Desalination Using Solar Evaporator

by

Mohd Zainul Ariffin Bin Abdul Hadi

Dissertation Submitted in partial fulfillment of the requirements for the

BACHELOR OF ENGINEERING (Hons)

(CHEMICAL ENGINEERING)

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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc Prof Ir. Abdul Aziz Bin Omar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Mohd Zainul Ariffin Bin Abdul Hadi)

ABSTRACT

This report discusses about **Desalination Using Solar Evaporator** process where the main objective of the project is to find the most promising process configuration which enable the process to produce an amount of 0.35m^3 freshwater per hour and at the same time is feasible for low and middle income people to utilize it. In this paper, focus is given to the Humidification Dehumidification (HDH) process due to its high efficiency and low environmental impact. Based on the configuration proposed, a simulation was run to obtain the optimum temperature which allows the process to produce the desired fresh water amount. A correlation between the temperature and the water production is compute hence it is used to get the optimum temperature for the process.

ACKNOWLEDGEMENT

First and foremost, I would like to thank my supervisor, **Assoc Prof Ir. Abdul Aziz Bin Omar**, for endless supports and ongoing guidance throughout finishing this project. I have acquired so much knowledge and experience from you. Words alone are insufficient to express our ultimate gratitude.

To the Chemical Engineering Department of Universiti Teknologi PETRONAS (UTP), thank you for organizing such project. Even though the going was tough, the experience gained would be cherished forever. The subject matter taught throughout almost five year period were put to good use during the course of the project in order to achieve the targeted goal.

Thank you to the Final Year Project committee for organizing lecture series as support knowledge for the team. The seminars were indeed very helpful and insightful. Special thanks to the lecturers of UTP who generously contributed their expertise to this project.

Looking back, the obstacles, the sleepless nights, the verge of giving ups, the impossibilities and the arguments, are definitely worthwhile once we have completed this valuable project.

Finally, this project offers an insight regarding the Desalination Using Solar Evaporator. Read along; take a journey through the astonishing mazes about the desalination process. I hope you will learn a lot of things and enjoy this thesis, just like we did.

"The flower that blooms in adversity is the most rarest in beautiful"

- Chinese Proverb –

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CHAPTER 1
INTRODUCTION

1.1. Water and Desalination

Water has always been earth's most valuable resource. All ecosystems and every field of human activity depend on water. Although almost 70% of the earths are actually covered by water, 97.5% of those huge amounts are actually saline water and only 2.5% is fresh water. From this 2.5%, approximately 6,910,000,000 human inhabitants of the planet shall use it for their daily purposes [1]. However, note that 80% of this global freshwater stock are actually either locked up in polar icecaps or combined as soil moisture [2].

By that statistic, it is clear how critical the global freshwater stocks are. Note that, many of us are actually not aware that there are many countries in the world that are facing with water crisis. Water crisis is basically a general term used to describe a situation where the available water within a region is less than the region's demand. The term has been used to describe the availability of potable water in a variety of regions by the United Nations and other world organizations [3] [4]. This issue is further magnified by the poor wastewater treatment from both industrial and domestic by the respective authorities which continuously has polluted the limited freshwater resources available [2]. United Nation Secretary-General, Ban Ki-moon said in a message to mark World Water Day "Let us also pledge to reverse the alarming decline in pro-poor investment in water and sanitation," [3]. In his speech, he urged governments to recognize that the water crisis facing many urban areas is the result of weak policies and poor management rather than scarcity, noting that the problem calls for increased investment in water and sanitation services.

Luckily, there are actually lots of efforts has been taken all over the world to find the solution of this problems. Some has resolve to the enforcement of laws and regulation of water protection to both industry and domestic sector and some resolved to research. Among the research that has been done, desalination is one of the most widely use method or technique where desalination basically is a process of converting saline water to freshwater by manipulating the evaporation and condensation concept.

Figure 1.1: Input – Output Diagram of Desalination Process

As shown in this figure, desalination process basically will convert brackish water which is the seawater into the freshwater targeted leaving behind a byproduct which is the brine. The processes are very simple and note that, the desalination process can occur either thermally or via membrane action [2]. What being mean by thermally is that, desalination can occur by manipulating the boiling temperature of the water itself to separate the water molecule from the salt molecule. As for the membrane action, it is basically just a filtering action by using a semi-permeable substance to separate these two molecules which are water molecule and salt molecule.

There are actually many types of desalination technique available and being practice by the industries such as Reverse Osmosis (RO), Multiple Effect Evaporator (MEE), Multiple Stage Flash (MSF), Electro-Dialysis (ED) and also Humidification Dehumidification (HDH). Every technique has its own advantages and disadvantages however, for this project, the focused shall be on the Humidification-Dehumidification technique due to its efficiency which based on the study conducted, it shall have a much higher efficiencies compare to the other methods [5][6].

A bit of desalination history, an early large-scale solar still was actually built in 1872 to supply a mining community in Chile with drinking water [7]. Mass production occurred for the first time during the Second World War when 200,000 inflatable plastic stills were made to be kept in life-crafts for the US Navy [8].

1.2. Project Background

Water crisis is a very serious issue that recently has been in focus of the world. Despite the abundant amount of water resources both saline and non-saline water that the world have, there are still lots of countries all over the world are actually facing water crisis in their homeland. This fact does not only true for poor and deserted country, but also it has been escalating to those developed countries such as Australia and Singapore.

Lots of initiatives have been taken to solve this issue however, more and more party has started to move towards desalination process since we have abundant resources to be use and hence, it is the most efficient initiatives. More countries are building desalination plant in addressing their water crisis issue such as Singapore who desalinizes seawater and also treats sewage with reverse osmosis for both industrial use and portable use [9].

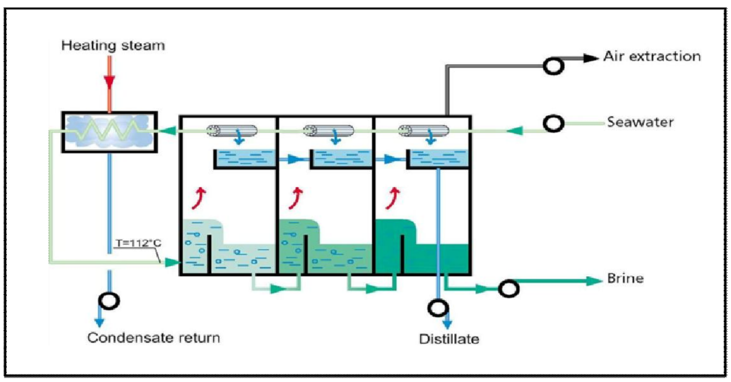

Figure 1.2: Multi-stage flash distillation

Note that, in the early stage, desalination process is being introduced for the sole purpose of producing drinking water. Hence up to the 1800, desalination technique was only used on ship boards [2]. But as the industrial era emerges, desalination technique such as Multi-Stage Flash (MSF) and Reverse Osmosis (RO) has started being adapted by the industry. In the industry, freshwater is used to as the cooking medium of the equipment such as reactor and cooler. The raw water are not supposedly being use to cool off their equipment since it can cause blockage in their pipeline and equipment which can bring to a much disastrous situation such as rupture and explosion.

As for a large freshwater production capacity, techniques such as Multi Stage Flash (MSF) and Multiple Effect Evaporator (MEE) are more preferable. However, these conventional techniques require large amounts of energy in the form either thermal energy or electric power which usually generated using fossil based fuel hence giving negative effects to the environment such as the increments of the carbon footprint and as the world now moving towards a greener technology, renewable energy based desalination such as solar powered desalination process is used [10].

In the sense of efficiency, lots of research has been done to identify the most efficient process or technique among all available technique under desalination process and it has been found that Humidification Dehumidification technique yield the best efficiency among them all [5][6]. Therefore, the focused of this project shall be towards this technique where further analysis of the process shall be observed and hence several appropriate modifications shall be applied.

1.3. Problem Statement

Water is a very essential resources not only to the human but also to every living creature in the planet and although water are actually covered almost 70% of the earth surface there are still lots of places facing with water crisis issue and the poor wastewater management which came from either domestic or industry has further magnified the issue and hence to solve the issue, desalination process is proposed

1.4. Objectives

Desalination using solar evaporator is a project initiated in order to solve water crisis issues that being faced by lots of company all around the world. Although various desalination techniques are available, this project shall focuses on the Humidification Dehumidification (HDH) desalination technique due to its high energy efficiency compare to the other technique [5][6]. Therefore, the following are the objectives being set for this project:

1.4.1. To understand the principles of Humidification-Dehumidification desalination technique.
1.4.2. To identify the preeminent process configuration of the process.
1.4.3. To perform simulation of the proposed process configuration.

1.5. Scope of Study

The scope of study in this project actually covers various aspects which shall be use as the foundation of the experimental study of the project. Among the scope are:

1.5.1. Understanding the principles of Humidification Dehumidification technique.
1.5.2. Identify the advantages and disadvantages of the Humidification Dehumidification technique.
1.5.3. Proposing appropriate modification which shall increase the efficiency of the process itself.
1.5.4. Performing simulation process to confirm that the proposed modification can give the expected results.
1.5.5. Analyzing the results hence concludes either to apply it or not.

CHAPTER 2
LITERATURE REVIEW

2.1. Desalination Process

As worldwide fresh water supplies become increasingly stressed and world populations continue to grow, seawater desalination has become an increasingly sought-after alternative for new water supply in coastal areas. While three-quarters of the globe is covered with water, less than 0.5 percent is considered a renewable freshwater supply. Desalination by definition is the process of removing salt from sea water for irrigation of the land or to provide drinking water [11]. Besides that, desalination which is also known as desalinization or desalting can also being defined as the process of removing dissolved salts and minerals from saline water to produce fresh, drinkable water [12]. There are lots of techniques available in the desalination process such as Reverse Osmosis (RO), Electrodialysis (ED), Multiple Effect Distillation (MED) and Vapour Compression (VC).

Figure 2.1: Desalination Plant

As being mention earlier, desalination concept has been widely adopted by lots of countries in order to solve their water crisis issue. However, among few problems that usually haunt the process's user are the cost and environmental impact of the process itself. Note that, the process is normally only economical if a cheap source of energy, such as the waste heat from a nuclear power station, can be used.

Desalination is first created to solve freshwater issues for the usage of seagoing ships and submarines. However, as the world change towards industrial era, most of the modern interest in desalination is now focused on developing cost-effective ways of providing fresh water for human use in regions where the availability of fresh water is, or is becoming, limited.

The world's largest desalination plant is the Jebel Ali Desalination Plant in the United Arab Emirates. It is a dual-purpose facility that uses multi-stage flash distillation and is capable of producing 300 million cubic meters of water per year. By comparison the largest desalination plant in the United States is located in Tampa Bay, Florida and operated by Tampa Bay Water, which began desalinating 34.7 million cubic meters of water per year in December 2007 [13]. The Tampa Bay plant runs at around 12% the output of the Jebel Ali Desalination Plants. A January 17, 2008 article in The Wall Street Journal states, "World-wide, 13,080 desalination plants produce more than 12 billion gallons of water a day, according to the International Desalination Association" [14].

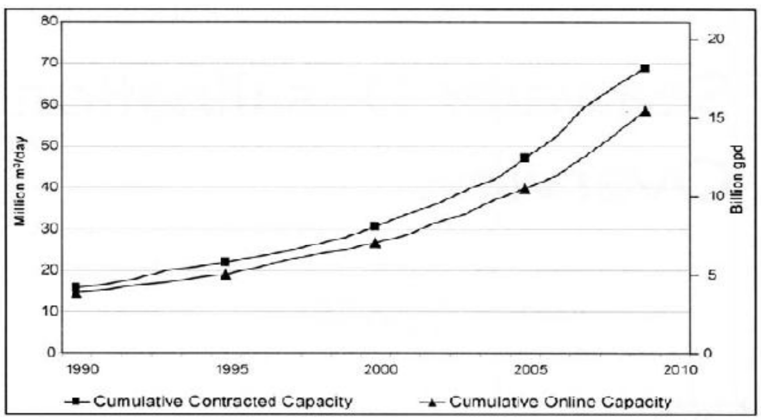

Figure 2.2: Global Growth of Desalination Facilities

Historically, the high cost of desalination has made it less attractive than freshwater supplies, even where those freshwater supplies were hundreds of miles away like Southern California. As desalination becomes more economical, its use for municipal water supply has increased dramatically. Figure 2.1above shows that the worldwide desalination capacity more than doubled between 2002 and 2010.

Desalination process can be categorized by the types of energy being used whereby it can be either thermal energy such as the Multiple Stage Flash (MSF), mechanical energy such as Reverse Osmosis (RO) and Mechanical Vapor Compression (MVC) or electrical energy such as Electrodialysis (ED). Besides that, desalination process can also being group based on the process mechanism which are membrane and thermal. See Appendix A and B for further details. Membrane-based desalination processes typically employ mechanical pressure, electrical potential, or a concentration gradient as the driving force across a semi-permeable membrane barrier to achieve physical separation while thermal desalination processes employ heat to evaporate the water from a salt solution, and the water vapor is then condensed and recovered.

Thermal technologies were the only options available for seawater desalination until reverse osmosis (RO) membranes were developed in the early 1960s. Since then, RO membrane processes have steadily been improved, and the efficiency has increased to the point that they are now the technology of choice for most seawater desalination applications. An exception to this is the Middle East and Asia, where low energy costs allow for thermal desalination to remain relatively competitive.

2.2. Membrane Separation

Membrane desalination technologies have been designed around the ability of semi-permeable membranes to selectively permit or minimize the passage of certain ions. Three fundamental driving forces can be used in membrane desalination systems including pressure, electric potential, and concentration gradient. Reverse Osmosis (RO) and Nano-Filtration (NF) are pressure driven processes. Electrodialysis (ED) and Electrodialysis Reversal (EDR) are electric potential driven processes. Forward osmosis (FO) is a concentration-driven process. Membrane-based seawater desalination processes have typically applied only RO. Nano-Filtration and Electrodialysis / Electrodialysis Reverse are mature technologies and can be used for desalination. However, Electrodialysis / Electrodialysis Reverse are typically not cost competitive for desalination of seawater while Nano-Filtration is not ordinarily considered for seawater desalination for potable water production [15].

2.3. Thermal desalination

Thermal desalination technologies work by evaporating water from a saline solution and then condensing the vapor or steam to produce distilled water. All large-scale thermal processes involve heating water to its boiling temperature to produce the maximum amount of water vapor. The pressure of the system is typically decreased so that the temperature required for boiling is reduced. Commercially available distillation systems are designed to allow for “multiple boiling” in a series of vessels that operate at successively lower temperatures and pressures. Thermal technologies that are used for desalination include Multistage Flash (MSF), Multiple Effect Distillation (MED), and Vapor Compression (VC). Multistage Flash and Multiple Effect Distillation systems typically use direct heat exchange from steam as the energy source for evaporation, while Vapor Compression systems use the heat from the compression of the vapor as the energy source for evaporation. Thermal processes can produce water with very low salt concentrations. However, there are limitations associated with distillation processes for seawater desalination.

One of the most significant limitations of thermal technologies is the energy requirement of the vaporization step. High levels of salts result in boiling point elevation, and the energy required to vaporize seawater ranges from around 25 to 100 kWh/1000 gal of fresh water produced [16]. Usually, large distillation plants are coupled with steam or gas turbine power plants, making use of low grade heat to reduce power input requirements. These thermal technologies are more commonly used in the Middle East, where energy costs are relatively low, the large land requirements are not cost prohibitive, and ecological permitting requirements are less stringent. There has long been interest in using solar energy as a source of heat for accomplishing the evaporation in distillation, but suitable technologies for a large-scale project are not yet available. Operational issues in the other hand for thermal desalination include corrosion and scaling. Because seawater is highly corrosive in nature, special alloys, such as cupronickel alloys, aluminum, and titanium, are used most commonly in desalination with distillation processes. These special alloys contribute significantly to the capital cost of a distillation plant, particularly with the large surface area required for efficient distillation.

2.4. Humidification Dehumidification (HDH) Process

As for this project, the focus shall be on Humidification Dehumidification (HDH) since in the sense of solar desalination, it has been proven that the most promising development in solar desalination was the use of the humidification dehumidification process [17] [18]. HDH is a thermal based process whereby it shall use thermal energy to evaporate water molecules from the brackish stream hence producing freshwater.

To help us understand this process, the most basic example that which explain the concept or principle behind HDH process is the rain/water cycle. The global water cycle is a redistributing agent that redistributes water from oceans to land through atmospheric circulation and then back to the ocean primarily through surface and sub-surface flows (runoff). Annually, there is a net flux of moisture from the world's oceans to the atmosphere as a result of the excess evaporation over oceans and net flux of water from the air to the land because land precipitation exceeds land evaporation when averaged over the globe.

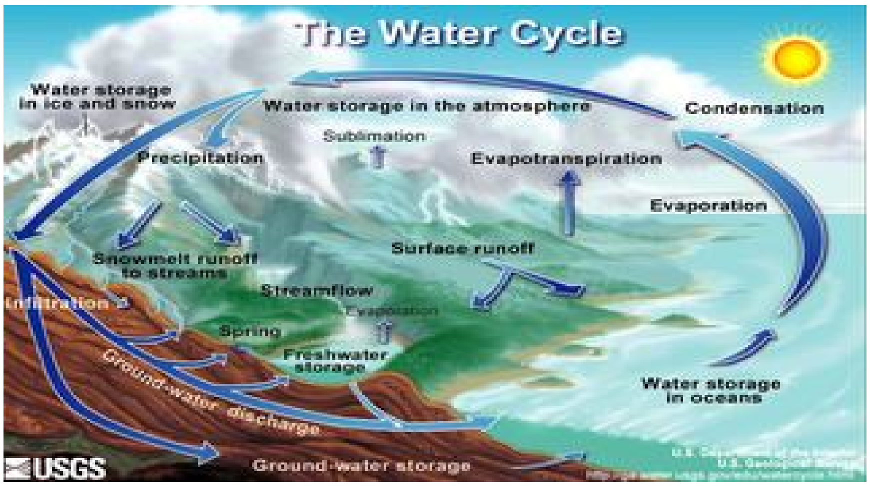

Figure 2.3: Water Cycle

The energy needed to keep the cycle operating is supplied by the sun's heat which creates an equator-to-pole atmospheric pressure differential that maintains the atmospheric circulation and provides the energy required for the phase transitions between the solid, liquid, and gaseous phases.

In the water cycle, the heat or energy provided by sun shall evaporate a portion of the seawater forming salt free water vapour. As the water vapors in the air were cooled down to its dewpoint, the air shall be saturated hence forming cloud [19]. The process shall go on and the continuation of temperature drop shall cause the water vapor to condense hence forming water droplet. Water vapour normally begins to condense on condensation nuclei such as dust, ice, and salt in order to form clouds. Condensation at surface level results in the formation of fog. If sufficient condensation particles are not present, the air will become supersaturated and the formation of cloud or fog will be inhibited.

In the HDH process, the same process as the water cycle took place. Evaporation of water molecule shall occur in the humidifier where the heat needed here is provided by a heater. The evaporated water molecule than shall move to the dehumidifier whereby in here, fresh sea water stream that shall flow into the humidifier is manipulated to absorb the heat from the water vapor stream hence allowing the water vapor stream to condense and form salt free water stream.

Note that, the concept of HDH process actually originated from a common solar still. Solar still is one of the non-conventional methods to desalinate brackish water or seawater. This process requires a comparatively simple technology and can be operated by unskilled workers and due to the low maintenance requirement, it basically can be used anywhere with a smaller number of problems. Solar still basically uses the greenhouse effect to evaporate salty water. It consists of a basin in which a constant amount of seawater is enclosed in an inverted V-shaped glass envelope as shown in Figure 2.4 below.

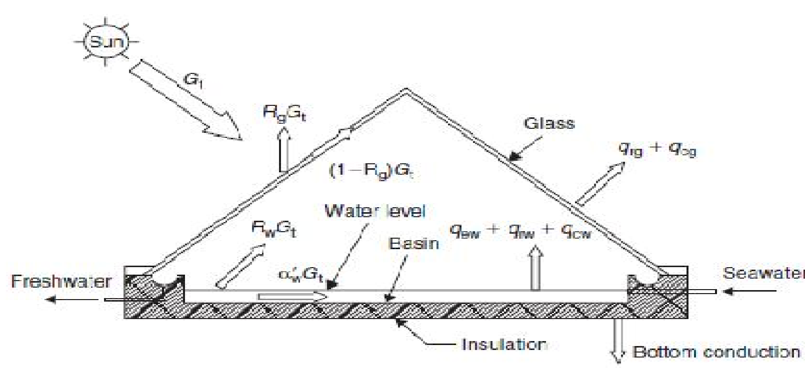

Figure 2.4: Solar Still Schematic

In the solar still, the sun's rays shall pass though the glass roof and are absorbed by the blackened bottom of the basin. As the water is heated, its vapor pressure is increased. The resultant water vapor is condensed on the underside of the roof and runs down into the troughs, which conduct the distilled water to the reservoir. The still acts as a heat trap because the roof is transparent to the incoming sunlight but opaque to the infrared radiation emitted by the hot water (greenhouse effect). The roof encloses the vapor, prevents losses, and keeps the wind from reaching and cooling the salty water.

The inner surface of the base, known as the basin liner, is blackened to efficiently absorb the solar radiation incident on it. There is also a provision to collect distillate output at the lower ends of the top cover. The brackish or saline water is fed inside the basin for purification using solar energy. The stills require frequent flushing, which is usually done during the night. Flushing is performed to prevent salt precipitation. Despite the easiness of the process, there are still few problems encountered with the solar still concept. Among the problems are:

2.4.1. The temperature of condenser surface is interrelated with the evaporating zone and hence as the evaporating zone gain heat, the amount of condensate produced shall decrease accordingly [20].

2.4.2. Water droplet or condensate formed at the condenser surface will reduce the amount of heat coming through the tank hence it will results in the decrement in the rate of evaporation.

2.4.3. Due to the design of the still itself, not all water droplet formed will go to the collecting tank since some of the water droplet are drop back into the still [20].

Now, in the case of HDH process, the humidification and dehumidification process took place in two distinct components which mean that, the correlation that relate the evaporation zone to the condensation zone can be eliminated. By doing so, it shall also allow the process's feed to be heated up to its maximum feasibility hence increase the amount of water vapor produce [21].

The HDH process also shall allow the condensate formed to be fully recovered hence avoiding the droplet to drop back into the brackish stream.

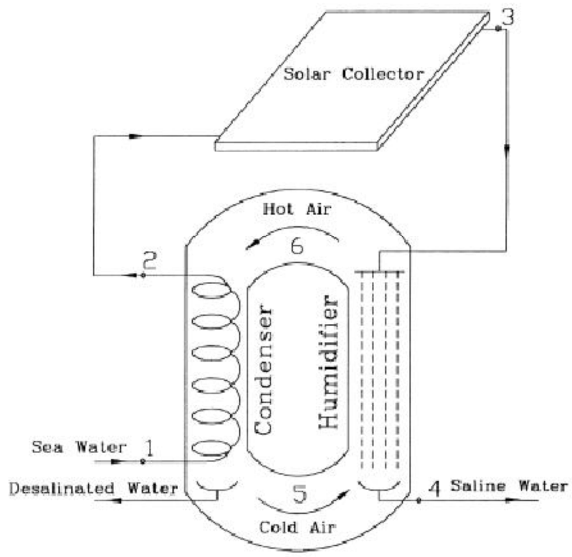

Figure 2.5: HDH process configuration

As shown in Figure 4.4 above, there are three main components that built up the HDH system which are the air and/or the water heater, which can use various sources of heat like solar, thermal, geothermal or combinations of these, the humidifier or the evaporator and lastly is the dehumidifier or the condenser.

2.5. HDH Process Classification

The HDH process can be classified based on the form of energy used such as solar, thermal, geothermal, or hybrid systems, the type of heating used -water or air heating systems or based on the cycle configuration. The cycle configuration of the HDH process can be either Closed Air Open Water system (CAOW) where air is being heated and circulated in a closed loop between the humidifier and dehumidifier or Closed Water Open Air system (CWOA) where air is heated, humidified and partially dehumidified and let out in an open cycle [22].

2.6. Proposed HDH Process Modification

The HDH process has been analyzed so that, possible improvement or modification can be made to the process. Based on the analysis, it has been found that there are few common feature of the process which shall give some room for improvement to it. One of the features identified is that in the normally used HDH process, the rejected brine stream is usually being directly bypassed into the cooling tank. Besides that, it has also been identified is that common HDH process is usually conducted or operated at atmospheric pressure. Therefore, as to increase the efficiency of the process, these modifications are proposed:

2.6.1. Installation of a simple heat exchanger to the rejected brine stream.

The idea here is that, in normal HDH process, the rejected brine stream is usually being directly bypassed into the cooling tank. So, by installing a simple heat exchanger for the rejected brine stream, it shall allow us to utilize the energy contained by the brine stream which is in the form of heat to increase the temperature of the fresh water stream which is flowing into the humidifier.

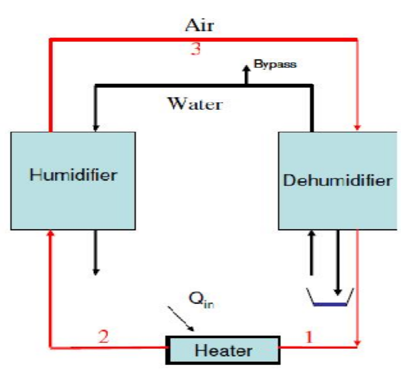

Figure 2.6: Common HDH process

By inserting the heat exchanger, in theory it should allow some work decrement for the heater hence allowing us to save some utilities cost.

2.6.2. Operate the system/process at vacuum condition.

Based on the studies, it has been found that the humidity ratios are actually much higher at a vacuum condition or at a pressures lower than atmospheric pressure. Currently, most of HDH process is conducted at atmospheric pressure but as being proven in the study, an operating pressure which is less than atmospheric should be considered.

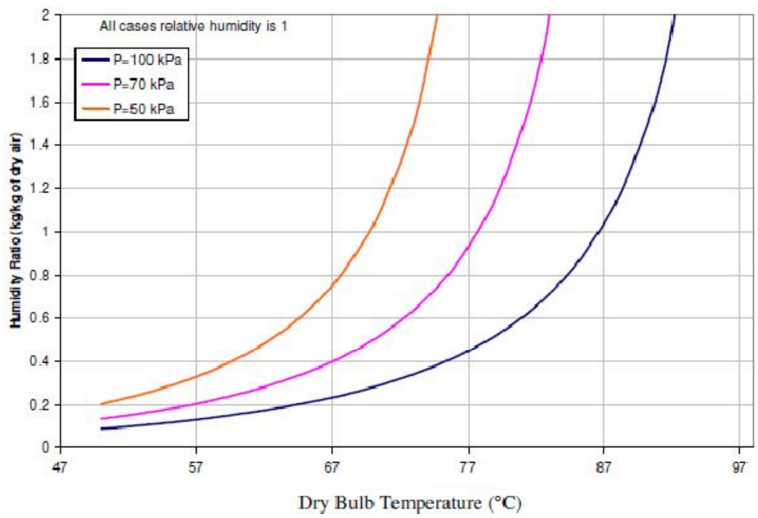

Figure 2.7: Graph of Humidity Ratio vs. Dry Bulb Temperature

This graph shows that the humidity ratio is actually increased as the pressure decrease. Note that, at temperature of 67 ^{0}C, the humidity ratio at 100 kPa is 0.21 kg/kg of dry air while at 50 kPa, the humidity ratio is 0.79 kg/kg of dry air. Note that humidity ratio here indicate the amount of water molecule per dry amount of air for a system [23]. Therefore, as the HDH systems were conducted at a pressure lower than atmospheric pressure, the amount of fresh water produce should increase accordingly.

2.6.3. **Both humidifier and dehumidifier shall adapt the heat exchanger concept.**

By adapting the concept of shell and tube heat exchanger, it will allows the air and water to exchange heat with each other where the air shall release its heat to water hence evaporate the water for further processes. The heat exchanger shape will also prolong the resident time of both air and water hence increase the heat transfer amount [24].

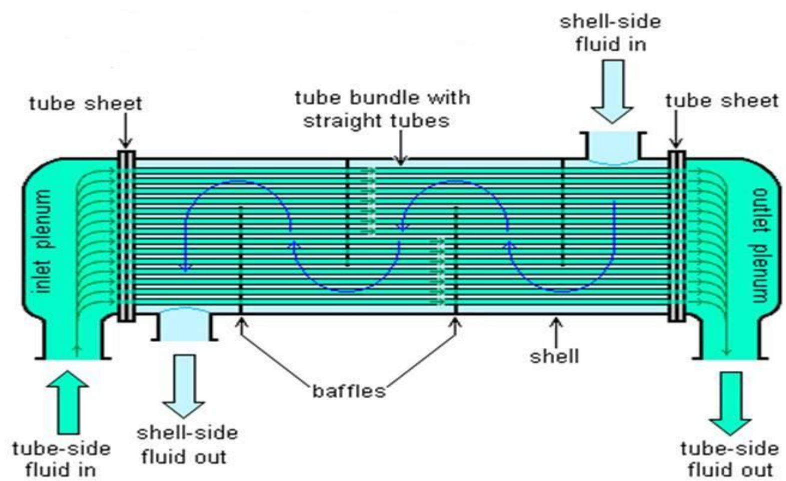

Figure 2.8: Shell and Tube Heat Exchanger

In addition to that, the surface of the device shall adapt the fin-like surface shape which will increase the heat transfer area hence increase the amount of heat being transferred from the hot air to the cold sea water stream in the humidifier and from the hot fresh water stream to the cold air in the dehumidifier. This shall also decrease the amount of work done by the heater hence saving some utility cost.

CHAPTER 3
METHODOLOGY

3.1. Methodology

The purpose of this project basically is to come out with a design of HDH process which comparatively is better than the normally use design. Therefore, this project has been further divided into three phase as shown in Figure 3.1 below.

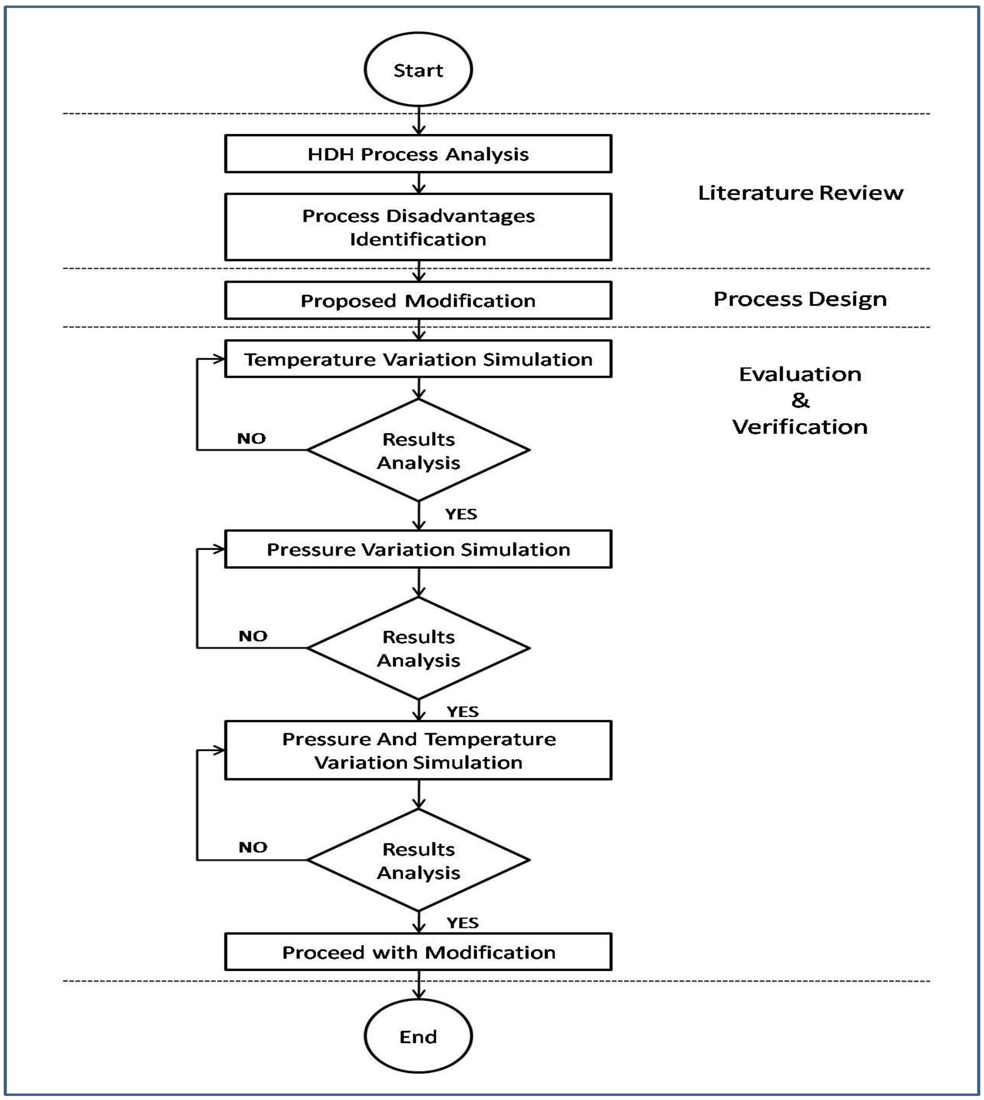

Figure 3.1: Project Methodology

3.2. Research and Data Gathering

To carry out this project, it is important to fully understand about concept of the Humidification Dehumidification (HDH). Therefore, reviewed on books, journals, papers and other technical documents related with HDH process have been thoroughly done. This stage of research and data gathering beneficially by giving insight and basic knowledge about project conducted. In this stage, the HDH process design shall be identified hence analysis is executed in order to find the advantages and disadvantages of the process. By doing so, some modification shall be made to the process design where theoretically, it shall increase the performance of the process.

3.3. Process Design

As being stated earlier, based on the analysis made on the currently existing process, some modifications shall be made to the currently used design as to increase its performances. Among the proposed modification to the process are to adapt the heat exchanger concept, to conduct the process at vacuum condition and also to insert an additional heat exchanger to the process. To confirm back these modifications can give us the expected results, simulations are conducted accordingly.

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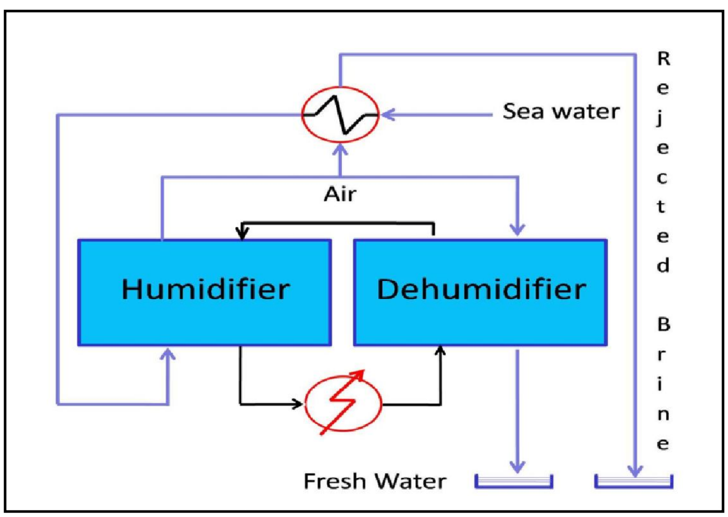

Figure 3.2: Proposed Design

3.4. Evaluation and Verification

This is the last stage of the project. In this stage or phase, simulation processes using the Aspen HYSYS® are conducted. The simulation process are actually being divided into three where in the first run, the simulation shall study the effect of the temperature to the system while the pressure being held constant at atmospheric pressure. Couples of temperature point were used for us to get the data variation pattern for further analysis. The data than shall be analyzed and based on that, decision shall be made either to proceed with the modification or not. This goes to all simulation run whereby the data shall be analyze hence decision either to proceed with the modification or not shall be made.

As for the second part of the simulation, the focus here is to identify the effect of pressure variation toward the system. Based on the research done in the first stage of the project, conduction the process in vacuum condition should help the process to increase the amount of freshwater yield. Couples of pressure point are used in order to get the variation pattern and hence analyses of the data are conducted accordingly.

In the last stage of the simulation, both temperature and pressure shall be used as the manipulated variables where the objective here is to identify the optimum temperature and pressure which shall give us the pre-determined freshwater production. Several pressure and temperature points are used and the data later on are analyzed accordingly.

3.5. Project Gantt chart

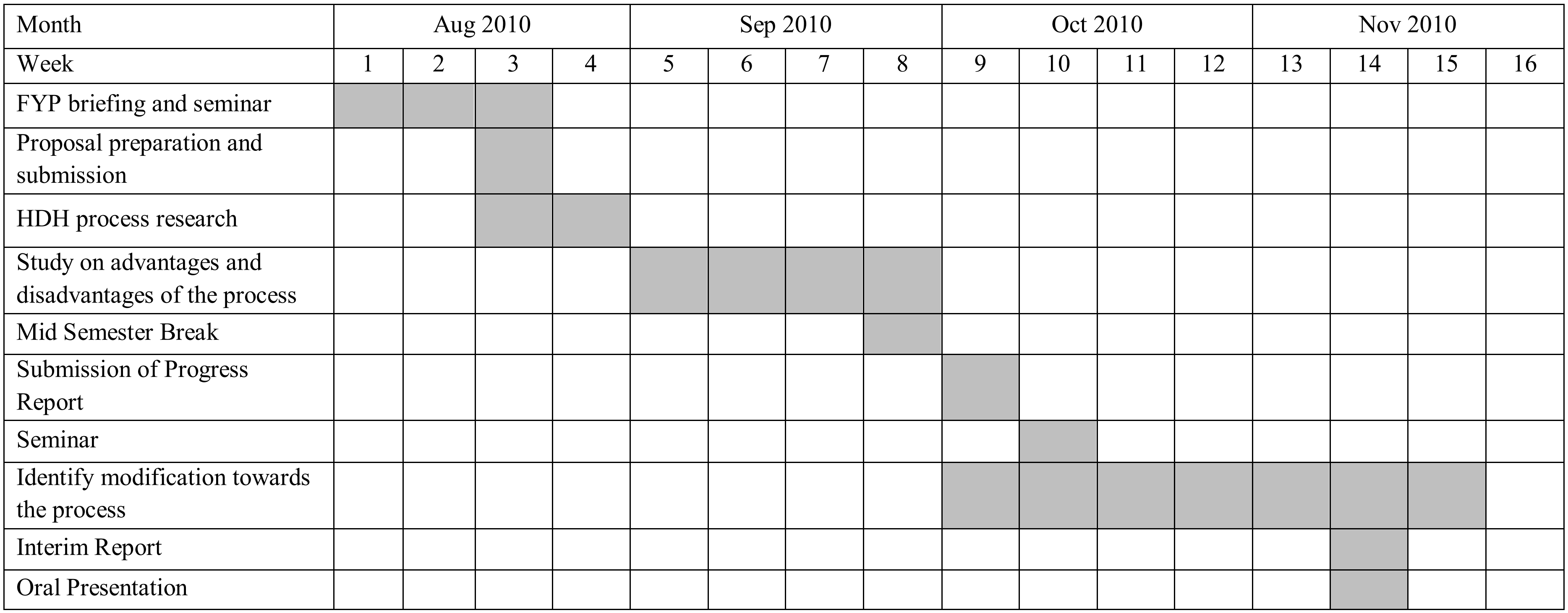

Figure 3.3: Gantt chart for Final Year Project 1

Month	Aug 2011				Sep 2011				Oct 2011				Nov 2011			
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project Work Continue (create mesh files, run simulation)	■	■	■													
Submission of Progress Report 1			■													
Project Work Continue (add buffer and run simulation)			■	■	■	■										
Submission of Progress Report 2							■									
Seminar (compulsory)											■					
Project Work Continue (collect all data and analyze data)						■	■	■	■	■						
Poster Exhibition											■					
Submission of Dissertation (soft bound)															■	
Oral Presentation	Week 18 - 19															
Submission of Project Dissertation (Hard Bound)																■

Figure 3.4: Gantt chart for Final Year Project

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1. Simulation Process.

A simulation has been done in order to find the appropriate temperature and pressure of the design. Several assumptions were made for the simulation. Those assumptions are:

4.1.1. The air composition was assumed to contain 79% of Nitrogen and 21% of Oxygen.
4.1.2. The water composition was assumed to contain only Sodium and Water.
4.1.3. Systems are at steady state.
4.1.4. The heat loss to surroundings is negligible.

Note that, these assumptions had been made due to several limitations to the simulator whereby it could not create an accurate hypothetical compound for the fluids used in this simulation. Figure 4.1 below illustrate the setup used in the simulation.

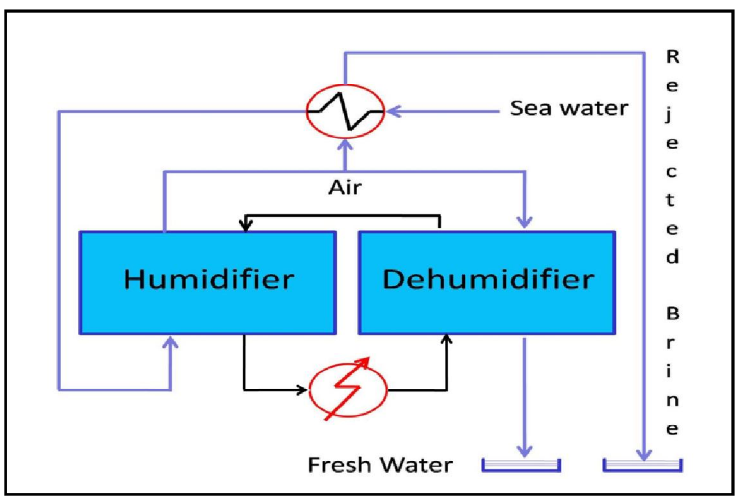

Figure 4.1: Simulation Setup

4.2. Results and Discussions.

Note that based on the statistic provided by the Organisation for Economic Co-operation and Development (OECD), the annual Malaysia's water consumption is 12.7 x 10^6 m^3which give us the average water consumption per capita per year of 92.8 m^3 [25], as shown in Table 4.1 below . By using those statistics for the basis, the targeted production of fresh water by daily basis shall be 0.25m^3. By assuming average number of every household is seven, the total production on daily basis is 1.75m^3 and by converting it to hourly basis, the targeted production is 0.35m^3 per hour.

Table 4.1: Malaysia Water Consumption Statistics

Country	Domestic Use, m^3 per Capita per Year	Country	Annual Water Consumption, billion m^3
Netherlands	29.9	**Ireland**	0.6
Switzerland	40.5	**Denmark**	1.2
United Kingdom	43.6	**Switzerland**	1.2
Ireland	47.6	**New Zealand**	2.0
Finland	57.8	**Norway**	2.0
Portugal	68.5	**Finland**	2.2
Germany	69.7	**Austria**	2.4
Denmark	72.1	**Sweden**	2.9
France	85.5	**Portugal**	7.3
Malaysia	92.8	**Netherlands**	7.8
Norway	100.8	**Greece**	8.7
Austria	104.1	**United Kingdom**	11.8
Australia	112.5	**Malaysia**	12.7

4.3. Temperature Variation Effect.

From the simulation performed, a clear relationship between two variables which are the temperature of the sea water in the humidifier and also the amount of fresh water yield can be observed where as the sea water temperature in humidifier increase, the higher fresh water yield will be. This is because as the temperature of the sea water increase, the rate of water evaporation shall increase proportionally.

By that logic, a very high temperature shall be proposed to be used in the process. However, the main objective of this project is to create desalination process of which is economical for the common people to use such as villagers and so on. Therefore, simulation process via the Aspen HYSYS simulator was conducted in order to determine the optimum temperature which will gives us the targeted production of fresh water which is $0.35m^3$.

Results of the simulations are as follow:

Table 4.2: Results of Simulation Process

Temperature	Fresh water (m^3)	Rejected Brine (m^3)
60	0.057	2.443
70	0.078	2.422
80	0.118	2.382
90	0.237	2.263

From the result, it is clear that the temperature play an important role in determining the amount of fresh water produced. The closest and highest fresh water production in this case is achieved at a temperature of 90 ^{0}C which is $0.237m^{3.}$ This indicates that in order to achieve the targeted production, the process's temperature must be in 100 ^{0}C to 90 ^{0}C range. Therefore, another simulation was run in order to find the exact temperature which will allow the system to produce $0.35m^3$ of fresh water.

Results of the second simulation can be observed in table 4.2 below.

Table 4.3: Fresh Water Yield Variation

Temperature	Fresh water (m^3)	Rejected Brine (m^3)
90	0.237	2.263
91	0.263	2.237
92	0.296	2.204
93	0.339	2.161
94	0.396	2.104
95	0.476	2.024
96	0.595	1.905
97	0.794	1.706
98	1.189	1.311
99	2.356	0.144

From the results, at 90 ^{0}C the amount of water yield is 0.237m^3. An increasing pattern in production can be observed from this point onwards however, there is no clear consistent increment in the production. As for the targeted water production which is 0.35m^3, the closest yield is achieved at 93 ^{0}C where the production in 0.339m^3. This indicate that the appropriate temperature which allow the targeted production to be achieved is between 92 ^{0}C to 94 ^{0}C.

Therefore, to get the exact value of the temperature which will gives us the targeted production, a regression analysis technique is use where a correlation that connects these two variables; the amount of fresh water yielded and the temperature was generated. Results of the analysis are shown in Figure 4.2.

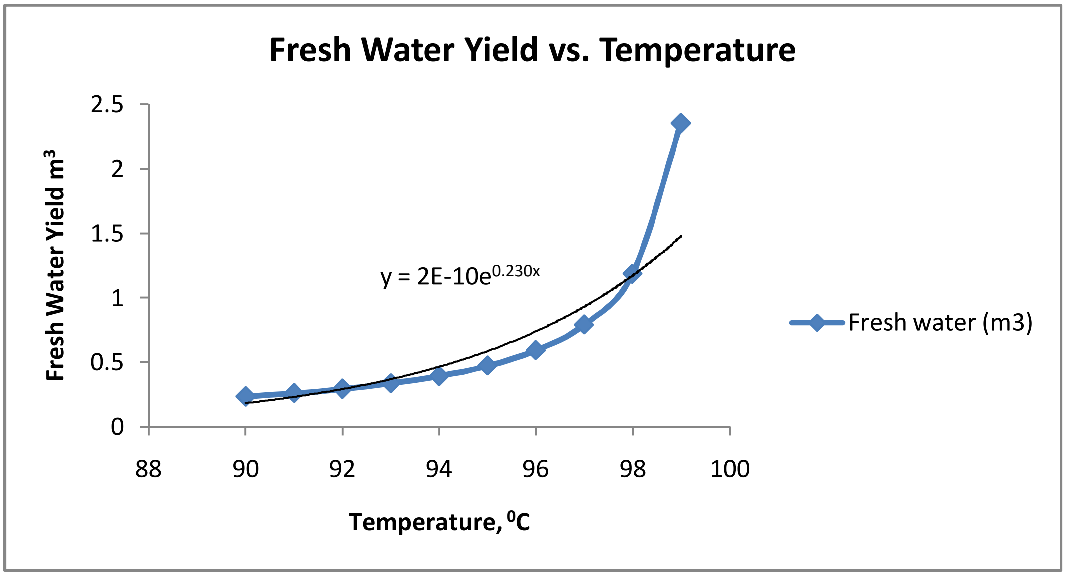

Figure 4.2: Temperature Variation Regression Analysis

From the analysis, a data distribution pattern can be observed whereby it is represented by an exponential equation where $y = 2E10^{-10}e^{0.230x}$. Therefore, in order for the process to yield 0.35m^3 of fresh water, the corresponding temperature that should be use is:

$$y = 2E10^{-10}e^{0.230x}$$

$$\frac{0.35}{2E10^{-10}} = e^{0.230x}$$

$$Therefore, x\ = 92.534\ ^0C$$

As the calculation indicates, the corresponding temperature which will give us the desired fresh water production is 92.534^{0}C which falls within the estimated value made earlier. Table 4.4 below summarise the analysis.

Table 4.4: Proposed HDH Design Temperature.

Fluids	Humidifier		Dehumidifier	
	In (^{0}C)	Out (^{0}C)	In (^{0}C)	Out (^{0}C)
Sea Water	30.0	92.534^{0}C	-	-
Fresh Water	-	-	92.534	30.1

Note that, as the simulation process take place, the temperatures readings of the air stream are also being recorded. Theoretically, by applying the proposed design of the Humidification Dehumidification process, it shall help in reducing the amount of work done by the heater in heating up the air whereby the proposed design shall allow the incoming sea water stream to be pre-heated first before entering the humidifier.

In the commonly use Humidification dehumidification design, the incoming water stream are not in contact with the hot water vapor stream flowing into the dehumidifier. Only air stream shall be in contact with it hence resulting in waste of energy since the air stream could not fully absorb the heat from the water vapor stream.

Table 4.5 here indicate the temperature condition as the commonly use Humidification Dehumidification design is used.

Table 4.5: HDH Common Design Temperature.

Fluids	**Humidifier**		**Dehumidifier**	
	In (^{0}C)	**Out (^{0}C)**	**In (^{0}C)**	**Out (^{0}C)**
Air	98.5	30.2	30.2	57.3
Sea Water	30.0	92.534^{0}C	-	-
Fresh Water	-	-	92.534	30.1

Based on the data, the commonly use design shall required us to heat up the air up to 98.5 ^{0}C in order to allow the water stream to heat up from 30 ^{0}C to 92.534 ^{0}C. Note that, the inlet water temperature here is considered to be at standard room temperature. Now, as for the proposed design, the temperature conditions are as follow:

Table 4.6: Proposed HDH Design Temperature

Fluids	**Humidifier**		**Dehumidifier**	
	In (^{0}C)	**Out (^{0}C)**	**In (^{0}C)**	**Out (^{0}C)**
Air	93.1	30.2	30.2	57.3
Sea Water	30.0	92.534^{0}C	-	-
Fresh Water	-	-	92.534	30.1

As the data indicate, the air stream here only needs to be heated up to 93.1 ^{0}C in order to heat up water stream to 92.534 ^{0}C. By comparison, the proposed Humidification Dehumidification design shall give a temperature reduction or difference, ΔT is 5.4^{0}C. Therefore, the amounts of energy saved are:

$$Q = mc\Delta T$$

$$Q = (971.8\ kg/m^3)(0.35\ m^3)(4.205\ kJ/kg\ ^oC)(5.4\ ^oC)$$

$$Therefore, Q = 7723.332\ kJ/kg$$

From this calculation, the proposed configuration can save us up to $7723.332\ kJ/kg$ of energy compare to the common configuration hence proving that the proposed design is better than the commonly use design.

4.4. Pressure Variation Effect

Research has been done with regards to the effect of pressure to the Humidification Dehumidification process whereby it was stated that by lowering the operating pressure or by making the system slightly vacuum, it can increase the amount of the fresh water yield [23]. However, there are no experimental or simulation data presented to support the theory.

Therefore, the objective of this second simulation is to prove this theory. Note that, the temperature used in this simulation is fixed at 92.534 ^{0}C ≈ 93 ^{0}C which is based on the predetermined/calculated temperature from the previous simulation analysis. The same process configurations are used as before to avoid deviation of results. Results of the simulation are shown in Table 4.7 below.

Table 4.7: Results of Simulation Process

Pressure (kPa)	Fresh water (m^3)	Rejected Brine (m^3)
101.325	0.332	2.168
90	0.689	1.811
80	1.931	0.569

Based on the results, it is clear that variation of pressure contribute significant effect to the Humidification Dehumidification process where, by operating the process in a vacuum condition, the amount of water production will increase significantly.

As the pressure decrease from 101.325 kPa which is 1 atm to 90 kPa or 0.89 atm, the amount of fresh water yielded increase more than two fold or 107.53% to be exact. When the pressure being further reduced to 80 kPa however, the amount of water production has further increase to 1.931 m^3 which is far more than the targeted production which is just 0.35m^3. Therefore, in order to find the appropriate pressure which will allow the process to reach the targeted production, another simulation process was run with a pressure variation value range from 90 kPa to 101.325 kPa.

Results of the simulation are as follow:

Table 4.8: Fresh Water Yield Variation

Pressure (kPa)	Fresh water (m^3)	Rejected Brine (m^3)
90	0.689	1.811
91	0.631	1.869
92	0.583	1.917
93	0.540	1.960
94	0.504	1.996
95	0.471	2.029
96	0.442	2.058
97	0.417	2.083
98	0.394	2.106
99	0.373	2.127
101.325	0.332	2.168

Here, it is observable that as the pressure increase, the fresh water yield shall decrease. At 90 kPa, the amount of fresh water yielded is 0.689 m^3 while at 95 kPa, the amount has decrease to 0.471 m^3 and at 101.325 kPa, the amount of fresh water obtained has dropped to just 0.332m^3. The reason behind this phenomenon is that as the pressure increase, it will provide external force which will compress the water molecule closer to one another hence, it shall be harder for us to break up these molecules since the attraction force between the molecule is stronger. Therefore, as the pressure increase, the boiling point of water shall increase and since in this simulation process the temperature is held constant, the amount of water production will decrease.

Now, a regression analysis was made in order to identify the data distribution pattern where it shall be used in determining the exact pressure which shall allow the process to achieve the targeted production.

Figure 4.3 here shows the regression analysis made.

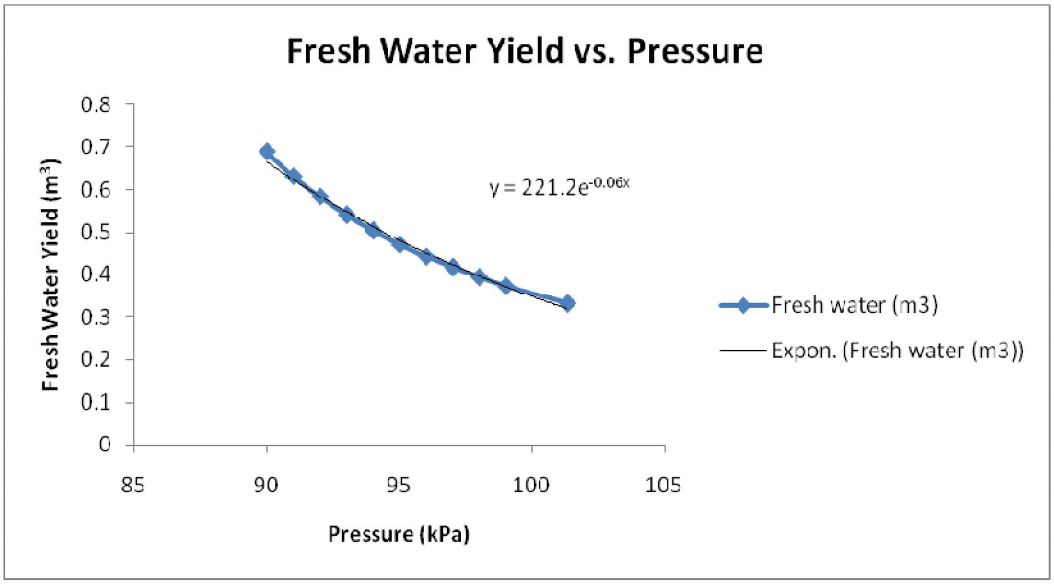

Figure 4.3: Pressure Variation Regression Analysis

From the analysis made, the effect of pressure variation to the Humidification Dehumidification process can be represented by a polynomial equation where $y = 221.2e^{-0.06x}$, hence the corresponding pressure in this case which allow us to achieve the targeted production is:

$$y = 221.2e^{-0.06x}$$

$$0.35 = 221.2e^{-0.06x}$$

$$Therefore, x = 99.507\ kPa$$

Therefore, the corresponding pressure which can satisfy the predetermined amount of fresh water is 99.507 kPa. However, recall that the temperature was remains constant as the simulation process to analyse pressure variation effect to desalination process. So, both calculated temperature and pressure from the data obtained via the simulation executed are cannot be consider as the final operating temperature and pressure to be used in the Humidification Dehumidification process. Hence, another simulation is run in order to identify the optimum operating condition where for this run, both temperature and pressure shall be treated as the manipulated variable.

4.5. Optimum Process's Temperature and Pressure

As being mention in the previous section, the identified pressure and temperature so far could not being consider as the optimum operating condition. In order to determine the optimum operating condition, another simulation was run whereby, based on the data collected so far, the temperature variation shall range from 80 ^{0}C to 100 ^{0}C while the pressure variation shall be from 90 kPa to 99 kPa.

The same process configuration was use in determining this. Two different random values are use in this simulation which were 90 kPa with a temperature variation range from 85 ^{0}C to 92 ^{0}C and 97 kPa with a temperature variation range from 90 ^{0}C to 97 ^{0}C.

Results of the simulation at 90 kPa are shown in Table 4.9 below:

Table 4.9: Fresh Water Yield at 90kPa

Pressure (kPa)	Temperature (^{0}C)	Fresh water (m^3)
90	85	0.225
	86	0.244
	87	0.268
	88	0.298
	89	0.335
	90	0.384
	91	0.450
	92	0.544

From these data, it is clear that by decreasing the pressure to 90 kPa, it shall allow the system to achieve the targeted production which is 0.35m^3 of fresh water at a much lower temperature that is 90 ^{0}C compared to temperature needed when the pressure was set at 101.325 kPa which is 92.534 ^{0}C. This means that by conducting the process at 90 kPa, the system shall have a temperature reduction of 2.534 ^{0}C.

Now, to further analyse the data, a regression analysis as shown in Figure 4.4 was conducted whereby the data distribution pattern is identified.

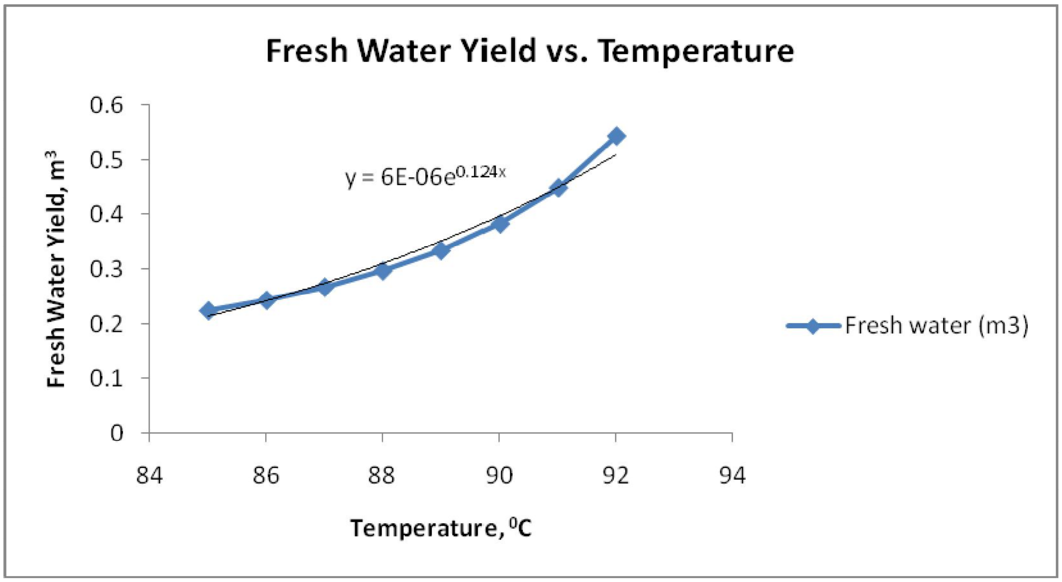

Figure 4.4: Regression Analysis - 90 kPa

From the regression analysis made, the data can be represented by an exponential equation where $y = 6E - 06e^{0.124x}$. Therefore, for the process to achieve the targeted production, the corresponding temperature is:

$$y = 6E - 06e^{0.124x}$$

$$0.35 = 6E - 06e^{0.124x}$$

$$Therefore, x = 89.57\,^{O}C$$

Based on this calculation, the system shall meet the targeted production of $0.35m^3$ at 89.57^0C which gives us a total temperature reduction of 2.964^0C. The given reductions actually are quite small compare to the amount of pressure being reduced. Note that, the pressure is being reduced from 101.325 kPa to 90 kPa. Therefore, a reduction of 1 kPa shall give us only 0.2617^0C of temperature reduction.

Now, for the second part of simulation, the pressure shall be fixed at 97 kPa. Results of the simulation are as follow:

Table 4.9: Fresh Water Yield at 97kPa

Pressure (kPa)	**Temperature (^{0}C)**	**Fresh water (m^3)**
97	90	0.276
	91	0.311
	92	0.356
	93	0.417
	94	0.504
	95	0.637
	96	0.866
	97	1.350

At 90 ^{0}C, the amount of fresh water yielded when the process is conducted at 97 kPa is just 0.276m^3 which is relatively smaller compared to the amount of fresh water yielded at the same temperature at 90 kPa. Further analysis was made using the regression analysis technique as shown in this figure:

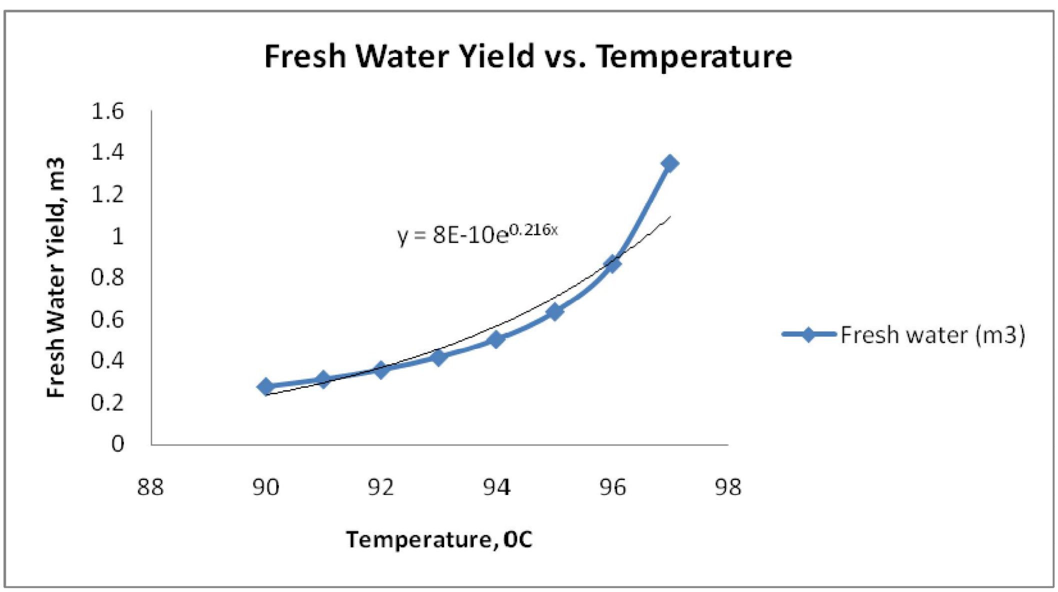

Figure 4.5: Regression Analysis - 97 kPa

As being shown on the graph, the data collected can be represented by an exponential equation where $y = 8E - 10e^{0.216x}$. Therefore, in order for the process to produce 0.35m^3 of fresh water, the temperature needed is:

$$y = 8E - 10e^{0.216x}$$
$$0.35 = 8E - 10e^{0.216x}$$
$$Therefore, x = 92.11\ ^{O}C$$

Based on the calculation, the corresponding temperature that shall allow the process to achieve the targeted production is 92.11 ^{0}C which give us a total temperature reduction of 0.424 ^{0}C as compared to the water stream temperature at 101.325 kPa. By that right, a reduction of 1 kPa shall only gives us a temperature reduction of 0.098 ^{0}C.

From these two sets of data, it can be conclude that by reducing the pressure, it shall allow increments in terms of the water production. However it is not significant enough for us to proceed with since when the process was held at 90 kPa, each reduction of 1 kPa shall only provide a temperature reduction of 0.2617 ^{0}C while when the process was held at 97 kPa, each pressure reduction shall only results in 0.098 ^{0}C.

Since the amount of temperature reductions are relatively small and in order for the process to operate at vacuum condition is relatively much expensive compared to normal condition (101.325 kPa), it is concluded that the process shall not be conducted at vacuum condition. This is because for the system to be in vacuum condition, a suction pump needs to be installed in order to create the vacuum condition whereby the vacuum pump alone shall cost us around $575 to $4000 excluding the maintenance cost.

Therefore, it is not feasible for the process to be operated at vacuum condition since they can't give any major increments in the water production and hence, the operating condition for the process shall be 92.534 ^{0}C and 101.325 kPa.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

As from the results obtained, it can be conclude that the temperature and pressure can give a significant impact to the process. Based on the simulation, by inserting an additional heat exchanger which shall utilize the heat from the rejected brine stream, it shall allow the system to reduce work done by the air heater. By inserting the additional heat exchanger, the air stream that flowing into the humidifier are only needed to be heated up to 93.1 ^{0}C in order to heat up water stream to 92.534 ^{0}C which give a temperature reduction or difference, ΔT is 5.4^{0}C or $7723.332\ kJ/kg$ of energy compare to the common configuration hence proving that the proposed design is better than the commonly use design. As for the pressure study, the analysis was made from two pressure points which are 90 kPa and 97 kPa. From the two sets of data, it can be conclude that by reducing the pressure, it shall allow increments in terms of the water production. However it is not significant enough for us to proceed with since when the process was held at 90 kPa, each reduction of 1 kPa shall only provide a temperature reduction of 0.2617 ^{0}C while when the process was held at 97 kPa, each pressure reduction shall only results in 0.098 ^{0}C. Since the amount of temperature reductions are relatively small and in order for the process to operate at vacuum condition is relatively much expensive compared to normal condition (101.325 kPa), it is concluded that the process shall not be conducted at vacuum condition. This is because for the system to be in vacuum condition, a suction pump needs to be installed in order to create the vacuum condition whereby the vacuum pump alone shall cost us around $575 to $4000 excluding the maintenance cost. However, for a much higher capacity of production, it is recommended for the process to be operated at vacuum condition hence allowing the process to increase the amount of freshwater production at a much lower temperature compared to common HDH configuration.

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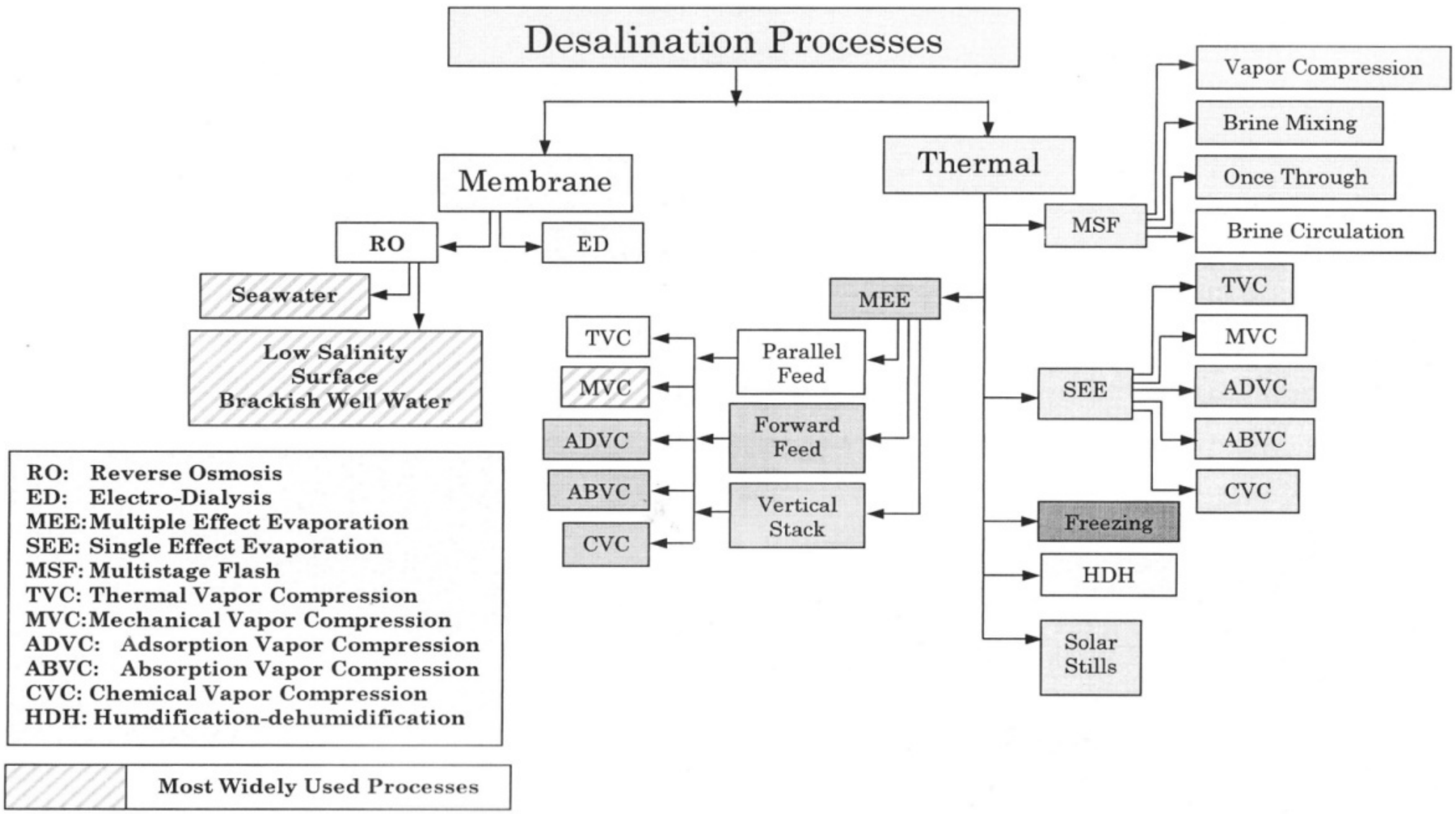
APPENDIX 1

1.0. Thermal and Membrane Desalination Process



APPENDIX 2

2.0. Energy Classification of Desalination Process