\text{ag1'2}} \leftarrow \frac{cp_{\text{ag1'2}} \cdot \mu_{\text{ag1'2}}}{k_{\text{ag1'2}}}$
        $\beta_a \leftarrow \frac{1}{T_{\text{ag1'2}}}$
        $Gr_{\text{ag1'2}} \leftarrow \frac{g \cdot \beta_a \cdot \left(T_{\text{g2oLoop}_j} - T_{\text{g1i}_{n+1}}\right) \cdot t_{\text{g1'2}}^{\;3}}{\left(\frac{\mu_{\text{ag1'2}}}{\rho_{\text{ag1'2}}}\right)^2}$
        $k_{ea} \leftarrow$
            $k_{\text{ag1'2}}$ if $Gr_{\text{ag1'2}} \cdot Pr_{\text{ag1'2}} < 1700$
            $k_{\text{ag1'2}} \cdot 0.059 \cdot \left(Gr_{\text{ag1'2}} \cdot Pr_{\text{ag1'2}}\right)^{0.4}$ if $1700 \le Gr_{\text{ag1'2}} \cdot Pr_{\text{ag1'2}} < 7000$
            $k_{\text{ag1'2}} \cdot 0.212 \cdot \left(Gr_{\text{ag1'2}} \cdot Pr_{\text{ag1'2}}\right)^{\frac{1}{4}}$ if $7000 \le Gr_{\text{ag1'2}} \cdot Pr_{\text{ag1'2}} < 3.2 \cdot 10^5$
            $k_{\text{ag1'2}} \cdot 0.061 \cdot \left(Gr_{\text{ag1'2}} \cdot Pr_{\text{ag1'2}}\right)^{\frac{1}{3}}$ if $Gr_{\text{ag1'2}} \cdot Pr_{\text{ag1'2}} \ge 3.2 \cdot 10^5$
        $k'_a \leftarrow$
            $k_{ea}$ if $T_{\text{g2oLoop}_j} > T_{\text{g1i}_{n+1}}$
            $k_{\text{ag1'2}}$ otherwise
        $\frac{k'_a}{t_{\text{g1'2}}} \cdot \Delta x \cdot W_e \left(T_{\text{g2oLoop}_j} - T_{\text{g1i}_{n+1}}\right)$
    $Q_{rg} \leftarrow Q_{\text{cong1}} - Q_{\text{cong}}$
    $T_{\text{g2oLoop}_{j+1}} \leftarrow \left[\left(T_{\text{g1i}_{n+1}}\right)^4 + \frac{Q_{rg} \left(\frac{1}{\varepsilon_{g1}} + \frac{1}{\varepsilon_{g2}} - 1\right)}{\sigma \cdot \Delta x \cdot W_e}\right]^{\frac{1}{4}}$
    $j \leftarrow j + 1$
    $\text{LoopStop}_j \leftarrow \left|\frac{T_{\text{g2oLoop}_j} - T_{\text{g2oLoop}_{j-1}}}{T_{\text{g2oLoop}_j}}\right|$
```

```
            $T_{g2oLoop_j}$
    $Q_{cong2} \leftarrow Q_{cong1} - E_{g2} \cdot W_e \cdot \Delta x$
    $T_{g2i_{n+1}} \leftarrow \frac{Q_{cong2}}{\frac{k_{g2}}{t_{g2}} \cdot \Delta x \cdot W_e} + T_{g2o_{n+1}}$
    $Q_{cg} \leftarrow$
        $hx_{cg} \leftarrow$
            $T_{fcg} \leftarrow \frac{T_{ae_n} + T_{swe_n}}{2}$
            $\rho_{fcg} \leftarrow$
                $p_{vfcg} \leftarrow$
                    $C \leftarrow \frac{C_1}{\left(\frac{T_{fcg}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{fcg}}{K}\right) + C_4 \cdot \left(\frac{T_{fcg}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{fcg}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{fcg}}{K}\right)$
                    $p_{sfcg} \leftarrow \left(e^C\right) \cdot Pa$
                    $RH_{e_n} \cdot p_{sfcg}$
                $v_{afcg} \leftarrow \frac{0.287035 \cdot T_{fcg}}{p_{ae_n} - p_{vfcg}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
                $r_{fcg} \leftarrow \frac{0.62198 \cdot p_{vfcg}}{p_{ae_n} - p_{vfcg}}$
                $\frac{1 + r_{fcg}}{v_{afcg}}$
            $\mu_{fcg} \leftarrow$
                $\mu_{vfcg} \leftarrow \left[1.299155 \cdot 10^{-12} \cdot \left(\frac{T_{fcg}}{K}\right)^2 + 3.872699 \cdot 10^{-8} \cdot \left(\frac{T_{fcg}}{K}\right) - 2.390839 \cdot 10^{-6}\right] \cdot kg \cdot m^{-1} \cdot s^{-1}$
                $\mu_{afcg} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{fcg}}{K} + 4.745 \cdot 10^{-6}\right) \cdot kg \cdot m^{-1} \cdot s^{-1}$
                $N_{vfcg} \leftarrow \frac{r_{fcg} \cdot m_{da}}{M_w}$
                $N_{afcg} \leftarrow \frac{m_{da}}{M_a}$
                $\left(\frac{N_{vfcg}}{N_{vfcg} + N_{afcg}}\right) \cdot \mu_{vfcg} + \left(\frac{N_{afcg}}{N_{vfcg} + N_{afcg}}\right) \cdot \mu_{afcg}$
            $Re_{xcg} \leftarrow \frac{\rho_{fcg} \cdot u_{ae_n} \cdot x_i}{\mu_{fcg}}$
```

```
            $Pr_{fcg} \leftarrow$
                $r_{fcg} \leftarrow$
                    $p_{vfcg} \leftarrow$
                        $C \leftarrow \frac{C_1}{\left(\frac{T_{fcg}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{fcg}}{K}\right) + C_4 \cdot \left(\frac{T_{fcg}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{fcg}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{fcg}}{K}\right)$
                        $p_{sfcg} \leftarrow \left(e^C\right) \cdot Pa$
                        $RH_{e_n} \cdot p_{sfcg}$
                    $v_{afcg} \leftarrow \frac{0.287035 \cdot T_{fcg}}{p_{ae_n} - p_{vfcg}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
                    $\frac{0.62198 \cdot p_{vfcg}}{p_{ae_n} - p_{vfcg}}$
                $cp_{fcg} \leftarrow$
                    $cp_{vfcg} \leftarrow \left[-5.103046 \cdot 10^{-10} \cdot \left(\frac{T_{fcg}}{K}\right)^3 + 1.252416 \cdot 10^{-6} \cdot \left(\frac{T_{fcg}}{K}\right)^2 - 3.165154 \cdot 10^{-4} \cdot \left(\frac{T_{fcg}}{K}\right) + 1.861896\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
                    $cp_{afcg} \leftarrow \left[3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{fcg}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{fcg}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                    $m_{vfcg} \leftarrow r_{fcg} \cdot m_{da}$
                    $\left(\frac{m_{vfcg}}{m_{da} + m_{vfcg}}\right) \cdot cp_{vfcg} + \left(\frac{m_{da}}{m_{da} + m_{vfcg}}\right) \cdot cp_{afcg}$
                $k_{fcg} \leftarrow$
                    $k_{vfcg} \leftarrow \left[3.767616 \cdot 10^{-14} \cdot \left(\frac{T_{fcg}}{K}\right)^3 + 1.247242 \cdot 10^{-10} \cdot \left(\frac{T_{fcg}}{K}\right)^2 + 3.184034 \cdot 10^{-9} \cdot \left(\frac{T_{fcg}}{K}\right) + 7.678236 \cdot 10^{-6}\right] \cdot 10^3 \cdot W \cdot$
                    $k_{afcg} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{fcg}}{K} + 3.479 \cdot 10^{-6}\right) \cdot 10^3 \cdot W \cdot m^{-1} \cdot K^{-1}$
                    $N_{vfcg} \leftarrow \frac{r_{fcg} \cdot m_{da}}{M_w}$
                    $N_{afcg} \leftarrow \frac{m_{da}}{M_a}$
                    $\left(\frac{N_{vfcg}}{N_{vfcg} + N_{afcg}}\right) \cdot k_{vfcg} + \left(\frac{N_{afcg}}{N_{vfcg} + N_{afcg}}\right) \cdot k_{afcg}$
                $\frac{cp_{fcg} \cdot \mu_{fcg}}{k_{fcg}}$
            $Nux_{cg} \leftarrow$
                $0.332 \cdot Pr_{fcg}^{\frac{1}{3}} \cdot Re_{xcg}^{\frac{1}{2}}$ if $Re_{xcg} < 0$
```

```
          $0.0296 \cdot Pr_{fcg}^{\frac{1}{3}} \cdot Re_{xcg}^{\frac{4}{5}}$ if $0 \le Re_{xcg} \le 10^{7}$
          $0.185 \cdot Pr_{fcg}^{\frac{1}{3}} \cdot Re_{xcg} \left(\log\left(Re_{xcg}\right)\right)^{-2.584}$ otherwise
        $Nux_{cg} \cdot \frac{k_{fcg}}{x_i}$
      $hx_{cg} \cdot \Delta x \cdot W_e \cdot \left(T_{ae_n} - T_{g2i_{n+1}}\right)$
    $Q_{rw} \leftarrow \frac{W_e \cdot \Delta x \cdot \sigma \cdot \left[\left(T_{swe_n}\right)^4 - \left(T_{g2i_{n+1}}\right)^4\right]}{\frac{1}{\varepsilon_w} + \upsilon \cdot \left(\frac{1}{\varepsilon_{g2}} - 1\right)}$
    $Q_{cw} \leftarrow$
      $hx_{cw} \leftarrow$
        $T_{fcw} \leftarrow \frac{T_{ae_n} + T_{swe_n}}{2}$
        $\rho_{fcw} \leftarrow$
          $p_{vfcw} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{fcw}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{fcw}}{K}\right) + C_4 \cdot \left(\frac{T_{fcw}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{fcw}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{fcw}}{K}\right)$
            $p_{sfcw} \leftarrow \left(e^{C}\right) \cdot Pa$
            $RH_{e_n} \cdot p_{sfcw}$
          $v_{afcw} \leftarrow \frac{0.287035 \cdot T_{fcw}}{p_{ae_n} - p_{vfcw}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
          $r_{fcw} \leftarrow \frac{0.62198 \cdot p_{vfcw}}{p_{ae_n} - p_{vfcw}}$
          $\frac{1 + r_{fcw}}{v_{afcw}}$
        $\mu_{fcw} \leftarrow$
          $\mu_{vfcw} \leftarrow \left[1.299155 \cdot 10^{-12} \left(\frac{T_{fcw}}{K}\right)^2 + 3.872699 \cdot 10^{-8} \cdot \left(\frac{T_{fcw}}{K}\right) - 2.390839 \cdot 10^{-6}\right] \cdot kg \cdot m^{-1} \cdot s^{-1}$
          $\mu_{afcw} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{fcw}}{K} + 4.745 \cdot 10^{-6}\right) \cdot kg \cdot m^{-1} \cdot s^{-1}$
          $N_{vfcw} \leftarrow \frac{r_{fcw} \cdot m_{da}}{M_w}$
```

```
          $N_{afcw} \leftarrow \frac{m_{da}}{M_a}$
          $\left(\frac{N_{vfcw}}{N_{vfcw} + N_{afcw}}\right) \cdot \mu_{vfcw} + \left(\frac{N_{afcw}}{N_{vfcw} + N_{afcw}}\right) \cdot \mu_{afcw}$
        $Re_{xcw} \leftarrow \frac{\rho_{fcw} \cdot \left(u_{ae_n} + u_{swe_n}\right) \cdot x_i}{\mu_{fcw}}$
        $Pr_{fcw} \leftarrow$
          $r_{fcw} \leftarrow$
            $p_{vfcw} \leftarrow$
              $C \leftarrow \frac{C_1}{\left(\frac{T_{fcw}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{fcw}}{K}\right) + C_4 \cdot \left(\frac{T_{fcw}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{fcw}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{fcw}}{K}\right)$
              $p_{sfcw} \leftarrow \left(e^{C}\right) \cdot Pa$
              $RH_{e_n} \cdot p_{sfcw}$
            $v_{afcw} \leftarrow \frac{0.287035 \cdot T_{fcw}}{p_{ae_n} - p_{vfcw}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
            $\frac{0.62198 \cdot p_{vfcw}}{p_{ae_n} - p_{vfcw}}$
          $cp_{fcw} \leftarrow$
            $cp_{vfcw} \leftarrow \left[-5.103046 \cdot 10^{-10} \left(\frac{T_{fcw}}{K}\right)^3 + 1.252416 \cdot 10^{-6} \left(\frac{T_{fcw}}{K}\right)^2 - 3.165154 \cdot 10^{-4} \cdot \left(\frac{T_{fcw}}{K}\right) + 1.861896\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $cp_{afcw} \leftarrow \left[3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{fcw}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{fcw}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $m_{vfcw} \leftarrow r_{fcw} \cdot m_{da}$
            $\left(\frac{m_{vfcw}}{m_{da} + m_{vfcw}}\right) \cdot cp_{vfcw} + \left(\frac{m_{da}}{m_{da} + m_{vfcw}}\right) \cdot cp_{afcw}$
          $k_{fcw} \leftarrow$
            $k_{vfcw} \leftarrow \left[3.767616 \cdot 10^{-14} \cdot \left(\frac{T_{fcw}}{K}\right)^3 + 1.247242 \cdot 10^{-10} \left(\frac{T_{fcw}}{K}\right)^2 + 3.184034 \cdot 10^{-9} \cdot \left(\frac{T_{fcw}}{K}\right) + 7.678236 \cdot 10^{-6}\right] \cdot 10^3 \cdot W \cdot m^{-1} \cdot K^{-1}$
            $k_{afcw} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{fcw}}{K} + 3.479 \cdot 10^{-6}\right) \cdot 10^3 \cdot W \cdot m^{-1} \cdot K^{-1}$
            $N_{vfcw} \leftarrow \frac{r_{fcw} \cdot m_{da}}{M_w}$
            $N_{afcw} \leftarrow \frac{m_{da}}{M_a}$
```

```
                $\left(\frac{N_{vfcw}}{N_{vfcw}+N_{afcw}}\right)\cdot k_{vfcw}+\left(\frac{N_{afcw}}{N_{vfcw}+N_{afcw}}\right)\cdot k_{afcw}$
            $\frac{cp_{fcw}\cdot\mu_{fcw}}{k_{fcw}}$
        $Nux_{cw} \leftarrow$
            $0.332\cdot Pr_{fcw}^{\frac{1}{3}}\cdot Re_{xcw}^{\frac{1}{2}}$ if $Re_{xcw} < 0$
            $0.0296\cdot Pr_{fcw}^{\frac{1}{3}}\cdot Re_{xcw}^{\frac{4}{5}}$ if $0 \le Re_{xcw} \le 10^7$
            $0.185\cdot Pr_{fcw}^{\frac{1}{3}}\cdot Re_{xcw}\cdot(\log(Re_{xcw}))^{-2.584}$ otherwise
        $Nux_{cw}\cdot\frac{k_{fcw}}{\upsilon\cdot x_i}$
    $hx_{cw}\cdot\Delta x\cdot\upsilon\cdot W_e\cdot\left(T_{swe_n}-T_{ae_n}\right)$
$Q_{mt} \leftarrow$
    $m_{mt_{n+1}} \leftarrow$
        $c_w \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{swe_n}}{K}\right)}+C_2+C_3\cdot\left(\frac{T_{swe_n}}{K}\right)+C_4\cdot\left(\frac{T_{swe_n}}{K}\right)^2+C_5\cdot\left(\frac{T_{swe_n}}{K}\right)^3+C_6\cdot\ln\left(\frac{T_{swe_n}}{K}\right)$
            $p_{ssw} \leftarrow \left(e^C\right)\cdot Pa$
            $\frac{p_{ssw}}{R_w\cdot T_{swe_n}}$
        $c_a \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{ae_n}}{K}\right)}+C_2+C_3\cdot\left(\frac{T_{ae_n}}{K}\right)+C_4\cdot\left(\frac{T_{ae_n}}{K}\right)^2+C_5\cdot\left(\frac{T_{ae_n}}{K}\right)^3+C_6\cdot\ln\left(\frac{T_{ae_n}}{K}\right)$
            $p_{samt_n} \leftarrow \left(e^C\right)\cdot Pa$
            $c_{amt} \leftarrow \frac{p_{samt_n}}{R_w\cdot T_{ae_n}}$
            $RH_{e_n}\cdot c_{amt}$
            $435.7\cdot\left(\frac{T_{ae_n}}{K}\right)^{\frac{3}{2}}$
```

```
            $D \leftarrow \frac{\left(\frac{\quad}{K}\right)}{\frac{p_{ae_n}}{Pa}\cdot\left(V_a^{\frac{1}{3}}+V_w^{\frac{1}{3}}\right)^2}\cdot\sqrt{\left(\frac{1}{M_w}+\frac{1}{M_a}\right)}\cdot 10^{-4}\cdot m^2\cdot s^{-1}$
            $Sc_{fcw} \leftarrow$
                $\rho_{fcw} \leftarrow \frac{1+\tau_{fcw}}{v_{afcw}}$
                $\frac{\mu_{fcw}}{\rho_{fcw}\cdot D}$
            $hx_{mt} \leftarrow 0.0296\cdot Re_{xcw}^{\frac{-1}{5}}\cdot u_{ae_n}\cdot Sc_{fcw}^{-\frac{2}{3}}$
            $m_{mtnorm} \leftarrow hx_{mt}\cdot\upsilon\cdot\Delta x\cdot W_e\cdot\left(c_w-c_a\right)$
            $m_{mtnorm}$
    $h_{gsw} \leftarrow \left[-0.00086\cdot\left(\frac{T_{swe_n}-273\cdot K}{K}\right)^2+1.855\cdot\left(\frac{T_{swe_n}-273\cdot K}{K}\right)+2500.6\right]\cdot 10^3\cdot J\cdot kg^{-1}$
    $m_{mt_{n+1}}\cdot h_{gsw}$
$Q_{ccw} \leftarrow$
    $Q_{conc} \leftarrow -0.05\cdot E_e\cdot\Delta x\cdot W_e$
    $E_e\cdot\Delta x\cdot W_e+Q_{conc}$
$\Delta Q_{ae_{n+1}} \leftarrow Q_{mt}+Q_{cw}-Q_{cg}$
$Q_{e_{n+1}} \leftarrow E_e\cdot W_e\cdot\Delta x+Q_{conc}-Q_{cong2}$
$\Delta Q_{swe_{n+1}} \leftarrow Q_{e_{n+1}}-\Delta Q_{ae_{n+1}}$
$Q'_{rw} \leftarrow -\Delta Q_{swe_{n+1}}-Q_{mt}-Q_{cw}+Q_{ccw}$
$T'_{g2i_{n+1}} \leftarrow \left[\frac{-Q'_{rw}\cdot\left[\frac{1}{\epsilon_w}+\upsilon\cdot\left(\frac{1}{\epsilon_{g2}}-1\right)\right]}{\upsilon\cdot W_e\cdot\Delta x\cdot\sigma}+\left(T_{swe_n}\right)^4\right]^{\frac{1}{4}}$
$T_{gloLoop_{(i+1)}} \leftarrow T_{gloLoop_i}+\left(\frac{T'_{g2i_{n+1}}-T_{g2i_{n+1}}}{100}\right)$
$i \leftarrow i+1$
$LoopStop_i \leftarrow \left|\frac{Q_{rw}-Q'_{rw}}{Q_{rw}}\right|$
```

```
        $gloLoop_i$
    $T_{ae_{n+1}} \leftarrow$
        $zz \leftarrow 0$
        $T_{aeLoop_0} \leftarrow T_{ae_n}$
        $LoopStop_{zz} \leftarrow 1$
        while $LoopStop_{zz} > \Lambda \wedge zz < 100$
            $\Delta r_e \leftarrow \frac{m_{mt_{n+1}}}{m_{da}}$
            $r_{e_{n+1}} \leftarrow r_{e_n} + \Delta r_e$
            $cp_{an1} \leftarrow \left[3.542857 \cdot 10^{-7} \left(\frac{T_{aeLoop_{zz}}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{aeLoop_{zz}}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $h_{gan1} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{aeLoop_{zz}} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{aeLoop_{zz}} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
            $T_{aeheat} \leftarrow$
                $vv \leftarrow 0$
                $T_{aeheatLoop_{vv}} \leftarrow T_{ae_n}$
                $\Delta Q_{aeheat} \leftarrow Q_{cw} - Q_{cg}$
                $LoopStop_{vv} \leftarrow 1$
                while $LoopStop_{vv} > \Lambda \wedge vv < 100$
                    $cp_{an} \leftarrow \left[3.542857 \cdot 10^{-7} \left(\frac{T_{ae_n}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{ae_n}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                    $cp_{aheat} \leftarrow \left[3.542857 \cdot 10^{-7} \left(\frac{T_{aeheatLoop_{vv}}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{aeheatLoop_{vv}}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                    $h_{gan} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{ae_n} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{ae_n} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
                    $h_{gaheat} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{aeheatLoop_{vv}} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{aeheatLoop_{vv}} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
                    $T_{aeheatLoop_{vv+1}} \leftarrow \frac{\Delta Q_{aeheat} + m_{da} \cdot cp_{an} \cdot T_{ae_n} - r_{e_n} \cdot m_{da} \cdot (h_{gaheat} - h_{gan})}{cp_{aheat} \cdot m_{da}}$
                    $vv \leftarrow vv + 1$
                    $|T_{aeheatLoop} - T_{aeheatLoop}|$
```

```
                    $LoopStop_{vv} \leftarrow \left|\frac{T_{aeheatLoop_{vv}} - T_{aeheatLoop_{vv-1}}}{T_{aeheatLoop_{vv}}}\right|$
                $T_{aeheatLoop_{vv}}$
            $T_{aeLoop_{zz+1}} \leftarrow \frac{cp_{aheat} \cdot m_{da} \cdot T_{aeheat} + m_{da} \cdot r_{e_n} \cdot h_{gaheat} + m_{mt_{n+1}} \cdot h_{gsw} - m_{da} \cdot r_{e_{n+1}} \cdot h_{gan1}}{cp_{an1} \cdot m_{da}}$
            $zz \leftarrow zz + 1$
            $LoopStop_{zz} \leftarrow \left|\frac{T_{aeLoop_{zz}} - T_{aeLoop_{zz-1}}}{T_{aeLoop_{zz}}}\right|$
        $T_{aeLoop_{zz}}$
    $m_{swe_{n+1}} \leftarrow m_{swe_n} + m_{mt_{n+1}}$
    $T_{swe_{n+1}} \leftarrow$
        $cp_{sw} \leftarrow 4147 \cdot J \cdot kg^{-1} \cdot K^{-1}$
        $h_{fsw} \leftarrow \left[4.183824 \cdot 10^3 \cdot \left(\frac{T_{swe_n}}{K}\right) - 1.141915 \cdot 10^6\right] \cdot J \cdot kg^{-1}$
        $\frac{(\Delta Q_{swe_{n+1}} + Q_{mt}) - m_{mt_{n+1}} \cdot (h_{gsw} - h_{fsw}) + m_{swe_n} \cdot cp_{sw} \cdot T_{swe_n}}{m_{swe_n} \cdot cp_{sw}}$
    $Z_{e_{n+1}} \leftarrow \frac{1000 \cdot m_{se}}{m_{swe_{n+1}}}$
    $H_{swe_{n+1}} \leftarrow$
        $qq \leftarrow 0$
        $H_{swLoop_0} \leftarrow 0.005 \cdot m$
        $\mu_{swe} \leftarrow$
            $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z_{e_{n+1}} + c_{2v} \cdot (Z_{e_{n+1}})^2$
            $\chi \leftarrow$
                $T_{sweC} \leftarrow \frac{T_{swe_{n+1}} - 273.15 \cdot K}{K}$
                $\chi_1 \leftarrow A_v \left[1 + a_{1v} \cdot Z_{e_{n+1}} + a_{2v} \cdot (Z_{e_{n+1}})^2\right]$
                $\chi_2 \leftarrow B_v \left[1 + b_{1v} \cdot Z_{e_{n+1}} + b_{2v} \cdot (Z_{e_{n+1}})^2\right]$
                $\left(\frac{T_{sweC} - 20}{T_{sweC} + 109}\right) \cdot [\chi_1 + \chi_2 (T_{sweC} - 20)]$
            $\frac{\mu_{20}}{10^{\chi}} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
```

```
            $10$
$\rho_{swe} \leftarrow$ for $\iota \in 0..2$
        $x_\iota \leftarrow \frac{2 \cdot Z_{e_{n+1}} - 150}{150}$
        $T_{\iota_0} \leftarrow 1$
        $T_{\iota_1} \leftarrow x_\iota$
        $T_{\iota_2} \leftarrow 2 \cdot x_\iota^2 - 1$
        for $\varepsilon \in 0..2$
            $x_\varepsilon \leftarrow \left(\frac{2 \cdot T_{sweC} - 250}{110}\right)$
            $T_{\varepsilon_0} \leftarrow 1$
            $T_{\varepsilon_1} \leftarrow x_\varepsilon$
            $T_{\varepsilon_2} \leftarrow 2 \cdot x_\varepsilon^2 - 1$
        $10^3 \cdot kg \cdot m^{-3} \cdot \sum_{\iota=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\iota,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\iota_\iota}\right)$
$V_{swe} \leftarrow \frac{m_{swe_{n+1}}}{\rho_{swe}}$
$LoopStop_{qq} \leftarrow 1$
while $LoopStop_{qq} > \Lambda \wedge qq < 100$
    $R \leftarrow \frac{W_e \cdot H_{swLoop_{qq}}}{W_e + 2 \cdot H_{swLoop_{qq}}}$
    $u_{swe_{n+1}} \leftarrow -(32 \cdot g \cdot R \cdot S)^{\frac{1}{2}} \cdot \left[\log\left[\frac{k_c}{14.8 \cdot R} + \frac{1.255 \cdot \mu_{swe}}{\rho_{swe} \cdot R \cdot (32 \cdot g \cdot R \cdot S)^{\frac{1}{2}}}\right]\right]$
    $H_{swLoop_{(qq+1)}} \leftarrow \frac{V_{swe}}{u_{swe_{n+1}} \cdot W_e}$
    $qq \leftarrow qq + 1$
    $LoopStop_{qq} \leftarrow \left|\frac{H_{swLoop_{qq}} - H_{swLoop_{qq-1}}}{\quad}\right|$
```

```
        $_{qq}$        $H_{swLoop_{qq}}$
    $H_{swLoop_{qq}}$
$p_{ae_{n+1}} \leftarrow$
    $jj \leftarrow 0$
    $p_{aeLoop_0} \leftarrow p_{ae_n}$
    $Re_{ae_{n+1}} \leftarrow$
        $Re_{ae_0} \leftarrow 0$
        $A_{ag} \leftarrow \left(2 \cdot H_{ae_n} + W_e\right) \cdot \Delta x$
        $A_{aw} \leftarrow W_e \cdot \upsilon \cdot \Delta x$
        $T_{fae} \leftarrow$
            $T_{fcg} \leftarrow \frac{T_{ae_n} + T_{g2i_{n+1}}}{2}$
            $T_{fcw} \leftarrow \frac{T_{ae_n} + T_{swe_n}}{2}$
            $\frac{T_{fcg} \cdot A_{ag} + T_{fcw} \cdot A_{aw}}{A_{aw} + A_{ag}}$
        $\rho_{fae} \leftarrow$
            $p_{vfae} \leftarrow$
                $C \leftarrow \frac{C_1}{\left(\frac{T_{fae}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{fae}}{K}\right) + C_4 \cdot \left(\frac{T_{fae}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{fae}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{fae}}{K}\right)$
                $p_{sfae} \leftarrow \left(e^C\right) \cdot Pa$
                $RH_{e_n} \cdot p_{sfae}$
            $v_{afae} \leftarrow \frac{0.287035 \cdot T_{fae}}{p_{ae_n} - p_{vfae}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
            $r_{fae} \leftarrow \frac{0.62198 \cdot p_{vfae}}{p_{ae_n} - p_{vfae}}$
            $\frac{1 + r_{fae}}{v_{afae}}$
        $\mu_{fae} \leftarrow$
            $\mu_{vfae} \leftarrow \left[1.299155 \cdot 10^{-12} \left(\frac{T_{fae}}{K}\right)^2 + 3.872699 \cdot 10^{-8} \cdot \left(\frac{T_{fae}}{K}\right) - 2.390839 \cdot 10^{-6}\right] \cdot kg \cdot m^{-1} \cdot s^{-1}$
            $\mu_{afae} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{fae}}{K} + 4.745 \cdot 10^{-6}\right) \cdot kg \cdot m^{-1} \cdot s^{-1}$
            $N_{vfae} \leftarrow \frac{r_{fae} \cdot m_{da}}{\quad}$
```

```
                $M_w$
                $N_{afae} \leftarrow \frac{m_{da}}{M_a}$
                $\left(\frac{N_{vfae}}{N_{vfae}+N_{afae}}\right)\cdot\mu_{vfae}+\left(\frac{N_{afae}}{N_{vfae}+N_{afae}}\right)\cdot\mu_{afae}$
            $u_{aerel} \leftarrow \frac{u_{ae_n}\cdot A_{ag}+\left(u_{ae_n}+u_{swe_n}\right)\cdot A_{aw}}{A_{ag}+A_{aw}}$
            $R_{ae} \leftarrow \frac{H_{ae_n}\cdot W_e}{2\cdot\left(H_{ae_n}+W_e\right)}$
            $\frac{\rho_{fae}\cdot u_{aerel}\cdot(4\cdot R_{ae})}{\mu_{fae}}$
$LoopStop_{jj} \leftarrow 1$
while $LoopStop_{jj} > \Lambda \wedge jj < 100$
    $u_{ae_{n+1}} \leftarrow$
        $A_e \leftarrow$
            $H_{ae_{n+1}} \leftarrow H_e - H_{swe_{n+1}}$
            $W_e\cdot H_{ae_{n+1}}$
        $\rho_{wae_{n+1}} \leftarrow$
            $p_{ve} \leftarrow \frac{r_{e_{n+1}}\cdot p_{aeLoop_{jj}}}{0.62198+r_{e_{n+1}}}$
            $v_{ae} \leftarrow \frac{0.287035\cdot T_{ae_{n+1}}}{p_{aeLoop_{jj}}-p_{ve}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
            $\frac{1+r_{e_{n+1}}}{v_{ae}}$
        $V_e \leftarrow \frac{m_{da}\cdot\left(1+r_{e_{n+1}}\right)}{\rho_{wae_{n+1}}}$
        $\frac{V_e}{A_e}$
    $z_{e_{n+1}} \leftarrow z_{e_n} + \Delta x\cdot S$
    $H_{fl} \leftarrow$
        $f_{fl} \leftarrow$
            $ii \leftarrow 0$
            $f_{flLoop_0} \leftarrow 0.1$
            $k \leftarrow 0.001\cdot m$
```

```
            $_{rsw}$
            $k_{rg} \leftarrow 10\cdot 10^{-9}\cdot m$
            $k_{fl} \leftarrow \frac{A_{aw}\cdot k_{rsw}+A_{ag}\cdot k_{rg}}{A_{aw}+A_{ag}}$
            $LoopStop_{ii} \leftarrow 1$
            while $LoopStop_{ii} > \frac{\Omega}{100} \wedge ii < 100$
                $f_{flLoop_{ii+1}} \leftarrow \left(-4\cdot\log\left(\frac{k_{fl}}{3.71\cdot 4\cdot R_{ae}}+\frac{1.255}{Re_{ae_{n+1}}\cdot\sqrt{f_{flLoop_{ii}}}}\right)\right)^{-2}$
                $ii \leftarrow ii + 1$
                $LoopStop_{ii} \leftarrow \left|f_{flLoop_{ii}} - f_{flLoop_{ii-1}}\right|$
            $f_{flLoop_{ii}}$
        $\frac{f_{fl}\cdot\Delta x\cdot {u_{aerel}}^2}{2\cdot g\cdot 4\cdot R_{ae}}$
    $\rho_{waeavg} \leftarrow \frac{\rho_{wae_n}+\rho_{wae_{n+1}}}{2}$
    $H_{wap} \leftarrow \frac{p_{ae_n}}{\rho_{waeavg}\cdot g}+\frac{\left(u_{ae_n}\right)^2}{2\cdot g}+z_{e_n}$
    $p_{aeLoop_{(jj+1)}} \leftarrow \rho_{waeavg}\cdot g\cdot\left[H_{wap}-\frac{\left(u_{ae_{n+1}}\right)^2}{2\cdot g}-z_{e_{n+1}}-H_{fl}\right]$
    $jj \leftarrow jj + 1$
    $LoopStop_{jj} \leftarrow \left|\frac{p_{aeLoop_{jj}}-p_{aeLoop_{jj-1}}}{p_{aeLoop_{jj}}}\right|$
$p_{aeLoop_{jj}}$
$RH_{e_{n+1}} \leftarrow$
    $p_{se} \leftarrow$
        $C \leftarrow \frac{C_1}{\left(\frac{T_{ae_{n+1}}}{K}\right)}+C_2+C_3\cdot\left(\frac{T_{ae_{n+1}}}{K}\right)+C_4\cdot\left(\frac{T_{ae_{n+1}}}{K}\right)^2+C_5\cdot\left(\frac{T_{ae_{n+1}}}{K}\right)^3+C_6\cdot\ln\left(\frac{T_{ae_{n+1}}}{K}\right)$
        $\left(e^C\right)\cdot Pa$
    $p$
```

```
            $\frac{{}_{ve}}{p_{se}}$
            $T_{dp_{n+1}} \leftarrow$ $\omega \leftarrow \ln\left(\frac{p_{ve}}{1000 \cdot Pa}\right)$
                        $\left[C_7 + C_8 \cdot \omega + C_9 \cdot \omega^2 + C_{10} \cdot \omega^3 + C_{11} \cdot \left(\frac{p_{ve}}{1000 \cdot Pa}\right)^{0.1984} + 273.15\right] \cdot K$
            break if $r_{e_{n+1}} > r_{ex}$
            $n \leftarrow n + 1$
        $L_{e_{E+1}} \leftarrow n \cdot \Delta x$
        $T_{swexEst_{E+1}} \leftarrow T_{swe_n}$
        $p_{aexEst_{E+1}} \leftarrow p_{ae_n}$
        $E \leftarrow E + 1$
        $LoopStop_E \leftarrow \left|L_{e_E} - L_{e_{E-1}}\right|$
    if $RH_{e_N} > RH_{ex}$
        $u_{aeiHigh_{U_e+1}} \leftarrow u_{aei}$
        $u_{aeiLow_{U_e+1}} \leftarrow u_{aeiLow_{U_e}}$
        $U_e \leftarrow U_e + 1$
    if $RH_{e_N} < RH_{ex}$
        $u_{aeiHigh_{U_e+1}} \leftarrow u_{aeiHigh_{U_e}}$
        $u_{aeiLow_{U_e+1}} \leftarrow u_{aei}$
        $U_e \leftarrow U_e + 1$
    $LoopStop_{Ue} \leftarrow \left|\frac{u_{aeiHigh_{U_e}} - u_{aeiLow_{U_e}}}{u_{aeiHigh_{U_e}}}\right|$
for $n \in 0..N$
    $M_{0,n} \leftarrow \frac{T_{ae_n}}{K}$
    $M_{1,n} \leftarrow \frac{m_{da}}{kg \cdot s^{-1}}$
```

```
    $M_{2,n} \leftarrow \frac{\rho_{wae_n}}{kg \cdot m^{-3}}$
    $M_{3,n} \leftarrow r_{e_n}$
    $M_{4,n} \leftarrow RH_{e_n}$
    $M_{5,n} \leftarrow \frac{p_{ae_n}}{Pa}$
    $M_{6,n} \leftarrow \frac{u_{ae_n}}{m \cdot s^{-1}}$
    $M_{7,n} \leftarrow Re_{ae_n}$
    $M_{8,n} \leftarrow \frac{T_{dp_n}}{K}$
    $M_{9,n} \leftarrow \frac{m_{mt_n}}{kg \cdot s^{-1}}$
    $M_{10,n} \leftarrow \frac{T_{swe_n}}{K}$
    $M_{11,n} \leftarrow \frac{m_{swe_n}}{kg \cdot s^{-1}}$
    $M_{12,n} \leftarrow 0$
    $M_{13,n} \leftarrow Z_{e_n}$
    $M_{14,n} \leftarrow 0$
    $M_{15,n} \leftarrow \frac{u_{swe_n}}{m \cdot s^{-1}}$
    $M_{16,n} \leftarrow \frac{H_{ae_n}}{m}$
    $M_{17,n} \leftarrow \frac{H_{swe_n}}{m}$
    $M_{18,n} \leftarrow \frac{H_e}{m}$
              $Q_{rg} + Q_{co} - Q_{conc}$
```

```
            $M_{19,n} \leftarrow \frac{}{W}$
            $M_{20,n} \leftarrow \frac{\Delta Q_{ae_n} + \Delta Q_{swe_n}}{W}$
            $M_{21,n} \leftarrow \frac{Q_{e_n}}{W}$
    SecHEAT ← $P \leftarrow 0$
              $L_{P_0} \leftarrow 800 \cdot m$
              $\Delta x \leftarrow 1 \cdot m$
              $LoopStop_P \leftarrow 10 \cdot m$
              while $LoopStop_P > 0 \cdot m$
                  $N_p \leftarrow \frac{L_{P_P}}{\Delta x}$
                  $n_p \leftarrow 0$
                  $T_{swp_0} \leftarrow T_{swe_N}$
                  $T_{swpi} \leftarrow T_{swei}$
                  $u_{swp_0} \leftarrow u_{swpx}$
                  $p_{swp_0} \leftarrow p_{atm}$
                  $Z \leftarrow Z_{e_N}$
                  $z_{p_0} \leftarrow \left(L_{e_E} + 50 \cdot m\right) \cdot S_p$
                  $H_p \leftarrow$ $m_{swp} \leftarrow m_{swe_N}$
                         $\rho_{swpx} \leftarrow$ for $\iota \in 0..2$
                               $x_\iota \leftarrow \frac{2 \cdot Z - 150}{150}$
                               $T_{\iota_0} \leftarrow 1$
                               $T_{\iota_1} \leftarrow x_\iota$
                               $T_{\iota_2} \leftarrow 2 \cdot x_\iota^{2} - 1$
                               for $\varepsilon \in 0..2$
                                   $T_{sweC} \leftarrow \frac{T_{swp_0} - 273.15 \cdot K}{K}$
```

```
                                   $x_\varepsilon \leftarrow \left(\frac{2 \cdot T_{sweC} - 250}{110}\right)$
                                   $T_{\varepsilon_0} \leftarrow 1$
                                   $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                                   $T_{\varepsilon_2} \leftarrow 2 \cdot x_\varepsilon^{2} - 1$
                               $10^{3} \cdot kg \cdot m^{-3} \cdot \sum_{\iota=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\iota,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\iota_\iota}\right)$
                         $Q_{swpx} \leftarrow \frac{m_{swp}}{\rho_{swpx}}$
                         $A_p \leftarrow \frac{Q_{swpx}}{u_{swpx}}$
                         $\frac{A_p}{W_p}$
                  $u_{swpi} \leftarrow$ $\rho_{swp_0} \leftarrow$ for $\iota \in 0..2$
                               $x_\iota \leftarrow \frac{2 \cdot Z - 150}{150}$
                               $T_{\iota_0} \leftarrow 1$
                               $T_{\iota_1} \leftarrow x_\iota$
                               $T_{\iota_2} \leftarrow 2 \cdot x_\iota^{2} - 1$
                               for $\varepsilon \in 0..2$
                                   $T_{sweC} \leftarrow \frac{T_{swpi} - 273.15 \cdot K}{K}$
                                   $x_\varepsilon \leftarrow \left(\frac{2 \cdot T_{sweC} - 250}{110}\right)$
                                   $T_{\varepsilon_0} \leftarrow 1$
                                   $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                                   $T_{\varepsilon_2} \leftarrow 2 \cdot x_\varepsilon^{2} - 1$
                               $10^{3} \cdot kg \cdot m^{-3} \cdot \sum^{2} \sum^{2} \left(b_{\iota,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\iota_\iota}\right)$
```

```
                    ı = 0  ε = 0
            $\frac{m_{swp}}{A_p \cdot \rho_{swp_0}}$
    while $n_p < N_p$
        $x_{xp} \leftarrow \left(n_p + \frac{1}{2}\right)\cdot \Delta x$
        $x_{lp} \leftarrow L_{Pp} - x_{xp}$
        $T_{glo_{n_p+1}} \leftarrow$
            $i \leftarrow 0$
            $T_{glo_0} \leftarrow \frac{T_{amb} + T_{swp_0}}{2}$
            $T_{gloLoop_0} \leftarrow T_{glo_{n_p}}$
            $LoopStop_i \leftarrow 1$
            while $LoopStop_i > \Lambda \wedge i < 200$
                $Q_{ro} \leftarrow \sigma \cdot \Delta x \cdot \varepsilon_{gl} \cdot W_p \cdot \left[{T_{bbsky}}^4 - \left(T_{gloLoop_i}\right)^4\right]$
                $Q_{co} \leftarrow$
                    $hx_{co} \leftarrow$
                        $T_{fco} \leftarrow \frac{T_{gloLoop_i} + T_{amb}}{2}$
                        $\rho_{fco} \leftarrow$
                            $p_{vfco} \leftarrow$
                                $C \leftarrow \frac{C_1}{\left(\frac{T_{fco}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{fco}}{K}\right) + C_4\cdot\left(\frac{T_{fco}}{K}\right)^2 + C_5\cdot\left(\frac{T_{fco}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{fco}}{K}\right)$
                                $p_{sfco} \leftarrow \left(e^C\right)\cdot Pa$
                                $RH_{amb}\cdot p_{sfco}$
                            $v_{afco} \leftarrow \frac{0.287035\cdot T_{fco}}{p_{atm} - p_{vfco}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
                            $r_{fco} \leftarrow \frac{0.62198\cdot p_{vfco}}{p_{atm} - p_{vfco}}$
                            $\frac{1 + r_{fco}}{v_{afco}}$
                        $k_{fco} \leftarrow$
                            $k_{vfco} \leftarrow \left[3.767616\cdot10^{-14}\cdot\left(\frac{T_{fco}}{K}\right)^3 + 1.247242\cdot10^{-10}\cdot\left(\frac{T_{fco}}{K}\right)^2 + 3.184034\cdot10^{-9}\cdot\left(\frac{T_{fco}}{K}\right) + 7.678236\cdot10^{-6}\right]\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
                            $k_{afco} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fco}}{K} + 3.479\cdot10^{-6}\right)\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
```

```
                            $Nratio_{vfco} \leftarrow \frac{r_{fco}\cdot 1\cdot kg}{M_w}$
                            $Nratio_{afco} \leftarrow \frac{1\cdot kg}{M_a}$
                            $\left(\frac{Nratio_{vfco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot k_{vfco} + \left(\frac{Nratio_{afco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot k_{afco}$
                        $\mu_{fco} \leftarrow$
                            $\mu_{vfco} \leftarrow \left[1.299155\cdot10^{-12}\cdot\left(\frac{T_{fco}}{K}\right)^2 + 3.872699\cdot10^{-8}\cdot\left(\frac{T_{fco}}{K}\right) - 2.390839\cdot10^{-6}\right]\cdot kg\cdot m^{-1}\cdot s^{-1}$
                            $\mu_{afco} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fco}}{K} + 4.745\cdot10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
                            $\left(\frac{Nratio_{vfco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot\mu_{vfco} + \left(\frac{Nratio_{afco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot\mu_{afco}$
                        $cp_{fco} \leftarrow$
                            $cp_{vfco} \leftarrow \left[-5.103046\cdot10^{-10}\cdot\left(\frac{T_{fco}}{K}\right)^3 + 1.252416\cdot10^{-6}\left(\frac{T_{fco}}{K}\right)^2 - 3.165154\cdot10^{-4}\left(\frac{T_{fco}}{K}\right) + 1.861896\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                            $cp_{afco} \leftarrow \left[3.542857\cdot10^{-7}\cdot\left(\frac{T_{fco}}{K}\right)^2 - 1.626857\cdot10^{-4}\cdot\frac{T_{fco}}{K} + 1.021769\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                            $mratio_{vfco} \leftarrow r_{fco}\cdot 1\cdot kg$
                            $\left(\frac{mratio_{vfco}}{1\cdot kg + mratio_{vfco}}\right)\cdot cp_{vfco} + \left(\frac{1\cdot kg}{1\cdot kg + mratio_{vfco}}\right)\cdot cp_{afco}$
                        $Pr_{fco} \leftarrow \frac{cp_{fco}\cdot\mu_{fco}}{k_{fco}}$
                        $Re_{xao} \leftarrow \frac{\rho_{fco}\cdot u_{ao}\cdot x_{xp}}{\mu_{fco}}$
                        $Nux_{co} \leftarrow$
                            $0.332\cdot {Pr_{fco}}^{\frac{1}{3}}\cdot {Re_{xao}}^{\frac{1}{2}}$ if $Re_{xao} < 0$
                            $0.0296\cdot {Pr_{fco}}^{\frac{1}{3}}\cdot {Re_{xao}}^{\frac{4}{5}}$ if $0 \le Re_{xao} \le 10^7$
                            $0.185\cdot {Pr_{fco}}^{\frac{1}{3}}\cdot Re_{xao}\cdot\left(\log\left(Re_{xao}\right)\right)^{-2.584}$ otherwise
                        $Nux_{co}\cdot\frac{k_{fco}}{\ }$
```

```
                $x_{xp}$
                $hx_{co}\cdot\Delta x\cdot W_p\cdot\left(T_{amb} - T_{g1oLoop_j}\right)$
            $Q_{cong1} \leftarrow -Q_{ro} - Q_{co} - E_{g1}\cdot W_p\cdot\Delta x$
            $T_{g1i_{n_p+1}} \leftarrow \frac{Q_{cong1}}{\frac{k_{g1}}{t_{g1}}\cdot\Delta x\cdot W_p} + T_{g1oLoop_j}$
            $T_{g2o_{n_p+1}} \leftarrow$
                $j \leftarrow 0$
                $T_{g2o_0} \leftarrow T_{swp_0}$
                $T_{g2oLoop_0} \leftarrow T_{g2o_{n_p}}$
                $T_{ag1'2} \leftarrow \frac{T_{g2oLoop_j} + T_{g1i_{n_p+1}}}{2}$
                $LoopStop_j \leftarrow 1$
                while $LoopStop_j > \Lambda \wedge j < 200$
                    $Q_{cong} \leftarrow$
                        $\rho_{ag1'2} \leftarrow$
                            $p_{vag1'2} \leftarrow$
                                $C \leftarrow \frac{C_1}{\left(\frac{T_{ag1'2}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{ag1'2}}{K}\right) + C_4\cdot\left(\frac{T_{ag1'2}}{K}\right)^2 + C_5\cdot\left(\frac{T_{ag1'2}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{ag1'2}}{K}\right)$
                                $p_{sag1'2} \leftarrow \left(e^C\right)\cdot Pa$
                                $RH_{amb}\cdot p_{sag1'2}$
                            $v_{aag1'2} \leftarrow \frac{0.287035\cdot T_{ag1'2}}{p_{atm} - p_{vag1'2}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
                            $r_{ag1'2} \leftarrow \frac{0.62198\cdot p_{vag1'2}}{p_{atm} - p_{vag1'2}}$
                            $\frac{1 + r_{ag1'2}}{v_{aag1'2}}$
                        $k_{ag1'2} \leftarrow$
                            $k_{vag1'2} \leftarrow \left[3.767616\cdot 10^{-14}\cdot\left(\frac{T_{ag1'2}}{K}\right)^3 + 1.247242\cdot 10^{-10}\cdot\left(\frac{T_{ag1'2}}{K}\right)^2 + 3.184034\cdot 10^{-9}\cdot\left(\frac{T_{fco}}{K}\right) + 7.678236\cdot 10^{-6}\right]\cdot 10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
                            $k_{aag1'2} \leftarrow \left(7.58\cdot 10^{-8}\cdot\frac{T_{ag1'2}}{K} + 3.479\cdot 10^{-6}\right)\cdot 10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
                            $Nratio_{vag1'2} \leftarrow \frac{r_{ag1'2}\cdot 1\cdot kg}{M_w}$
```

```
                            $Nratio_{aag1'2} \leftarrow \frac{1\cdot kg}{M_a}$
                            $\left(\frac{Nratio_{vag1'2}}{Nratio_{vag1'2} + Nratio_{aag1'2}}\right)\cdot k_{vag1'2} + \left(\frac{Nratio_{aag1'2}}{Nratio_{vag1'2} + Nratio_{aag1'2}}\right)\cdot k_{aag1'2}$
                        $\mu_{ag1'2} \leftarrow$
                            $\mu_{vag1'2} \leftarrow \left[1.299155\cdot 10^{-12}\cdot\left(\frac{T_{ag1'2}}{K}\right)^2 + 3.872699\cdot 10^{-8}\cdot\left(\frac{T_{ag1'2}}{K}\right) - 2.390839\cdot 10^{-6}\right]\cdot kg\cdot m^{-1}\cdot s^{-1}$
                            $\mu_{aag1'2} \leftarrow \left(7.58\cdot 10^{-8}\cdot\frac{T_{ag1'2}}{K} + 4.745\cdot 10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
                            $\left(\frac{Nratio_{vag1'2}}{Nratio_{vag1'2} + Nratio_{aag1'2}}\right)\cdot\mu_{vag1'2} + \left(\frac{Nratio_{aag1'2}}{Nratio_{vag1'2} + Nratio_{aag1'2}}\right)\cdot\mu_{aag1'2}$
                        $cp_{ag1'2} \leftarrow$
                            $cp_{vag1'2} \leftarrow \left[-5.103046\cdot 10^{-10}\cdot\left(\frac{T_{ag1'2}}{K}\right)^3 + 1.252416\cdot 10^{-6}\left(\frac{T_{ag1'2}}{K}\right)^2 - 3.165154\cdot 10^{-4}\left(\frac{T_{ag1'2}}{K}\right) + 1.861896\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                            $cp_{aag1'2} \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{ag1'2}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{ag1'2}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                            $mratio_{vag1'2} \leftarrow r_{ag1'2}\cdot 1\cdot kg$
                            $\left(\frac{mratio_{vag1'2}}{1\cdot kg + mratio_{vag1'2}}\right)\cdot cp_{vag1'2} + \left(\frac{1\cdot kg}{1\cdot kg + mratio_{vag1'2}}\right)\cdot cp_{aag1'2}$
                        $Pr_{ag1'2} \leftarrow \frac{cp_{ag1'2}\cdot\mu_{ag1'2}}{k_{ag1'2}}$
                        $\beta_a \leftarrow \frac{1}{T_{ag1'2}}$
                        $Gr_{ag1'2} \leftarrow \frac{g\cdot\beta_a\cdot\left(T_{g2oLoop_j} - T_{g1i_{n_p+1}}\right)\cdot t_{g1'2}^3}{\left(\frac{\mu_{ag1'2}}{\rho_{ag1'2}}\right)^2}$
                        $k_{ea} \leftarrow$
                            $k_{ag1'2}$ if $Gr_{ag1'2}\cdot Pr_{ag1'2} < 1700$
                            $k_{ag1'2}\cdot 0.059\cdot\left(Gr_{ag1'2}\cdot Pr_{ag1'2}\right)^{0.4}$ if $1700 \le Gr_{ag1'2}\cdot Pr_{ag1'2} < 7000$
                            $k_{ag1'2}\cdot 0.212\cdot\left(Gr_{ag1'2}\cdot Pr_{ag1'2}\right)^{\frac{1}{4}}$ if $7000 \le Gr_{ag1'2}\cdot Pr_{ag1'2} < 3.2\cdot 10^5$
                            $k_{ag1'2}\cdot 0.061\cdot\left(Gr_{ag1'2}\cdot Pr_{ag1'2}\right)^{\frac{1}{3}}$ if $Gr_{ag1'2}\cdot Pr_{ag1'2} \ge 3.2\cdot 10^5$
```

```
                $k'_a \leftarrow$ | $k_{ea}$ if $T_{g2oLoop_j} > T_{g1i_{n_p+1}}$
                                  | $k_{eg1'2}$ otherwise
                $\frac{k'_a}{t_{g1'2}} \cdot \Delta x \cdot W_p \cdot \left(T_{g2oLoop_j} - T_{g1i_{n_p+1}}\right)$
            $Q_{rg} \leftarrow Q_{cong1} - Q_{cong}$
            $T_{g2oLoop_{j+1}} \leftarrow \left[\left(T_{g1i_{n_p+1}}\right)^4 + \frac{Q_{rg} \cdot \left(\frac{1}{\varepsilon_{g1}} + \frac{1}{\varepsilon_{g2}} - 1\right)}{\sigma \cdot \Delta x \cdot W_p}\right]^{\frac{1}{4}}$
            $j \leftarrow j + 1$
            $LoopStop_j \leftarrow \left|\frac{T_{g2oLoop_j} - T_{g2oLoop_{j-1}}}{T_{g2oLoop_j}}\right|$
          $T_{g2oLoop_j}$
        $Q_{cong2} \leftarrow Q_{cong1} - E_{g2} \cdot W_p \cdot \Delta x$
        $T_{g2i_{n_p+1}} \leftarrow \frac{Q_{cong2}}{\frac{k_{g2}}{t_{g2}} \cdot \Delta x \cdot W_p} + T_{g2o_{n_p+1}}$
        $Q_{ccw} \leftarrow$ | $Q_{conc} \leftarrow -0.05 \cdot E_p \cdot \Delta x \cdot W_p$
                            | $E_p \cdot \Delta x \cdot W_p + Q_{conc}$
        $T_{cp_{n_p+1}} \leftarrow$
            $v \leftarrow 0$
            $T_{cp_0} \leftarrow T_{swp_{n_p}}$
            $T_{cpLoop_v} \leftarrow$ | $T_{swp_{n_p}}$ if $n_p = 0$
                                     | $T_{cp_{n_p}}$ otherwise
            $LoopStop_v \leftarrow 1 \cdot K$
            while $LoopStop_v > \Omega \cdot K$
              $hx_{ccw} \leftarrow$
                  $T_{fccw} \leftarrow \frac{T_{cpLoop_v} + T_{swp_{n_p}}}{2}$
                  $Pr_{fccw} \leftarrow$
                      $k_{fccw} \leftarrow$
                          $X \leftarrow Z \cdot 0.2$
                          $Y \leftarrow Z \cdot 0.03$
                          $G \leftarrow 343.5 + Z \cdot 0.37$
```

```
                          $\lambda \leftarrow \ln\left(\frac{k_{swcrit}}{10^{-3} \cdot W \cdot m^{-1} \cdot K^{-1}} + X\right) + \left(2.3 - \frac{G}{\frac{T_{fccw}}{K}}\right) \cdot \left(1 - \frac{\frac{T_{fccw}}{K}}{\frac{T_{swcrit}}{K} + Y}\right)^{0.333}$
                          $e^{\lambda} \cdot 10^{-3} \cdot W \cdot m^{-1} \cdot K^{-1}$
                      $\mu_{fccw} \leftarrow$
                          $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z + c_{2v} \cdot (Z)^2$
                          $\chi \leftarrow$
                              $t_{fccw} \leftarrow \left(\frac{T_{fccw} - 273.15 \cdot K}{K}\right)$
                              $\chi_1 \leftarrow A_v \cdot \left[1 + a_{1v} \cdot Z + a_{2v} \cdot (Z)^2\right]$
                              $\chi_2 \leftarrow B_v \cdot \left[1 + b_{1v} \cdot Z + b_{2v} \cdot (Z)^2\right]$
                              $\left(\frac{t_{fccw} - 20}{t_{fccw} + 109}\right) \cdot \left[\chi_1 + \chi_2 \cdot \left(t_{fccw} - 20\right)\right]$
                          $\frac{\mu_{20}}{10^{\chi}} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
                      $cp_{sw} \leftarrow 4174 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                      $\frac{cp_{sw} \cdot \mu_{fccw}}{k_{fccw}}$
                  $Re_{xccw} \leftarrow$
                      $\rho_{fccw} \leftarrow$ for $\eta \in 0..2$
                          $t_{fccw} \leftarrow \left(\frac{T_{fccw} - 273 \cdot K}{K}\right)$
                          $x_{\eta} \leftarrow \left(\frac{2 \cdot Z - 150}{150}\right)$
                          $T_{\eta_0} \leftarrow 1$
                          $T_{\eta_1} \leftarrow x_{\eta}$
                          $T_{\eta_2} \leftarrow 2 \cdot {x_{\eta}}^2 - 1$
                          for $\varepsilon \in 0..2$
                              $x_{\varepsilon} \leftarrow \left(\frac{2 \cdot t_{fccw} - 250}{110}\right)$
                              $T_{\varepsilon_0} \leftarrow 1$
                              $T \leftarrow x$
```

```
                        $T_{\varepsilon_2} \leftarrow 2 \cdot x_\varepsilon^{2} - 1$
                    $10^3 \cdot kg \cdot m^{-3} \cdot \sum_{\eta=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\eta,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\eta_\eta}\right)$
                $\mu_{fccw} \leftarrow$
                    $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z + c_{2v} \cdot Z^2$
                    $\chi \leftarrow$
                        $\chi_1 \leftarrow A_v \cdot \left(1 + a_{1v} \cdot Z + a_{2v} \cdot Z^2\right)$
                        $\chi_2 \leftarrow B_v \cdot \left(1 + b_{1v} \cdot Z + b_{2v} \cdot Z^2\right)$
                        $\left(\frac{t_{fccw} - 20}{t_{fccw} + 109}\right) \cdot \left[\chi_1 + \chi_2 \cdot \left(t_{fccw} - 20\right)\right]$
                    $\frac{\mu_{20}}{10^{\chi}} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
                $\frac{\rho_{fccw} \cdot \left(\frac{u_{swp_{n_p}} + u_{swpi}}{2}\right) \cdot x_{ip}}{\mu_{fccw}}$
            $Nux_{ccw} \leftarrow$
                $0.332 \cdot Pr_{fccw}^{\frac{1}{3}} \cdot Re_{xccw}^{\frac{1}{2}}$ if $Re_{xccw} < 0$
                $0.0296 \cdot Pr_{fccw}^{\frac{1}{3}} \cdot Re_{xccw}^{\frac{4}{5}}$ if $0 \le Re_{xccw} \le 10^7$
                $0.185 \cdot Pr_{fccw}^{\frac{1}{3}} \cdot Re_{xccw} \cdot \left(\log\left(Re_{xccw}\right)\right)^{-2.584}$ otherwise
            $Nux_{ccw} \cdot \frac{k_{fccw}}{x_{ip}}$
        $T_{cpLoop_{v+1}} \leftarrow \frac{Q_{ccw}}{hx_{ccw} \cdot \Delta x \cdot W_p} + T_{swp_{n_p}}$
        $v \leftarrow v + 1$
        $LoopStop_v \leftarrow \left|T_{cpLoop_v} - T_{cpLoop_{v-1}}\right|$
    $T_{cpLoop_v}$
$Q_{p_{n_p}+1} \leftarrow E_p \cdot W_p \cdot \Delta x + Q_{conc} - Q_{cong2}$
```

```
$\Delta Q_{swp_{n_p}+1} \leftarrow Q_{p_{n_p}+1}$
$Q_{cgw} \leftarrow \Delta Q_{swp_{n_p}+1} - Q_{cong2}$
$T_{g2i_{n_p}+1} \leftarrow$
    $ss \leftarrow 0$
    $T_{g2iLoop_0} \leftarrow T_{g2i_{n_p}+1}$
    $LoopStop_{ss} \leftarrow 1$
    while $LoopStop_{ss} > \Lambda$
        $hx_{cgw} \leftarrow$
            $T_{fcgw} \leftarrow \frac{T_{g2iLoop_{ss}} + T_{swp_{n_p}}}{2}$
            $Pr_{fcgw} \leftarrow$
                $k_{fcgw} \leftarrow$
                    $X \leftarrow Z \cdot 0.2$
                    $Y \leftarrow Z \cdot 0.03$
                    $G \leftarrow 343.5 + Z \cdot 0.37$
                    $\lambda \leftarrow \ln\left(\frac{k_{swcrit}}{10^{-3} \cdot W \cdot m^{-1} \cdot K^{-1}} + X\right) + \left(2.3 - \frac{G}{\frac{T_{fcgw}}{K}}\right) \cdot \left(1 - \frac{\frac{T_{fcgw}}{K}}{\frac{T_{fcgw}}{K} + Y}\right)^{0.333}$
                    $e^{\lambda} \cdot 10^{-3} \cdot W \cdot m^{-1} \cdot K^{-1}$
                $\mu_{fcgw} \leftarrow$
                    $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z + c_{2v} \cdot Z^2$
                    $\chi \leftarrow$
                        $t_{fcgw} \leftarrow \left(\frac{T_{fcgw} - 273.15 \cdot K}{K}\right)$
                        $\chi_1 \leftarrow A_v \cdot \left(1 + a_{1v} \cdot Z + a_{2v} \cdot Z^2\right)$
                        $\chi_2 \leftarrow B_v \cdot \left(1 + b_{1v} \cdot Z + b_{2v} \cdot Z^2\right)$
                        $\left(\frac{t_{fcgw} - 20}{t_{fcgw} + 109}\right) \cdot \left[\chi_1 + \chi_2 \cdot \left(t_{fcgw} - 20\right)\right]$
                    $\frac{\mu_{20}}{10^{\chi}} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
                $cp_{fcgw} \leftarrow 4174 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                $\frac{cp_{fcgw} \cdot \mu_{fcgw}}{k_{fcgw}}$
            $Re_{xcgw} \leftarrow$
                $\rho_{fcgw} \leftarrow$ for $\eta \in 0..2$
                    $\left(T_{fcow} - 273 \cdot K\right)$
```

```
              $t_{fcgw} \leftarrow \left(\frac{\quad}{K}\right)$
              $x_\eta \leftarrow \left(\frac{2\cdot Z-150}{150}\right)$
              $T_{\eta_0} \leftarrow 1$
              $T_{\eta_1} \leftarrow x_\eta$
              $T_{\eta_2} \leftarrow 2\cdot {x_\eta}^2-1$
              for $\varepsilon \in 0..2$
                $x_\varepsilon \leftarrow \left(\frac{2\cdot t_{fcgw}-250}{110}\right)$
                $T_{\varepsilon_0} \leftarrow 1$
                $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                $T_{\varepsilon_2} \leftarrow 2\cdot {x_\varepsilon}^2-1$
              $10^3\cdot kg\cdot m^{-3}\cdot \sum_{\eta=0}^{2}\sum_{\varepsilon=0}^{2}\left(b_{\eta,\varepsilon}\cdot T_{\varepsilon_\varepsilon}\cdot T_{\eta_\eta}\right)$
            $\mu_{fcgw} \leftarrow$
              $\mu_{20} \leftarrow 1.002+c_{1v}\cdot Z+c_{2v}\cdot Z^2$
              $\chi \leftarrow$
                $\chi_1 \leftarrow A_v\cdot\left(1+a_{1v}\cdot Z+a_{2v}\cdot Z^2\right)$
                $\chi_2 \leftarrow B_v\cdot\left(1+b_{1v}\cdot Z+b_{2v}\cdot Z^2\right)$
                $\left(\frac{t_{fcgw}-20}{t_{fcgw}+109}\right)\cdot\left[\chi_1+\chi_2\cdot\left(t_{fcgw}-20\right)\right]$
              $\frac{\mu_{20}}{10^{\chi}}\cdot 10^{-3}\cdot kg\cdot m^{-1}\cdot s^{-1}$
            $\frac{\rho_{fcgw}\cdot u_{swp_{n_p}}\cdot x_{ip}}{\mu_{fcgw}}$
          $Nux_{cgw} \leftarrow$
            $0.332\cdot {Pr_{fcgw}}^{\frac{1}{3}}\cdot {Re_{xcgw}}^{\frac{1}{2}}$ if $Re_{xcgw} < 0$
            $0.0296\cdot {Pr_{fcgw}}^{\frac{1}{3}}\cdot {Re_{xcgw}}^{\frac{4}{5}}$ if $0 \le Re_{xcgw} \le 10^7$
            1
```

```
            $0.185\cdot {Pr_{fcgw}}^{\overline{3}}\cdot Re_{xcgw}\cdot\left(\log\left(Re_{xcgw}\right)\right)^{-2.584}$ otherwise
          $Nux_{cgw}\cdot\frac{k_{fcgw}}{x_{ip}}$
        $T_{g2iLoop_{ss+1}} \leftarrow \frac{Q_{cgw}}{\left(hx_{cgw}\cdot \Delta x\cdot W_p\right)}+T_{swp_{n_p}}$
        $ss \leftarrow ss+1$
        $LoopStop_{ss} \leftarrow \left|\frac{T_{g2iLoop_{ss}}-T_{g2iLoop_{ss-1}}}{T_{g2iLoop_{ss}}}\right|$
      $T_{g2iLoop_{ss}}$
    $T_{g1oLoop_{(i+1)}} \leftarrow T_{g1oLoop_i}+\left(\frac{T_{g2i_{n_p+1}}-T_{g2i_{n_p+1}}}{100}\right)$
    $i \leftarrow i+1$
    $LoopStop_i \leftarrow \left|\frac{T_{g2i_{n_p+1}}-T_{g2i_{n_p+1}}}{T_{g2i_{n_p+1}}}\right|$
  $T_{g1oLoop_i}$
$T_{swp_{n_p+1}} \leftarrow$
  $cp_{sw} \leftarrow 4147\cdot J\cdot kg^{-1}\cdot K^{-1}$
  $\frac{\frac{\Delta Q_{swp_{n_p+1}}}{m_{swp}}-cp_{sw}\cdot T_{swp_{n_p}}}{-cp_{sw}}$
$u_{swp_{n_p+1}} \leftarrow$
  $\rho_{swp_{n_p+1}} \leftarrow$ for $\iota \in 0..2$
      $x_\iota \leftarrow \frac{2\cdot Z-150}{150}$
      $T_{\iota_0} \leftarrow 1$
      $T_{\iota_1} \leftarrow x_\iota$
      $T_{\iota_2} \leftarrow 2\cdot {x_\iota}^2-1$
      for $\varepsilon \in 0..2$
        $T_{sweC} \leftarrow \frac{T_{swp_{n_p+1}}-273.15\cdot K}{K}$
```

```
                        $x_\varepsilon \leftarrow \left(\frac{2\cdot t_{sweC} - 250}{110}\right)$
                        $T_{\varepsilon_0} \leftarrow 1$
                        $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                        $T_{\varepsilon_2} \leftarrow 2\cdot {x_\varepsilon}^2 - 1$
                    $10^3\cdot kg\cdot m^{-3}\cdot \sum_{\iota=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\iota,\varepsilon}\cdot T_{\varepsilon_\varepsilon}\cdot T_{\iota_\iota}\right)$
            $\frac{m_{swp}}{A_p\cdot \rho_{swp_{n_p+1}}}$
    $\rho_{swp_{n_p+1}} \leftarrow$
            $H_p \leftarrow$
                $Re_{wp_{n_p+1}} \leftarrow$
                    $Re_{wp_0} \leftarrow 0$
                    $A_{wg} \leftarrow (2\cdot H_p + W_p)\cdot \Delta x$
                    $A_{wc} \leftarrow W_e\cdot \Delta x$
                    $T_{fwp} \leftarrow$
                        $T_{fccw} \leftarrow \frac{T_{cpLoop_v} + T_{swp_{n_p}}}{2}$
                        $T_{fcgw} \leftarrow \frac{T_{g2i_{n_p+1}} + T_{swp_{n_p}}}{2}$
                        $\frac{T_{fcgw}\cdot A_{wg} + T_{fccw}\cdot A_{wc}}{A_{wg} + A_{wc}}$
                    $\rho_{fwp} \leftarrow$ for $\eta \in 0..2$
                        $t_{fwp} \leftarrow \left(\frac{T_{fwp} - 273\cdot K}{K}\right)$
                        $x_\eta \leftarrow \left(\frac{2\cdot Z - 150}{150}\right)$
                        $T_{\eta_0} \leftarrow 1$
                        $T_{\eta_1} \leftarrow x_\eta$
                        $T_{\eta_2} \leftarrow 2\cdot {x_\eta}^2 - 1$
                        for $\varepsilon \in 0..2$
                            $x_\varepsilon \leftarrow \left(\frac{2\cdot t_{fwp} - 250}{110}\right)$
                            $T$
```

```
                            $T_{\varepsilon_0} \leftarrow 1$
                            $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                            $T_{\varepsilon_2} \leftarrow 2\cdot {x_\varepsilon}^2 - 1$
                        $10^3\cdot kg\cdot m^{-3}\cdot \sum_{\eta=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\eta,\varepsilon}\cdot T_{\varepsilon_\varepsilon}\cdot T_{\eta_\eta}\right)$
                    $\mu_{fwp} \leftarrow$
                        $\mu_{20} \leftarrow 1.002 + c_{1v}\cdot Z + c_{2v}\cdot Z^2$
                        $\chi \leftarrow$
                            $\chi_1 \leftarrow A_v\cdot\left(1 + a_{1v}\cdot Z + a_{2v}\cdot Z^2\right)$
                            $\chi_2 \leftarrow B_v\cdot\left(1 + b_{1v}\cdot Z + b_{2v}\cdot Z^2\right)$
                            $\left(\frac{t_{fwp} - 20}{t_{fwp} + 109}\right)\cdot\left[\chi_1 + \chi_2\cdot(t_{fwp} - 20)\right]$
                        $\frac{\mu_{20}}{10^\chi}\cdot 10^{-3}\cdot kg\cdot m^{-1}\cdot s^{-1}$
                    $R_{wp} \leftarrow \frac{W_p\cdot H_p}{2\cdot(W_p + H_p)}$
                    $\frac{\rho_{fwp}\cdot u_{swp_{n_p}}\cdot(4\cdot R_{wp})}{\mu_{fwp}}$
                $f_p \leftarrow$
                    $jj \leftarrow 0$
                    $f_{pLoop_0} \leftarrow 0.1$
                    $k_p \leftarrow \frac{k_{rg}\cdot A_{wg} + k_c\cdot A_{wc}}{A_{wg} + A_{wc}}$
                    $LoopStop_{jj} \leftarrow 1$
                    while $LoopStop_{jj} > \frac{\Omega}{100} \wedge jj < 100$
                        $f_{pLoop_{jj+1}} \leftarrow \left(-4\cdot \log\left(\frac{k_p}{3.71\cdot 4\cdot R_{wp}} + \frac{1.255}{Re_{wp_{n_p+1}}\cdot\sqrt{f_{pLoop_{jj}}}}\right)\right)^{-2}$
                        $jj \leftarrow jj + 1$
                        $LoopStop_{jj} \leftarrow \left|f_{pLoop_{jj}} - f_{pLoop_{jj-1}}\right|$
                    $f_{pLoop_{jj}}$
```

```
                $\dfrac{f_p \cdot \Delta x \cdot \left(u_{swp_{n_p+1}}\right)^2}{2 \cdot g \cdot R_{wp}}$
            $z_{p_{n_p+1}} \leftarrow z_{p_{n_p}} + \Delta x \cdot S_p$
            $\rho_{swavg} \leftarrow \dfrac{\rho_{swp_{n_p+1}} + \rho_{swp_{n_p}}}{2}$
            $\rho_{swavg} \cdot g \left[\dfrac{p_{swp_{n_p}}}{\rho_{swavg} \cdot g} + \dfrac{\left(u_{swp_{n_p}}\right)^2 - \left(u_{swp_{n_p+1}}\right)^2}{2 \cdot g} + \left(z_{p_{n_p}} - z_{p_{n_p+1}}\right) + H_{lp}\right]$
        break  if  $T_{swp_{n_p+1}} < T_{swpi}$
        $n_p \leftarrow n_p + 1$
    $L_{p_{P+1}} \leftarrow n_p \cdot \Delta x$
    $P \leftarrow P + 1$
    $LoopStop_P \leftarrow \left|L_{p_P} - L_{p_{P-1}}\right|$
for  $n_p \in 0..N_p$
    $n_{dp} \leftarrow N + 1 + n_p$
    $M_{0,n_{dp}} \leftarrow \dfrac{T_{ae_N}}{K}$
    $M_{1,n_{dp}} \leftarrow \dfrac{m_{da}}{kg \cdot s^{-1}}$
    $M_{2,n_{dp}} \leftarrow \dfrac{\rho_{wae_N}}{kg \cdot m^{-3}}$
    $M_{3,n_{dp}} \leftarrow r_{e_N}$
    $M_{4,n_{dp}} \leftarrow RH_{e_N}$
    $M_{5,n_{dp}} \leftarrow \dfrac{p_{ae_N}}{Pa}$
    $M_{6,n_{dp}} \leftarrow \dfrac{u_{ae_N}}{m \cdot s^{-1}}$
    $M_{7,n_{dp}} \leftarrow Re_{ae_N}$
```

```
    $M_{8,n_{dp}} \leftarrow \dfrac{T_{dp_N}}{K}$
    $M_{9,n_{dp}} \leftarrow 0$
    $M_{10,n_{dp}} \leftarrow \dfrac{T_{swp_{n_p}}}{K}$
    $M_{11,n_{dp}} \leftarrow \dfrac{m_{swe_N}}{kg \cdot s^{-1}}$
    $M_{12,n_{dp}} \leftarrow \dfrac{\rho_{swp_{n_p}}}{kg \cdot m^{-3}}$
    $M_{13,n_{dp}} \leftarrow Z$
    $M_{14,n_{dp}} \leftarrow \dfrac{p_{swp_{n_p}}}{Pa}$
    $M_{15,n_{dp}} \leftarrow \dfrac{u_{swp_{n_p}}}{m \cdot s^{-1}}$
    $M_{16,n_{dp}} \leftarrow \dfrac{H_p}{m}$
    $M_{17,n_{dp}} \leftarrow 0$
    $M_{18,n_{dp}} \leftarrow 0$
    $M_{19,n_{dp}} \leftarrow \dfrac{Q_{rg} + Q_{co} - Q_{conc}}{W}$
    $M_{20,n_{dp}} \leftarrow 0$
    $M_{21,n_{dp}} \leftarrow \dfrac{Q_{p_{n_p}}}{W}$
COND ←
    $E_c \leftarrow 0$
    $m_{swcHigh_0} \leftarrow 3500 \cdot kg \cdot s^{-1}$
    $m_{swcLow_0} \leftarrow 500 \cdot kg \cdot s^{-1}$
```

```
$LoopStop_{Ec} \leftarrow 1$
while $LoopStop_{Ec} > A$
    $m_{swcE_c} \leftarrow \frac{m_{swcHighE_c} + m_{swcLowE_c}}{2}$
    $C_c \leftarrow 0$
    $p_{acxEst_0} \leftarrow 100000 \cdot Pa$
    $L_{c_0} \leftarrow 1000 \cdot m$
    $\Delta x \leftarrow 1 \cdot m$
    $LoopStop_{Cc} \leftarrow 100 \cdot m$
    while $LoopStop_{Cc} > 0 \cdot m$
        $n_c \leftarrow 0$
        $N_c \leftarrow \frac{L_{cC_c}}{\Delta x}$
        $T_{ac_0} \leftarrow T_{ae_N}$
        $RH_{c_0} \leftarrow RH_{e_N}$
        $u_{ac_0} \leftarrow u_{aci}$
        $r_{c_0} \leftarrow r_{e_N}$
        $\rho_{wac_0} \leftarrow \rho_{wae_N}$
        $z_{c_0} \leftarrow z_{e_N}$
        $S_c \leftarrow \frac{L_{e_E} \cdot S}{L_{cC_c}}$
        $p_{ac_0} \leftarrow$
            $pp \leftarrow 0$
            $p_{aciLoop_0} \leftarrow p_{ae_N} - 0 \cdot Pa$
            $LoopStop_{pp} \leftarrow 1$
            while $LoopStop_{pp} > A$
                $A_t \leftarrow$
                    $H_c \leftarrow$
                        $A_{ca} \leftarrow$
                            $m_{dac} \leftarrow \frac{m_{da}}{2}$
                            $\frac{m_{dac} \cdot (1 + r_{c_0})}{\rho_{wac_0} \cdot u_{ac_0}}$
```

```
                        $A_{cp} \leftarrow \frac{N_{cp} \cdot \pi \cdot d_{cpo}^2}{4}$
                        $A_{cT} \leftarrow A_{ca} + A_{cp}$
                        $t_{cpp} \leftarrow \sqrt{\frac{A_{cT}}{N_{cpc} \cdot N_{cpr}}} - d_{cpo}$
                        $N_{cpr} \cdot (d_{cpo} + t_{cpp})$
                    $W_c \leftarrow N_{cpc} \cdot (d_{cpo} + t_{cpp})$
                    $H_c \cdot W_c$
                $H_{tec} \leftarrow$
                    $K_{tec} \leftarrow 2 \cdot K_{tr} + 3 \cdot K_{45}$
                    $u_{atec} \leftarrow \frac{m_{dac} \cdot (1 + r_{c_0})}{\rho_{wac_0} \cdot A_t}$
                    $f_t \leftarrow$
                        $ii \leftarrow 0$
                        $f_{tLoop_0} \leftarrow 0.1$
                        $Re_t \leftarrow$
                            $\mu_{wat} \leftarrow$
                                $\mu_{vt} \leftarrow \left[1.299155 \cdot 10^{-12} \cdot \left(\frac{T_{ac_0}}{K}\right)^2 + 3.872699 \cdot 10^{-8} \cdot \left(\frac{T_{ac_0}}{K}\right) - 2.390839 \cdot 10^{-6}\right] \cdot kg \cdot m^{-1} \cdot s^{-1}$
                                $\mu_{at} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{ac_0}}{K} + 4.745 \cdot 10^{-6}\right) \cdot kg \cdot m^{-1} \cdot s^{-1}$
                                $N_{vt} \leftarrow \frac{r_{c_0} \cdot m_{dac}}{M_w}$
                                $N_{at} \leftarrow \frac{m_{dac}}{M_a}$
                                $\left(\frac{N_{vt}}{N_{vt} + N_{at}}\right) \cdot \mu_{vt} + \left(\frac{N_{at}}{N_{vt} + N_{at}}\right) \cdot \mu_{at}$
                            $R_t \leftarrow \frac{A_t}{2 \cdot (H_c + W_c)}$
                            $\frac{\rho_{wac_0} \cdot u_{atec} \cdot 4 \cdot R_t}{\mu_{wat}}$
                        $LoopStop_{ii} \leftarrow 1$
```

```
                    while $LoopStop_{ii} > \frac{}{100} \wedge ii < 100$
                        $f_{tLoop_{ii+1}} \leftarrow \left(-4 \cdot \log\left(\frac{k_c}{3.71 \cdot 4 \cdot R_t} + \frac{1.255}{Re_t \cdot \sqrt{f_{tLoop_{ii}}}}\right)\right)^{-2}$
                        $ii \leftarrow ii + 1$
                        $LoopStop_{ii} \leftarrow \left|f_{tLoop_{ii}} - f_{tLoop_{ii-1}}\right|$
                    $f_{tLoop_{ii}}$
                $l_{tec} \leftarrow 550 \cdot m + 1500 \cdot m + \frac{z_{c_0}}{\sin(45)}$
                $C_D \leftarrow 1$
                $\frac{K_{sec} \cdot u_{atec}^2}{2 \cdot g} + \frac{f_t \cdot l_{tec} \cdot u_{atec}^2}{2 \cdot g \cdot R_t} + \frac{N_{cpr} \cdot \left(N_{cpc} - \frac{1}{2}\right) \cdot t_{cpp} \cdot \left(\frac{d_{cpo} + d_{tsw}}{2}\right) \cdot C_D \cdot u_{atec}^2}{2 \cdot g \cdot A_t}$
            $p_{aciLoop_{pp+1}} \leftarrow \rho_{wac_0} \cdot g \cdot \left(\frac{p_{ae_N}}{\rho_{wac_0} \cdot g} - H_{tec}\right)$
            $pp \leftarrow pp + 1$
            $LoopStop_{pp} \leftarrow \left|\frac{p_{aciLoop_{pp}} - p_{aciLoop_{pp-1}}}{p_{aciLoop_{pp}}}\right|$
        $p_{aciLoop_{pp}}$
    $p_{acx} \leftarrow p_{acxEst_{C_c}}$
    $T_{swc_0} \leftarrow T_{swpN_p}$
    $r_{cx} \leftarrow$
        $C \leftarrow \frac{C_1}{\left(\frac{T_{acx}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{acx}}{K}\right) + C_4 \cdot \left(\frac{T_{acx}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{acx}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{acx}}{K}\right)$
        $p_{vcx} \leftarrow$
            $p_{scx} \leftarrow \left(e^C\right) \cdot Pa$
            $p_{scx} \cdot RH_{cx}$
        $\frac{0.62198 \cdot p_{vcx}}{p_{acx} - p_{vcx}}$
            $m_{sweE_c}$
```

```
    $u_{swc_0} \leftarrow$
        $m_{swcp} \leftarrow \frac{}{2 \cdot N_{cp}}$
        $\rho_{swc_0} \leftarrow$ for $\iota \in 0..2$
            $t \leftarrow \left(\frac{T_{swc_0} - 273 \cdot K}{K}\right)$
            $x_\iota \leftarrow \left(\frac{2 \cdot Z - 150}{150}\right)$
            $T_{\iota_0} \leftarrow 1$
            $T_{\iota_1} \leftarrow x_\iota$
            $T_{\iota_2} \leftarrow 2 \cdot x_\iota^2 - 1$
            for $\varepsilon \in 0..2$
                $x_\varepsilon \leftarrow \left(\frac{2 \cdot t - 250}{110}\right)$
                $T_{\varepsilon_0} \leftarrow 1$
                $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                $T_{\varepsilon_2} \leftarrow 2 \cdot x_\varepsilon^2 - 1$
            $10^3 \cdot kg \cdot m^{-3} \cdot \sum_{\iota=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\iota,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\iota_\iota}\right)$
        $V_{swi} \leftarrow \frac{m_{swcp}}{\rho_{swc_0}}$
        $\frac{V_{swi}}{A_{cpi}}$
    $p_{swc_0} \leftarrow$
        $H_{ltcp} \leftarrow$
            $K_{scp} \leftarrow 3 \cdot K_{lr} + 4 \cdot K_v$
            $u_{swtcp} \leftarrow$
                $m_{swtp} \leftarrow \frac{m_{sweE_c}}{2 \cdot N_{cpr}}$
                $A_{tcp} \leftarrow \pi \cdot \frac{d_{tsw}^2}{4}$
                $\frac{m_{swtp}}{\rho_{swc_0} \cdot \pi \cdot \frac{d_{tsw}^2}{4}}$
```

```
$Re_{tcp} \leftarrow$
    $\mu_{swct} \leftarrow$
        $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z + c_{2v} \cdot Z^2$
        $\chi \leftarrow$
            $t_{fcgw} \leftarrow \left(\frac{T_{swc_0} - 273.15 \cdot K}{K}\right)$
            $\chi_1 \leftarrow A_v \cdot \left(1 + a_{1v} \cdot Z + a_{2v} \cdot Z^2\right)$
            $\chi_2 \leftarrow B_v \cdot \left(1 + b_{1v} \cdot Z + b_{2v} \cdot Z^2\right)$
            $\left(\frac{t_{fcgw} - 20}{t_{fcgw} + 109}\right) \left[\chi_1 + \chi_2 \cdot \left(t_{fcgw} - 20\right)\right]$
        $\frac{\mu_{20}}{10^{\chi}} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
    $\frac{\rho_{swc_0} \cdot u_{swtcp} \cdot d_{tsw}}{\mu_{swct}}$
$f_{tcp} \leftarrow$
    $jj \leftarrow 0$
    $f_{tcpLoop_0} \leftarrow 0.1$
    $LoopStop_{jj} \leftarrow 1$
    while $LoopStop_{jj} > \frac{\Omega}{100} \wedge jj < 100$
        $f_{tcpLoop_{jj+1}} \leftarrow \left(-4 \cdot \log\left(\frac{k_c}{3.71 \cdot d_{tsw}} + \frac{1.255}{Re_{tcp} \cdot \sqrt{f_{tcpLoop_{jj}}}}\right)\right)^{-2}$
        $jj \leftarrow jj + 1$
        $LoopStop_{jj} \leftarrow \left|f_{tcpLoop_{jj}} - f_{tcpLoop_{jj-1}}\right|$
    $f_{tcpLoop_{jj}}$
$l_{tcp} \leftarrow 2 \cdot \left(L_{pp} + 50 \cdot m\right) + 300 \cdot m + t_{cpp} \cdot N_{cpc}$
$\frac{4 \cdot f_{tcp} \cdot \Delta x \cdot u_{swtcp}^2}{2 \cdot g \cdot d_{tsw}} + \frac{K_{scp} \cdot u_{swtcp}^2}{2 \cdot g}$
$\Delta z_{tcp} \leftarrow$
    $z_{lp} \leftarrow \frac{\left(M_{14,N+N_p+1} - M_{14,N+1}\right) \cdot Pa}{g \cdot \frac{1 \cdot kg \cdot m^{-3}}{N_p + 1} \cdot \sum_{v=N+1}^{N+N_p+1} M_{12,v}}$
```

```
    $\rho_{swc_0} \cdot g \cdot \left(\frac{P_{atm}}{\rho_{swc_0} \cdot g} + \Delta z_{tcp} + H_{ltcp}\right)$
$u_{acx} \leftarrow$
    $\rho_{wacx} \leftarrow$
        $v_{acx} \leftarrow \frac{0.287035 \cdot T_{acx}}{p_{acx} - p_{vcx}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
        $\frac{1 + r_{cx}}{v_{acx}}$
    $\frac{m_{dac}}{\rho_{wacx} \cdot A_{cs}}$
$m_{dacp} \leftarrow \frac{m_{dac}}{N_{cp}}$
$T_{cpi_0} \leftarrow T_{swc_0}$
$T_{cpo_0} \leftarrow T_{ac_0}$
$Q_{cwpc_0} \leftarrow 0 \cdot W$
$Q_{ccpa_0} \leftarrow 0 \cdot W$
while $n_c < N_c$
    $T_{cpi_{n_c+1}} \leftarrow$
        $i \leftarrow 0$
        $T_{cpiLoop_0} \leftarrow T_{swc_{n_c}}$
        $LoopStop_i \leftarrow 1 \cdot W$
        while $LoopStop_i > \Omega \cdot W \wedge i < 750$
            $Q_{cwpc_{n_c+1}} \leftarrow$
                $T_{fcwp} \leftarrow \frac{T_{cpiLoop_i} + T_{swc_{n_c}}}{2}$
                $hx_{cwp} \leftarrow$
                    $k_{fcwp} \leftarrow$
                        $X \leftarrow Z \cdot 0.2$
                        $Y \leftarrow Z \cdot 0.03$
                        $G \leftarrow 343.5 + Z \cdot 0.37$
                        $\lambda \leftarrow \ln\left(\frac{k_{swcrit}}{10^{-3} \cdot W m^{-1} \cdot K^{-1}} + X\right) + \left(2.3 - \frac{G}{\frac{T_{fcwp}}{K}}\right) \left(1 - \frac{\frac{T_{fcwp}}{K}}{\frac{T_{fcwp}}{K} + Y}\right)^{0.333}$
                        $e^{\lambda} \cdot 10^{-3} \cdot W \cdot m^{-1} \cdot K^{-1}$
```

```
$\rho_{fcwp} \leftarrow$ for $\eta \in 0..2$
    $t_{fcwp} \leftarrow \left(\frac{T_{fcwp} - 273 \cdot K}{K}\right)$
    $x_\eta \leftarrow \left(\frac{2 \cdot Z - 150}{150}\right)$
    $T_{\eta_0} \leftarrow 1$
    $T_{\eta_1} \leftarrow x_\eta$
    $T_{\eta_2} \leftarrow 2 \cdot {x_\eta}^2 - 1$
    for $\varepsilon \in 0..2$
        $x_\varepsilon \leftarrow \left(\frac{2 \cdot t_{fcwp} - 250}{110}\right)$
        $T_{\varepsilon_0} \leftarrow 1$
        $T_{\varepsilon_1} \leftarrow x_\varepsilon$
        $T_{\varepsilon_2} \leftarrow 2 \cdot {x_\varepsilon}^2 - 1$
    $10^3 \cdot kg \cdot m^{-3} \cdot \sum_{\eta=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\eta,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\eta_\eta}\right)$
$\mu_{fcwp} \leftarrow$
    $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z + c_{2v} \cdot Z^2$
    $\chi \leftarrow$
        $\chi_1 \leftarrow A_v \cdot \left(1 + a_{1v} \cdot Z + a_{2v} \cdot Z^2\right)$
        $\chi_2 \leftarrow B_v \cdot \left(1 + b_{1v} \cdot Z + b_{2v} \cdot Z^2\right)$
        $\left(\frac{t_{fcwp} - 20}{t_{fcwp} + 109}\right) \cdot \left[\chi_1 + \chi_2 \cdot \left(t_{fcwp} - 20\right)\right]$
    $\frac{\mu_{20}}{10^\chi} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
$cp_{sw} \leftarrow 4174 \cdot J \cdot kg^{-1} \cdot K^{-1}$
$Pr_{cwp} \leftarrow \frac{cp_{sw} \cdot \mu_{fcwp}}{k_{fcwp}}$
$Re_{xcwp} \leftarrow \frac{\rho_{fcwp} \cdot u_{swc_{n_c}} \cdot d_{cpi}}{\mu_{fcwp}}$
```

```
            $Nux_{cwp} \leftarrow 0.023 \cdot {Re_{xcwp}}^{0.8} \cdot {Pr_{cwp}}^{0.4}$
            $Nux_{cwp} \cdot \frac{k_{fcwp}}{d_{cpi}}$
        $hx_{cwp} \cdot \Delta x \cdot P_{cpi} \cdot \left(T_{cpiLoop_i} - T_{swc_{n_c}}\right)$
$T_{cpo_{n_c+1}} \leftarrow$
    $A_{concp} \leftarrow \pi \cdot \ln\left(\frac{d_{cpo}}{d_{cpi}}\right) \cdot m \cdot \Delta x$
    $T_{cpiLoop_i} + \frac{Q_{cwpc_{n_c+1}} \cdot t_{cp}}{kc_{cp} \cdot A_{concp}}$
$Q_{ccpa_{n_c+1}} \leftarrow$
    $h_{ccpa} \leftarrow$
        $T_{fpa} \leftarrow \frac{T_{cpo_{n_c+1}} + T_{ac_{n_c}}}{2}$
        $k_f \leftarrow \left[2.259439 \cdot 10^{-8} \cdot \left(\frac{T_{fpa}}{K}\right)^3 - 3.041060 \cdot 10^{-5} \cdot \left(\frac{T_{fpa}}{K}\right)^2 + 1.367881 \cdot 10^{-2} \cdot \left(\frac{T_{fpa}}{K}\right) - 1.362377\right] \cdot W \cdot m^{-1} \cdot K^{-1}$
        $\rho_f \leftarrow \left[7.512806 \cdot 10^{-6} \cdot \left(\frac{T_{fpa}}{K}\right)^3 - 1.093361 \cdot 10^{-2} \cdot \left(\frac{T_{fpa}}{K}\right)^2 + 4.272160 \cdot \left(\frac{T_{fpa}}{K}\right) + 4.956224 \cdot 10^2\right] \cdot kg \cdot m^{-3}$
        $\mu_f \leftarrow \left[3.797761 \cdot 10^{-11} \cdot \left(\frac{T_{fpa}}{K}\right)^4 - 5.120425 \cdot 10^{-8} \cdot \left(\frac{T_{fpa}}{K}\right)^3 + 2.595053 \cdot 10^{-5} \cdot \left(\frac{T_{fpa}}{K}\right)^2 - 5.865816 \cdot 10^{-3} \cdot \left(\frac{T_{fpa}}{K}\right) + 4.999443 \cdot 10^{-1}\right] \cdot kg \cdot m^{-1} \cdot s^{-1}$
        $h_{fgf} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{fpa} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{fpa} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
        $\rho_{da} \leftarrow$
            $p_{spa} \leftarrow$
                $C \leftarrow \frac{C_1}{\left(\frac{T_{ac_{n_c}}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{ac_{n_c}}}{K}\right) + C_4 \cdot \left(\frac{T_{ac_{n_c}}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{ac_{n_c}}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{ac_{n_c}}}{K}\right)$
                $\left(e^C\right) \cdot Pa$
            $v_{pa} \leftarrow \frac{0.287035 \cdot \left(\frac{T_{ac_{n_c}}}{K}\right)}{\frac{p_{ac_{n_c}} - p_{spa}}{10^3 \cdot Pa}} \cdot m^3 \cdot kg^{-1}$
            $\frac{r_{c_{n_c}}}{v_{pa}}$
```

```
                    $0.725 \cdot \left[ \frac{k_f^{3} \cdot \rho_f (\rho_f - \rho_{da}) \cdot g \cdot h_{fgf}}{\mu_f \cdot d_{cpo} \cdot (T_{ac_{n_c}} - T_{cpo_{n_c+1}})} \right]^{\frac{1}{4}} \cdot N_{cpr}^{-\frac{1}{6}}$
                $h_{ccpa} \cdot \Delta x \cdot P_{cpo} \cdot (T_{ac_{n_c}} - T_{cpo_{n_c+1}})$
            $T_{cpiLoop_{i+1}} \leftarrow T_{cpiLoop_i} + \frac{Q_{ccpa_{n_c+1}} - Q_{cwpc_{n_c+1}}}{10000 \cdot W} \cdot K$
            $i \leftarrow i + 1$
            $LoopStop_i \leftarrow \left| Q_{ccpa_{n_c+1}} - Q_{cwpc_{n_c+1}} \right|$
        $T_{cpiLoop_i}$
    $T_{ac_{n_c+1}} \leftarrow$
        $z \leftarrow 0$
        $T_{acLoop_0} \leftarrow T_{ac_{n_c}}$
        $LoopStop_z \leftarrow 1 \cdot K$
        while $LoopStop_z > \Omega \cdot K \wedge z < 500$
            $T_{dpc} \leftarrow$
                $p_{vcd} \leftarrow \frac{r_{c_{n_c}} \cdot p_{ac_{n_c}}}{0.62198 + r_{c_{n_c}}}$
                $\varpi \leftarrow \ln\left(\frac{p_{vcd}}{1000 \cdot Pa}\right)$
                $\left[ C_7 + C_8 \cdot \varpi + C_9 \cdot \varpi^2 + C_{10} \cdot \varpi^3 + C_{11} \cdot \left(\frac{p_{vcd}}{1000 \cdot Pa}\right)^{0.1984} + 273.15 \right] \cdot K$
            $Q_{acdp} \leftarrow$
                $h_{gi} \leftarrow \left[ -0.00086 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right) + 2500.6 \right] \cdot 10^3 \cdot J \cdot kg^{-1}$
                $h_{gx} \leftarrow \left[ -0.00086 \cdot \left(\frac{T_{dpc} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{dpc} - 273 \cdot K}{K}\right) + 2500.6 \right] \cdot 10^3 \cdot J \cdot kg^{-1}$
                $cp_i \leftarrow \left[ 3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{ac_{n_c}}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{ac_{n_c}}}{K} + 1.021769 \right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                $cp_x \leftarrow \left[ 3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{dpc}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{dpc}}{K} + 1.021769 \right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                $cp_x \cdot m_{dacp} \cdot T_{dpc} + r_{c_{n_c}} \cdot m_{dacp} \cdot h_{gx} - cp_i \cdot m_{dacp} \cdot T_{ac_{n_c}} - r_{c_{n_c}} \cdot m_{dacp} \cdot h_{gi}$
```

```
            if $RH_{c_{n_c}} < 1 \wedge \left| Q_{ccpa_{n_c+1}} \right| < \left| -Q_{acdp} \right|$
                $T_{acLoop_{z+1}} \leftarrow$
                    $h_{gi} \leftarrow \left[ -0.00086 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right) + 2500.6 \right] \cdot 10^3 \cdot J \cdot kg^{-1}$
                    $h_{gx} \leftarrow \left[ -0.00086 \cdot \left(\frac{T_{acLoop_z} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{acLoop_z} - 273 \cdot K}{K}\right) + 2500.6 \right] \cdot 10^3 \cdot J \cdot kg^{-1}$
                    $cp_i \leftarrow \left[ 3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{ac_{n_c}}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{ac_{n_c}}}{K} + 1.021769 \right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                    $cp_x \leftarrow \left[ 3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{acLoop_z}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{acLoop_z}}{K} + 1.021769 \right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
                    $\frac{-Q_{ccpa_{n_c+1}} + cp_x \cdot m_{dacp} \cdot T_{ac_{n_c}} - r_{c_{n_c}} \cdot m_{dacp} \cdot (h_{gx} - h_{gi})}{cp_i \cdot m_{dacp}}$
                $RH_{c_{n_c+1}} \leftarrow$
                    $p_{sc} \leftarrow$
                        $C \leftarrow \frac{C_1}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{acLoop_z}}{K}\right) + C_4 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{acLoop_z}}{K}\right)$
                        $(e^C) \cdot Pa$
                    $\frac{p_{vcd}}{p_{sc}}$
                $r_{c_{n_c+1}} \leftarrow$
                    $C \leftarrow \frac{C_1}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{acLoop_z}}{K}\right) + C_4 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{acLoop_z}}{K}\right)$
                    $p_{vc} \leftarrow$
                        $p_{sc} \leftarrow (e^C) \cdot Pa$
                        $p_{sc} \cdot RH_{c_{n_c+1}}$
                    $\frac{0.62198 \cdot p_{vc}}{p_{ac_{n_c}} - p_{vc}}$
            if $RH_{c_{n_c}} < 1 \wedge \left| Q_{ccpa_{n_c+1}} \right| > \left| -Q_{acdp} \right|$
                $T_{acLoop_{z+1}} \leftarrow T_{dpc}$
                $RH_{c_{n_c+1}} \leftarrow 1$
```

```
        $r_{c_{n_c}+1} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{acLoop_z}}{K}\right) + C_4 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{acLoop_z}}{K}\right)$
            $p_{vc} \leftarrow$
                $p_{sc} \leftarrow \left(e^C\right) \cdot Pa$
                $p_{sc} \cdot RH_{c_{n_c}+1}$
            $\frac{0.62198 \cdot p_{vc}}{p_{ac_{n_c}} - p_{vc}}$
    if $RH_{c_{n_c}} = 1$
        $T_{acLoop} \leftarrow$
            $r_{c_{n_c}+1} \leftarrow$
                $C \leftarrow \frac{C_1}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{acLoop_z}}{K}\right) + C_4 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{acLoop_z}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{acLoop_z}}{K}\right)$
                $p_{vc} \leftarrow$
                    $p_{sc} \leftarrow \left(e^C\right) \cdot Pa$
                    $p_{sc} \cdot RH_{c_{n_c}}$
                $\frac{0.62198 \cdot p_{vc}}{p_{ac_{n_c}} - p_{vc}}$
            $h_{gi} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
            $h_{gx} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{acLoop_z} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{acLoop_z} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
            $cp_i \leftarrow \left[3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{ac_{n_c}}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{ac_{n_c}}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $cp_x \leftarrow \left[3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{acLoop_z}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{acLoop_z}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $hf_{ix} \leftarrow \left(4.183824 \cdot 10^3 \cdot \frac{T_{ac_{n_c}} + T_{acLoop_z}}{2 \cdot K} - 1.141915 \cdot 10^6\right) \cdot J \cdot kg^{-1}$
            $-Q_{ccpa_{n_c}+1} + cp_i \cdot m_{dacp} \cdot T_{ac_{n_c}} - r_{c_{n_c}+1} \cdot m_{dacp} \cdot \left(h_{gx} - h_{gi}\right) - \left(r_{c_{n_c}} - r_{c_{n_c}+1}\right) \cdot m_{dacp} \cdot \left(hf_{ix} - h_{gi}\right)$
```

```
            $\frac{\quad}{cp_x \cdot m_{dacp}}$
        $RH_{c_{n_c}+1} \leftarrow 1$
        $T_{acLoop_{z+1}} \leftarrow T_{acLoop_z} - \frac{T_{acLoop_z} - T_{acLoop}}{1000}$
    $z \leftarrow z + 1$
    $LoopStop_z \leftarrow \left|T_{acLoop_z} - T_{acLoop_{z-1}}\right|$
$T_{acLoop_z}$
$T_{ac_{n_c}+1} \leftarrow$
    $z \leftarrow 0$
    $T_{acLoop_0} \leftarrow T_{ac_{n_c}}$
    $LoopStop_z \leftarrow 1 \cdot K$
    while $LoopStop_z > \Omega \cdot K \wedge z < 500$
        $T_{dpc} \leftarrow$
            $p_{vcd} \leftarrow \frac{r_{c_{n_c}} \cdot p_{ac_{n_c}}}{0.62198 + r_{c_{n_c}}}$
            $\varpi \leftarrow \ln\left(\frac{p_{vcd}}{1000 \cdot Pa}\right)$
            $\left[C_7 + C_8 \cdot \varpi + C_9 \cdot \varpi^2 + C_{10} \cdot \varpi^3 + C_{11} \cdot \left(\frac{p_{vcd}}{1000 \cdot Pa}\right)^{0.1984} + 273.15\right] \cdot K$
        $Q_{acdp} \leftarrow$
            $h_{gi} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{ac_{n_c}} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
            $h_{gx} \leftarrow \left[-0.00086 \cdot \left(\frac{T_{dpc} - 273 \cdot K}{K}\right)^2 + 1.855 \cdot \left(\frac{T_{dpc} - 273 \cdot K}{K}\right) + 2500.6\right] \cdot 10^3 \cdot J \cdot kg^{-1}$
            $cp_i \leftarrow \left[3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{ac_{n_c}}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{ac_{n_c}}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $cp_x \leftarrow \left[3.542857 \cdot 10^{-7} \cdot \left(\frac{T_{dpc}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{dpc}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
            $cp_x \cdot m_{dacp} \cdot T_{dpc} + r_{c_{n_c}} \cdot m_{dacp} \cdot h_{gx} - cp_i \cdot m_{dacp} \cdot T_{ac_{n_c}} - r_{c_{n_c}} \cdot m_{dacp} \cdot h_{gi}$
        if $RH_{c_{n_c}} < 1 \wedge \left|Q_{ccpa_{n_c}+1}\right| < \left|-Q_{acdp}\right|$
```

```
$T_{acLoop_{z+1}} \leftarrow$
    $h_{gi} \leftarrow \left[-0.00086\cdot\left(\frac{T_{ac_{n_c}} - 273\cdot K}{K}\right) + 1.855\cdot\left(\frac{T_{ac_{n_c}} - 273\cdot K}{K}\right) + 2500.6\right]\cdot 10^3\cdot J\cdot kg^{-1}$
    $h_{gx} \leftarrow \left[-0.00086\cdot\left(\frac{T_{acLoop_z} - 273\cdot K}{K}\right)^2 + 1.855\cdot\left(\frac{T_{acLoop_z} - 273\cdot K}{K}\right) + 2500.6\right]\cdot 10^3\cdot J\cdot kg^{-1}$
    $cp_i \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{ac_{n_c}}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{ac_{n_c}}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
    $cp_x \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{acLoop_z}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{acLoop_z}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
    $\frac{-Q_{ccpa_{n_c+1}} + cp_x\cdot m_{dacp}\cdot T_{ac_{n_c}} - r_{c_{n_c}}\cdot m_{dacp}\cdot\left(h_{gx} - h_{gi}\right)}{cp_i\cdot m_{dacp}}$
$RH_{c_{n_c}+1} \leftarrow$
    $p_{sc} \leftarrow$
        $C \leftarrow \frac{C_1}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{acLoop_z}}{K}\right) + C_4\cdot\left(\frac{T_{acLoop_z}}{K}\right)^2 + C_5\cdot\left(\frac{T_{acLoop_z}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{acLoop_z}}{K}\right)$
        $\left(e^C\right)\cdot Pa$
    $\frac{p_{vcd}}{p_{sc}}$
$r_{c_{n_c}+1} \leftarrow$
    $C \leftarrow \frac{C_1}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{acLoop_z}}{K}\right) + C_4\cdot\left(\frac{T_{acLoop_z}}{K}\right)^2 + C_5\cdot\left(\frac{T_{acLoop_z}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{acLoop_z}}{K}\right)$
    $p_{vc} \leftarrow$
        $p_{sc} \leftarrow \left(e^C\right)\cdot Pa$
        $p_{sc}\cdot RH_{c_{n_c}+1}$
    $\frac{0.62198\cdot p_{vc}}{p_{ac_{n_c}} - p_{vc}}$
if $RH_{c_{n_c}} < 1 \wedge \left|Q_{ccpa_{n_c+1}}\right| > \left|-Q_{acdp}\right|$
    $T_{acLoop_{z+1}} \leftarrow T_{dpc}$
    $RH_{c_{n_c}+1} \leftarrow 1$
        $C_1 \qquad \left(T_{acLoop_z}\right) \qquad \left(T_{acLoop_z}\right)^2 \qquad \left(T_{acLoop_z}\right)^3 \qquad \left(T_{acLoop_z}\right)$
```

```
    $r_{c_{n_c}+1} \leftarrow$
        $C \leftarrow \frac{}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3\cdot\left(\frac{}{K}\right) + C_4\cdot\left(\frac{}{K}\right) + C_5\cdot\left(\frac{}{K}\right) + C_6\cdot\ln\left(\frac{}{K}\right)$
        $p_{vc} \leftarrow$
            $p_{sc} \leftarrow \left(e^C\right)\cdot Pa$
            $p_{sc}\cdot RH_{c_{n_c}+1}$
        $\frac{0.62198\cdot p_{vc}}{p_{ac_{n_c}} - p_{vc}}$
if $RH_{c_{n_c}} = 1$
    $T_{acLoop} \leftarrow$
        $r_{c_{n_c}+1} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{acLoop_z}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{acLoop_z}}{K}\right) + C_4\cdot\left(\frac{T_{acLoop_z}}{K}\right)^2 + C_5\cdot\left(\frac{T_{acLoop_z}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{acLoop_z}}{K}\right)$
            $p_{vc} \leftarrow$
                $p_{sc} \leftarrow \left(e^C\right)\cdot Pa$
                $p_{sc}\cdot RH_{c_{n_c}}$
            $\frac{0.62198\cdot p_{vc}}{p_{ac_{n_c}} - p_{vc}}$
        $h_{gi} \leftarrow \left[-0.00086\cdot\left(\frac{T_{ac_{n_c}} - 273\cdot K}{K}\right)^2 + 1.855\cdot\left(\frac{T_{ac_{n_c}} - 273\cdot K}{K}\right) + 2500.6\right]\cdot 10^3\cdot J\cdot kg^{-1}$
        $h_{gx} \leftarrow \left[-0.00086\cdot\left(\frac{T_{acLoop_z} - 273\cdot K}{K}\right)^2 + 1.855\cdot\left(\frac{T_{acLoop_z} - 273\cdot K}{K}\right) + 2500.6\right]\cdot 10^3\cdot J\cdot kg^{-1}$
        $cp_i \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{ac_{n_c}}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{ac_{n_c}}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
        $cp_x \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{acLoop_z}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{acLoop_z}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
        $hf_{ix} \leftarrow \left(4.183824\cdot 10^3\cdot\frac{T_{ac_{n_c}} + T_{acLoop_z}}{2\cdot K} - 1.141915\cdot 10^6\right)\cdot J\cdot kg^{-1}$
        $\frac{-Q_{ccpa_{n_c+1}} + cp_i\cdot m_{dacp}\cdot T_{ac_{n_c}} - r_{c_{n_c}+1}\cdot m_{dacp}\cdot\left(h_{gx} - h_{gi}\right) - \left(r_{c_{n_c}} - r_{c_{n_c}+1}\right)\cdot m_{dacp}\cdot\left(hf_{ix} - h_{gi}\right)}{cp_x\cdot m_{dacp}}$
    $RH_{c_{n_c}+1} \leftarrow 1$
```

```
            $T_{acLoop_{z+1}} \leftarrow T_{acLoop_z} - \frac{T_{acLoop_z} - T_{acLoop}}{1000}$
          $z \leftarrow z + 1$
          $LoopStop_z \leftarrow \left| T_{acLoop_z} - T_{acLoop_{z-1}} \right|$
        $T_{acLoop_z}$
    $\delta_{c_{n_c+1}} \leftarrow$
      $Re_{acp_{n_c+1}} \leftarrow$
        $Re_{acp_0} \leftarrow 0$
        $T_{fal} \leftarrow \frac{\frac{T_{ac_{n_c}} + T_{cpo_{n_c+1}}}{2} + T_{ac_{n_c}}}{2}$
        $\rho_{fal} \leftarrow$
          $p_{vfal} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{fal}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{fal}}{K}\right) + C_4 \cdot \left(\frac{T_{fal}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{fal}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{fal}}{K}\right)$
            $p_{sfal} \leftarrow \left(e^C\right) \cdot Pa$
            $RH_{c_{n_c}} \cdot p_{sfal}$
          $v_{afal} \leftarrow \frac{0.287035 \cdot T_{fal}}{p_{ac_{n_c}} - p_{vfal}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
          $r_{fal} \leftarrow \frac{0.62198 \cdot p_{vfal}}{p_{ac_{n_c}} - p_{vfal}}$
          $\frac{1 + r_{fal}}{v_{afal}}$
        $k_{fal} \leftarrow$
          $k_{vfal} \leftarrow \left[3.767616 \cdot 10^{-14} \cdot \left(\frac{T_{fal}}{K}\right)^3 + 1.247242 \cdot 10^{-10} \cdot \left(\frac{T_{fal}}{K}\right)^2 + 3.184034 \cdot 10^{-9} \cdot \left(\frac{T_{fal}}{K}\right) + 7.678236 \cdot 10^{-6}\right] \cdot 10^3 \cdot W \cdot m^{-1} \cdot K^{-1}$
          $k_{afal} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{fal}}{K} + 3.479 \cdot 10^{-6}\right) \cdot 10^3 \cdot W \cdot m^{-1} \cdot K^{-1}$
          $N_{vfal} \leftarrow \frac{r_{fal} \cdot m_{da}}{M_w}$
          $N_{afal} \leftarrow \frac{m_{da}}{M_a}$
          $\left( N_{vfal} \right) \cdot \quad \left( N_{afal} \right) \cdot$
```

```
          $\left(\overline{N_{vfal} + N_{afal}}\right) \cdot k_{vfal} + \left(\overline{N_{vfal} + N_{afal}}\right) \cdot k_{afal}$
        $\mu_{fal} \leftarrow$
          $\mu_{vfal} \leftarrow \left[1.299155 \cdot 10^{-12} \cdot \left(\frac{T_{fal}}{K}\right)^2 + 3.872699 \cdot 10^{-8} \cdot \left(\frac{T_{fal}}{K}\right) - 2.390839 \cdot 10^{-6}\right] \cdot kg \cdot m^{-1} \cdot s^{-1}$
          $\mu_{afal} \leftarrow \left(7.58 \cdot 10^{-8} \cdot \frac{T_{fal}}{K} + 4.745 \cdot 10^{-6}\right) \cdot kg \cdot m^{-1} \cdot s^{-1}$
          $\left(\frac{N_{vfal}}{N_{vfal} + N_{afal}}\right) \cdot \mu_{vfal} + \left(\frac{N_{afal}}{N_{vfal} + N_{afal}}\right) \cdot \mu_{afal}$
        $cp_{fal} \leftarrow$
          $cp_{vfal} \leftarrow \left[-5.103046 \cdot 10^{-10} \cdot \left(\frac{T_{fal}}{K}\right)^3 + 1.252416 \cdot 10^{-6} \left(\frac{T_{fal}}{K}\right)^2 - 3.165154 \cdot 10^{-4} \left(\frac{T_{fal}}{K}\right) + 1.861896\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
          $cp_{afal} \leftarrow \left[3.542857 \cdot 10^{-7} \left(\frac{T_{fal}}{K}\right)^2 - 1.626857 \cdot 10^{-4} \cdot \frac{T_{fal}}{K} + 1.021769\right] \cdot 10^3 \cdot J \cdot kg^{-1} \cdot K^{-1}$
          $m_{vfal} \leftarrow r_{fal} \cdot m_{da}$
          $\left(\frac{m_{vfal}}{m_{da} + m_{vfal}}\right) \cdot cp_{vfal} + \left(\frac{m_{da}}{m_{da} + m_{vfal}}\right) \cdot cp_{afal}$
        $x_i \leftarrow \left(n_c + \frac{1}{2}\right) \cdot \Delta x$
        $\frac{\rho_{fal} \cdot u_{ac_{n_c}} \cdot x_i}{\mu_{fal}}$
      $Re_{acpavg} \leftarrow \frac{1}{n_c + 1} \cdot \sum_{v=1}^{n_c+1} Re_{acp_v}$
      $5 \cdot x_i \cdot Re_{acpavg}^{-\frac{1}{2}}$ if $Re_{acpavg} < 5 \cdot 10^5$
      $0.37 \cdot x_i \cdot Re_{acpavg}^{-\frac{1}{5}}$ if $Re_{acpavg} > 5 \cdot 10^5$
    $Re_{f_{n_c+1}} \leftarrow$
      $Re_{f_0} \leftarrow 0$
      $\Gamma_{cpmax} \leftarrow \frac{\left(r_{c_{n_c+1}} - r_{c_{n_c}}\right) \cdot N_{cpr} \cdot m_{dacp}}{\Delta x}$
      $Pr_f \leftarrow$
        $cp_f \leftarrow \left[-6.491353 \cdot 10^{-8} \cdot \left(\frac{T_{fpa}}{K}\right)^5 + 1.059176 \cdot 10^{-4} \cdot \left(\frac{T_{fpa}}{K}\right)^4 - 6.915147 \cdot 10^{-2} \cdot \left(\frac{T_{fpa}}{K}\right)^3 + 22.59288 \cdot \left(\frac{T_{fpa}}{K}\right)^2 - 3.695396 \cdot 10^3 \cdot \left(\frac{T_{fpa}}{K}\right) + 2.463334 \cdot 10^5\right] \cdot J \cdot kg^{-1} \cdot K^{-1}$
        $cp_f \cdot \mu_f$
```

```
            $k_f$
        $0.023\cdot\left(\frac{2\cdot\Gamma_{cpmax}}{\mu_f}\right)^{\frac{1}{4}}\cdot Pr_f^{\frac{1}{2}}$
    $T_{swc_{n_c+1}} \leftarrow$
        $cp_{sw} \leftarrow 4186\cdot J\cdot kg^{-1}\cdot K^{-1}$
        $\frac{\frac{Q_{cwpc_{n_c+1}}}{m_{swcp}} - cp_{sw}\cdot T_{swc_{n_c}}}{-cp_{sw}}$
    $u_{swc_{n_c+1}} \leftarrow$
        $\rho_{swc_{n_c+1}} \leftarrow$ for $\iota \in 0..2$
            $T_{sweC} \leftarrow \frac{T_{swc_{n_c+1}} - 273.15\cdot K}{K}$
            $x_\iota \leftarrow \frac{2\cdot Z - 150}{150}$
            $T_{\iota_0} \leftarrow 1$
            $T_{\iota_1} \leftarrow x_\iota$
            $T_{\iota_2} \leftarrow 2\cdot x_\iota^2 - 1$
            for $\varepsilon \in 0..2$
                $x_\varepsilon \leftarrow \left(\frac{2\cdot T_{sweC} - 250}{110}\right)$
                $T_{\varepsilon_0} \leftarrow 1$
                $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                $T_{\varepsilon_2} \leftarrow 2\cdot x_\varepsilon^2 - 1$
            $10^3\cdot kg\cdot m^{-3}\cdot\sum_{\iota=0}^{2}\sum_{\varepsilon=0}^{2}\left(b_{\iota,\varepsilon}\cdot T_{\varepsilon_\varepsilon}\cdot T_{\iota_\iota}\right)$
        $\frac{m_{swcp}}{\rho_{swc_{n_c+1}}\cdot A_{cpi}}$
    $p_{ac_{n_c+1}} \leftarrow$
        $zz \leftarrow 0$
        $p_{acLoop_0} \leftarrow p_{ac_{n_c}}$
```

```
        $LoopStop_{zz} \leftarrow 1\cdot Pa$
        while $LoopStop_{zz} > \Omega\cdot Pa \wedge zz < 200$
            $H_{flc} \leftarrow$
                $u_{ac_{n_c+1}} \leftarrow$
                    $\rho_{wac_{n_c+1}} \leftarrow$
                        $p_{vc} \leftarrow \frac{r_{c_{n_c+1}}\cdot p_{acLoop_{zz}}}{0.62198 + r_{c_{n_c+1}}}$
                        $v_{ac} \leftarrow \frac{0.287035\cdot T_{ac_{n_c+1}}}{p_{acLoop_{zz}} - p_{vc}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
                        $\frac{1 + r_{c_{n_c+1}}}{v_{ac}}$
                    $\frac{m_{dac}\cdot\left(1 + r_{c_{n_c+1}}\right)}{\rho_{wac_{n_c+1}}\cdot A_{ca}}$
                $Re_{flc} \leftarrow$
                    $T_{acavgs} \leftarrow \frac{T_{ac_{n_c+1}} + T_{ac_{n_c}}}{2}$
                    $u_{acavg} \leftarrow \frac{1}{n_c + 2}\cdot\sum_{\upsilon=0}^{n_c+1} u_{ac_\upsilon}$
                    $\rho_{flc} \leftarrow \rho_{wac_{n_c+1}}$
                    $\mu_{flc} \leftarrow$
                        $\mu_{vflc} \leftarrow \left[1.299155\cdot 10^{-12}\cdot\left(\frac{T_{acavgs}}{K}\right)^2 + 3.872699\cdot 10^{-8}\cdot\left(\frac{T_{acavgs}}{K}\right) - 2.390839\cdot 10^{-6}\right]\cdot kg\cdot m^{-1}\cdot s^{-1}$
                        $\mu_{aflc} \leftarrow \left(7.58\cdot 10^{-8}\cdot\frac{T_{acavgs}}{K} + 4.745\cdot 10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
                        $r_{cavg} \leftarrow \frac{r_{c_{n_c+1}} + r_{c_{n_c}}}{2}$
                        $N_{vflc} \leftarrow \frac{r_{cavg}\cdot m_{dac}}{M_w}$
                        $N_{aflc} \leftarrow \frac{m_{dac}}{M_a}$
                        $\left(\frac{N_{vflc}}{N_{vflc} + N_{aflc}}\right)\cdot\mu_{vflc} + \left(\frac{N_{aflc}}{N_{vflc} + N_{aflc}}\right)\cdot\mu_{aflc}$
                    $R_{-} \leftarrow \frac{A_{ca}}{}$
```

```
            $N_{cp} \cdot P_{cpo} + 2 \cdot (H_c + W_c)$
            $\frac{\rho_{flc} \cdot u_{acavg} \cdot 4 \cdot R_c}{\mu_{flc}}$
        $k_{cavg} \leftarrow \frac{N_{cp} \cdot P_{cpo} \cdot k_{cp} + 2 \cdot (H_c + W_c) \cdot k_c}{N_{cp} \cdot P_{cpo} + 2 \cdot (H_c + W_c)}$
        $f_{flc} \leftarrow$
          $ii \leftarrow 0$
          $f_{flcLoop_0} \leftarrow 0.1$
          $LoopStop_{ii} \leftarrow 1$
          while $LoopStop_{ii} > \frac{\Omega}{100} \wedge ii < 100$
            $f_{flcLoop_{ii+1}} \leftarrow \left(-4 \cdot \log\left(\frac{k_{cavg}}{3.71 \cdot 4 \cdot R_c} + \frac{1.255}{Re_{flc} \cdot \sqrt{f_{flcLoop_{ii}}}}\right)\right)^{-2}$
            $ii \leftarrow ii + 1$
            $LoopStop_{ii} \leftarrow \left|f_{flcLoop_{ii}} - f_{flcLoop_{ii-1}}\right|$
          $f_{flcLoop_{ii}}$
        $\frac{f_{flc} \cdot \Delta x \cdot u_{acavg}^2}{2 \cdot g \cdot R_c}$
      $\rho_{wacavg} \leftarrow \frac{\rho_{wac_{n_c+1}} + \rho_{wac_{n_c}}}{2}$
      $z_{c_{n_c+1}} \leftarrow z_{c_{n_c}} - S_c \cdot \Delta x$
      $H_{wapc} \leftarrow \frac{p_{ac_{n_c}}}{\rho_{wacavg} \cdot g} + \frac{\left(u_{ac_{n_c}}\right)^2}{2 \cdot g} + z_{c_{n_c}}$
      $p_{acLoop_{(zz+1)}} \leftarrow \rho_{wacavg} \cdot g \cdot \left[H_{wapc} - \frac{\left(u_{ac_{n_c+1}}\right)^2}{2 \cdot g} - z_{c_{n_c+1}} - H_{flc}\right]$
      $zz \leftarrow zz + 1$
      $LoopStop_{zz} \leftarrow \left|p_{acLoop_{zz}} - p_{acLoop_{zz-1}}\right|$
    $p_{acLoop_{zz}}$
$p_{swc_{n_c+1}} \leftarrow$
    $H_{lcp} \leftarrow$
        $f_{cp} \leftarrow$
          $ij \leftarrow 0$
          $\leftarrow 0.1$
```

```
          $cpLoop_0$
          $LoopStop_{ij} \leftarrow 1$
          while $LoopStop_{ij} > \frac{\Omega}{100} \wedge ij < 100$
            $f_{cpLoop_{ij+1}} \leftarrow \left(-4 \cdot \log\left(\frac{k_{cp}}{3.71 \cdot d_{cpi}} + \frac{1.255}{Re_{xcwp} \cdot \sqrt{f_{cpLoop_{ij}}}}\right)\right)^{-2}$
            $ij \leftarrow ij + 1$
            $LoopStop_{ij} \leftarrow \left|f_{cpLoop_{ij}} - f_{cpLoop_{ij-1}}\right|$
          $f_{cpLoop_{ij}}$
        $\frac{4 \cdot f_{cp} \cdot \Delta x \cdot \left(u_{swc_{n_c+1}}\right)^2}{2 \cdot g \cdot d_{cpi}}$
    $z_{c_{n_c+1}} \leftarrow z_{c_{n_c}} - \Delta x \cdot S_c$
    $\rho_{swavg} \leftarrow \frac{\rho_{swc_{n_c+1}} + \rho_{swc_{n_c}}}{2}$
    $\rho_{swavg} \cdot g \cdot \left[\frac{p_{swc_{n_c}}}{\rho_{swavg} \cdot g} + \frac{\left(u_{swc_{n_c}}\right)^2 - \left(u_{swc_{n_c+1}}\right)^2}{2 \cdot g} + \left(z_{c_{n_c}} - z_{c_{n_c+1}}\right) + H_{lcp}\right]$
  break if $T_{swc_{n_c+1}} < T_{swcx}$
  $n_c \leftarrow n_c + 1$
$L_{cC_c+1} \leftarrow n_c \cdot \Delta x$
$p_{acxEst_{C_c+1}} \leftarrow p_{ac_{n_c}}$
$C_c \leftarrow C_c + 1$
$LoopStop_{Cc} \leftarrow \left|L_{cC_c} - L_{cC_c-1}\right|$
if $T_{ac_{N_c}} > T_{acx}$
  $m_{swcHigh_{E_c+1}} \leftarrow m_{swcHigh_{E_c}}$
  $m_{swcLow_{E_c+1}} \leftarrow m_{swc_{E_c}}$
  $E_c \leftarrow E_c + 1$
if $T < T$
```

```
            $_{acN_c}$   acx
                $m_{swcHigh_{E_c+1}} \leftarrow m_{swc_{E_c}}$
                $m_{swcLow_{E_c+1}} \leftarrow m_{swcLow_{E_c}}$
                $E_c \leftarrow E_c + 1$
            $LoopStop_{E_c} \leftarrow \left|\frac{m_{swcHigh_{E_c}} - m_{swcLow_{E_c}}}{1 \cdot kg \cdot s^{-1}}\right|$
        for $n_c \in 0..N_c$
            $n_{dc} \leftarrow n_c + 2 + N + N_p$
            $M_{0,n_{dc}} \leftarrow \frac{T_{ac_{n_c}}}{K}$
            $M_{1,n_{dc}} \leftarrow \frac{m_{da}}{kg \cdot s^{-1}}$
            $M_{2,n_{dc}} \leftarrow \frac{\rho_{wac_{n_c}}}{kg \cdot m^{-3}}$
            $M_{3,n_{dc}} \leftarrow r_{c_{n_c}}$
            $M_{4,n_{dc}} \leftarrow RH_{c_{n_c}}$
            $M_{5,n_{dc}} \leftarrow \frac{p_{ac_{n_c}}}{Pa}$
            $M_{6,n_{dc}} \leftarrow \frac{u_{ac_{n_c}}}{m \cdot s^{-1}}$
            $M_{7,n_{dc}} \leftarrow Re_{acp_{n_c}}$
            $M_{8,n_{dc}} \leftarrow 0$
            $M_{9,n_{dc}} \leftarrow 0$
            $M_{10,n_{dc}} \leftarrow \frac{T_{swc_{n_c}}}{K}$
            $M_{11,n_{dc}} \leftarrow \frac{m_{swc_{E_c-1}}}{kg \cdot s^{-1}}$
```

```
            $M_{12,n_{dc}} \leftarrow \frac{\rho_{swc_{n_c}}}{kg \cdot m^{-3}}$
            $M_{13,n_{dc}} \leftarrow 0$
            $M_{14,n_{dc}} \leftarrow \frac{p_{swc_{n_c}}}{Pa}$
            $M_{15,n_{dc}} \leftarrow \frac{u_{swc_{n_c}}}{m \cdot s^{-1}}$
            $M_{16,n_{dc}} \leftarrow \frac{H_c}{m}$
            $M_{17,n_{dc}} \leftarrow \frac{t_{cpp}}{m}$
            $M_{18,n_{dc}} \leftarrow \frac{W_c}{m}$
            $M_{19,n_{dc}} \leftarrow 0$
            $M_{20,n_{dc}} \leftarrow 0$
            $M_{21,n_{dc}} \leftarrow 0$
    FAN ←
        $p_{acif} \leftarrow$
            $rr \leftarrow 0$
            $p_{aciLoop_0} \leftarrow p_{acN_c}$
            $LoopStop_{rr} \leftarrow 1$
            while $LoopStop_{rr} > A$
                $H_{lce} \leftarrow$
                    $K_{sce} \leftarrow 2 \cdot K_{ir} + K_{45}$
                    $u_{atce} \leftarrow \frac{m_{dac} \cdot \left(1 + r_{cN_c}\right)}{\rho_{wacN_c} \cdot A_t}$
                    $f_t \leftarrow$
                        $ii \leftarrow 0$
                        $f_{tLoop_0} \leftarrow 0.1$
                        $Re_t \leftarrow$
                            $\mu_{vrat} \leftarrow$
                                $\mu_{vt} \leftarrow \left[1.299155 \cdot 10^{-12} \left(\frac{T_{acN_c}}{K}\right)^2 + 3.872699 \cdot 10^{-8} \left(\frac{T_{acN_c}}{K}\right) - 2.390839 \cdot 10^{-6}\right] \cdot kg \cdot m^{-1} s^{-1}$
```

```
            $\mu_{at} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{ac_{N_c}}}{K} + 4.745\cdot10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
            $N_{vt} \leftarrow \frac{r_{c_{N_c}}\cdot m_{dac}}{M_w}$
            $N_{at} \leftarrow \frac{m_{dac}}{M_a}$
            $\left(\frac{N_{vt}}{N_{vt}+N_{at}}\right)\cdot\mu_{vt} + \left(\frac{N_{at}}{N_{vt}+N_{at}}\right)\cdot\mu_{at}$
          $\frac{\rho_{wac_{N_c}}\cdot u_{atce}\cdot 4\cdot R_t}{\mu_{wat}}$
        $LoopStop_{ii} \leftarrow 1$
        while $LoopStop_{ii} > \frac{\Omega}{100} \wedge ii < 100$
          $f_{tLoop_{ii+1}} \leftarrow \left(-4\cdot\log\left(\frac{k_c}{3.71\cdot4\cdot R_t} + \frac{1.255}{Re_t\cdot\sqrt{f_{tLoop_{ii}}}}\right)\right)^{-2}$
          $ii \leftarrow ii + 1$
          $LoopStop_{ii} \leftarrow \left|f_{tLoop_{ii}} - f_{tLoop_{ii-1}}\right|$
        $f_{tLoop_{ii}}$
      $l_{tce} \leftarrow L_{e_E} + 2\cdot\left(25\cdot m + \frac{1}{2}\cdot W_c\right) - \frac{\left[z_{c_0} + S\cdot\left(L_{e_E}\right)\right]}{\cos(45)} - 1500\cdot m$
      $C_D \leftarrow 1$
      $\frac{K_{sce}\cdot u_{atce}^2}{2\cdot g} + \frac{f_t\cdot l_{tce}\cdot u_{atce}^2}{2\cdot g\cdot R_t} + \frac{N_{cpr}\cdot\left(N_{cpc} - \frac{1}{2}\right)\cdot t_{cpp}\cdot\left(\frac{d_{cpo} + d_{tsw}}{2}\right)\cdot C_D\cdot u_{atce}^2}{2\cdot g\cdot A_t}$
    $p_{aeiLoop_{rr+1}} \leftarrow \rho_{wac_{N_c}}\cdot g\cdot\left(\frac{p_{ac_{N_c}}}{\rho_{wac_{N_c}}\cdot g} - H_{lce}\right)$
    $rr \leftarrow rr + 1$
    $LoopStop_{rr} \leftarrow \left|\frac{p_{aeiLoop_{rr}} - p_{aeiLoop_{rr-1}}}{p_{aeiLoop_{rr}}}\right|$
```

```
      $p_{aeiLoop_{rr}}$
  $Power_{Fan} \leftarrow g\cdot m_{da}\cdot\left(1 + r_{c_{N_c}}\right)\cdot\frac{p_{ac_0} - p_{acif}}{g\cdot\rho_{wac_{N_c}}}$
  $M_{5,n_{dc}+1} \leftarrow \frac{p_{acif}}{Pa}$
  $M_{5,n_{dc}+2} \leftarrow \frac{Power_{Fan}}{W}$
$PUMP \leftarrow$ $\rho_{swsi} \leftarrow$ $H_{ltsc} \leftarrow$ $K_{ssc} \leftarrow 3\cdot K_{lr} + 4\cdot K_v$
      $u_{swtsc} \leftarrow$ $A_{tsc} \leftarrow \pi\cdot\frac{d_{tsw}^2}{4}$
        $\frac{m_{swtp}}{\rho_{swc_{N_c}}\cdot\pi\cdot\frac{d_{tsw}^2}{4}}$
      $Re_{tsc} \leftarrow$ $\mu_{swsc} \leftarrow$ $\mu_{20} \leftarrow 1.002 + c_{1v}\cdot Z + c_{2v}\cdot Z^2$
          $\chi \leftarrow$ $t_{tsc} \leftarrow \left(\frac{T_{swc_{N_c}} - 273.15\cdot K}{K}\right)$
            $\chi_1 \leftarrow A_v\cdot\left(1 + a_{1v}\cdot Z + a_{2v}\cdot Z^2\right)$
            $\chi_2 \leftarrow B_v\cdot\left(1 + b_{1v}\cdot Z + b_{2v}\cdot Z^2\right)$
            $\left(\frac{t_{tsc} - 20}{t_{tsc} + 109}\right)\cdot\left[\chi_1 + \chi_2\cdot\left(t_{tsc} - 20\right)\right]$
          $\frac{\mu_{20}}{10^{\chi}}\cdot10^{-3}\cdot kg\cdot m^{-1}\cdot s^{-1}$
        $\frac{\rho_{swc_{N_c}}\cdot u_{swtsc}\cdot d_{tsw}}{\mu_{swsc}}$
      $f_{tsc} \leftarrow$ $jj \leftarrow 0$
        $f_{tscLoop_0} \leftarrow 0.1$
        $LoopStop_{jj} \leftarrow 1$
        while $LoopStop_{jj} > \frac{\Omega}{100} \wedge jj < 100$
```

```
                        $f_{tscLoop_{jj+1}} \leftarrow \left(-4\cdot\log\left(\frac{k_c}{3.71\cdot d_{tsw}}+\frac{1.255}{Re_{tsc}\cdot\sqrt{f_{tscLoop_{jj}}}}\right)\right)^{11}$
                        $jj \leftarrow jj+1$
                        $LoopStop_{jj} \leftarrow \left|f_{tscLoop_{jj}}-f_{tscLoop_{jj-1}}\right|$
                    $f_{tscLoop_{jj}}$
                $l_{tsc} \leftarrow l_{tce}-\frac{W_e}{2}$
                $\frac{4\cdot f_{tsc}\cdot\Delta x\cdot u_{swtsc}^{2}}{2\cdot g\cdot d_{tsw}}+\frac{K_{ssc}\cdot u_{swtsc}^{2}}{2\cdot g}$
            $\rho_{swcN_c}\cdot g\cdot\left(\frac{p_{swcN_c}}{\rho_{swcN_c}\cdot g}+H_{asc}\right)$
        $Power_{Pump} \leftarrow g\cdot(2\cdot N_{cpr}\cdot m_{swtp})\cdot\left[\frac{p_{swsi}-p_{atm}}{g\cdot\rho_{swcN_c}}+(1-\eta_{wts})\cdot z_{sl}\right]$
        $M_{14,n_{dc}+1} \leftarrow \frac{p_{swsi}}{Pa}$
        $M_{14,n_{dc}+2} \leftarrow \frac{Power_{Pump}}{W}$
    $Design \leftarrow$
        $M_{0,n_{dc}+3} \leftarrow \frac{H_e}{m}$
        $M_{1,n_{dc}+3} \leftarrow \frac{L_{e_E}}{m}$
        $M_{2,n_{dc}+3} \leftarrow \frac{H_p}{m}$
        $M_{3,n_{dc}+3} \leftarrow \frac{L_{p_P}}{m}$
        $M_{4,n_{dc}+3} \leftarrow \frac{t_{cpp}}{m}$
        $M_{5,n_{dc}+3} \leftarrow \frac{L_{cC_c}}{m}$
    $M$
```

APPENDIX B

Pilot Plant

Test Data

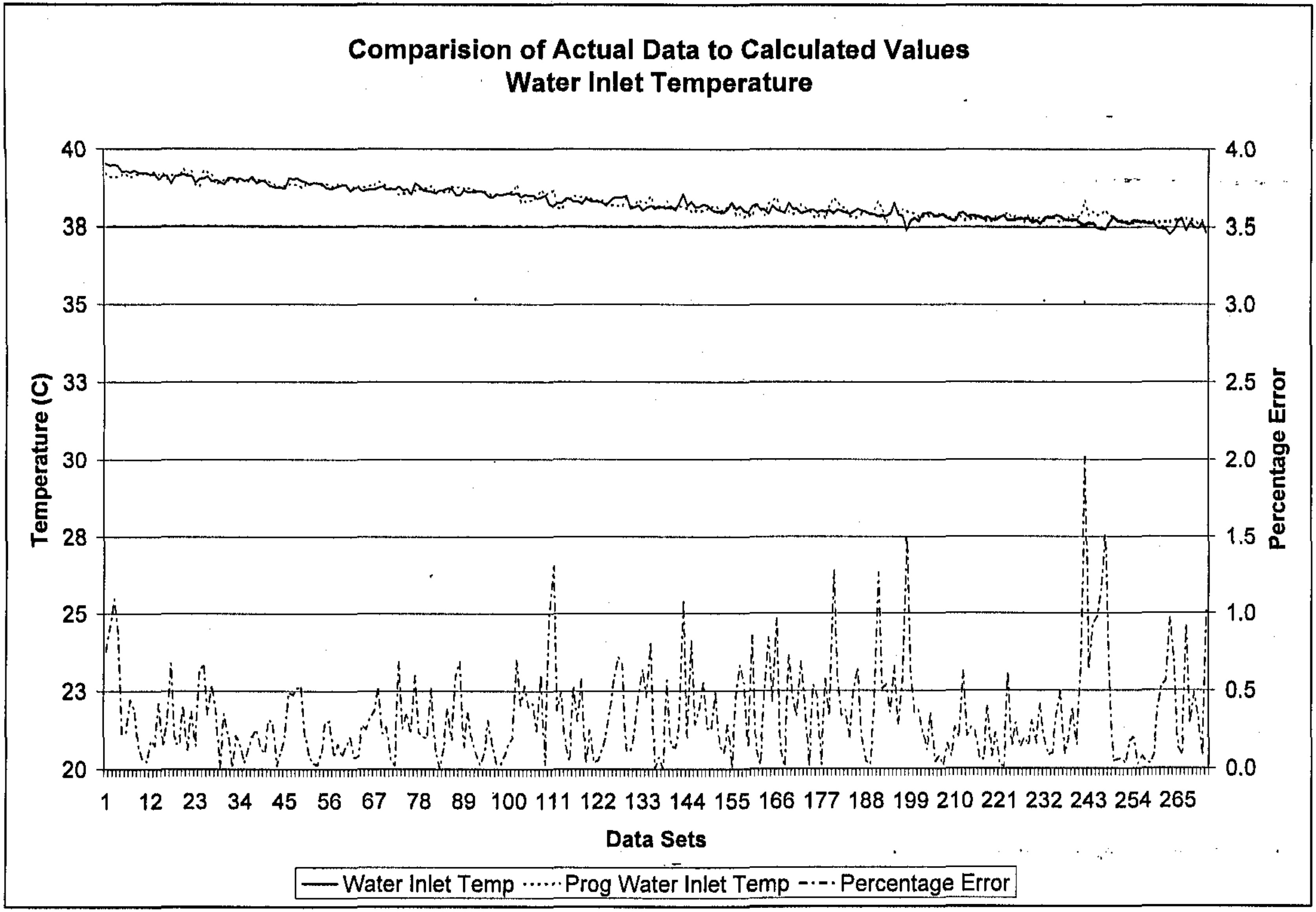
Date	Time	WaterFlow Rate	WaterTemp Bottom	WaterTemp Top	RelHumidity Bottom	RelHumidity Top	Solar Radiation	AirTemp Bottom	WndSpeed Bottom	AirTemp Top	WindSpeed Top	ProgWater TempTop	ProgHumidity Top	ProgAir TempTop	MassFlow Rate Air	Water Temp%	Humidity %	Air Temp%
11/8/2006	12:29 PM	26.44	39.32	39.52	35.34	49.68	854.79	26.40	4.30	34.10	5.20	39.22	53.43	31.36	0.58	0.76	7.76	8.03
11/8/2006	12:29 PM	26.42	39.21	39.45	34.84	49.69	852.53	26.50	4.40	34.10	5.40	39.09	53.02	31.33	0.60	0.92	6.70	8.13
11/8/2006	12:29 PM	26.42	39.20	39.48	33.65	50.02	853.31	25.70	4.30	34.20	5.60	39.05	52.75	30.75	0.63	1.09	5.46	10.09
11/8/2006	12:29 PM	26.42	39.24	39.44	34.19	49.32	849.70	25.90	4.20	33.70	5.50	39.09	52.94	30.91	0.62	0.88	7.35	8.28
11/8/2006	12:29 PM	26.43	39.25	39.24	34.37	49.66	853.26	26.00	4.00	34.00	5.20	39.15	52.99	31.07	0.58	0.23	6.71	8.61
11/8/2006	12:29 PM	26.39	39.27	39.27	34.35	49.62	853.63	25.80	3.00	33.90	5.20	39.17	52.80	30.90	0.58	0.24	6.41	8.84
11/8/2006	12:29 PM	26.38	39.16	39.23	34.89	50.34	852.73	26.40	4.30	33.80	5.30	39.05	53.07	31.27	0.59	0.44	5.43	7.49
11/8/2006	12:30 PM	26.39	39.24	39.29	34.73	50.17	851.57	26.30	4.00	34.00	5.30	39.13	52.99	31.22	0.59	0.39	5.63	8.16
11/8/2006	12:30 PM	26.44	39.29	39.21	34.84	49.57	851.41	25.80	3.90	34.00	5.40	39.16	53.34	30.89	0.60	0.14	7.59	9.16
11/8/2006	12:30 PM	26.44	39.35	39.19	35.09	49.91	854.50	25.60	4.00	33.70	5.40	39.21	53.67	30.78	0.61	0.06	7.53	8.65
11/8/2006	12:30 PM	26.42	39.32	39.20	35.04	49.80	848.69	25.80	4.20	33.70	5.40	39.18	53.56	30.91	0.61	0.05	7.55	8.28
11/8/2006	12:30 PM	26.44	39.34	39.14	34.92	49.38	854.61	26.00	4.20	33.70	5.40	39.21	53.37	31.04	0.61	0.18	8.08	7.88
11/8/2006	12:30 PM	26.37	39.36	39.17	35.23	49.26	853.84	26.30	4.10	33.80	5.40	39.23	53.35	31.24	0.61	0.15	8.30	7.68
11/8/2006	12:30 PM	26.34	39.26	38.99	35.33	49.72	855.07	26.20	4.00	33.90	5.30	39.16	53.41	31.17	0.59	0.42	7.44	8.06
11/8/2006	12:30 PM	26.38	39.30	39.12	35.29	50.07	853.33	26.10	3.90	33.80	5.40	39.17	53.42	31.08	0.60	0.15	6.69	8.05
11/8/2006	12:30 PM	26.43	39.12	39.12	35.54	49.80	849.83	25.90	4.30	33.80	5.30	39.00	53.73	30.94	0.59	0.29	7.91	8.47
11/8/2006	12:31 PM	26.39	39.25	38.86	35.43	49.62	853.80	25.90	4.30	33.70	5.40	39.12	53.71	30.95	0.61	0.68	8.26	8.16
11/8/2006	12:31 PM	26.39	39.28	39.09	35.61	49.80	857.61	26.10	4.50	33.60	5.40	39.16	53.77	31.10	0.61	0.17	7.96	7.44
11/8/2006	12:31 PM	26.40	39.17	39.13	35.20	49.66	857.04	25.80	3.10	33.80	5.30	39.07	53.27	30.84	0.59	0.16	7.26	8.76
11/8/2006	12:31 PM	26.42	39.44	39.17	34.87	49.82	855.02	26.00	3.90	33.70	5.20	39.33	53.34	31.13	0.58	0.41	7.07	7.61
11/8/2006	12:31 PM	26.37	39.28	39.10	34.55	49.17	855.42	25.90	4.50	33.70	5.40	39.15	53.27	30.97	0.61	0.13	8.35	8.09
11/8/2006	12:31 PM	26.38	39.37	39.13	34.28	49.90	855.30	26.20	4.60	33.80	5.10	39.27	53.07	31.30	0.67	0.37	6.35	7.39
11/8/2006	12:31 PM	26.43	38.94	38.89	34.42	49.63	852.56	26.10	4.00	33.80	5.40	38.83	52.76	30.95	0.61	0.15	6.32	8.42
11/8/2006	12:31 PM	26.43	38.86	39.01	34.21	49.32	854.26	25.70	3.80	33.80	5.30	38.76	52.80	30.69	0.59	0.64	7.08	9.19
11/8/2006	12:31 PM	26.36	39.42	39.03	34.26	49.79	856.78	25.30	3.80	33.60	5.30	39.29	53.38	30.64	0.59	0.67	7.21	8.80
11/8/2006	12:32 PM	26.36	39.36	39.09	34.39	49.43	852.19	25.60	4.10	33.50	5.30	39.22	53.32	30.82	0.59	0.36	7.86	7.99
11/8/2006	12:32 PM	26.32	39.26	38.92	34.65	49.07	853.25	25.80	4.30	33.50	5.30	39.13	53.34	30.92	0.59	0.54	8.71	7.70
11/8/2006	12:32 PM	26.37	38.92	38.98	35.24	49.44	855.89	25.70	4.00	33.50	5.30	38.82	53.49	30.73	0.59	0.39	8.19	8.28
11/8/2006	12:32 PM	26.41	39.04	38.92	35.12	50.17	853.39	25.80	4.50	33.50	5.30	38.92	53.56	30.85	0.59	0.01	6.75	7.91
11/8/2006	12:32 PM	26.40	39.09	38.83	35.49	49.47	852.17	25.60	4.30	33.50	5.40	38.97	53.86	30.70	0.61	0.36	8.88	8.35
11/8/2006	12:32 PM	26.41	39.08	39.04	36.15	48.99	849.83	25.50	4.30	33.50	5.40	38.95	54.29	30.63	0.61	0.23	10.82	8.56
11/8/2006	12:32 PM	26.44	39.15	39.04	36.22	48.84	856.25	26.00	3.80	33.50	5.40	39.04	53.92	30.96	0.61	0.01	10.42	7.59
11/8/2006	12:32 PM	26.39	38.99	38.97	36.09	49.89	855.52	26.00	4.00	33.60	5.30	38.89	53.84	30.94	0.59	0.22	7.91	7.92
11/8/2006	12:32 PM	26.41	39.06	39.02	36.15	49.76	849.39	26.10	4.10	33.70	5.20	38.97	53.90	31.06	0.58	0.15	8.33	7.82
11/8/2006	12:33 PM	26.42	39.06	38.94	35.91	50.06	854.06	26.20	3.90	33.70	5.30	38.96	53.62	31.09	0.59	0.04	7.11	7.75
11/8/2006	12:33 PM	26.37	39.00	38.98	35.75	49.52	854.96	26.40	3.90	33.80	5.20	38.92	53.41	31.23	0.58	0.14	7.84	7.61
11/8/2006	12:33 PM	26.33	39.07	39.08	35.47	49.93	854.77	26.60	3.90	33.80	5.20	38.99	53.16	31.38	0.58	0.21	6.46	7.16
11/8/2006	12:33 PM	26.39	39.05	38.87	35.12	50.19	853.97	26.20	3.90	33.90	5.20	38.97	53.18	31.12	0.58	0.26	5.95	8.20
11/8/2006	12:33 PM	26.40	39.10	38.94	35.12	49.57	852.65	26.00	4.40	33.70	5.30	38.99	53.45	31.00	0.59	0.13	7.83	8.02
11/8/2006	12:33 PM	26.37	39.04	38.97	35.52	49.81	856.00	26.00	4.40	33.70	5.40	38.93	53.63	30.95	0.61	0.10	7.66	8.17
11/8/2006	12:33 PM	26.35	39.01	38.80	35.83	49.34	854.01	26.30	3.90	33.70	5.30	38.92	53.50	31.13	0.59	0.31	8.43	7.62
11/8/2006	12:33 PM	26.33	38.97	38.76	35.42	49.43	856.91	26.00	3.50	33.70	5.30	38.88	53.29	30.91	0.59	0.31	7.81	8.27
11/8/2006	12:33 PM	26.37	38.84	38.72	35.90	49.45	855.52	25.90	4.00	33.50	5.50	38.73	53.69	30.76	0.62	0.02	8.58	8.18
11/8/2006	12:34 PM	26.35	38.87	38.73	36.18	50.05	853.03	26.40	4.10	33.60	5.40	38.78	53.62	31.12	0.61	0.12	7.13	7.37
11/8/2006	12:34 PM	26.35	38.86	38.70	36.30	49.36	851.80	26.40	4.10	33.80	5.30	38.78	53.71	31.15	0.59	0.21	8.82	7.84
11/8/2006	12:34 PM	26.40	38.92	39.03	36.06	50.91	856.32	26.40	3.60	33.80	5.30	38.84	53.45	31.15	0.59	0.49	4.97	7.83
11/8/2006	12:34 PM	26.36	38.90	39.00	36.06	50.72	854.61	26.70	4.00	33.60	5.40	38.81	53.37	31.32	0.61	0.48	5.22	6.78
11/8/2006	12:34 PM	26.32	38.92	39.03	35.88	50.80	853.77	26.40	3.80	33.80	5.30	38.83	53.40	31.16	0.59	0.52	5.12	7.81
11/8/2006	12:34 PM	26.32	38.83	38.95	35.82	50.90	856.84	26.00	4.30	33.80	5.30	38.74	53.69	30.90	0.59	0.53	5.50	8.59
11/8/2006	12:34 PM	26.33	38.91	38.91	36.39	50.54	854.88	26.20	3.90	33.60	5.30	38.82	53.84	31.03	0.59	0.21	6.53	7.64
11/8/2006	12:34 PM	26.38	38.96	38.83	36.26	49.94	855.82	26.10	4.00	33.60	5.40	38.86	53.86	30.96	0.61	0.08	7.83	7.85
11/8/2006	12:34 PM	26.41	38.96	38.87	36.40	50.20	854.56	26.00	4.10	33.60	5.40	38.86	54.02	30.90	0.61	0.04	7.61	8.03
11/8/2006	12:35 PM	26.43	38.98	38.87	36.88	49.82	854.71	26.20	4.20	33.50	5.40	38.88	54.22	31.04	0.61	0.03	8.83	7.35
11/8/2006	12:35 PM	26.40	38.91	38.86	36.93	50.10	853.37	26.30	4.40	33.50	5.40	38.81	54.22	31.09	0.61	0.11	8.22	7.20
11/8/2006	12:35 PM	26.36	38.94	38.73	37.18	50.82	853.89	26.30	4.60	33.50	5.30	38.85	54.45	31.14	0.59	0.30	7.15	7.05
11/8/2006	12:35 PM	26.40	38.89	38.69	37.26	50.43	853.47	26.20	4.10	33.70	5.30	38.81	54.40	31.04	0.59	0.31	7.86	7.90
11/8/2006	12:35 PM	26.39	38.82	38.72	36.78	50.72	853.21	26.30	4.20	33.60	5.20	38.75	54.07	31.11	0.58	0.08	6.60	7.42

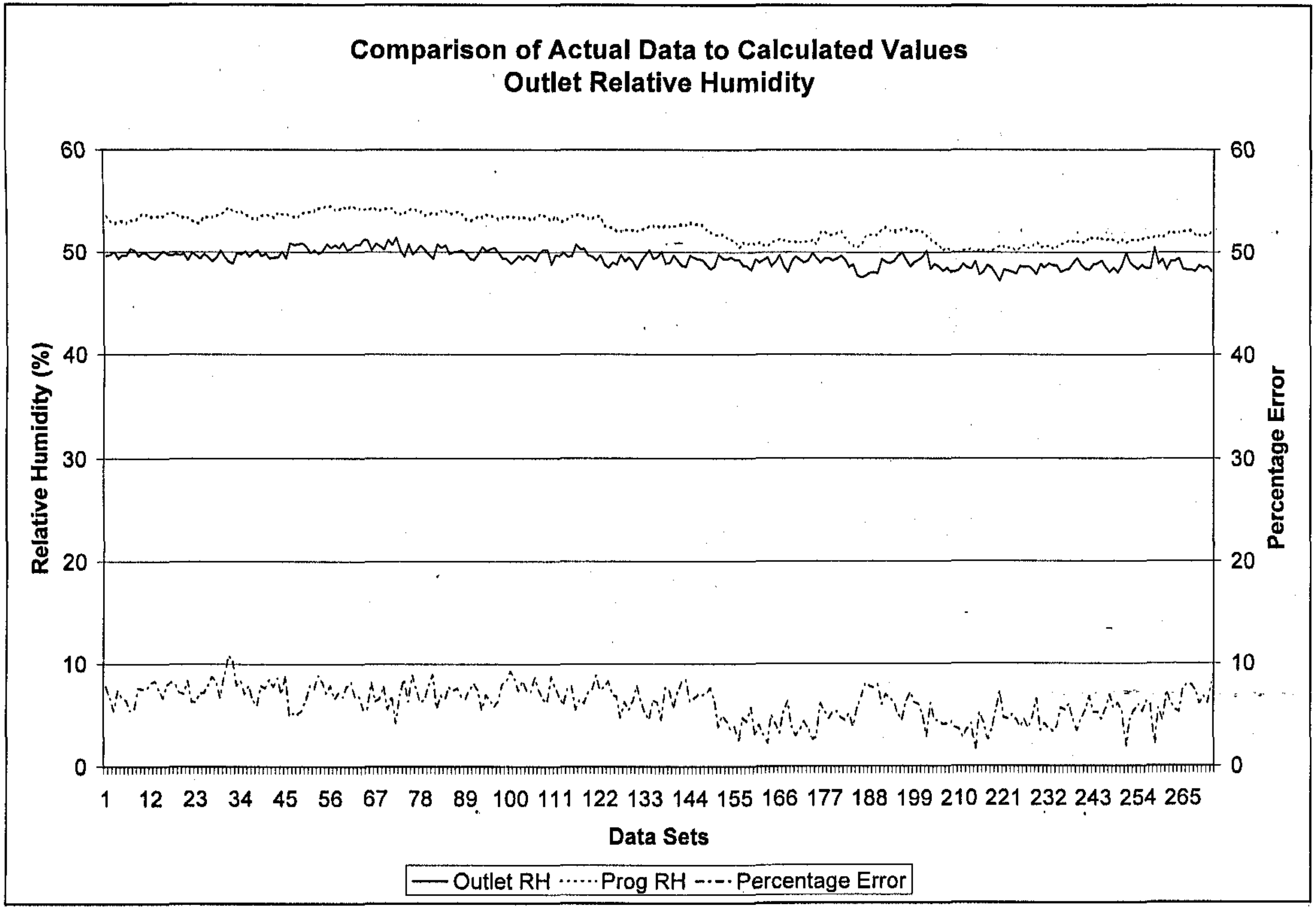
Date	Time	WaterFlow Rate	WaterTemp Bottom	WaterTemp Top	RelHumidity Bottom	RelHumidity Top	Solar Radiation	AirTemp Bottom	WndSpeed Bottom	AirTemp Top	WindSpeed Top	ProgWater TempTop	ProgHumidity Top	ProgAir TempTop	MassFlow Rate Air	Water Temp%	Humidity %	Air Temp%
11/8/2006	12:35 PM	26.37	38.93	38.77	36.67	50.44	855.71	26.10	3.90	33.70	5.40	38.83	54.05	30.95	0.61	0.16	7.16	8.17
11/8/2006	12:35 PM	26.34	38.95	38.81	36.50	50.95	853.95	25.60	4.40	33.60	5.40	38.84	54.40	30.66	0.61	0.08	6.77	8.75
11/8/2006	12:35 PM	26.30	38.86	38.82	36.49	50.21	853.59	25.70	3.80	33.20	5.40	38.76	54.12	30.66	0.61	0.15	7.79	7.66
11/8/2006	12:36 PM	26.29	38.81	38.62	36.83	50.37	852.20	25.40	3.90	33.40	5.40	38.70	54.50	30.45	0.61	0.20	8.19	8.82
11/8/2006	12:36 PM	26.30	38.82	38.72	36.81	50.75	855.36	25.70	3.50	33.20	5.20	38.75	54.23	30.70	0.56	0.07	6.85	7.54
11/8/2006	12:36 PM	26.33	38.87	38.74	36.84	50.72	850.88	26.10	4.00	33.20	5.40	38.77	54.15	30.92	0.61	0.09	6.77	6.86
11/8/2006	12:36 PM	26.36	38.81	38.62	36.84	51.27	849.10	26.10	4.10	33.50	5.30	38.72	54.17	30.94	0.59	0.28	5.65	7.64
11/8/2006	12:36 PM	26.37	38.65	38.65	36.60	51.16	851.29	26.20	4.10	33.40	5.40	38.75	53.97	30.99	0.61	0.26	5.50	7.22
11/8/2006	12:36 PM	26.34	38.90	38.67	36.67	50.20	848.99	25.60	3.70	33.50	5.30	38.80	54.29	30.64	0.59	0.33	8.13	8.55
11/8/2006	12:36 PM	26.34	38.90	38.68	37.03	50.86	847.04	26.40	3.80	33.40	5.20	38.82	54.08	31.18	0.58	0.37	6.34	6.65
11/8/2006	12:36 PM	26.34	39.00	38.73	36.64	50.64	848.08	26.00	3.30	33.70	5.00	38.93	54.00	31.01	0.56	0.52	6.64	7.99
11/8/2006	12:36 PM	26.32	38.96	38.77	36.96	50.26	847.92	26.40	4.30	33.40	5.40	38.86	54.18	31.16	0.61	0.23	7.80	6.70
11/8/2006	12:37 PM	26.32	38.87	38.66	36.83	51.25	847.21	26.10	3.90	33.70	5.40	38.77	54.12	30.92	0.60	0.27	5.60	8.24
11/8/2006	12:37 PM	26.32	38.78	38.70	36.74	50.74	846.93	25.80	4.00	33.50	5.40	38.67	54.23	30.70	0.61	0.06	6.88	8.36
11/8/2006	12:37 PM	26.33	38.77	38.67	36.01	51.46	845.30	26.20	4.30	33.40	5.30	38.67	53.66	31.00	0.59	0.02	4.28	7.20
11/8/2006	12:37 PM	26.30	38.59	38.77	36.34	50.16	846.87	26.20	4.00	33.40	5.40	38.50	53.67	30.89	0.61	0.69	7.01	7.52
11/8/2006	12:37 PM	26.34	38.61	38.64	36.48	49.53	847.13	26.30	4.00	33.50	5.30	38.53	53.73	30.99	0.59	0.27	8.47	7.50
11/8/2006	12:37 PM	26.33	38.63	38.68	36.89	50.79	846.92	26.10	3.80	33.50	5.40	38.54	54.02	30.83	0.61	0.36	6.35	7.97
11/8/2006	12:37 PM	26.35	38.68	38.51	37.11	49.76	845.98	26.30	4.20	33.50	5.30	38.60	54.19	31.02	0.59	0.23	8.89	7.39
11/8/2006	12:37 PM	26.36	38.73	38.86	36.10	50.21	846.36	25.60	4.10	33.50	5.30	38.63	53.99	30.59	0.59	0.60	7.52	8.68
11/8/2006	12:37 PM	26.38	38.77	38.77	36.68	50.69	847.21	26.20	3.70	33.20	5.40	38.68	53.88	30.94	0.61	0.24	6.28	6.81
11/8/2006	12:38 PM	26.37	38.82	38.64	36.06	50.24	848.35	26.40	4.00	33.50	5.40	38.72	53.50	31.10	0.61	0.21	6.49	7.17
11/8/2006	12:38 PM	26.38	38.82	38.61	35.61	49.72	845.94	25.60	3.90	33.50	5.50	38.69	53.66	30.55	0.62	0.21	7.93	8.80
11/8/2006	12:38 PM	26.36	38.90	38.59	36.19	49.35	843.91	26.10	3.90	33.20	5.40	38.79	53.76	30.93	0.61	0.52	8.93	6.84
11/8/2006	12:38 PM	26.31	38.68	38.54	36.35	50.77	845.21	26.20	3.80	33.50	5.40	38.59	53.67	30.91	0.61	0.12	5.70	7.73
11/8/2006	12:38 PM	26.40	38.73	38.63	36.43	50.43	844.81	26.00	4.00	33.40	5.40	38.63	53.91	30.81	0.61	0.01	6.90	7.75
11/8/2006	12:38 PM	26.38	38.69	38.64	36.51	50.68	844.79	26.00	4.30	33.40	5.40	38.59	54.02	30.81	0.61	0.14	6.59	7.76
11/8/2006	12:38 PM	26.34	38.65	38.71	36.14	49.81	844.98	26.10	4.10	33.40	5.40	68.56	53.67	30.85	0.61	0.39	7.75	7.64
11/8/2006	12:38 PM	26.33	38.86	38.68	36.43	50.00	843.06	26.40	3.80	33.40	5.40	38.76	53.68	31.10	0.61	0.19	7.37	6.89
11/8/2006	12:38 PM	26.40	38.83	38.50	36.31	50.06	842.97	26.20	4.30	33.50	5.30	38.73	53.87	31.02	0.59	0.60	7.61	7.42
11/8/2006	12:39 PM	26.35	38.84	38.49	36.00	50.19	844.05	26.30	4.20	33.50	5.20	38.76	53.63	31.11	0.58	0.69	6.86	7.13
11/8/2006	12:39 PM	26.35	38.78	38.64	35.57	49.90	840.49	26.60	4.30	33.50	5.20	38.70	53.20	31.28	0.58	0.15	6.63	6.62
11/8/2006	12:39 PM	26.33	38.79	38.57	35.47	49.33	840.94	26.80	4.30	33.50	5.20	38.71	53.04	31.41	0.58	0.37	7.52	6.23
11/8/2006	12:39 PM	26.39	38.75	38.60	35.28	49.18	840.92	26.40	4.30	33.70	5.20	38.67	53.13	31.15	0.58	0.18	8.03	7.58
11/8/2006	12:39 PM	26.40	38.73	38.60	35.87	49.75	843.11	26.20	4.00	33.50	5.40	38.63	53.46	30.94	0.61	0.09	7.46	7.65
11/8/2006	12:39 PM	26.34	38.68	38.62	36.15	50.55	840.97	26.40	3.40	33.50	5.20	38.61	53.36	31.08	0.58	0.03	5.66	7.22
11/8/2006	12:39 PM	26.30	38.71	38.57	36.27	50.08	837.83	26.40	3.90	33.50	5.40	38.61	53.55	31.05	0.61	0.11	6.93	7.31
11/8/2006	12:39 PM	26.31	38.64	38.44	36.39	50.30	836.35	26.60	4.00	33.50	5.20	38.56	53.55	31.21	0.58	0.31	6.45	6.82
11/8/2006	12:39 PM	26.36	38.55	38.41	35.99	50.45	835.13	26.30	3.90	33.50	5.20	38.47	53.40	30.99	0.58	0.15	5.85	7.50
11/8/2006	12:40 PM	26.31	38.61	38.52	35.51	49.98	838.74	26.30	4.00	33.40	5.40	38.51	53.13	30.95	0.61	0.04	6.31	7.32
11/8/2006	12:40 PM	26.36	38.60	38.48	35.12	49.37	835.60	25.80	4.40	33.50	5.30	38.49	53.33	30.68	0.59	0.03	8.01	8.42
11/8/2006	12:40 PM	26.37	38.59	38.52	35.54	49.35	836.64	26.00	4.40	33.40	5.30	38.49	53.45	30.80	0.60	0.09	8.31	7.76
11/8/2006	12:40 PM	26.30	38.69	38.55	35.82	48.85	837.04	26.50	4.30	33.40	5.20	38.61	53.37	31.18	0.58	0.17	9.26	6.64
11/8/2006	12:40 PM	26.35	38.68	38.52	35.80	49.18	833.58	26.10	3.60	33.60	5.20	38.59	53.38	30.89	0.58	0.20	8.54	8.05
11/8/2006	12:40 PM	26.34	38.93	38.55	35.52	49.65	834.13	26.20	3.80	33.50	5.30	38.82	53.32	31.03	0.59	0.70	7.39	7.38
11/8/2006	12:40 PM	26.33	38.35	38.43	35.94	49.24	835.21	26.20	3.90	33.40	5.30	38.27	53.32	30.82	0.60	0.41	8.29	7.72
11/8/2006	12:40 PM	26.24	38.40	38.50	35.36	49.71	834.98	25.60	4.20	33.50	5.40	38.29	53.41	30.44	0.61	0.53	7.45	9.13
11/8/2006	12:40 PM	26.30	38.41	38.47	35.38	49.46	833.60	25.90	3.60	33.20	5.40	38.31	53.09	30.61	0.61	0.40	7.32	7.81
11/8/2006	12:41 PM	26.33	38.42	38.49	35.79	49.14	833.34	26.10	4.10	33.20	5.40	38.33	53.36	30.76	0.61	0.42	8.60	7.35
11/8/2006	12:41 PM	26.34	38.57	38.38	36.05	49.89	833.34	26.20	4.20	33.40	5.30	38.48	53.58	30.91	0.59	0.25	7.38	7.44
11/8/2006	12:41 PM	26.27	38.74	38.42	36.04	50.27	834.47	26.40	4.30	33.40	5.20	38.65	53.58	31.14	0.58	0.60	6.59	6.77
11/8/2006	12:41 PM	26.25	38.59	38.48	35.85	50.23	830.88	26.50	4.60	33.50	5.30	38.50	53.38	31.12	0.59	0.03	6.26	7.10
11/8/2006	12:41 PM	26.30	38.68	38.21	35.37	48.77	828.94	26.40	3.90	33.50	5.30	38.58	53.02	31.07	0.59	0.99	8.73	7.27
11/8/2006	12:41 PM	26.33	38.74	38.13	35.86	49.68	828.61	26.10	3.90	33.40	5.40	38.63	53.50	30.87	0.61	1.31	7.68	7.58
11/8/2006	12:41 PM	26.34	38.17	38.24	35.73	49.61	829.99	26.40	3.90	33.40	5.30	38.10	53.00	30.88	0.59	0.38	6.84	7.55
11/8/2006	12:42 PM	26.32	38.10	38.22	35.60	49.94	826.75	26.30	3.80	33.60	5.30	38.03	52.93	30.79	0.58	0.80	8.00	8.37

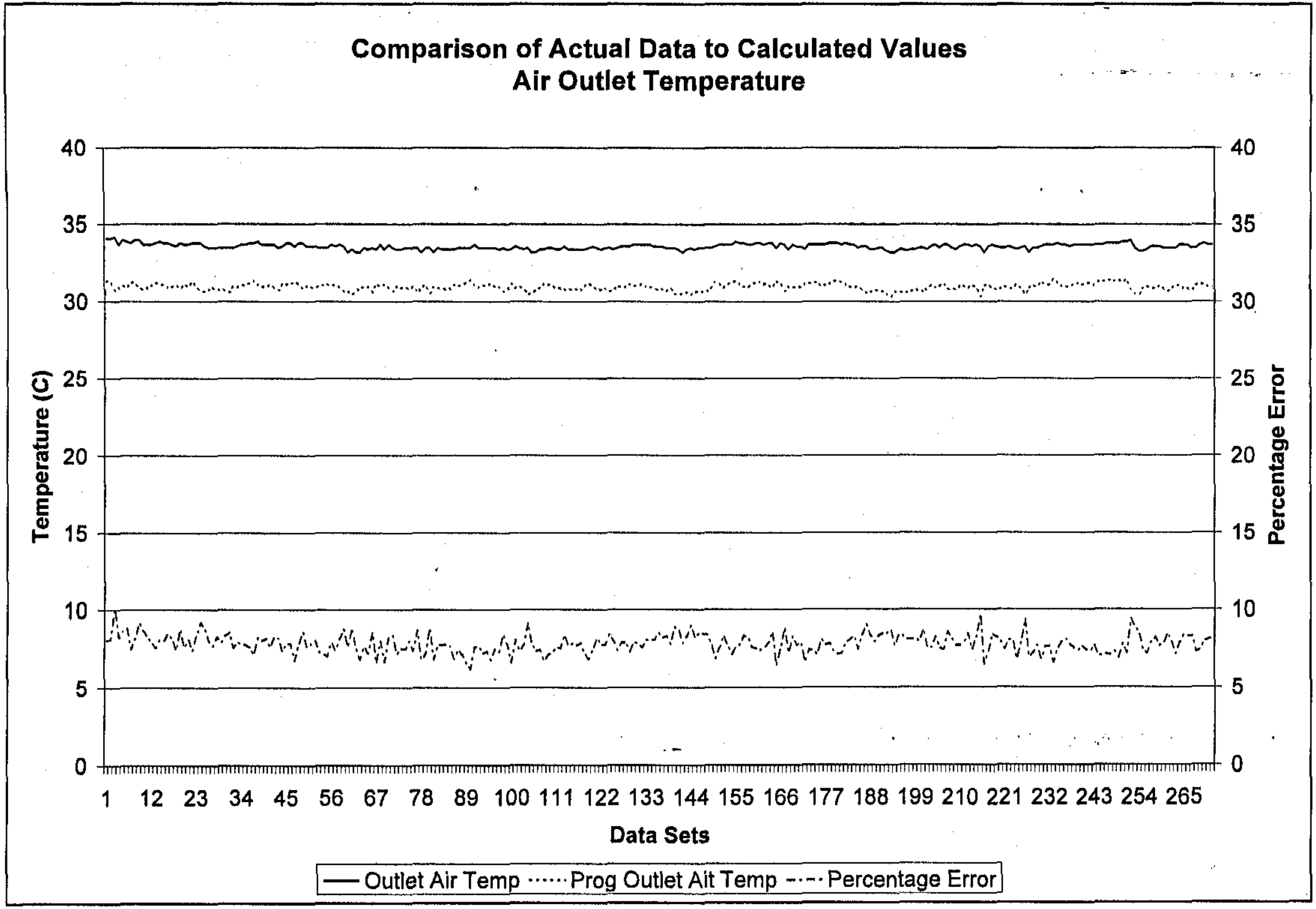
Date	Time	WaterFlow Rate	WaterTemp Bottom	WaterTemp Top	RelHumidity Bottom	RelHumidity Top	Solar Radiation	AirTemp Bottom	WndSpeed Bottom	AirTemp Top	WindSpeed Top	ProgWater TempTop	ProgHumidity Top	ProgAir TempTop	MassFlow Rate Air	Water Temp%	Humidity %	Air Temp%
11/8/2006	12:42 PM	26.35	38.46	38.38	35.85	49.59	828.21	26.10	4.20	33.40	5.40	38.36	53.44	30.78	0.61	0.05	7.78	7.85
11/8/2006	12:42 PM	26.34	38.69	38.28	36.03	50.78	828.69	26.10	4.20	33.40	5.40	38.48	53.61	30.83	0.61	0.53	5.59	7.71
11/8/2006	12:42 PM	26.33	38.50	38.30	36.06	50.34	824.00	26.00	3.90	33.40	5.20	38.42	53.60	30.78	0.58	0.31	6.47	7.85
11/8/2006	12:42 PM	26.35	38.53	38.22	36.08	50.34	823.48	26.40	4.10	33.40	5.30	38.44	53.44	31.02	0.59	0.57	6.17	7.13
11/8/2006	12:42 PM	26.37	38.49	38.39	35.95	49.67	824.55	26.70	4.20	33.50	5.30	38.41	53.20	31.20	0.59	0.04	7.12	6.87
11/8/2006	12:42 PM	26.40	38.49	38.31	35.83	49.54	827.87	26.50	4.20	33.60	5.30	38.40	53.24	31.07	0.59	0.25	7.49	7.52
11/8/2006	12:42 PM	26.37	38.42	38.30	35.97	49.17	821.29	26.10	4.20	33.50	5.40	38.32	53.50	30.76	0.61	0.04	8.81	8.17
11/8/2006	12:43 PM	26.32	38.41	38.29	35.97	49.69	819.91	26.20	4.00	33.40	5.40	38.31	53.39	30.81	0.61	0.06	7.44	7.74
11/8/2006	12:43 PM	26.33	38.41	38.26	34.54	48.77	821.90	26.30	4.30	33.50	5.40	38.31	52.56	30.89	0.61	0.13	7.77	7.79
11/8/2006	12:43 PM	26.34	38.37	38.17	34.13	48.47	819.31	26.00	4.30	33.50	5.40	38.25	52.47	30.68	0.61	0.22	8.25	8.41
11/8/2006	12:43 PM	26.32	38.26	38.31	34.17	48.93	819.15	26.10	4.20	33.40	5.30	38.16	52.37	30.73	0.60	0.38	7.03	7.99
11/8/2006	12:43 PM	26.30	38.27	38.42	34.03	48.75	818.63	26.50	4.10	33.50	5.20	38.19	52.06	31.02	0.58	0.58	6.79	7.42
11/8/2006	12:43 PM	26.34	38.25	38.43	34.18	49.73	818.42	26.50	4.10	33.60	5.40	38.15	52.10	30.95	0.61	0.72	4.77	7.88
11/8/2006	12:43 PM	26.37	38.25	38.43	34.04	49.09	817.30	26.40	4.30	33.60	5.20	38.17	52.18	30.95	0.58	0.67	6.28	7.88
11/8/2006	12:43 PM	26.36	38.51	38.46	34.16	49.48	816.73	26.60	4.20	33.60	5.30	38.41	52.21	31.14	0.59	0.12	5.52	7.32
11/8/2006	12:43 PM	26.35	38.21	38.08	34.28	49.05	814.43	26.60	4.30	33.70	5.30	38.12	52.16	31.03	0.59	0.12	6.34	7.91
11/8/2006	12:44 PM	26.32	38.29	38.11	34.06	48.32	814.05	26.60	4.40	33.70	5.30	38.20	52.10	31.07	0.59	0.23	7.82	7.81
11/8/2006	12:44 PM	26.27	38.44	38.17	34.21	49.12	812.07	26.60	4.30	33.70	5.20	38.35	52.25	31.15	0.58	0.47	6.38	7.56
11/8/2006	12:44 PM	26.24	38.35	38.00	34.40	49.68	813.60	26.50	4.20	33.70	5.40	38.24	52.30	30.99	0.61	0.64	5.28	8.05
11/8/2006	12:44 PM	26.30	38.37	38.09	34.47	50.25	815.00	26.40	4.60	33.70	5.30	38.27	52.55	30.98	0.59	0.47	4.59	8.07
11/8/2006	12:44 PM	26.32	38.58	38.15	34.23	49.35	812.58	26.20	4.40	33.60	5.40	38.46	52.55	30.89	0.61	0.81	6.48	8.06
11/8/2006	12:44 PM	26.39	38.19	38.08	34.64	49.49	815.05	26.20	4.30	33.60	5.40	38.09	52.57	30.74	0.61	0.01	6.23	8.50
11/8/2006	12:44 PM	26.42	38.20	38.13	34.29	50.05	814.10	26.30	4.40	33.60	5.30	38.11	52.36	30.85	0.59	0.07	4.62	8.20
11/8/2006	12:44 PM	26.40	38.20	38.10	34.50	48.87	811.19	26.10	4.40	33.50	5.30	38.10	52.60	30.71	0.59	0.01	7.63	8.31
11/8/2006	12:44 PM	26.40	38.41	38.08	34.49	48.92	812.41	26.30	4.20	33.50	5.40	38.30	52.51	30.88	0.61	0.57	7.33	7.82
11/8/2006	12:45 PM	26.34	38.19	38.13	34.39	49.70	814.02	25.90	4.20	33.50	5.50	38.08	52.55	30.52	0.62	0.15	5.74	8.89
11/8/2006	12:45 PM	26.33	38.21	38.04	34.49	49.11	807.73	25.80	4.00	33.40	5.40	38.09	52.65	30.48	0.61	0.14	7.21	8.74
11/8/2006	12:45 PM	26.35	38.24	38.24	34.47	48.66	808.25	25.90	4.10	33.20	5.30	38.14	52.64	30.59	0.60	0.26	8.18	7.86
11/8/2006	12:45 PM	26.37	38.24	38.54	34.63	48.59	808.58	26.00	4.20	33.40	5.40	38.12	52.68	30.63	0.61	1.09	8.43	8.31
11/8/2006	12:45 PM	26.36	38.19	38.15	34.68	49.68	808.02	25.80	4.40	33.50	5.40	38.07	52.86	30.49	0.61	0.21	6.41	8.99
11/8/2006	12:45 PM	26.37	38.06	38.28	34.79	49.43	808.99	26.10	4.30	33.40	5.30	37.97	52.69	30.66	0.60	0.82	6.59	8.20
11/8/2006	12:45 PM	26.37	38.12	38.12	34.89	49.31	807.48	26.10	4.30	33.50	5.40	38.01	52.75	30.65	0.61	0.29	6.99	8.51
11/8/2006	12:45 PM	26.37	38.07	38.13	34.76	49.24	808.16	26.10	4.20	33.50	5.30	37.98	52.64	30.66	0.59	0.39	6.90	8.48
11/8/2006	12:45 PM	26.33	38.09	38.21	34.37	48.78	809.47	26.20	3.90	33.50	5.40	38.00	52.26	30.69	0.61	0.55	7.14	8.38
11/8/2006	12:46 PM	26.35	38.16	38.16	34.30	48.35	807.60	26.50	3.70	33.50	5.40	38.06	52.02	30.90	0.61	0.27	7.59	7.77
11/8/2006	12:46 PM	26.36	38.19	38.02	34.25	48.60	805.72	27.00	3.70	33.60	5.20	38.12	51.77	31.28	0.58	0.25	6.53	6.90
11/8/2006	12:46 PM	26.37	38.25	37.97	33.77	49.76	804.66	26.80	4.10	33.70	5.30	38.16	51.71	31.17	0.59	0.50	3.91	7.52
11/8/2006	12:46 PM	26.36	38.11	37.95	33.75	49.37	802.30	26.50	4.20	33.70	5.40	38.00	51.81	30.90	0.61	0.14	4.95	8.31
11/8/2006	12:46 PM	26.29	38.08	37.95	33.40	49.30	800.29	26.80	4.40	33.70	5.30	37.99	51.50	31.11	0.59	0.11	4.47	7.68
11/8/2006	12:46 PM	26.29	38.25	38.05	33.34	49.49	803.05	27.00	4.00	33.70	5.30	38.16	51.31	31.29	0.59	0.28	3.69	7.16
11/8/2006	12:46 PM	26.34	38.34	38.26	32.98	49.23	803.65	27.00	3.90	33.90	5.20	38.26	51.14	31.35	0.58	0.01	3.87	7.53
11/8/2006	12:46 PM	26.37	37.93	38.05	32.56	49.25	802.52	27.00	3.20	33.80	5.20	37.87	50.48	31.17	0.58	0.46	2.51	7.76
11/8/2006	12:46 PM	26.37	38.00	38.15	32.58	48.69	796.76	26.70	4.40	33.80	5.40	37.89	51.00	30.99	0.61	0.66	4.73	8.31
11/8/2006	12:47 PM	26.37	37.88	38.00	32.48	48.62	798.48	26.70	4.00	33.70	5.40	37.79	50.76	30.93	0.61	0.55	4.40	8.21
11/8/2006	12:47 PM	26.40	37.96	37.94	32.96	48.27	800.59	26.90	4.00	33.70	5.20	37.88	51.03	31.14	0.58	0.14	5.71	7.58
11/8/2006	12:47 PM	26.38	37.89	38.14	32.88	49.30	800.00	27.20	4.20	33.80	5.40	37.81	50.79	31.27	0.61	0.85	3.02	7.49
11/8/2006	12:47 PM	26.30	38.35	38.20	32.68	48.98	801.45	27.00	4.10	33.80	5.40	38.25	50.97	31.30	0.61	0.12	4.05	7.39
11/8/2006	12:47 PM	26.32	38.13	38.04	32.36	49.21	797.49	26.90	4.20	33.70	5.40	38.03	50.76	31.16	0.61	0.03	3.14	7.53
11/8/2006	12:47 PM	26.33	37.94	38.04	32.39	49.48	798.90	27.00	4.20	33.80	5.40	37.85	50.63	31.16	0.61	0.50	2.32	7.82
11/8/2006	12:47 PM	26.41	38.33	37.89	32.27	48.63	798.24	26.40	4.00	33.80	5.40	38.21	51.03	30.91	0.61	0.84	4.95	8.56
11/8/2006	12:47 PM	26.29	38.45	38.17	32.86	49.07	797.64	27.00	4.10	33.50	5.40	38.33	51.12	31.33	0.61	0.44	4.17	6.47
11/8/2006	12:48 PM	26.30	38.51	38.03	32.88	49.70	798.56	26.80	4.20	33.80	5.30	38.40	51.33	31.26	0.59	0.97	3.29	7.50
11/8/2006	12:48 PM	26.31	38.14	37.98	32.30	48.62	799.67	26.20	4.40	33.70	5.40	38.02	51.19	30.73	0.61	0.11	5.30	8.82
11/8/2006	12:48 PM	26.38	38.03	37.92	33.00	48.11	801.77	26.70	4.00	33.40	5.40	37.93	51.14	30.99	0.61	0.02	6.31	7.23
11/8/2006	12:48 PM	26.35	38.06	38.25	32.55	49.11	797.21	26.50	3.80	33.70	5.20	37.97	51.00	30.92	0.58	0.73	3.85	8.25
11/8/2006	12:48 PM	26.37	37.98	38.06	32.68	49.56	797.39	26.70	4.40	33.60	5.30	37.89	51.07	31.01	0.59	0.46	3.04	7.70
11/8/2006	12:48 PM	26.38	38.03	38.06	32.53	49.21	795.34	26.60	4.20	33.60	5.30	37.93	51.01	30.96	0.59	0.34	3.65	7.86

Date	Time	WaterFlow Rate	WaterTemp Bottom	WaterTemp Top	RelHumidity Bottom	RelHumidity Top	Solar Radiation	AirTemp Bottom	WndSpeed Bottom	AirTemp Top	WindSpeed Top	ProgWater TempTop	ProgHumidity Top	ProgAir TempTop	MassFlow Rate Air	Water Temp%	Humidity %	Air Temp%
11/8/2006	12:48 PM	26.30	38.29	37.93	32.76	48.97	796.76	26.80	4.00	33.40	5.30	38.19	51.09	31.17	0.60	0.69	4.34	6.67
11/8/2006	12:49 PM	26.31	38.20	37.94	32.87	49.19	797.57	26.90	3.90	33.70	5.30	38.10	51.03	31.20	0.59	0.43	3.76	7.42
11/8/2006	12:49 PM	26.35	38.10	38.01	33.27	49.92	795.07	27.00	4.20	33.70	5.40	38.00	51.24	31.21	0.61	0.02	2.65	7.38
11/8/2006	12:49 PM	26.33	37.90	38.04	33.10	49.41	793.96	27.20	3.70	33.70	5.20	37.83	50.84	31.30	0.56	0.53	2.90	7.12
11/8/2006	12:49 PM	26.34	37.83	37.94	34.19	48.98	792.67	26.70	4.40	33.70	5.20	37.76	51.95	30.98	0.56	0.47	6.07	8.05
11/8/2006	12:49 PM	26.29	38.10	38.01	34.23	49.39	794.67	26.80	4.60	33.70	5.40	37.99	52.04	31.10	0.61	0.03	5.36	7.72
11/8/2006	12:49 PM	26.28	37.63	37.97	34.03	49.41	795.87	27.00	4.60	33.80	5.30	37.75	51.72	31.16	0.59	0.58	4.66	7.82
11/8/2006	12:49 PM	26.27	38.23	38.01	33.84	49.17	794.04	27.00	4.30	33.80	5.20	38.14	51.72	31.32	0.58	0.34	5.19	7.35
11/8/2006	12:49 PM	26.25	38.51	37.92	34.13	49.33	795.00	27.00	4.10	33.80	5.30	38.40	51.94	31.38	0.59	1.28	5.30	7.15
11/8/2006	12:49 PM	26.29	38.35	38.03	34.16	49.62	795.69	26.90	4.30	33.70	5.30	38.25	52.00	31.27	0.59	0.59	4.79	7.21
11/8/2006	12:50 PM	26.36	38.21	37.99	33.51	49.26	793.47	26.80	3.80	33.80	5.30	38.12	51.46	31.14	0.59	0.35	4.47	7.68
11/8/2006	12:50 PM	26.38	38.18	37.94	32.70	48.54	791.53	26.60	3.50	33.70	5.30	38.08	50.98	30.99	0.59	0.37	5.03	8.06
11/8/2006	12:50 PM	26.30	37.94	37.91	31.98	48.79	791.68	26.60	4.50	33.70	5.40	37.83	50.69	30.91	0.61	0.20	3.90	8.28
11/8/2006	12:50 PM	26.30	37.88	37.97	31.94	47.77	790.87	26.80	4.30	33.50	5.40	37.78	50.46	31.01	0.61	0.51	5.63	7.45
11/8/2006	12:50 PM	26.37	37.92	38.05	31.96	47.58	793.64	26.40	4.60	33.60	5.40	37.80	50.81	30.78	0.61	0.64	6.79	8.40
11/8/2006	12:50 PM	26.37	38.05	38.00	32.73	47.72	792.88	26.00	4.50	33.60	5.40	37.93	51.55	30.57	0.61	0.18	8.03	9.03
11/8/2006	12:50 PM	26.35	38.06	37.96	33.23	48.00	794.04	26.10	4.30	33.40	5.40	37.94	51.73	30.62	0.61	0.05	7.78	8.31
11/8/2006	12:50 PM	26.35	37.98	37.89	33.47	48.06	793.99	26.30	4.20	33.40	5.30	37.88	51.72	30.75	0.60	0.02	7.61	7.94
11/8/2006	12:50 PM	26.33	38.13	37.88	33.51	47.99	793.25	26.20	3.80	33.50	5.30	38.02	51.76	30.72	0.60	0.37	7.87	8.29
11/8/2006	12:51 PM	26.35	38.43	37.82	33.66	49.31	792.64	25.90	4.20	33.50	5.30	38.30	52.29	30.66	0.59	1.26	6.05	8.48
11/8/2006	12:51 PM	26.32	38.17	37.85	33.95	49.03	794.29	25.80	4.50	33.30	5.40	38.04	52.46	30.48	0.61	0.51	6.99	8.46
11/8/2006	12:51 PM	26.36	37.73	37.83	33.86	48.92	795.12	25.80	4.40	33.20	5.40	37.62	52.15	30.32	0.61	0.54	6.61	8.68
11/8/2006	12:51 PM	26.32	38.15	37.89	34.02	49.13	796.57	26.10	4.10	33.20	5.40	38.03	52.19	30.65	0.61	0.37	6.24	7.68
11/8/2006	12:51 PM	26.32	38.10	38.25	33.80	49.65	799.19	26.00	4.20	33.40	5.30	37.99	52.15	30.60	0.59	0.66	5.03	8.37
11/8/2006	12:51 PM	26.34	38.08	37.88	33.92	50.02	797.26	26.00	4.30	33.40	5.20	37.98	52.27	30.63	0.58	0.28	4.50	8.29
11/8/2006	12:51 PM	26.34	38.17	37.84	34.02	49.23	799.78	26.00	4.40	33.30	5.40	38.05	52.35	30.61	0.61	0.57	6.33	8.09
11/8/2006	12:51 PM	26.28	38.10	37.42	33.92	48.62	798.53	26.20	4.20	33.40	5.40	37.99	52.08	30.70	0.61	1.51	7.13	8.08
11/8/2006	12:51 PM	26.28	38.04	37.70	33.94	49.04	798.95	26.20	4.30	33.40	5.40	37.93	52.09	30.68	0.61	0.62	6.21	8.13
11/8/2006	12:52 PM	26.30	38.01	37.78	34.16	49.23	800.54	26.40	4.60	33.50	5.30	37.91	52.20	30.84	0.59	0.37	6.03	7.94
11/8/2006	12:52 PM	26.29	37.93	37.68	33.74	49.51	799.34	26.10	4.50	33.50	5.40	37.82	52.03	30.59	0.61	0.38	5.08	8.69
11/8/2006	12:52 PM	26.31	37.90	37.90	33.74	50.18	801.91	26.60	4.20	33.40	5.40	37.81	51.65	30.89	0.61	0.24	2.94	7.52
11/8/2006	12:52 PM	26.33	37.96	37.92	33.34	48.38	802.31	26.80	4.10	33.60	5.30	37.88	51.31	31.06	0.59	0.12	6.06	7.57
11/8/2006	12:52 PM	26.29	37.87	37.93	32.72	48.82	801.29	26.60	4.10	33.70	5.20	37.79	51.04	30.93	0.58	0.36	4.54	8.23
11/8/2006	12:52 PM	26.27	37.94	37.83	32.43	48.60	802.95	26.70	3.90	33.50	5.30	37.85	50.75	30.98	0.59	0.05	4.42	7.53
11/8/2006	12:52 PM	26.25	37.95	37.85	31.77	48.21	806.37	27.00	3.80	33.70	5.20	37.88	50.18	31.20	0.58	0.08	4.10	7.42
11/8/2006	12:52 PM	26.26	37.98	37.89	31.52	48.50	805.02	26.40	4.30	33.70	5.30	37.88	50.51	30.82	0.59	0.02	4.15	8.54
11/8/2006	12:52 PM	26.27	37.93	37.76	30.86	48.13	806.46	26.40	4.70	33.50	5.40	37.82	50.18	30.79	0.61	0.16	4.27	8.09
11/8/2006	12:53 PM	26.27	37.85	37.72	31.19	48.13	807.82	26.60	3.90	33.40	5.50	37.75	49.95	30.83	0.62	0.08	3.80	7.69
11/8/2006	12:53 PM	26.34	37.86	37.68	31.41	48.29	807.23	26.80	3.90	33.60	5.30	37.78	50.03	31.02	0.59	0.27	3.62	7.69
11/8/2006	12:53 PM	26.33	37.91	37.91	31.64	48.84	807.86	26.80	4.00	33.70	5.30	37.83	50.23	31.04	0.59	0.21	2.85	7.69
11/8/2006	12:53 PM	26.30	37.77	37.94	31.66	48.51	812.11	26.60	3.90	33.70	5.30	37.70	50.26	30.86	0.59	0.62	3.62	8.43
11/8/2006	12:53 PM	26.29	37.81	37.81	32.19	48.38	809.60	27.00	4.00	33.60	5.40	37.73	50.37	31.10	0.61	0.21	4.11	7.43
11/8/2006	12:53 PM	26.27	37.84	37.85	31.07	49.08	811.66	26.70	4.10	33.70	5.40	37.75	49.91	30.93	0.61	0.26	1.69	8.22
11/8/2006	12:53 PM	26.30	37.84	37.83	30.93	47.86	812.07	25.80	3.90	33.60	5.40	37.74	50.31	30.35	0.61	0.24	5.14	9.68
11/8/2006	12:53 PM	26.33	37.91	37.81	31.63	48.12	810.37	26.80	3.90	33.20	5.30	37.83	50.19	31.03	0.60	0.06	4.30	6.53
11/8/2006	12:53 PM	26.33	37.80	37.76	31.45	48.71	816.90	27.00	4.20	33.60	5.30	37.74	50.00	31.14	0.59	0.06	2.65	7.33
11/8/2006	12:54 PM	26.26	37.73	37.81	31.38	48.47	813.14	26.60	4.20	33.70	5.30	37.66	50.16	30.86	0.59	0.41	3.49	8.43
11/8/2006	12:54 PM	26.29	37.76	37.72	31.60	47.86	813.56	26.50	4.30	33.60	5.20	37.69	50.42	30.84	0.58	0.08	5.34	8.23
11/8/2006	12:54 PM	26.32	37.89	37.73	31.94	47.26	815.52	26.50	4.30	33.50	5.30	37.81	50.66	30.86	0.60	0.23	7.20	7.90
11/8/2006	12:54 PM	26.34	37.87	37.79	32.03	48.30	815.39	26.70	4.20	33.50	5.20	37.80	50.58	31.00	0.58	0.03	4.73	7.47
11/8/2006	12:54 PM	26.32	37.93	37.84	31.74	48.22	815.39	26.60	4.20	33.60	5.40	37.84	50.44	30.90	0.61	0.01	4.61	8.03
11/8/2006	12:54 PM	26.33	38.03	37.70	31.53	48.11	816.45	26.40	4.30	33.50	5.40	37.93	50.51	30.81	0.61	0.62	4.98	8.02
11/8/2006	12:54 PM	26.28	37.84	37.71	31.75	47.96	816.47	27.00	4.10	33.40	5.40	37.76	50.14	31.12	0.61	0.15	4.54	6.83
11/8/2006	12:54 PM	26.30	37.91	37.72	32.15	48.65	819.26	26.60	3.60	33.50	5.40	37.83	50.51	30.87	0.61	0.29	3.83	7.84
11/8/2006	12:54 PM	26.30	37.82	37.77	31.77	48.55	817.74	26.00	4.20	33.60	5.50	37.72	50.74	30.45	0.62	0.14	4.51	9.36
11/8/2006	12:55 PM	26.28	37.73	37.73	32.05	48.63	818.87	26.70	4.10	33.20	5.40	37.66	50.44	30.89	0.61	0.20	3.72	6.96
11/8/2006	12:55 PM	26.29	37.89	37.77	32.12	48.37	820.35	26.60	4.30	33.50	5.20	37.83	50.62	31.07	0.58	0.15	4.67	7.24

Date	Time	WaterFlow Rate	WaterTemp Bottom	WaterTemp Top	RelHumidity Bottom	RelHumidity Top	Solar Radiation	AirTemp Bottom	WndSpeed Bottom	AirTemp Top	WindSpeed Top	ProgWater TempTop	ProgHumidity Top	ProgAir TempTop	MassFlow Rate Air	Water Temp%	Humidity %	Air Temp%
11/8/2006	12:55 PM	26.30	37.82	37.64	32.87	47.89	823.52	26.70	4.20	33.50	5.40	37.76	51.01	30.93	0.61	0.31	6.52	7.67
11/8/2006	12:55 PM	26.24	37.81	37.70	32.50	48.84	820.40	27.20	4.20	33.60	5.20	37.76	50.57	31.30	0.58	0.16	3.54	6.86
11/8/2006	12:55 PM	26.26	37.63	37.61	32.39	48.50	821.97	27.00	3.90	33.70	5.30	37.77	50.50	31.14	0.59	0.41	4.13	7.60
11/8/2006	12:55 PM	26.30	37.75	37.76	32.59	48.68	824.67	27.00	4.30	33.70	5.30	37.69	50.70	31.13	0.59	0.18	3.71	7.64
11/8/2006	12:55 PM	26.29	37.82	37.81	32.53	48.71	825.05	27.50	4.10	33.70	5.30	37.77	50.37	31.46	0.59	0.09	3.41	6.64
11/8/2006	12:56 PM	26.34	37.88	37.79	32.32	48.68	825.68	27.10	4.20	33.80	5.20	37.83	50.54	31.26	0.58	0.10	3.81	7.52
11/8/2006	12:56 PM	26.32	37.77	37.85	32.51	48.10	824.63	26.80	4.40	33.70	5.20	37.71	50.83	31.04	0.58	0.35	5.67	7.91
11/8/2006	12:56 PM	26.33	37.69	37.82	32.71	48.28	827.07	26.80	4.50	33.70	5.30	37.63	50.91	30.98	0.59	0.49	5.45	8.06
11/8/2006	12:56 PM	26.36	37.82	37.72	33.36	48.36	828.27	26.80	4.20	33.60	5.40	37.76	51.25	31.00	0.61	0.10	5.98	7.75
11/8/2006	12:56 PM	26.35	37.83	37.70	33.26	48.91	828.17	27.00	4.10	33.70	5.30	37.78	51.09	31.15	0.59	0.20	4.46	7.57
11/8/2006	12:56 PM	26.38	37.91	37.71	33.10	49.39	829.52	27.00	4.30	33.70	5.20	37.86	51.11	31.21	0.58	0.39	3.49	7.38
11/8/2006	12:56 PM	26.38	37.82	37.71	32.92	48.76	829.16	26.90	4.20	33.70	5.20	37.77	50.99	31.11	0.58	0.16	4.57	7.66
11/8/2006	12:56 PM	26.37	37.89	37.60	33.02	48.40	827.30	27.00	4.10	33.70	5.20	37.84	50.99	31.20	0.58	0.66	5.36	7.43
11/8/2006	12:56 PM	26.34	38.40	37.57	33.47	48.29	828.70	26.80	4.00	33.70	5.30	38.32	51.56	31.23	0.59	2.02	6.77	7.34
11/8/2006	12:57 PM	26.38	37.93	37.62	33.49	48.80	830.79	26.90	4.30	33.70	5.40	37.86	51.36	31.10	0.61	0.64	5.23	7.71
11/8/2006	12:57 PM	26.39	38.03	37.62	33.67	48.88	830.68	27.10	4.20	33.70	5.20	37.98	51.43	31.32	0.58	0.94	5.20	7.08
11/8/2006	12:57 PM	26.33	37.89	37.49	33.94	49.17	831.08	27.20	4.00	33.70	5.20	37.85	51.42	31.32	0.58	0.97	4.58	7.06
11/8/2006	12:57 PM	26.31	37.93	37.45	33.67	48.53	832.62	27.30	4.10	33.80	5.30	37.88	51.22	31.38	0.59	1.15	5.53	7.17
11/8/2006	12:57 PM	26.28	38.06	37.44	33.63	48.11	831.97	27.20	4.40	33.80	5.20	38.01	51.42	31.40	0.58	1.52	6.88	7.10
11/8/2006	12:57 PM	26.29	37.89	37.61	33.48	48.49	835.91	27.20	4.30	33.80	5.20	37.85	51.22	31.33	0.58	0.63	5.63	7.30
11/8/2006	12:57 PM	26.34	37.85	37.82	33.53	48.09	832.56	27.50	4.20	33.80	5.40	37.80	50.99	31.45	0.61	0.05	6.05	6.94
11/8/2006	12:57 PM	26.30	37.75	37.68	33.64	48.73	833.47	27.20	4.60	33.90	5.30	37.70	51.31	31.27	0.59	0.06	5.31	7.77
11/8/2006	12:57 PM	26.26	37.72	37.67	33.51	49.94	832.27	27.50	4.10	33.90	5.20	37.69	50.95	31.45	0.58	0.06	2.02	7.22
11/8/2006	12:58 PM	26.28	37.72	37.65	32.89	48.99	833.21	26.50	4.50	34.00	5.30	37.66	51.20	30.81	0.59	0.03	4.52	9.38
11/8/2006	12:58 PM	26.28	37.74	37.60	32.84	48.65	831.48	26.10	4.10	33.50	5.40	37.67	51.27	30.52	0.61	0.18	5.40	8.91
11/8/2006	12:58 PM	26.26	37.69	37.70	33.05	48.37	832.39	26.10	3.70	33.30	5.40	37.63	51.26	30.48	0.61	0.20	5.96	8.46
11/8/2006	12:58 PM	26.29	37.75	37.67	33.45	48.76	832.74	26.60	4.10	33.30	5.40	37.68	51.35	30.84	0.61	0.03	5.32	7.40
11/8/2006	12:58 PM	26.26	37.74	37.66	33.76	48.49	831.01	26.80	4.40	33.40	5.30	37.69	51.54	31.00	0.60	0.08	6.29	7.19
11/8/2006	12:58 PM	26.27	37.67	37.64	33.67	48.44	832.61	26.80	4.00	33.60	5.40	37.62	51.32	30.93	0.61	0.05	5.94	7.93
11/8/2006	12:58 PM	26.28	37.67	37.61	33.75	50.48	831.06	26.60	4.30	33.60	5.30	37.62	51.59	30.85	0.59	0.03	2.20	8.20
11/8/2006	12:58 PM	26.28	37.71	37.64	33.75	48.86	835.33	26.80	4.60	33.60	5.20	37.67	51.60	31.03	0.58	0.08	5.61	7.66
11/8/2006	12:58 PM	26.32	37.69	37.48	33.71	49.31	831.96	26.70	4.40	33.50	5.40	37.63	51.51	30.89	0.61	0.39	4.48	7.79
11/8/2006	12:59 PM	26.32	37.73	37.47	33.90	48.35	831.49	26.30	4.20	33.50	5.30	37.68	51.84	30.67	0.60	0.54	7.23	8.44
11/8/2006	12:59 PM	26.33	37.70	37.43	34.58	49.13	830.47	26.60	4.40	33.50	5.30	37.64	52.13	30.86	0.59	0.56	6.11	7.89
11/8/2006	12:59 PM	26.35	37.69	37.29	34.68	49.18	832.98	27.00	4.10	33.50	5.30	37.66	51.89	31.10	0.59	0.97	5.51	7.17
11/8/2006	12:59 PM	26.35	37.73	37.42	34.69	49.40	833.73	26.90	4.20	33.70	5.30	37.68	51.99	31.05	0.59	0.70	5.25	7.86
11/8/2006	12:59 PM	26.33	37.79	37.69	34.50	48.41	836.74	26.60	4.10	33.70	5.30	37.74	52.04	30.88	0.59	0.13	7.49	8.36
11/8/2006	12:59 PM	26.27	37.82	37.73	34.47	48.30	835.06	26.60	4.40	33.70	5.30	37.76	52.11	30.90	0.59	0.09	7.90	8.30
11/8/2006	12:59 PM	26.28	37.81	37.40	34.58	48.32	834.92	26.40	3.90	33.50	5.40	37.75	52.12	30.72	0.61	0.92	7.86	8.29
11/8/2006	12:59 PM	26.28	37.80	37.65	34.53	48.15	834.32	26.90	3.50	33.50	5.30	37.76	51.72	31.05	0.60	0.30	7.42	7.31
11/8/2006	12:59 PM	26.30	37.72	37.51	34.35	48.71	834.83	27.10	4.10	33.70	5.20	37.69	51.67	31.20	0.58	0.48	6.08	7.42
11/8/2006	01:00 PM	26.34	37.62	37.47	34.34	48.47	836.29	27.00	4.30	33.80	5.20	37.60	51.73	31.11	0.58	0.34	6.73	7.96
11/8/2006	01:00 PM	26.33	37.72	37.64	34.07	48.62	835.01	26.80	4.00	33.70	5.30	37.67	51.60	30.98	0.59	0.08	6.15	8.07
11/8/2006	01:00 PM	26.33	37.77	37.33	34.47	48.17	836.98	26.70	4.40	33.70	5.30	37.72	52.03	30.95	0.59	1.04	8.02	8.16


Comparision of Actual Data to Calculated Values
Water Inlet Temperature
Temperature (C)
40
38
35
33
30
28
25
23
20
Percentage Error
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
12
23
34
45
56
67
78
89
100
111
122
133
144
155
166
177
188
199
210
221
232
243
254
265
Data Sets
Water Inlet Temp
Prog Water Inlet Temp
Percentage Error


Comparison of Actual Data to Calculated Values
Outlet Relative Humidity
Relative Humidity (%)
0
10
20
30
40
50
60
Percentage Error
0
10
20
30
40
50
60
1
12
23
34
45
56
67
78
89
100
111
122
133
144
155
166
177
188
199
210
221
232
243
254
265
Data Sets
Outlet RH
Prog RH
Percentage Error


Comparison of Actual Data to Calculated Values
Air Outlet Temperature
Temperature (C)
Percentage Error
0
5
10
15
20
25
30
35
40
1
12
23
34
45
56
67
78
89
100
111
122
133
144
155
166
177
188
199
210
221
232
243
254
265
Data Sets
Outlet Air Temp
Prog Outlet Ait Temp
Percentage Error

APPENDIX C

Pilot Plant

Program Listing

(Font scaled to fit one page width)

General Information:

Water Properties:

Emisivity: $\varepsilon_w := 0.96$

Steel Properties (Painted Black):

Emisivity: $\varepsilon_s := 0.8$
Absorbtivity: $\alpha_s := 0.9$

Roughness: $k_s := 100 \cdot 10^{-7} m$

Glass Panel:

Absorbtiviy: $\alpha_g := 0.025$
Emisivity: $\varepsilon_g := 0.95$

Conductivity: $k_g := 1.25 \cdot W \cdot m^{-1} \cdot K^{-1}$
Thickness: $t_g := 0.005m$

Roughness: $k_{rg} := 10 \cdot 10^{-9} \cdot m$

Ambient:

Air Velocity: $u_{ao} := 0.1 \frac{m}{s}$

Air Pressure: $p_{atm} := 101325Pa$

Loop:

Accuracy: $\Omega := 0.000005$ or $A := 0.01\%$

Data Set: DATA := .\Output 11-8-2006 12-29 PM_50_F-S3.xl

EvaporatorDesign:

Slope: $S := 0.0036$

Width: $W_e := 1.8m$

Length: $L_e := 18m$

Total Solar Absorption Area: $A_{es} := W_e \cdot L_e$

Total Solar Interference Area: $A_s := L_e \cdot 0.025 \cdot 2m + L_e \cdot 0.05m + (W_e - 0.1m) \cdot 0.025m \cdot 2 + (W_e - 0.1m) \cdot 0.05m \cdot 11$

Total Glass Area: $A_g := A_{es} - A_s$

Absorption Area Ratio: $r_{Ai} := \frac{A_g}{A_{es}}$

Inlet Duct Cross-sectional Area: $A_{eid} := 0.2718m^2$

Exit Duct Cross-sectional Area: $A_{exd} := 0.2342m^2$

Avearage Depth of Water: $H_{sweavg} := 0.0175m$

Inner Height: $H_{ein} := 0.18m$

Average Height of Air: $H_{aeavg} := 0.18m - H_{sweavg}$

Average Cross-sectional Air Flow Area: $A_{ef} := H_{aeavg} \cdot W_e$

Inlet Duct Max to Avg Velocity Ratio: $r_{avgfi} := 0.434$

Inlet Duct Max to Avg Velocity Ratio: $r_{avgfx} := 0.427$

Salinaty of Pilot Plant Water: $Z := 0$ ***NOTE : Units is grams/kilogram.***

Pressure Inside: $p_{ae} := 101325Pa$

Wave Ratio: $\upsilon := 1.2$

Integration Section Length: $\Delta x := 1m$

Constants:

Air Property Constants:

Saturation Pressure

$C_1 := -5.8002206 \cdot 10^3$

$C_2 := 1.3914993$

$C_3 := -4.8640239 \cdot 10^{-2}$

$C_4 := 4.1764768 \cdot 10^{-5}$

$C_5 := -1.4452093 \cdot 10^{-8}$

$C_6 := 6.5459673$

Dewpoint Temperature

$C_7 := 6.54$

$C_8 := 14.526$

$C_9 := 0.7389$

$C_{10} := 0.09486$

$C_{11} := 0.4569$

Seawater Property Constants:

Conductivity

$T_{swcrit} := 647K$

$k_{swcrit} := 240 \cdot 10^{-3} \cdot W \cdot m^{-1} \cdot K^{-1}$

Density

$$b := \begin{pmatrix} \frac{3.972600}{4} & \frac{-0.084913}{2} & \frac{-0.005318}{2} \\ \frac{0.115079}{2} & 0.002695 & 0.000682 \\ \frac{0.000109}{2} & -0.000330 & -0.000011 \end{pmatrix}$$

Viscosity

$A_v := 1.37220$

$a_{1v} := -0.001015$

$a_{2v} := 0.000005$

$B_v := 0.000813$

$b_{1v} := 0.006102$

$b_{2v} := -0.000040$

$c_{1v} := 0.001550$

$c_{2v} := 0.0000093$

Genaral Constants:

Stafan-Boltzman Constant: $\sigma := 5.669 \cdot 10^{-8} \cdot W \cdot m^{-2} \cdot K^{-4}$

Universal Gas Constant: $R_o := 8314.41 \cdot J \cdot kg^{-1} \cdot K^{-1}$

	Water:	**Air:**
Specific Heat Capacity at Constant Pressure	$cp_w := 4187 \cdot J \cdot kg^{-1} \cdot K^{-1}$	$cp_a := 1005 \cdot J \cdot kg^{-1} \cdot K^{-1}$
Molecular Weight	$M_w := 18$	$M_a := 28.96$
Molecular Volume	$V_w := 18.8$	$V_a := 29$
Gas Constants	$R_w := \frac{R_o}{M_w}$	$R_a := \frac{R_o}{M_a}$

```
$M :=$
  $\Sigma \leftarrow 1$
  while $DATA_{\Sigma,2} > 0$
    $V_{swex} \leftarrow \frac{DATA_{\Sigma,2}}{3600} \cdot m^3 \cdot s^{-1}$
    $T_{swe_0} \leftarrow (DATA_{\Sigma,3} + 273.15) \cdot K$
    $RH_{e_0} \leftarrow DATA_{\Sigma,5} \cdot \%$
    $RH_{exact} \leftarrow DATA_{\Sigma,6} \%$
    $E_i \leftarrow DATA_{\Sigma,7} \cdot W \cdot m^{-2}$
    $E_e \leftarrow E_i \cdot r_{Ai}$
    $T_{ae_0} \leftarrow (DATA_{\Sigma,8} + 273.15) \cdot K$
    $T_{aexact} \leftarrow (DATA_{\Sigma,10} + 273.15) K$
    $u_{aeid} \leftarrow DATA_{\Sigma,9} \cdot m \cdot s^{-1}$
    $u_{aexd} \leftarrow DATA_{\Sigma,11} \cdot m \cdot s^{-1}$
    $E_g \leftarrow E_e \cdot \alpha_g$
    $T_{bbsky} \leftarrow T_{ae_0}$
    $U \leftarrow 0$
    $T_{swex_0} \leftarrow T_{swe_0}$
    $RH_{ex_0} \leftarrow (RH_{e_0} + 20) \cdot \%$
    $T_{aex_0} \leftarrow T_{ae_0}$
    $RH_{amb} \leftarrow RH_{e_0}$
    $LoopStop_U \leftarrow 100$
    while $LoopStop_U > \Omega$
      $N \leftarrow \frac{L_e}{\Delta x}$
      $Z_{ex} \leftarrow Z$
      $T_{go_0} \leftarrow T_{ae_0}$
      $T_{gi_0} \leftarrow T_{ae_0}$
      $m \leftarrow 0 \cdot kg \cdot s^{-1}$
```

```
      $m_{m_0}$
      $m_{da} \leftarrow$
        $\rho_{aei} \leftarrow$
          $p_{vei} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{ae_0}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{ae_0}}{K}\right) + C_4 \cdot \left(\frac{T_{ae_0}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{ae_0}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{ae_0}}{K}\right)$
            $p_{sei} \leftarrow (e^C) \cdot Pa$
            $RH_{e_0} \cdot p_{sei}$
          $v_{aei} \leftarrow \frac{0.287035 \cdot T_{ae_0}}{p_{ae} - p_{vei}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
          $r_{e_0} \leftarrow \frac{0.62198 \cdot p_{vei}}{p_{ae} - p_{vei}}$
          $\frac{1}{v_{aei}}$
        $\rho_{aex} \leftarrow$
          $p_{vex} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{aexact}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{aexact}}{K}\right) + C_4 \cdot \left(\frac{T_{aexact}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{aexact}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{aexact}}{K}\right)$
            $p_{sex} \leftarrow (e^C) \cdot Pa$
            $RH_{exact} \cdot p_{sex}$
          $v_{aex} \leftarrow \frac{0.287035 \cdot T_{aexact}}{p_{ae} - p_{vex}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m^3}{kg}$
          $r_{ex} \leftarrow \frac{0.62198 \cdot p_{vex}}{p_{ae} - p_{vex}}$
          $\frac{1}{v_{aex}}$
        $u_{ae_0} \leftarrow r_{avgfi} \cdot u_{aeid} \cdot \frac{A_{eid}}{A_{ef}}$
        $\rho_{aex} \cdot (u_{aexd} \cdot r_{avgfx}) \cdot A_{exd}$
      $m_{swe_0} \leftarrow$
        $r_{ex} \leftarrow$
          $p_{vex} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{aex_U}}{K}\right)} + C_2 + C_3 \cdot \left(\frac{T_{aex_U}}{K}\right) + C_4 \cdot \left(\frac{T_{aex_U}}{K}\right)^2 + C_5 \cdot \left(\frac{T_{aex_U}}{K}\right)^3 + C_6 \cdot \ln\left(\frac{T_{aex_U}}{K}\right)$
            $p_{sex} \leftarrow (e^C) \cdot Pa$
            $RH_{ex_U} \cdot p_{sex}$
          $0.287035 \cdot T$
```

```
            $v_{aex} \leftarrow \frac{T_{aex_U}}{p_{ae} - p_{vex}} \cdot \frac{1000 \cdot Pa}{K} \cdot \frac{m}{kg}$
            $\frac{0.62198 \cdot p_{ae}}{p_{ae} - p_{vex}}$
        $m_{swex} \leftarrow$
            $\rho_{swex} \leftarrow$ for $\iota \in 0..2$
                $x_\iota \leftarrow \frac{2 \cdot Z_{ex} - 150}{150}$
                $T_{\iota_0} \leftarrow 1$
                $T_{\iota_1} \leftarrow x_\iota$
                $T_{\iota_2} \leftarrow 2 \cdot {x_\iota}^2 - 1$
                for $\varepsilon \in 0..2$
                    $x_\varepsilon \leftarrow \left(\frac{2 \cdot \frac{T_{swex_U}}{K} - 250}{110}\right)$
                    $T_{\varepsilon_0} \leftarrow 1$
                    $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                    $T_{\varepsilon_2} \leftarrow 2 \cdot {x_\varepsilon}^2 - 1$
                $10^3 \cdot kg \cdot m^{-3} \cdot \sum_{\iota=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\iota,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\iota_\iota}\right)$
            $\rho_{swex} \cdot V_{swex}$
        $m_{swex} - m_{da} \cdot (r_{ex} - r_{e_0})$
    $\Delta Q_{ae_0} \leftarrow 0 \cdot W$
    $\Delta Q_{swe_0} \leftarrow 0 \cdot W$
    $Q_{e_0} \leftarrow 0 \cdot W$
    $Re_0 \leftarrow 0$
    $Z_{e_0} \leftarrow$
        $m_{se} \leftarrow \frac{Z_{ex} \cdot m_{swex}}{1000}$
        $m_{swe_0} \leftarrow m_{swex} - m_{da} \cdot (r_{ex} - r_{e_0})$
        $\frac{1000 \cdot m_{se}}{m_{swe_0}}$
```

```
    $u_{swe} \leftarrow$
        $\mu_{swei} \leftarrow$
            $\mu_{20} \leftarrow 1.002 + c_{1v} \cdot Z_{e_0} + c_{2v} \cdot (Z_{e_0})^2$
            $\chi \leftarrow$
                $T_{sweC} \leftarrow \frac{T_{swe_0} - 273.15 \cdot K}{K}$
                $\chi_1 \leftarrow A_v \cdot \left[1 + a_{1v} \cdot Z_{e_0} + a_{2v} \cdot (Z_{e_0})^2\right]$
                $\chi_2 \leftarrow B_v \cdot \left[1 + b_{1v} \cdot Z_{e_0} + b_{2v} \cdot (Z_{e_0})^2\right]$
                $\left(\frac{T_{sweC} - 20}{T_{sweC} + 109}\right) \cdot \left[\chi_1 + \chi_2 \cdot (T_{sweC} - 20)\right]$
            $\frac{\mu_{20}}{10^\chi} \cdot 10^{-3} \cdot kg \cdot m^{-1} \cdot s^{-1}$
        $\rho_{swei} \leftarrow$ for $\iota \in 0..2$
            $x_\iota \leftarrow \frac{2 \cdot Z_{e_0} - 150}{150}$
            $T_{\iota_0} \leftarrow 1$
            $T_{\iota_1} \leftarrow x_\iota$
            $T_{\iota_2} \leftarrow 2 \cdot {x_\iota}^2 - 1$
            for $\varepsilon \in 0..2$
                $x_\varepsilon \leftarrow \left(\frac{2 \cdot T_{sweC} - 250}{110}\right)$
                $T_{\varepsilon_0} \leftarrow 1$
                $T_{\varepsilon_1} \leftarrow x_\varepsilon$
                $T_{\varepsilon_2} \leftarrow 2 \cdot {x_\varepsilon}^2 - 1$
            $10^3 \cdot kg \cdot m^{-3} \cdot \sum_{\iota=0}^{2} \sum_{\varepsilon=0}^{2} \left(b_{\iota,\varepsilon} \cdot T_{\varepsilon_\varepsilon} \cdot T_{\iota_\iota}\right)$
        $R \leftarrow \frac{W_c \cdot H_{sweavg}}{W_c + 2 \cdot H_{sweavg}}$
        $-(32 \cdot g \cdot R \cdot S)^{\frac{1}{2}} \cdot \left[\log\left[\frac{k_s}{14.8 \cdot R} + \frac{1.255 \cdot \mu_{swei}}{\rho_{swei} \cdot R \cdot (32 \cdot g \cdot R \cdot S)^{\frac{1}{2}}}\right]\right]$
    $n \leftarrow 0$
```

```
while $n < N$
  $x_i \leftarrow (n + 0.5)\cdot\Delta x$
  $x_x \leftarrow L_e - x_i$
  $T_{go_{n+1}} \leftarrow$
    $i \leftarrow 0$
    $T_{goLoop_0} \leftarrow T_{go_n}$
    $LoopStop_i \leftarrow 1$
    while $LoopStop_i > A \wedge i < 2000$
      $Q_{ro} \leftarrow \sigma\cdot\Delta x\cdot\varepsilon_g W_e\left[{T_{bbsky}}^4 - \left(T_{goLoop_i}\right)^4\right]$
      $Q_{co} \leftarrow$
        $hx_{co} \leftarrow$
          $T_{fco} \leftarrow \frac{T_{goLoop_i} + T_{ae_0}}{2}$
          $\rho_{fco} \leftarrow$
            $p_{vfco} \leftarrow$
              $C \leftarrow \frac{C_1}{\left(\frac{T_{fco}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{fco}}{K}\right) + C_4\cdot\left(\frac{T_{fco}}{K}\right)^2 + C_5\cdot\left(\frac{T_{fco}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{fco}}{K}\right)$
              $p_{sfco} \leftarrow \left(e^C\right)\cdot Pa$
              $RH_{amb}\cdot p_{sfco}$
            $v_{afco} \leftarrow \frac{0.287035\cdot T_{fco}}{p_{atm} - p_{vfco}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
            $r_{fco} \leftarrow \frac{0.62198\cdot p_{vfco}}{p_{atm} - p_{vfco}}$
            $\frac{1 + r_{fco}}{v_{afco}}$
          $k_{fco} \leftarrow$
            $k_{vfco} \leftarrow \left[3.767616\cdot10^{-14}\cdot\left(\frac{T_{fco}}{K}\right)^3 + 1.247242\cdot10^{-10}\cdot\left(\frac{T_{fco}}{K}\right)^2 + 3.184034\cdot10^{-9}\cdot\left(\frac{T_{fco}}{K}\right) + 7.678236\cdot10^{-6}\right]\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
            $k_{afco} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fco}}{K} + 3.479\cdot10^{-6}\right)\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
            $Nratio_{vfco} \leftarrow \frac{r_{fco}\cdot1\cdot kg}{M_w}$
            $Nratio_{afco} \leftarrow \frac{1\cdot kg}{M_a}$
            $\left(\frac{Nratio_{vfco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot k_{vfco} + \left(\frac{Nratio_{afco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot k_{afco}$
          $\mu_{fco} \leftarrow$
            $\mu_{vfco} \leftarrow \left[1.299155\cdot10^{-12}\cdot\left(\frac{T_{fco}}{K}\right)^2 + 3.872699\cdot10^{-8}\cdot\left(\frac{T_{fco}}{K}\right) - 2.390839\cdot10^{-6}\right]\cdot kg\cdot m^{-1}\cdot s^{-1}$
```

```
            $\mu_{afco} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fco}}{K} + 4.745\cdot10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
            $\left(\frac{Nratio_{vfco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot\mu_{vfco} + \left(\frac{Nratio_{afco}}{Nratio_{vfco} + Nratio_{afco}}\right)\cdot\mu_{afco}$
          $cp_{fco} \leftarrow$
            $cp_{vfco} \leftarrow \left[-5.103046\cdot10^{-10}\cdot\left(\frac{T_{fco}}{K}\right)^3 + 1.252416\cdot10^{-6}\cdot\left(\frac{T_{fco}}{K}\right)^2 - 3.165154\cdot10^{-4}\cdot\left(\frac{T_{fco}}{K}\right) + 1.861896\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
            $cp_{afco} \leftarrow \left[3.542857\cdot10^{-7}\cdot\left(\frac{T_{fco}}{K}\right)^2 - 1.626857\cdot10^{-4}\cdot\frac{T_{fco}}{K} + 1.021769\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
            $mratio_{vfco} \leftarrow r_{fco}\cdot1\cdot kg$
            $\left(\frac{mratio_{vfco}}{1\cdot kg + mratio_{vfco}}\right)\cdot cp_{vfco} + \left(\frac{1\cdot kg}{1\cdot kg + mratio_{vfco}}\right)\cdot cp_{afco}$
          $Pr_{fco} \leftarrow \frac{cp_{fco}\cdot\mu_{fco}}{k_{fco}}$
          $Re_{xao} \leftarrow \frac{\rho_{fco}\cdot u_{ao}\cdot x_i}{\mu_{fco}}$
          $Nux_{co} \leftarrow$
            $0.332\cdot {Pr_{fco}}^{\frac{1}{3}}\cdot {Re_{xao}}^{\frac{1}{2}}$ if $Re_{xao} < 5\cdot10^5$
            $0.0296\cdot {Pr_{fco}}^{\frac{1}{3}}\cdot {Re_{xao}}^{\frac{4}{5}}$ if $5\cdot10^5 \le Re_{xao} \le 10^7$
            $0.185\cdot {Pr_{fco}}^{\frac{1}{3}}\cdot Re_{xao}\cdot\left(\log\left(Re_{xao}\right)\right)^{-2.584}$ otherwise
          $Nux_{co}\cdot\frac{k_{fco}}{x_i}$
        $hx_{co}\cdot\Delta x\cdot W_e\left(T_{ae_0} - T_{goLoop_i}\right)$
      $Q_{cong} \leftarrow -Q_{ro} - Q_{co} - E_g\cdot W_e\cdot\Delta x$
      $T_{gi_{n+1}} \leftarrow \frac{Q_{cong}}{\frac{k_g}{t_g}\cdot\Delta x\cdot W_e} + T_{goLoop_i}$
      $Q_{cg} \leftarrow$
        $hx_{cg} \leftarrow$
          $T_{fcg} \leftarrow \frac{T_{ae_n} + T_{swe_n}}{2}$
          $\rho_{fcg} \leftarrow$
            $p_{vfcg} \leftarrow$
              $C \leftarrow \frac{C_1}{\left(\frac{T_{fcg}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{fcg}}{K}\right) + C_4\cdot\left(\frac{T_{fcg}}{K}\right)^2 + C_5\cdot\left(\frac{T_{fcg}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{fcg}}{K}\right)$
```

```
            $p_{sfcg} \leftarrow \left(e^{C}\right)\cdot Pa$
            $RH_{e_n}\cdot p_{sfcg}$
        $v_{afcg} \leftarrow \frac{0.287035\cdot T_{fcg}}{p_{ae}-p_{vfcg}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
        $r_{fcg} \leftarrow \frac{0.62198\cdot p_{vfcg}}{p_{ae}-p_{vfcg}}$
        $\frac{1+r_{fcg}}{v_{afcg}}$
    $\mu_{fcg} \leftarrow$
        $\mu_{vfcg} \leftarrow \left[1.299155\cdot10^{-12}\cdot\left(\frac{T_{fcg}}{K}\right)^2+3.872699\cdot10^{-8}\cdot\left(\frac{T_{fcg}}{K}\right)-2.390839\cdot10^{-6}\right]\cdot kg\cdot m^{-1}\cdot s^{-1}$
        $\mu_{afcg} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fcg}}{K}+4.745\cdot10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
        $N_{vfcg} \leftarrow \frac{r_{fcg}\cdot m_{da}}{M_w}$
        $N_{afcg} \leftarrow \frac{m_{da}}{M_a}$
        $\left(\frac{N_{vfcg}}{N_{vfcg}+N_{afcg}}\right)\cdot\mu_{vfcg}+\left(\frac{N_{afcg}}{N_{vfcg}+N_{afcg}}\right)\cdot\mu_{afcg}$
    $Re_{xcg} \leftarrow \frac{\rho_{fcg}\cdot u_{ae_n}\cdot x_i}{\mu_{fcg}}$
    $Pr_{fcg} \leftarrow$
        $r_{fcg} \leftarrow$
            $p_{vfcg} \leftarrow$
                $C \leftarrow \frac{C_1}{\left(\frac{T_{fcg}}{K}\right)}+C_2+C_3\cdot\left(\frac{T_{fcg}}{K}\right)+C_4\cdot\left(\frac{T_{fcg}}{K}\right)^2+C_5\cdot\left(\frac{T_{fcg}}{K}\right)^3+C_6\cdot\ln\left(\frac{T_{fcg}}{K}\right)$
                $p_{sfcg} \leftarrow \left(e^{C}\right)\cdot Pa$
                $RH_{e_n}\cdot p_{sfcg}$
            $v_{afcg} \leftarrow \frac{0.287035\cdot T_{fcg}}{p_{ae}-p_{vfcg}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
            $\frac{0.62198\cdot p_{vfcg}}{p_{ae}-p_{vfcg}}$
        $cp_{fcg} \leftarrow$
            $cp_{vfcg} \leftarrow \left[-5.103046\cdot10^{-10}\cdot\left(\frac{T_{fcg}}{K}\right)^3+1.252416\cdot10^{-6}\cdot\left(\frac{T_{fcg}}{K}\right)^2-3.165154\cdot10^{-4}\cdot\left(\frac{T_{fcg}}{K}\right)+1.861896\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
```

```
            $cp_{afcg} \leftarrow \left[3.542857\cdot10^{-7}\cdot\left(\frac{T_{fcg}}{K}\right)-1.626857\cdot10^{-4}\cdot\frac{T_{fcg}}{K}+1.021769\right]\cdot10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
            $m_{vfcg} \leftarrow r_{fcg}\cdot m_{da}$
            $\left(\frac{m_{vfcg}}{m_{da}+m_{vfcg}}\right)\cdot cp_{vfcg}+\left(\frac{m_{da}}{m_{da}+m_{vfcg}}\right)\cdot cp_{afcg}$
        $k_{fcg} \leftarrow$
            $k_{vfcg} \leftarrow \left[3.767616\cdot10^{-14}\cdot\left(\frac{T_{fcg}}{K}\right)^3+1.247242\cdot10^{-10}\cdot\left(\frac{T_{fcg}}{K}\right)^2+3.184034\cdot10^{-9}\cdot\left(\frac{T_{fcg}}{K}\right)+7.678236\cdot10^{-6}\right]\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
            $k_{afcg} \leftarrow \left(7.58\cdot10^{-8}\cdot\frac{T_{fcg}}{K}+3.479\cdot10^{-6}\right)\cdot10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
            $N_{vfcg} \leftarrow \frac{r_{fcg}\cdot m_{da}}{M_w}$
            $N_{afcg} \leftarrow \frac{m_{da}}{M_a}$
            $\left(\frac{N_{vfcg}}{N_{vfcg}+N_{afcg}}\right)\cdot k_{vfcg}+\left(\frac{N_{afcg}}{N_{vfcg}+N_{afcg}}\right)\cdot k_{afcg}$
        $\frac{cp_{fcg}\cdot\mu_{fcg}}{k_{fcg}}$
    $Nux_{cg} \leftarrow$
        $0.332\cdot Pr_{fcg}^{\frac{1}{3}}\cdot Re_{xcg}^{\frac{1}{2}}$ if $Re_{xcg} < 0$
        $0.0296\cdot Pr_{fcg}^{\frac{1}{3}}\cdot Re_{xcg}^{\frac{4}{5}}$ if $0 \le Re_{xcg} \le 10^7$
        $0.185\cdot Pr_{fcg}^{\frac{1}{3}}\cdot Re_{xcg}\cdot\left(\log\left(Re_{xcg}\right)\right)^{-2.584}$ otherwise
    $Nux_{cg}\cdot\frac{k_{fcg}}{x_i}$
  $hx_{cg}\cdot\Delta x\cdot W_e\cdot\left(T_{ae_n}-T_{gi_{n+1}}\right)$
$Q_{rw} \leftarrow \frac{W_e\cdot\Delta x\cdot\sigma\cdot\left[\left(T_{swe_n}\right)^4-\left(T_{gi_{n+1}}\right)^4\right]}{\frac{1}{\varepsilon_w}+\upsilon\cdot\left(\frac{1}{\varepsilon_g}-1\right)}$
$Q_{cw} \leftarrow$
  $hx_{cw} \leftarrow$
    $T_{fcw} \leftarrow \frac{T_{ae_n}+T_{swe_n}}{2}$
    $\rho_{fcw} \leftarrow$
      $p_{vfcw} \leftarrow$
        $C \leftarrow \frac{C_1}{\left(\frac{T_{fcw}}{K}\right)}+C_2+C_3\cdot\left(\frac{T_{fcw}}{K}\right)+C_4\cdot\left(\frac{T_{fcw}}{K}\right)^2+C_5\cdot\left(\frac{T_{fcw}}{K}\right)^3+C_6\cdot\ln\left(\frac{T_{fcw}}{K}\right)$
```

```
                  | $p_{sfcw} \leftarrow \left(e^{C}\right)\cdot Pa$
                  | $RH_{e_n}\cdot p_{sfcw}$
        | $v_{afcw} \leftarrow \frac{0.287035\cdot T_{fcw}}{p_{ae} - p_{vfcw}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
        | $r_{fcw} \leftarrow \frac{0.62198\cdot p_{vfcw}}{p_{ae} - p_{vfcw}}$
        | $\frac{1 + r_{fcw}}{v_{afcw}}$
$\mu_{fcw} \leftarrow$ | $\mu_{vfcw} \leftarrow \left[1.299155\cdot 10^{-12}\left(\frac{T_{fcw}}{K}\right)^2 + 3.872699\cdot 10^{-8}\left(\frac{T_{fcw}}{K}\right) - 2.390839\cdot 10^{-6}\right]\cdot kg\cdot m^{-1}\cdot s^{-1}$
        | $\mu_{afcw} \leftarrow \left(7.58\cdot 10^{-8}\cdot\frac{T_{fcw}}{K} + 4.745\cdot 10^{-6}\right)\cdot kg\cdot m^{-1}\cdot s^{-1}$
        | $N_{vfcw} \leftarrow \frac{r_{fcw}\cdot m_{da}}{M_w}$
        | $N_{afcw} \leftarrow \frac{m_{da}}{M_a}$
        | $\left(\frac{N_{vfcw}}{N_{vfcw} + N_{afcw}}\right)\cdot\mu_{vfcw} + \left(\frac{N_{afcw}}{N_{vfcw} + N_{afcw}}\right)\cdot\mu_{afcw}$
$Re_{xcw} \leftarrow \frac{\rho_{fcw}\cdot\left(u_{ae_n} + u_{swe}\right)\cdot x_i}{\mu_{fcw}}$
$Pr_{fcw} \leftarrow$ | $r_{fcw} \leftarrow$ | $p_{vfcw} \leftarrow$ | $C \leftarrow \frac{C_1}{\left(\frac{T_{fcw}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{fcw}}{K}\right) + C_4\cdot\left(\frac{T_{fcw}}{K}\right)^2 + C_5\cdot\left(\frac{T_{fcw}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{fcw}}{K}\right)$
                                      | $p_{sfcw} \leftarrow \left(e^{C}\right)\cdot Pa$
                                      | $RH_{e_n}\cdot p_{sfcw}$
                         | $v_{afcw} \leftarrow \frac{0.287035\cdot T_{fcw}}{p_{ae} - p_{vfcw}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^3}{kg}$
                         | $\frac{0.62198\cdot p_{vfcw}}{p_{ae} - p_{vfcw}}$
          | $cp_{fcw} \leftarrow$ | $cp_{vfcw} \leftarrow \left[-5.103046\cdot 10^{-10}\left(\frac{T_{fcw}}{K}\right)^3 + 1.252416\cdot 10^{-6}\left(\frac{T_{fcw}}{K}\right)^2 - 3.165154\cdot 10^{-4}\left(\frac{T_{fcw}}{K}\right) + 1.861896\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
```

```
                      | $cp_{afcw} \leftarrow \left[3.542857\cdot 10^{-7}\left(\frac{T_{fcw}}{K}\right) - 1.626857\cdot 10^{-4}\cdot\frac{T_{fcw}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                      | $m_{vfcw} \leftarrow r_{fcw}\cdot m_{da}$
                      | $\left(\frac{m_{vfcw}}{m_{da} + m_{vfcw}}\right)\cdot cp_{vfcw} + \left(\frac{m_{da}}{m_{da} + m_{vfcw}}\right)\cdot cp_{afcw}$
          | $k_{fcw} \leftarrow$ | $k_{vfcw} \leftarrow \left[3.767616\cdot 10^{-14}\left(\frac{T_{fcw}}{K}\right)^3 + 1.247242\cdot 10^{-10}\left(\frac{T_{fcw}}{K}\right)^2 + 3.184034\cdot 10^{-9}\left(\frac{T_{fcw}}{K}\right) + 7.678236\cdot 10^{-6}\right]\cdot 10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
                      | $k_{afcw} \leftarrow \left(7.58\cdot 10^{-8}\cdot\frac{T_{fcw}}{K} + 3.479\cdot 10^{-6}\right)\cdot 10^3\cdot W\cdot m^{-1}\cdot K^{-1}$
                      | $N_{vfcw} \leftarrow \frac{r_{fcw}\cdot m_{da}}{M_w}$
                      | $N_{afcw} \leftarrow \frac{m_{da}}{M_a}$
                      | $\left(\frac{N_{vfcw}}{N_{vfcw} + N_{afcw}}\right)\cdot k_{vfcw} + \left(\frac{N_{afcw}}{N_{vfcw} + N_{afcw}}\right)\cdot k_{afcw}$
          | $\frac{cp_{fcw}\cdot\mu_{fcw}}{k_{fcw}}$
$Nux_{cw} \leftarrow$ | $0.332\cdot Pr_{fcw}^{\frac{1}{3}}\cdot Re_{xcw}^{\frac{1}{2}}$ if $Re_{xcw} < 0$
          | $0.0296\cdot Pr_{fcw}^{\frac{1}{3}}\cdot Re_{xcw}^{\frac{4}{5}}$ if $0 \le Re_{xcw} \le 10^7$
          | $0.185\cdot Pr_{fcw}^{\frac{1}{3}}\cdot Re_{xcw}\cdot\left(\log\left(Re_{xcw}\right)\right)^{-2.584}$ otherwise
$Nux_{cw}\cdot\frac{k_{fcw}}{x_i}$
| $hx_{cw}\cdot\Delta x\cdot\left(o\cdot W_e + 2\cdot H_{aeavg}\right)\cdot\left(T_{swe_n} - T_{ae_n}\right)$
$Q_{mt} \leftarrow$ | $m_{mt_{n+1}} \leftarrow$ | $c_w \leftarrow$ | $C \leftarrow \frac{C_1}{\left(\frac{T_{swe_n}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{swe_n}}{K}\right) + C_4\cdot\left(\frac{T_{swe_n}}{K}\right)^2 + C_5\cdot\left(\frac{T_{swe_n}}{K}\right)^3 + C_6\cdot\ln\left(\frac{T_{swe_n}}{K}\right)$
                                      | $p_{ssw} \leftarrow \left(e^{C}\right)\cdot Pa$
                                      | $\frac{p_{ssw}}{R_w\cdot T_{swe_n}}$
```

```
c_a ← | $C \leftarrow \frac{C_1}{\left(\frac{T_{ae_n}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{ae_n}}{K}\right) + C_4\cdot\left(\frac{T_{ae_n}}{K}\right) + C_5\cdot\left(\frac{T_{ae_n}}{K}\right) + C_6\cdot\ln\left(\frac{T_{ae_n}}{K}\right)$
      | $p_{samt_n} \leftarrow \left(e^{C}\right)\cdot Pa$
      | $c_{amt} \leftarrow \frac{p_{samt_n}}{R_w\cdot T_{ae_n}}$
      | $RH_{e_n}\cdot c_{amt}$
$D \leftarrow \frac{435.7\cdot\left(\frac{T_{ae_n}}{K}\right)^{\frac{3}{2}}}{\frac{p_{ae}}{Pa}\cdot\left(V_a^{\frac{1}{3}} + V_w^{\frac{1}{3}}\right)^2}\cdot\sqrt{\left(\frac{1}{M_w} + \frac{1}{M_a}\right)}\cdot 10^{-4}\cdot m^2\cdot s^{-1}$
Sc_fcw ← | $\rho_{fcw} \leftarrow \frac{1 + r_{fcw}}{v_{afcw}}$
         | $\frac{\mu_{fcw}}{\rho_{fcw}\cdot D}$
$hx_{mt} \leftarrow 0.0296\cdot Re_{xcw}^{\frac{-1}{5}}\cdot u_{ae_n}\cdot Sc_{fcw}^{-\frac{2}{3}}$
$m_{mtnorm} \leftarrow hx_{mt}\cdot \upsilon\cdot\Delta x\cdot W_e\cdot\left(c_w - c_a\right)$
$m_{mtnorm}$
    $h_{gsw} \leftarrow \left[-0.00086\cdot\left(\frac{T_{swe_n} - 273\cdot K}{K}\right)^2 + 1.855\cdot\left(\frac{T_{swe_n} - 273\cdot K}{K}\right) + 2500.6\right]\cdot 10^3\cdot J\cdot kg^{-1}$
    $m_{mt_{n+1}}\cdot h_{gsw}$
Q_ccw ← | $Q_{conc} \leftarrow -(0.5)\cdot E_e\cdot\Delta x\cdot W_e$
        | $E_e\cdot\Delta x\cdot W_e + Q_{conc}$
$\Delta Q_{ae_{n+1}} \leftarrow Q_{mt} + Q_{cw} - Q_{cg}$
$Q_{e_{n+1}} \leftarrow E_e\cdot W_e\cdot\Delta x + Q_{conc} - Q_{cong}$
$\Delta Q_{swe_{n+1}} \leftarrow Q_{e_{n+1}} - \Delta Q_{ae_{n+1}}$
$Q'_{rw} \leftarrow -\Delta Q_{swe_{n+1}} - Q_{mt} - Q_{cw} + Q_{ccw}$
```

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```
        | $T'_{gi_{n+1}} \leftarrow \left[\frac{-Q'_{rw}\cdot\left[\frac{1}{\varepsilon_w} + \upsilon\cdot\left(\frac{1}{\varepsilon_g} - 1\right)\right]}{W_e\cdot\Delta x\cdot\sigma} + \left(T_{swe_n}\right)^4\right]^{\frac{1}{4}}$
        | $T_{goLoop_{(i+1)}} \leftarrow T_{goLoop_i} + \left(\frac{T'_{gi_{n+1}} - T_{gi_{n+1}}}{10}\right)$
        | $i \leftarrow i + 1$
        | $LoopStop_i \leftarrow \left|\frac{Q_{rw} - Q'_{rw}}{Q_{rw}}\right|$
    | $T_{goLoop_i}$
T_ae_{n+1} ← | $zz \leftarrow 0$
             | $T_{aeLoop_0} \leftarrow T_{ae_n}$
             | $LoopStop_{zz} \leftarrow 1$
             | while $LoopStop_{zz} > \frac{\Omega}{1000}$
                 | $\Delta r_e \leftarrow \frac{m_{mt_{n+1}}}{m_{da}}$
                 | $r_{e_{n+1}} \leftarrow r_{e_n} + \Delta r_e$
                 | $cp_{an1} \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{aeLoop_{zz}}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{aeLoop_{zz}}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                 | $h_{gan1} \leftarrow \left[-0.00086\cdot\left(\frac{T_{aeLoop_{zz}} - 273.15\cdot K}{K}\right)^2 + 1.855\cdot\left(\frac{T_{aeLoop_{zz}} - 273.15\cdot K}{K}\right) + 2500.6\right]\cdot 10^3\cdot J\cdot kg^{-1}$
                 | T_aeheat ← | $vv \leftarrow 0$
                 |            | $T_{aeheatLoop_{vv}} \leftarrow T_{ae_n}$
                 |            | $\Delta Q_{aeheat} \leftarrow Q_{cw} - Q_{cg}$
                 |            | $LoopStop_{vv} \leftarrow 1$
                 |            | while $LoopStop_{vv} > \frac{\Omega}{1000}$
                 |            |     | $cp_{an} \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{ae_n}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{ae_n}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                 |            |     | $cp_{aheat} \leftarrow \left[3.542857\cdot 10^{-7}\cdot\left(\frac{T_{aeheatLoop_{vv}}}{K}\right)^2 - 1.626857\cdot 10^{-4}\cdot\frac{T_{aeheatLoop_{vv}}}{K} + 1.021769\right]\cdot 10^3\cdot J\cdot kg^{-1}\cdot K^{-1}$
                 |            |     | $\left[ \quad (T - 273.15\cdot K)^2 \quad (T - 273.15\cdot K) \quad \right]$
```

```
                    $h_{gan} \leftarrow \left[-0.00086\left(\frac{\ \ n}{K}\right) + 1.855\left(\frac{\ \ n}{K}\right) + 2500.6\right]\cdot 10^{3}\cdot J\cdot kg^{-1}$
                    $h_{gaheat} \leftarrow \left[-0.00086\left(\frac{T_{aheatLoop_{vv}} - 273.15\cdot K}{K}\right)^{2} + 1.855\left(\frac{T_{aheatLoop_{vv}} - 273.15\cdot K}{K}\right) + 2500.6\right]\cdot 10^{3}\cdot J\cdot kg^{-1}$
                    $T_{aheatLoop_{vv+1}} \leftarrow \frac{\Delta Q_{aheat} + m_{da}\cdot cp_{air}\cdot T_{ae_n} - r_{e_n}\cdot m_{da}\cdot(h_{gaheat} - h_{gan})}{cp_{aheat}\cdot m_{da}}$
                    $vv \leftarrow vv + 1$
                    $LoopStop_{vv} \leftarrow \left|\frac{T_{aheatLoop_{vv}} - T_{aheatLoop_{vv-1}}}{T_{aheatLoop_{vv}}}\right|$
                $T_{aheatLoop_{vv}}$
            $T_{aeLoop_{zz+1}} \leftarrow \frac{cp_{aheat}\cdot m_{da}\cdot T_{aheat} + m_{da}\cdot r_{e_n}\cdot h_{gaheat} + m_{mt_{n+1}}\cdot h_{gsw} - m_{da}\cdot r_{e_{n+1}}\cdot h_{gan1}}{cp_{an1}\cdot m_{da}}$
            $zz \leftarrow zz + 1$
            $LoopStop_{zz} \leftarrow \left|\frac{T_{aeLoop_{zz}} - T_{aeLoop_{zz-1}}}{T_{aeLoop_{zz}}}\right|$
        $T_{aeLoop_{zz}}$
    $m_{swe_{n+1}} \leftarrow m_{swe_n} + m_{mt_{n+1}}$
    $T_{swe_{n+1}} \leftarrow$
        $cp_{sw} \leftarrow 4147\cdot J\cdot kg^{-1}\cdot K^{-1}$
        $h_{fsw} \leftarrow \left[4.183824\cdot 10^{3}\left(\frac{T_{swe_n}}{K}\right) - 1.141915\cdot 10^{6}\right]\cdot J\cdot kg^{-1}$
        $\frac{(\Delta Q_{swe_{n+1}} + Q_{mt}) - m_{mt_{n+1}}\cdot(h_{gsw} - h_{fsw}) + m_{swe_n}\cdot cp_{sw}\cdot T_{swe_n}}{m_{swe_n}\cdot cp_{sw}}$
    $Z_{e_{n+1}} \leftarrow \frac{1000\cdot m_{se}}{m_{swe_{n+1}}}$
    $u_{ae_{n+1}} \leftarrow$
        $A_e \leftarrow W_e\cdot H_{aeavg}$
        $\rho_{wae_{n+1}} \leftarrow$
            $p_{ve} \leftarrow \frac{r_{e_{n+1}}\cdot p_{ae}}{0.62198 + r_{e_{n+1}}}$
            $v_{ae} \leftarrow \frac{0.287035\cdot T_{ae_{n+1}}}{p_{ae} - p_{ve}}\cdot\frac{1000\cdot Pa}{K}\cdot\frac{m^{3}}{kg}$
            $\frac{1 + r_{e_{n+1}}}{v_{ae}}$
```

```
        $V_e \leftarrow \frac{m_{da}\cdot(1 + r_{e_{n+1}})}{\rho_{wae_{n+1}}}$
        $\frac{V_e}{A_e}$
    $RH_{e_{n+1}} \leftarrow$
        $p_{se} \leftarrow$
            $C \leftarrow \frac{C_1}{\left(\frac{T_{ae_{n+1}}}{K}\right)} + C_2 + C_3\cdot\left(\frac{T_{ae_{n+1}}}{K}\right) + C_4\cdot\left(\frac{T_{ae_{n+1}}}{K}\right)^{2} + C_5\cdot\left(\frac{T_{ae_{n+1}}}{K}\right)^{3} + C_6\cdot\ln\left(\frac{T_{ae_{n+1}}}{K}\right)$
            $(e^{C})\cdot Pa$
        $\frac{p_{ve}}{p_{se}}$
    $n \leftarrow n + 1$
  $T_{aex_{U+1}} \leftarrow T_{ae_N}$
  $T_{swex_{U+1}} \leftarrow T_{swe_N}$
  $RH_{ex_{U+1}} \leftarrow RH_{e_N}$
  $U \leftarrow U + 1$
  $\Delta T_{aex} \leftarrow |T_{aex_U} - T_{aex_{U-1}}|$
  $\Delta T_{swex} \leftarrow |T_{swex_U} - T_{swex_{U-1}}|$
  $\Delta RH_{ex} \leftarrow |RH_{ex_U} - RH_{ex_{U-1}}|$
  $LoopStop_U \leftarrow \frac{\Delta T_{aex}}{K} + \frac{\Delta T_{swex}}{K} + \Delta RH_{ex}$
for $n \in 0..N$
  $M_{0,\Sigma-1} \leftarrow \frac{T_{swe_N} - 273.15\cdot K}{K}$
  $M_{1,\Sigma-1} \leftarrow DATA_{\Sigma,4}$
  $M_{2,\Sigma-1} \leftarrow RH_{e_N}\cdot 100$
  $M_{3,\Sigma-1} \leftarrow DATA_{\Sigma,6}$
  $M_{4,\Sigma-1} \leftarrow \frac{T_{ae_N} - 273.15\cdot K}{K}$
  $M_{5,\Sigma-1} \leftarrow DATA_{\Sigma,10}$
  $M \leftarrow$ $\frac{A_{cf}}{\ }$
```

```
        $_{6,\Sigma-1}$    $_{N}\ r_{avgfx}\cdot A_{exd}$
                           $\frac{u_{aexd}}{m\cdot s^{-1}}$
        $M_{7,\Sigma-1} \leftarrow DATA_{\Sigma,11}$
        $M_{9,\Sigma-1} \leftarrow$
            $r_{eax} \leftarrow$
                $p_{vex} \leftarrow$
                    $C \leftarrow \frac{C_1}{(DATA_{\Sigma,10}+273.15)} + C_2 + C_3\cdot(DATA_{\Sigma,10}+273.15) + C_4\cdot(DATA_{\Sigma,10}+273.15)^2 + C_5\cdot(DATA_{\Sigma,10}+273.15)^3 + C_6\cdot\ln(DATA_{\Sigma,10}+273.15)$
                    $p_{sex} \leftarrow (e^C)\cdot Pa$
                    $DATA_{\Sigma,6}\cdot\%\cdot p_{sex}$
                $v_{aex} \leftarrow \frac{0.287035\cdot(DATA_{\Sigma,10}+273.15)}{p_{ae}-p_{vex}}\cdot 1000\cdot Pa\cdot\frac{m^3}{kg}$
                $\frac{0.62198\cdot p_{vex}}{p_{ae}-p_{vex}}$
            $r_{eax}$
        $M_{8,\Sigma-1} \leftarrow r_{e_N}$
        $M_{10,\Sigma-1} \leftarrow \frac{\sum_{i=0}^{N} m_{mt_i}}{\frac{kg}{s}}$
        $M_{11,\Sigma-1} \leftarrow r_{e_0}$
        $M_{12,\Sigma-1} \leftarrow \frac{m_{da}}{\frac{kg}{s}}$
        $M_{13,\Sigma-1} \leftarrow \frac{m_{swe_0}}{\frac{kg}{s}}$
        $M_{14,\Sigma-1} \leftarrow U$
    $\Sigma \leftarrow \Sigma + 1$
$M$
```

APPENDIX D

Pilot Plant

Equipment Specification

Sensor	**Sensor Type**	**Measurement**	**Unit**	**Signal Type**	**Signal**
PT 100	Model 4003 LED Univ. Temp. Indicator	Temperature	°C	Analogue	4-20mA
RH sensor	TR-HUM1A4 Humidity Transmitter - Lutron	Relative Humidity	%	Analogue	4-20mA
Magnetic-Inductive Flowmeter	MAG 910E Arkon	Flow Rate	l/s	Analogue	4-20mA
Hot Wire Anemometer	Am-4204 Hot Wire Anemometer - Lutron	Wind Speed & Temperature	m/s & °C	Digital	* & **
Solar Radiation Sensor	SPLite Pyranometer	Solar Radiation	W/m^2	Analogue	µV

*	Digits 9-11 Temperature (D9D10,D11)
**	Digits 13-15 Wind Speed (D13D14,D15)

Data Logging Equipment	
Data Cables:	Twisted 2 Core Woven Shielding
	Twisted 4 Core Woven Shielding
RS485 ↔ RS232 Converters	
Instrument ↔ Computer Converter Card	
Dell Optiplex GX 260 Computer	

Water Temperature Control
Sensor: PT 100
Controler: Gefran 600

Other
Fan: 0,55kW 4 Blade φ400mm
Pump: 1,5kW Q=300-900l/min H=4,5-11m

APPENDIX E

ICUE

Conference Paper

LOW TEMPERATURE SOLAR POWERED DISTILLATION OF SEAWATER

CL Lourens, EA Uken and M Kilfoil
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ABSTRACT

Too much pressure is being put on the world's natural water resources. Hence many countries are now looking to the sea as a possible source of water. Existing desalination systems are not feasible for some countries, because of the high cost of producing large quantities of potable water from seawater. A new system is thus proposed, which receives all the energy required for production from the sun. Seawater is evaporated and then it condenses to form potable water. This process occurs at low temperatures and pressures close to that of ambient conditions, keeping the system's energy requirements low. A computer model of the plant has been developed and some of the early results obtained are presented in this paper.

1. INTRODUCTION

A recent study by the United Nations has shown that nearly half the world's population will experience critical water shortages by the year 2025.[1] Areas of South Africa are likely to be among those facing increasingly frequent water shortages. The much debated concern over the world's changing climate adds to the urgency of focusing attention on this potentially crippling threat to South Africa's population and economy. The vast water supply of the sea could be the answer and much research has been done into reverse osmosis plants. A major drawback of such high pressure systems is the enormous energy requirements associated with them.[2] Hence the cost of water produced will be very high. Many of the countries with water shortages also have looming energy problems. A system that produces large quantities of desalinated seawater which only, or at least to a large extent, relies on solar energy would assist in solving this global problem.

The idea of producing potable water by the evaporation and condensation, or distillation, of impure water is by no means new. In fact Aristotle, who lived during the fourth century BC, mentioned it in his work.[3] Low temperature distillation, powered by solar energy, is also not new. A device known as a solar still has been in use for some time now.[3] This device consists of a shallow pan of water covered by an angled glass panel. Solar energy passes through the glass panel, and heats and evaporates the water. The air near the glass panel cools down and some of the moisture it contains condenses onto the glass, runs down the glass and is gathered in a container or other storage device. Desalinated water production in this device is extremely slow. Therefore, it is only suitable for remote settlements where brackish water is the only type of moisture available, where power is scarce or expensive, and the demand is less than 200 m^3/day.[3]

There are ways of improving on this basic design. In order to increase the evaporation one could force the air into motion and thereby increase the rate of evaporation. Alternatively, one could increase the temperature difference between the air and water, which would also increase the evaporation rate. Doing both is even better.

2. PLANT DESCRIPTION

The proposed desalination plant consists of an evaporator, condenser and a secondary water heater.

The water is pumped from the sea through the condenser, where it is heated by energy transfer from warm air leaving the evaporator. The water is then heated further in the secondary heater before it flows into and through the evaporator. Sea water not evaporated (which has an increased salt concentration) flows back to the sea.

Air from the condenser flows into the evaporator where it is heated and it picks up moisture from the water. Warm, moist air leaves the evaporator and flows into the condenser, where it is cooled down by cold water from the sea. During cooling vapour in the air condenses. Cold dry air leaves the condenser and flows back into the evaporator.

Desalinated water flows out at the bottom of the condenser.

A schematic representation of the process is shown in Fig.1. The dashed lines with arrows represent the flow of salt water. The solid lines with arrows represent the flow of air. The dotted line represents the flow of desalinated water.

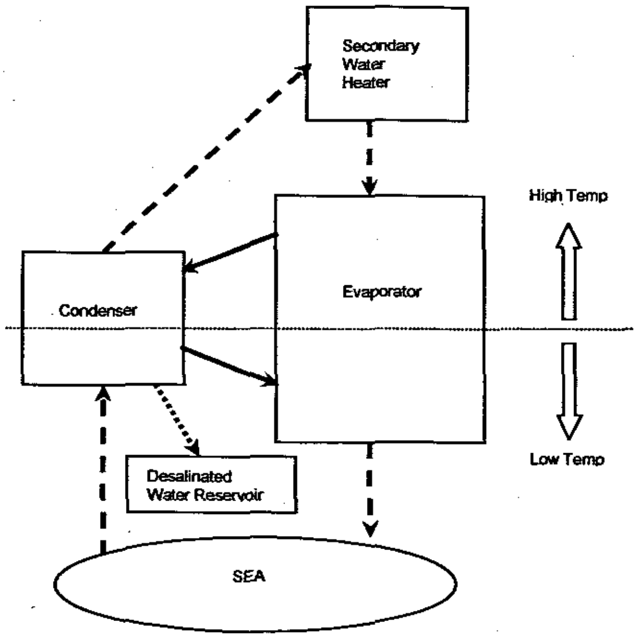

Fig.1: Schematic representation of distillation plant

This plant is ideal for coastal areas with cold sea currents, high solar radiation and mostly clear skies. South Africa's entire western coast falls into this category. In fact most coastal areas with cold sea currents have a low rainfall, predominantly clear skies and can therefore benefit from this design. The plant would function best if it is built at the minimum elevation above sea level required to ensure its safety and as close to the sea as possible to reduce pipe losses.

Water fit for human consumption is fit for livestock and irrigation as well. Consequently this plant may assist in extending arable land and increasing food production.

2.1 EVAPORATOR

The evaporator is a simple structure consisting of a sloped concrete floor covered and enclosed by double-glazed glass. Heated water, from the water pre-heater, enters the evaporator, runs down the slope of the concrete floor and exits at the bottom, running back into the sea. The air, on the other hand, flows between the glass panels and the water, from the bottom of the slope upwards. Solar energy enters through the glass panels and is trapped by the greenhouse effect. Most of this energy is absorbed by the concrete which in turn heats the water. Energy is transferred from the water to the air by forced convection and by the water being evaporated.

Premature condensation or condensation on the inner surface of the innermost glass layer would greatly reduce the solar energy entering the evaporator. The use of double-glazed glass panels increases the surface temperature on the inside of the lower glass panel to prevent condensation there. Having two glass panels with an air gap between them reduces heat loss back to the atmosphere.

2.2 CONDENSER

The condenser is of the counter flow shell-and-tube type. Cold water pumped directly from the sea flows in the pipes. Warm moist air from the evaporator flows on the outside of the pipes. The cold sea water absorbs heat from the warm moist air, thereby reducing the temperature of the air. This reduces its relative humidity to saturation. Further cooling in the condenser causes condensation, thus some of the water vapour in the air turns into pure liquid water.

The slope of the condenser is such that it takes the air back down to the inlet level of the evaporator, thus restarting the process.

2.3 SECONDARY WATER HEATER

The water temperature at the exit of the condenser will be lower than that of the air. The water is used to heat the air inside the evaporator, which is not possible if the water is colder than the air. To overcome this problem a secondary water heater is introduced. The heater used is essentially of the same structure as that of the evaporator, consisting of double glass panels with water flowing under them over a concrete surface. Solar energy enters though the glass and is absorbed, mostly, by the concrete which heats the water.

The water, already heated partially in the condenser, enters the heater at a higher elevation than the evaporator, flowing downhill through the heater into the evaporator.

2.4 OPTIMISATION

Owing to the limited energy available from the sun and the large amount of energy transfer required during evaporation and condensation, the process must be as effective as possible. Two basic principles were employed towards achieving this goal :

Firstly, reduce the amount of energy exiting the system. The largest quantity of energy is saved by ensuring the lowest temperature at which the seawater exits the evaporator and flows back to the sea. The temperature is very nearly that of the air entering the evaporator and is achieved by determining the optimum air-flow speed. Reducing the temperature of the seawater to close to its original temperature also prevents thermal pollution of the coastal water around the desalination plant. The double layer of glass panels and the regaining of energy from the water by the air and *vice versa* further improves efficiency of the process. Some energy is also regained by introducing a low head water turbine powered by the water flowing back to the sea.

The second and equally important principle is to reduce the energy requirements of the process. Little can be done to reduce the energy required for evaporating or condensing water or to heat the water and air. One can really only reduce the energy required to keep the air in motion and pump the water. The optimum air-flow speed required in the evaporator to prevent condensation on the inner glass panel is very low, which also results in a very small drop in pressure. Keeping the slope of the evaporator at the minimum required for the water flow helps reduce the pressure lost by elevation change. The slope of the condenser, due to its shorter length, is much greater than that of the evaporator. This helps to regain some air pressure as it is cooling down. To reduce the pump energy required by the water the overall elevation of the plant is kept at a minimum and parallel pipe systems are used, where possible, to reduce friction losses.

2.5 OUTPUT OF DESALINATION PLANT

Originally it was hoped that a daily production of 10 000m^3 or 10 million litres of desalinated water would be possible, but computer modelling has shown that 5 000m^3/day is more realistic. This is of course dependent on the solar absorption size of the evaporator. With the current design the plant could produce, at maximum production rate, approximately 217 kg of water per second. The energy required to keep the air flowing at this maximum production rate is approximately 110kW. Although the exact power required to pump the water has not yet been determined, the authors are confident that the extra energy required for this plant can be supplied by solar panels.

The curves shown in the figures below, are based on data from a computer model simulating the entire process and not on data from physical models.

3. COMPUTER MODEL

The computer program was written employing the principles of mass and energy conservation. Mathematical models of each of the three systems were drawn up and then linked by taking the results from one, such as mass flow rate, pressure and physical properties, to the next. Throughout the model numerical integration was employed allowing the continuous calculation of property changes for both the water and the air.

Before starting the model a few system limits had to be put in place. These were the maximum and minimum temperature of the air, humidity of the air exiting the evaporator and the air pressure at inlet to the evaporator. Some other guidelines helped to simplify the problem, such as setting the temperature differences between the air and water at key points to a preset value.

The evaporator model starts from the air inlet side with the known and required values and properties. Some figures, such as the mass flow rate of seawater exiting and the air pressure at various key points in the system, are not known at this stage. Integrating through all process models back to the evaporator inlet and looping the entire model again solves this small obstacle. The evaporator model runs until it has solved for the required size of the evaporator and calculated all the necessary properties of the air and seawater at the other end of the evaporator. It also determines the air-flow speed that would prevent condensation from forming on the inner glass surface and produce the desired relative humidity and temperature of the air at exit. One of the most important outputs of this model is the required temperature of the seawater when it enters the evaporator. This, along with the desired temperature of the seawater at exit from the condenser, sets the basis for the next model - the secondary water heater.

Knowing the inlet temperature and required outlet temperature as well as the mass flow rate of the heater, the size of the absorption area is calculated by integrating from one end to the other.

The computer model of the condenser is written in such a way that it determines the required mass flow rate of the seawater to cool down the air and still achieve the desired outlet temperature of seawater. It also determines the length of the condenser necessary to achieve the required effect.

Throughout the system the pressure loss of the air is calculated and after the first system loop is completed, the values that were originally unknown are redefined and the loop started anew. This continues until the preset accuracy is achieved.

4. OUTPUT FROM MODEL

The computer model is currently being used to optimise the distillation plant. With the help of the computer model the effect of design changes can be easily obtained.

4.1 EVAPORATOR

This is the heart of the system. Some of the curves obtained from the model are shown below.

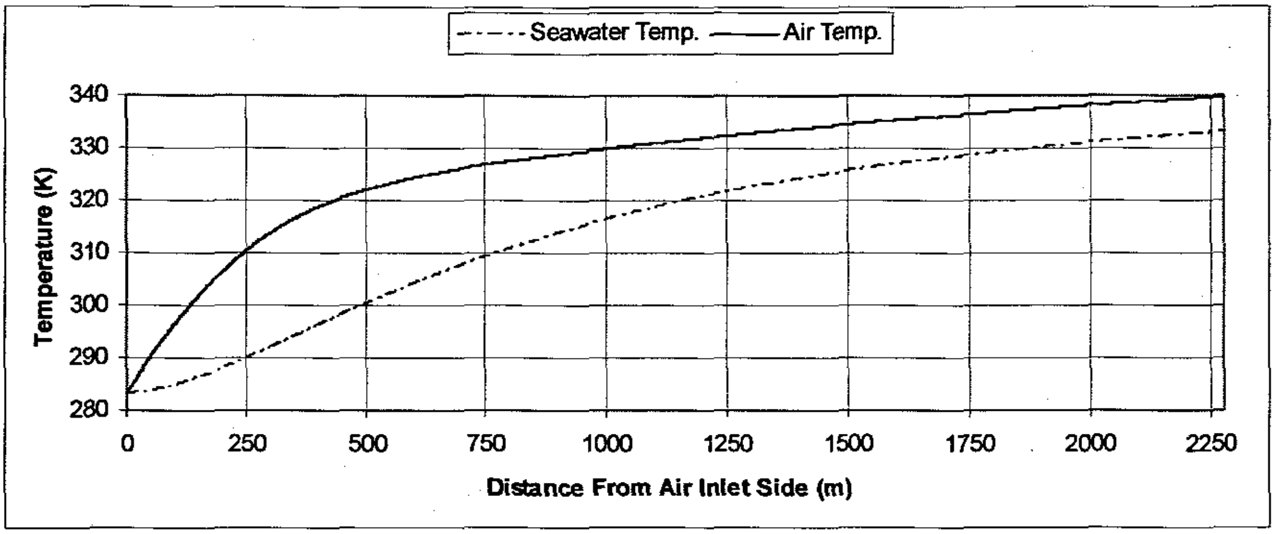

Fig.2: Air & seawater temperatures through evaporator

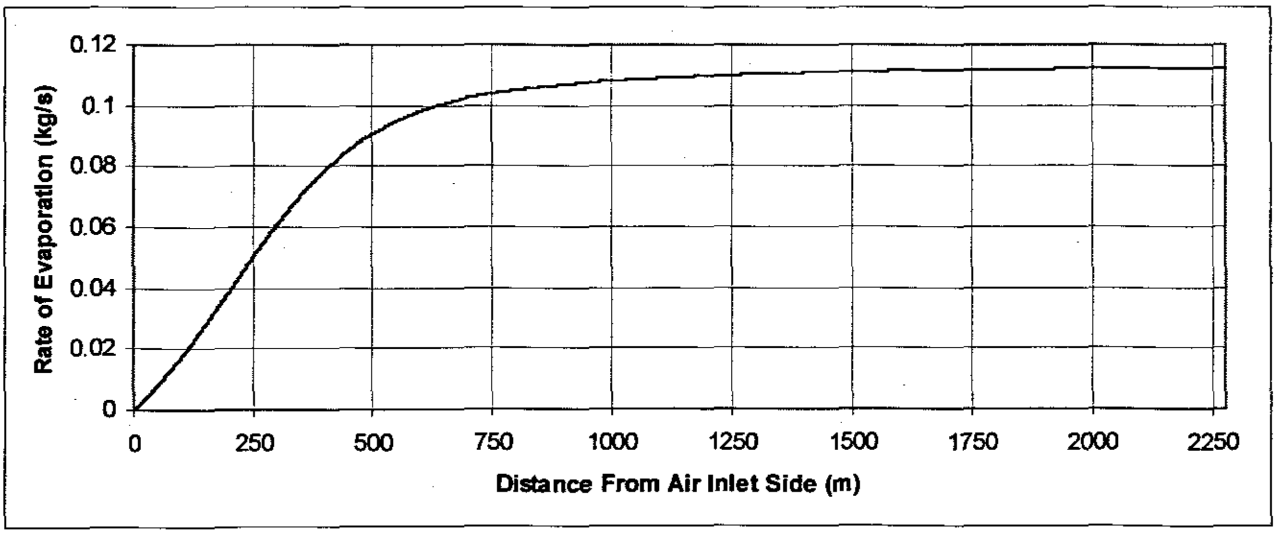

Fig.3: Rate of water evaporation through evaporator

As mentioned before, most of the solar energy is absorbed into the water from the concrete floor of the evaporator. The effect is that, when moving from the air inlet side to the other, the water gains more energy than the air and is heated more rapidly. As the temperature gradient between the water and air increases, more energy is transferred through convection and evaporation from the water to the air, increasing the temperature change of the air and the rate at which evaporation proceeds. As both the air and water's temperatures increase, so does that of the glass panel, thereby causing greater energy loss through it back to the atmosphere. With higher energy losses less energy is available to increase the temperature of the two fluids. This causes the slower temperature rise at higher temperatures.

4.2 CONDENSER

From the onset of this project the evaporator was seen as the most important design problem. Many changes can be made to the condenser to make it more effective. The effect of this will be a shorter, more compact condenser, but it would have no effect on the energy requirements related to condensing the water vapour. The design of the condenser, therefore, will have little effect on whether or not this plant could operate. For this reason the simplest design was selected, to simplify the computer programming associated with modelling the condenser and to minimise pressure losses therein.

Fig.4 below shows the temperature change of both the water and air in the condenser from the air inlet side. Initially the drop in temperature of the air is rapid. Air enters the condenser at a relative humidity of approximately 95%. Less energy is required to cool the air to saturation than is needed to condense the vapour and cool the air after saturation has been achieved. Hence a more rapid temperature drop. The S-shape of the curve is what one would expect with smaller temperature changes, when the temperatures of the two mediums are closer together, becoming more rapid as the gradient increases.

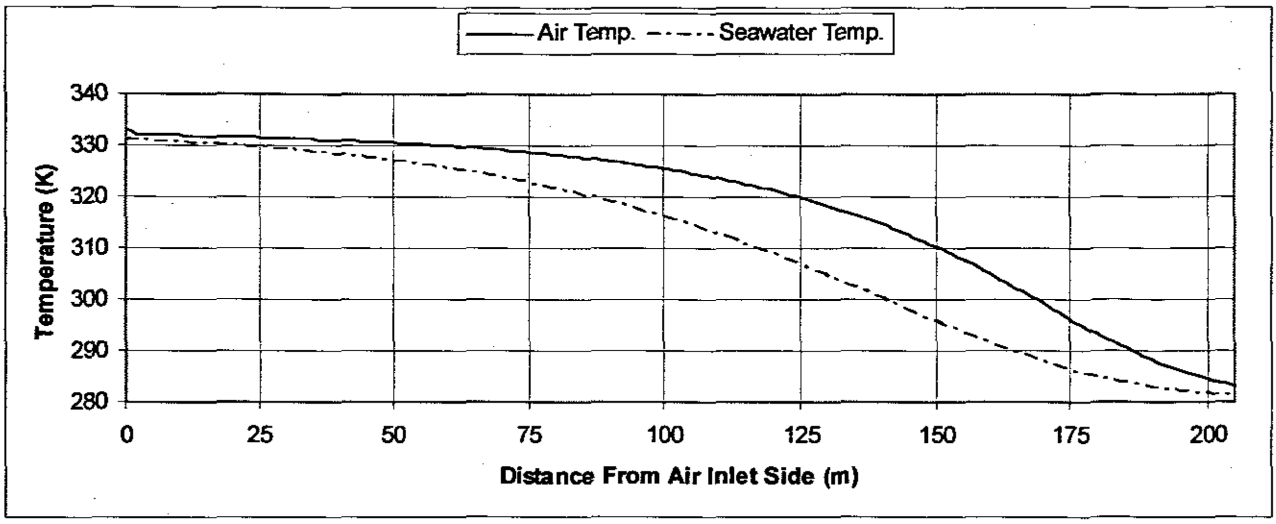

Fig.4: Air & seawater temperatures through condenser

4.3 SECONDARY WATER HEATER

Fig. 5 shows the water temperature rise through the heater. The graph appears to be linear but is, in fact, not. As the temperature of the water increases more energy is lost through the glass and thus less energy available to further heat water. The graph looks linear because there is only a small increase in water temperature through the heater, about 10°C, and owing to the insulating effect of the double glass panels the outer glass surface's temperature increases even less. Thus the energy available remains fairly constant.

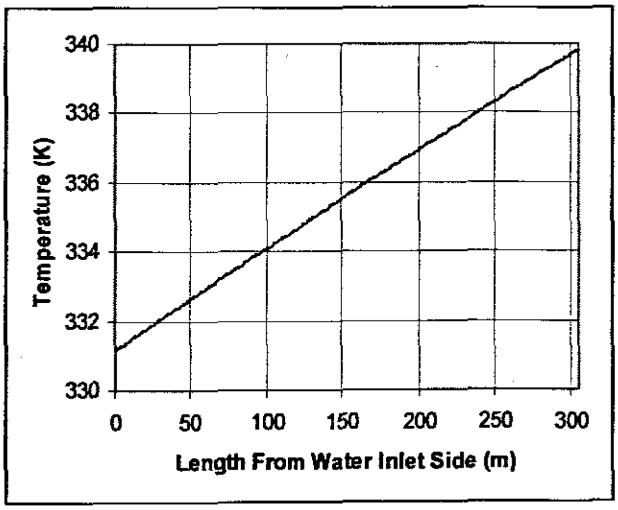

Fig.5: Seawater temperature through secondary water heater

5. PRELIMINARY DESIGN

According to the model, if:

- the air properties are to change from 10°C at a relative humidity of 100% to 65°C at 95% relative humidity, and
- a maximum desalinated water production of 217 kg/s is to be achieved,

then an evaporator area of 2,25km^2 is required with a mass flow rate of air and water of approximately 1570kg/s and 1460kg/s, respectively. At the first glance this seems very large, but if one considers that 2,2MW is required to evaporate 1kg of water, the picture changes. In addition, energy is required to heat the air and vapour. Also take into account that at maximum solar radiation, not including any energy losses, only 1kW of energy is available per square meter.[4] This is the major draw-back of solar energy systems.

It is estimated that the extra energy requirements of the plant will be in the region of 400kW. The true value remains to be determined. Since this plant will only be in true production when sufficient solar energy is available all the extra energy requirements could be fulfilled by solar panels.

6. FUTURE PLANS

A pilot plant will be built within the next few months. Extensive tests will be performed on it to determine whether the computer simulation of the plant is accurate enough. This will also show how much additional energy is needed to keep the air in motion and to pump the water.

7. CONCLUSION

A plant that, on a clear day, can produce 5 million litres of potable water a day without any energy required from the national grid has some potential. Essentially this plant would produce water without any energy source costs. However, maintenance and capital costs still have to be determined. The capital cost would have to be regained by selling the water to consumers over the lifespan of the plant. The aim of the project is to determine if a simple design such as the one discussed is worth pursuing further.

8. REFERENCES

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Presenter: The paper is presented by Christo Lourens.