# MARMARA UNIVERSITY
# FACULTY OF ENGINEERING

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## Müdek Final Project Commission

**The essential features of an acceptable design Project**

| | | Satisfied | Unsatisfied |
|---|---|---|---|
| 1 | Mechanical or Thermal Design | ✓ | |
| 2 | Report writing technique | ✓ | |
| 3 | Development of student creativity | | ✓ |
| 4 | Use of open-ended problems | | ✓ |
| 5 | Formation of design | ✓ | |
| 6 | Problem statement and specification | ✓ | |
| 7 | Synthesis of alternative solutions | | ✓ |
| 8 | Feasibility | ✓ | |
| 9 | Detailed system description | ✓ | |
| 10 | Consideration of constraints (e.g. economic, safety, reliability, etc. ) | Cost analyses is not clear | ✓ |
| 11 | Utilization of engineering and scientific principle | ✓ | |

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| **Accepted but not approved** | 27.08.2021 |
| Prof. Dr. Bülent Ekici, | |
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| Ar. Gör Serkan Öğüt | |

## GRADUATION PROJECT REPORT

Department of Mechanical Engineering

**Supervisor**

RA MUSTAFA CEM ÇELİK

ISTANBUL, 2021

# MARMARA UNIVERSITY
# FACULTY OF ENGINEERING

# THERMAL ANALYSIS AND DESIGN

# OF A

# DESALINATION SYSTEM

**by**

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Signature of Author(s) ......................Aylin Yılmaz, Özcan Akbıyık...........................................

Department of Mechanical Engineering

6.07.2021        Dr. M. Cem Çelik

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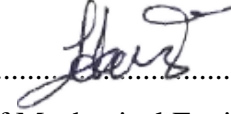
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Head of the Department of Mechanical Engineering

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Özcan Akbıyık, Aylin Yılmaz

# İçindekiler

# ABSTRACT

Our water reserves started to decrease with the increase of climate change and drought in the world. Within the increasing population, our requirements for clean water are increasing day by day. With the decrease in existing water resources, the treatment of sea water and the provision of drinking and utility water has started to become the main topic of the world. Many processes that are currently under development may be referred to as conventional in the future. However, now unconventional water resources are being used. Thanks to the developing technology, it becomes possible to obtain fresh water from these sources.
In recent years, fresh water, drinking water and tap water can be obtained from sea water and wastewater by evaporation in many countries.

Free surface water reservoirs are used for different purposes in many industrial factories. Heat transfer and diffusion occurs on the free surface, which allows the steam to mix with air. There are many different empirical calculation methods that calculate that the amount of air evaporated. The rate of evaporation we find may differ depending on the driving forces between gas and water or the temperature-based driving forces.

In this study, methods of obtaining clean water from wastewater, under what conditions the wastewater comes from, how it can be recycled, how much energy will be spent for this, cost calculation, etc. We will examine the topics covered. We will examine the dimensionless equations in two ways according to the evaporation rate and natural or forced convection.[6]

# ÖZET

Dünyadaki iklim değişikliği ve kuraklığın artmasıyla su rezervlerimiz azalmaya başladı. Artan nüfusla birlikte temiz suya olan ihtiyacımız gün geçtikçe artıyor. Mevcut su kaynaklarındaki azalma ile birlikte son zamanlarda, deniz suyunun arıtılarak içme ve kullanma suyu temin edilmesi gündeme gelmeye başlamıştı. Şu an gelişme aşamasında olan pek çok proses belki ileride konvansiyonel olarak anılacak. Bununla beraber artık konvansiyonel olmayan su kaynaklarından faydalanılmaya başlanıyor. Gelişen teknoloji sayesinde bu kaynaklarından tatlı su elde etmek mümkün hale geliyor.

Son yıllarda artık birçok ülkede deniz suyundan, atık sulardan buharlaştırma yöntemiyle tatlı su, içme suyu, çeşme suyu elde edilebiliyor. Birçok endüstriyel fabrikada serbest yüzeyli su rezervleri değişik amaçlarla kullanılıyor. Serbest yüzeyde ısı transferi ve difüzyon oluşuyor ki bu da buharın hava karışmasını sağlıyor. Buharlaşan hava miktarını hesaplayan birbirinden farklı birçok ampirik hesaplama yöntemi var. Bulduğumuz buharlaşma oranı gaz ve su arasındaki itici güçlere göre veya sıcaklık bazlı itici güçlere göre farklılık gösterebilir.

Bu çalışmamızda atık sudan temiz su elde etme yöntemlerini, atık suyun hangi koşullarda geldiği, nasıl geri dönüştürülebileceği, bunun için ne kadar enerji harcanacağı, maliyet hesabı vb. kapsayan konuları inceleyeceğiz. Boyutsuz denklemleri buharlaşma oranına göre doğal veya zorlanmış konveksiyona göre iki şekilde inceleyeceğiz.[6]

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# KEY TO SYMBOLS AND ABBREVIATIONS

**Nomenclature**

$A$ Area
$C_{sf}$ surface constant
$c_p$ specific heat capacity
g gravitational acceleration
$h_{fg}$ latent heat
$k$ thermal conductivity
$P$ pressure
$Pr$ Prandtl Number
$q''$ heat flux
$T$ Temperature
$L$ length
$Q$ heat transfer rate
$\dot{m}$ mass flow rate
$V$ velocity
$D$ pipe diameter
$h_m$ mass convection coefficient
$Nu$ Nusselt number
$Re$ Reynolds number
$\bar{h}$ average convection coefficient

**Greek Symbols**

$\propto$ thermal diffusivity
$\mu$ dynamic viscosity
$\rho$ density
$\sigma$ surface tension
$\varphi$ relative humidity

**Subscripts**

$f$ fluid
$g$ gas
$l$ liquid
$sat$ saturated
$v$ vapor
$in$ inlet
$out$ outlet
$s$ surface

## Abbreviations

| | |
|---|---|
| SD | Solar Distillation |
| MED | Multi-effective Distillation |
| MSF | Multistage Distillation |
| MD | Membrane Distillation |
| MVC | Mechanical Vapor Compression |
| TVC | Thermal Vapor Compression |
| RO | Reverse Osmosis |
| ED | Electrodialysis |

# CHAPTER 1

# 1. INTRODUCTION

Although three quarters of the world is water, freshwater resources suitable for drinking and use are very limited. The total freshwater capacity of the world is approximately 35 million $km^3$, of which only 105 thousand $km^3$ (0.3%) are freshwater resources suitable for natural environment and human use needs. Other freshwater resources are at the poles and underground and their use is very limited. Available freshwater resources: It is decreasing day by day due to drought, climate change, industrialization, increasing population density, unplanned urbanization. Insufficiencies in water resources, constantly increasing water demand have led to the application of alternative water production methods for drinking and utility water supply.

Turkey's total surface area is 783 562 $km^2$ and is a country surrounded by sea on three sides. Turkey is not a country rich in water resources and temperate, is a semi-arid climate where there are extremes in temperature and. The annual average rainfall is calculated as 643 mm, and it is seen that this amount is below the world average (800 mm). The total amount of water consumed is increasing every year and it is estimated that the increase will continue in the coming years. According to the freshwater consumption estimates for 2023, it is expected that the entire current freshwater capacity will be used. According to the current water situation and forecasts, serious problems occur in water supply and studies have started to implement alternative water treatments methods. [1]

Water treatment is any process that improves water quality to make it more acceptable for a particular end use. End use can be drinking water, industrial water supply, irrigation, river flow maintenance, water recreation, or many other uses, including safe return to the environment. Water treatment removes contaminants and unwanted components or reduces their concentration, making the water suitable for the desired end use. There is also wastewater treatment or wastewater treatment, which is the reclamation of water after it is used for domestic or industrial purposes. With the decrease in existing water resources, the treatment of sea water has recently come to the fore together with the provision of drinking and utility water. The main technologies applied for the treatment of salt water are divided into desalination and

evaporation. [2]

# 2. LITERATURE SURVEY

## 2.1. DESALINATION

Desalination or sea water treatment is the process of separation of salt from sea water and other substances in order to obtain usage and potable water. Processes aiming to obtain water for drinking, irrigation and use by removing salt, minerals and other impurities in the water are generally called desalination processes.
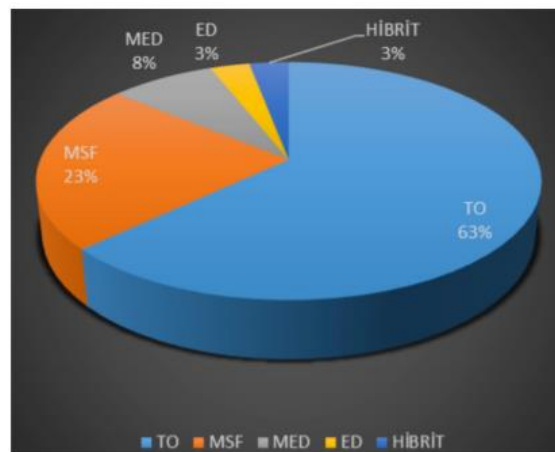


*Figure 1: Desalination Techniques*

Thermal processes include an evaporator and condenser system to purify clean water by evaporation. Membrane processes include the separation of dissolved salts by mechanical or chemical/electrical methods and the production of drinking water. Thermal desalination technologies include solar distillation (SD), multi-effective distillation (MED) and multi-stage distillation (MSF) processes. Membrane desalination technologies include electrodialysis and reverse osmosis. In addition, in recent years, hybrid systems using both thermal and membrane processes have been used. In this context, especially membrane distillation (MD) and reverse osmosis supported MSF and MED processes stand out.

In 2005, while 60% thermal methods were used in desalination technologies, 40% membrane technologies were used. This is now shared by 60% membrane technologies and the rest by thermal and hybrid technologies. Approximately 70% of the desalination facilities established after 2000 were established with membrane desalination technology. The current desalination industry consists of 63% reverse osmosis, 23% MSF and 8% MED processes, while the remainder includes electrodialysis and other hybrid processes (Gude, 2016). [3]

### 2.1.1. <u>Desalination Types</u>

There are basic processes to separate salt from water: thermal and membrane processes.

### a. <u>Thermal Technologies</u>

Thermal desalination technologies are based on the principle of evaporation of water from the brine solution and then the condensation of the resulting steam to produce pure water. All large-scale thermal processes require the water to be heated to boiling temperature to produce the maximum amount of water vapor. Generally, the pressure of the system is lowered to reduce the temperature required for boiling. Distillation systems can be designed to allow multiple boiling in series units at successively lower temperature and pressure.

#### i. Pre-treatment

Although thermal processes are not very sensitive to seawater concentration, they are less sensitive to suspended particles than membrane-based systems. A simple screen filtration technique is often suitable to remove coarse particles. By using simple ejector condensers, there is a need to remove non-condensing gases and oxygen that may accumulate in the system in this process and cause corrosion. In addition, these processes are more susceptible to the possibility of calcium salts (mostly gypsum on heat transfer surfaces) precipitation than membrane-based systems.[4]
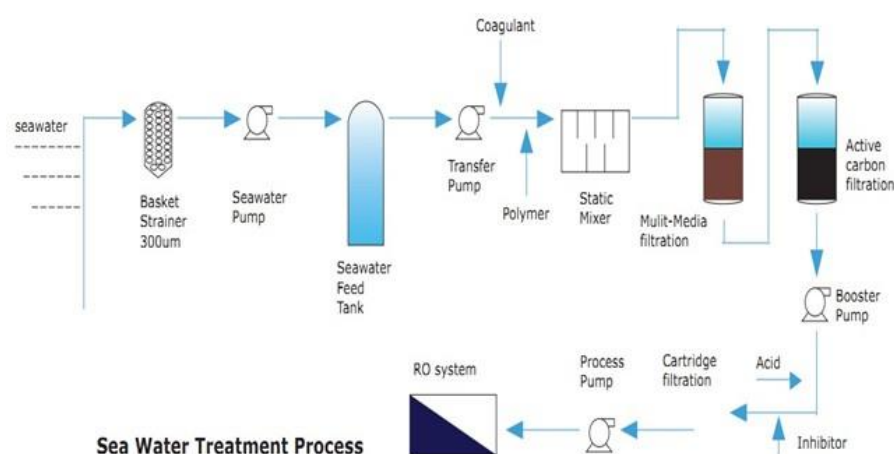


*Figure 2: Water Treatment Stages*

## ii.   Multistage Thermal Distillation (MSF)

In the MSF process shown in the figure 3, water is boiled at temperatures below normal boiling temperature. This is called rapid boiling in the literature.  Seawater is heated in the heater before it can enter the stages in series. These stages constitute the evaporator. These stages are operated at reduced pressure compared to atmospheric pressure so that rapid boiling can occur when the heated water enters these stages. Steam generated at each stage is converted to fresh water by condensation in tubes and collected separately from salt water. Subsequently, the tubes are cooled by the seawater flow towards the heater. This increases the temperature of the sea water. Thus, the amount of thermal energy needed in the heater to raise its temperature is also reduced. Fresh water flowing from stage to stage is collected as a product in the last stage. Chemical can then be added to adjust its pH and hardness before its storage or use.[5]

Most MSF facilities are dual-purpose. It covers both power generation and water distillation jobs. The waste heat generated during electricity generation is used to heat sea water. This ensures high thermal efficiency and low operating costs.

Some of the disadvantages of these plants create air pollution mainly due to their high energy consumption and they consume higher energy compared to reverse osmosis. In addition, the high rate of encrustation of the surfaces inside the tubes is a disadvantage. It is also sensitive to fluctuations in water demand.
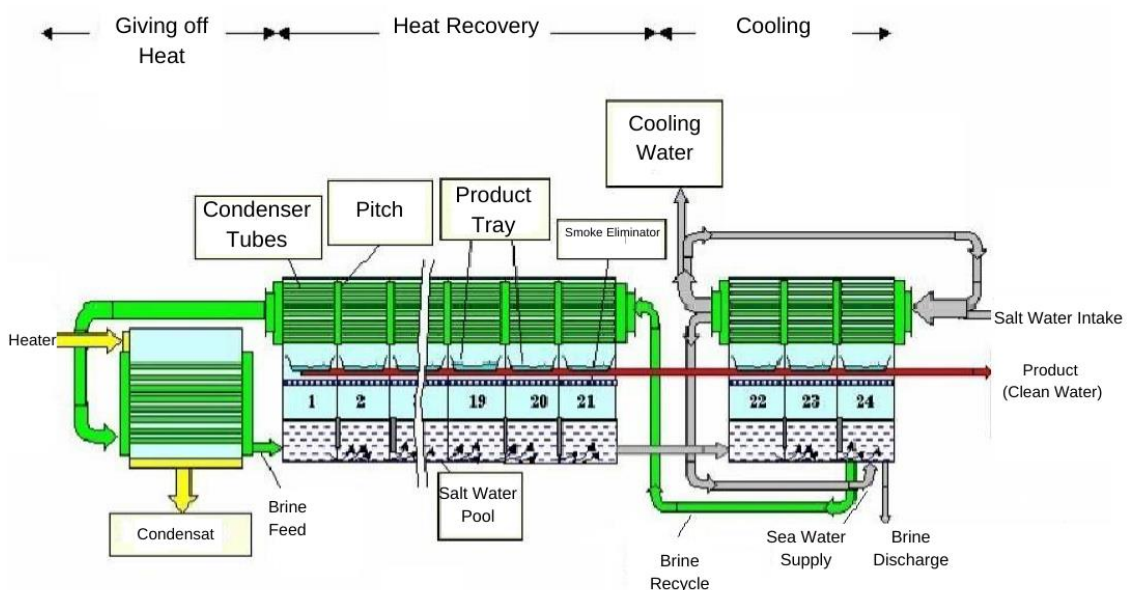


*Figure 3: Multistage Thermal Distillation*

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### iii. Multi Effective Distillation (MED)

In these facilities shown in Figure 4, sea water passes through a series of evaporators in series. The steam produced in one series is used to evaporate the water in the other series. This approach is based on reuse of the evaporation heat by the evaporators and condensers placed in series. The heat of vaporization resulting from the condensation of the steam produced is used to heat the brine in the next lower temperature and pressure stages. Thus, multiple boiling of water is allowed after the first impact without requiring additional heat.

In these facilities, sea water takes the first effect and is heated to boiling point. Brine is sprayed onto heated tubes or flows into vertical surfaces in a weak layer to promote rapid boiling and evaporation. A small portion of the brine transferred to the tubes evaporates on the first effect. The other part passes to the tubes where the second effect is applied, which is heated by the steam produced in the first effect. As this steam condenses, the heat it gives off allows the salty water in the other stage to evaporate. As can be seen below, the condensate is recycled.

These facilities have a wide selection of sources and produce high quality products with high reliability. However, as an advantage, it has low energy consumption compared to MSF and its low operating temperature is sufficient (reduces encrustation and energy costs).
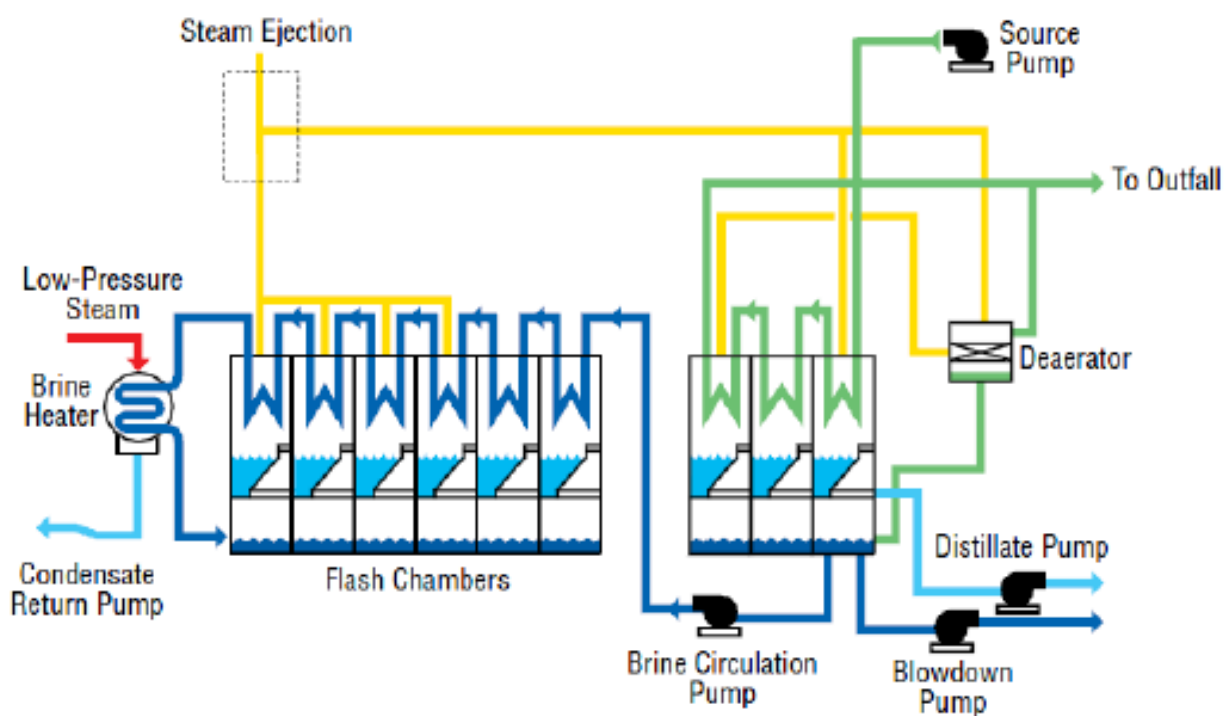


*Figure 4: Multi Effective Distillation*

### iv. Vapor Compression (VC)

These systems shown in the figure function by compressing the water vapor. This causes condensation on the heat transfer surface (tubes). Thus, the heat of condensation is transferred to the salt water on the other side of the surface. This provides evaporation. The main energy requirement in these systems is for the compressor. The compressor increases the pressure on the steam side while decreasing the pressure on the brine side to lower its boiling temperature. There are two approaches to heat supply for evaporation in vapor compression systems, mechanical (MVC) and thermal (TVC).
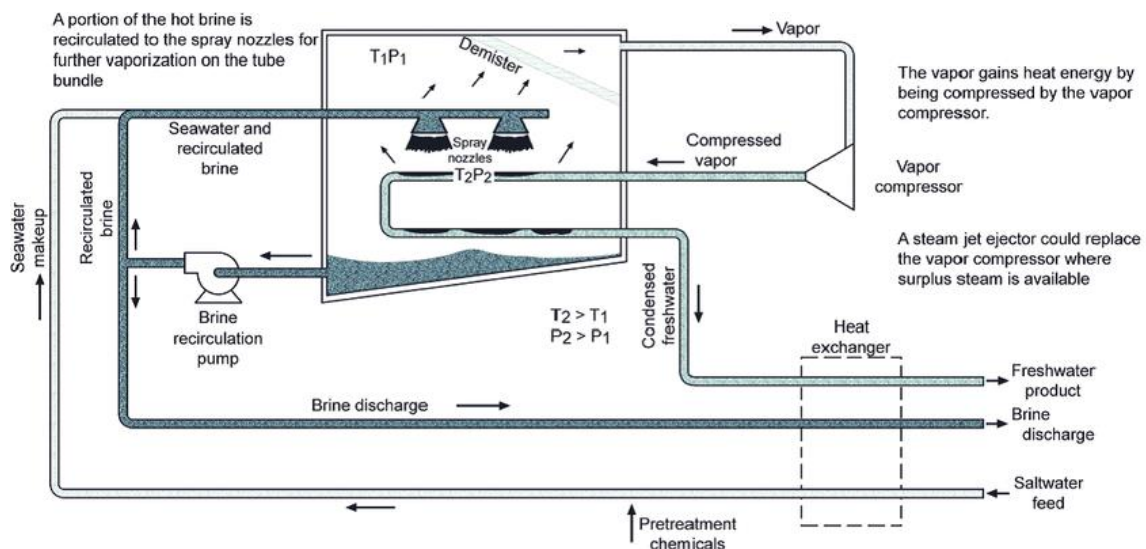


*Figure 5: Vapor Compression*

### b. Membrane Processes

Membrane processes are processes where the membrane system is used to physically separate components. The two most used membrane processes in seawater treatment are reverse osmosis and electrodialysis.

### i. Reverse Osmosis (RO)

The most used membrane process in desalination plants is reverse osmosis. Reverse osmosis is the process of separating microparticles and heavy metals in water by applying pressure to water during the filtration process. Reverse osmosis water purification devices, which have the most effective water purification method known, are successful in removing water from small-sized substances that are difficult to separate in the previous stages.

Desalination systems operated by reverse osmosis process consist of three stages (AWWA, 2007). These are pre-treatment, membrane system and post-treatment. The flowchart of a typical reverse osmosis desalination system is given in the figure below. Water taken with a

suitable water intake structure is first pre-treated. Since Reverse Osmosis membranes are operated at high pressure and are costly materials, pre-treatment of raw water ensures long-lasting use of reverse osmosis membranes and prevents possible operational problems. Since reverse osmosis membranes provide 99% ion removal, the exiting water must be conditioned and disinfected with free chlorine to be used for human consumption.
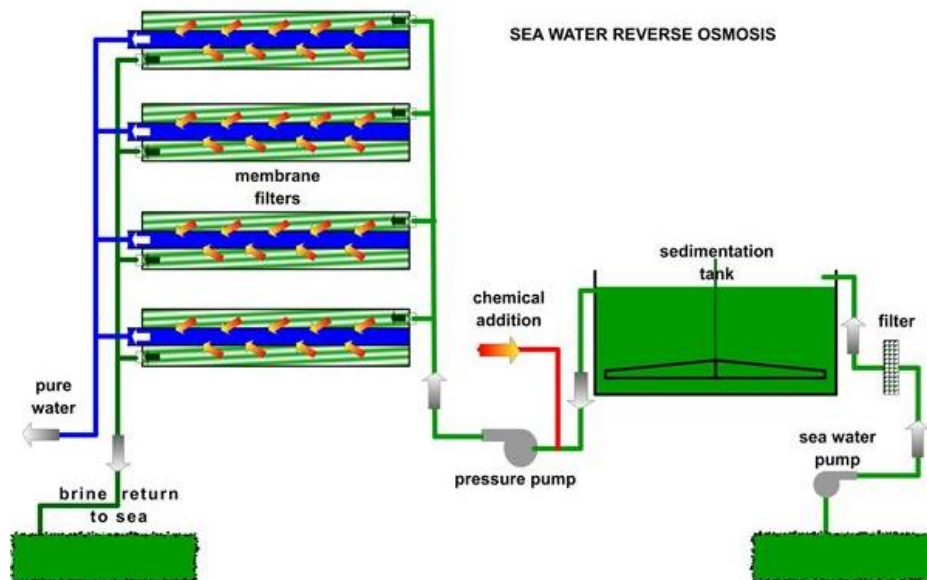


*Figure 6: Reverse Osmosis*

### ii. Electrodialysis

Electrodialysis processes use ion-selective membranes and use electric potential as a driving force to separate charged species from water. An electrical field is used to separate and collect dissolved ions from the water along the flow. An electrodialysis process involves alternating anionic and cationic ion-selective flat membranes. These create channels of water that are desalinated and rejected. While cations pass to the cathode, anions pass to the anode. Meanwhile, cation selective membranes allow only cations, and anion selective membranes allow only anions. The net effect also appears to be the removal of salt from each cell.

### iii. Nanofiltration

Nanofiltration is a technology that is generally applied to soften water and remove disinfection by-products, and although some configurations of two-pass NF are successfully used in seawater desalination, it is not generally used in this field.

These systems are used for hardness removal, bacteria and virus removal, demineralization, desalination, and wastewater recovery by passing water through a semi-permeable membrane with an average porosity of 0.001 microns.

Since the membrane porosity is greater than the RO technology, there is a limited amount of conductivity removal, so it can be used for hardness removal in some applications where conductivity is not required.

## 2.1.2. **Comparison of Desalination Techniques**

By making use of the seas and oceans, which are an almost unlimited saltwater resource, a vital opportunity can be created for people living in water-stressed settlements. However, it can be said that desalination methods in distance and cost studies conducted to increase the sources of new fresh water will be less costly with the developing technology in the coming years compared to water transport from long distances. There are many factors affecting the production of fresh water from seawater:

- The size of the facility,
- Chemical composition of treated water,
- The required degree of purity in the product,
- Unit cost of electrical and thermal energy,
- Climate and other building conditions,
- Ambient and water temperature,
- Annual loading factor,
- Depreciation and interest rates,
- The life of the components, including the heat transfer area,
- The selected type of transformation.

It can be seen in the figure that for MSF, which does not include steam generation equipment in terms of initial investment, the cost varies between 1.5 and 30 million dollars according to its total capacity.[5]
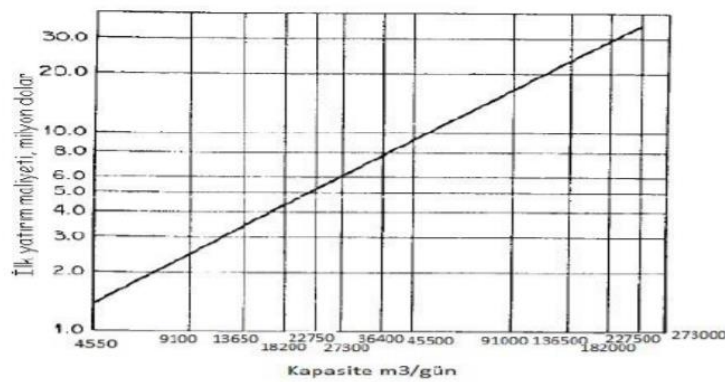


*Figure 7: Relation Between İnvestment and Capacity*

| Conversion Technology | Specifications | Pretreatment | Operating Temperature (ºC) | Fresh Water Efficiency (%) | TÇK (mg / L) |
|---|---|---|---|---|---|
| Membrane | • Low operating and investment costs.<br>• Electrical energy is required.<br>• Low energy requirement.<br>• Less facility spaces.<br>• A performance that has been improving for almost 20 years. | Filtration and dosing are required | Ambient Temperature | 30 - 60 | 350 - 1000 |
| Thermal | • High operating and investment costs.<br>• Heat energy is required.<br>• High energy requirement.<br>• An old and reliable system. | Virtually no pretreatment is required. | 60 - 110 | 10 – 20 | < 25 |

*Table 1: Differences Between Membrane and Thermal Technology in Terms of How They Work*

| | MSF | MED | TVC | MVC | RO | ED |
|---|---|---|---|---|---|---|
| Operating Temperature | < 120 | < 70 | < 70 | < 70 | < 45 | < 45 |
| Form of Energy | Vapor | Vapor | Vapor | Mechanic (Electric) | Mechanic (Electric) | Mechanic (Electric) |
| Electricity Consumption (kWh / m3) | 3,5 | 1,5 | 1,5 | 8 - 14 | 4 - 7 | 1 |
| Typical salt content of raw water (ppm TÇK) | 30k - 100k | 30k - 100k | 30k - 100k | 30k - 50k | 1000 - 45k | 100 - 3000 |
| Product Water Quality (ppm TÇK) | < 10 | < 10 | < 10 | < 10 | < 5000 | < 500 |
| Single module capacity (m3 / day) | 5000 - 60k | 500 - 12k | 100 - 20k | 10 - 2500 | 1 - 10000 | 1 - 12000 |

*Table 2: Process Data Comparison*

## 2.2. Evaporation Rate

### 2.2.1.    <u>Evaporation</u>

Evaporation is the process of changing from a liquid state to a gas or vapor. Evaporation is the way it is transported from its liquid state as a gas or vapor to the atmosphere. Research shows that oceans, seas, lakes and rivers provide about 90% of the moisture in the atmosphere, with the remaining 10% coming from evaporation at the plant surface.

Heat (energy) is one of the others for evaporation to occur. Energy is other important for the bonds that hold water molecules together; so, water evaporates at its boiling point (100 ° C, 212 ° F) but much more slowly at freezing point. Evaporation cannot continue in the saturated air environment (ie if the relative humidity is 100%). The evaporation process takes the heat away from the environment, so evaporation of the water gives coolness to the person.[9]

### 2.2.2.    <u>Evaporation Rate</u>

Evaporation of water from a water surface - like an open tank, a swimming pool or similar - depends on water temperature, air temperature, air humidity and air velocity above the water surface.

### a. <u>Methods for Estimation Evaporation Rate from Water Surface</u>

The amount of water evaporated from a water surface can be measured using the

following methods:

1.      Evaporimeter method.
2.      Analytical methods.
3.      Empirical evaporation equations, i.e., evaluated from experimental results.

#### i.  Evaporimeter Method

To estimate the evaporation rate of lake evaporation, this method is used, and it is known as the simplest and cheapest process. The storage equation can be evaluated in this process, and the pan evaporation rate is greater than the actual evaporation of the lake. Therefore, the evaporation of the pan to real lake evaporation using a pan coefficient must be minimized. Pan coefficient depends on the types of pan used, such as Class A evaporation pan, Colorado sunken pan, and US geological survey floating pan.

$$Lake\ Evaporation = \ P_c * Pan\ Evaporation$$

$P_c$ = Pan Coefficient. the values of $P_c$ in use for different pans are given in the following table.

| Serial number | Types of pan | Average value | Range |
|---|---|---|---|
| 1 | Class a land pan | 0.70 | O.60-0.80 |
| 2 | Colorado sunken pan | 0.78 | 0.75-0.86 |
| 3 | USGS floating pan | 0.80 | 0.70-0.82 |

*Table 3: Value of Pan Coefficient $P_c$*

The methods of the evaporation pan are not exactly models that can be used to estimate the evaporation rate of large reservoirs for the following reasons: they vary in the ability of heat storage and heat transfer from the sides and bottom; thus, to minimize this deficiency, sunken pan and floating pan are used; the height of the rim in an evaporation pan determines the wind movement on the water surface, and the heat transfer characteristic of the pan material varies from the reservoirs. The evaporimeter was thus considered to measure the rate in evaporation from small ponds used in a field test.[7]

### ii. Analytical Methods

The analytical approaches used to assess the rate of evaporation can be widely used.

Classified into four classifications as:

    A. Water Budget Method.
    B. Energy Budget Method.
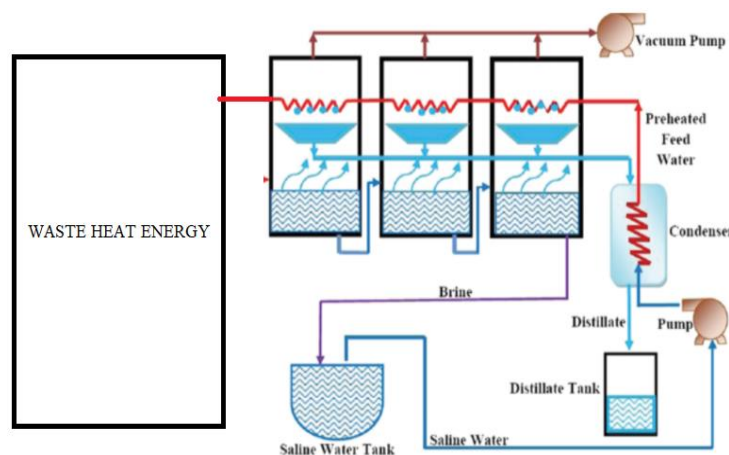    C. Mass Transfer Method.
    D. Combined method



*Figure 8: Schematic Representation of a waste heat energy powered multi-stage flash desalination system*

## A. Water-Budget Method

Water-Budget approaches are clear in principle, but in practice they yield inconsistent results. The unreliability of the results can be attributed to the fact that the accuracy of the calculation is heavily dependent on the reliability of the inflow, outflow, and filtration data. Some of the variables are very difficult to calculate, such as the seepage rate in the water systems. Consequently, this method's implementation is not commonly used. The water storage expenditure equation is as follows:

$$E = P_p + I - G_w - O - \Delta S$$

E is defined evaporation rate (kg/m$^2$.sec), P$_p$ is defined as the precipitation over the storage(kg/m$^2$.sec), I is defined as the inflow (kg/m$^2$.sec), G$_w$ is defined as the net groundwater(kg/m$^2$.sec), O is defined as the outflow(kg/m$^2$.sec), and ΔS is defined as the change in reservoir contents (kg/m$^2$.sec).[7]
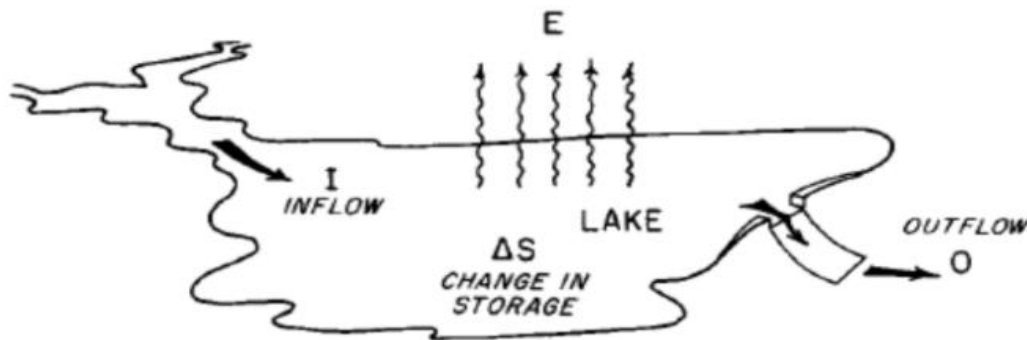


*Figure 9: Water-Budget Method for Measuring Evaporation*

## B. Energy -Budget Method

A significant amount of heat flux is needed for the phase change from liquid to vapor. The approach of energy budgeting is based on energy conservation within the water body. A balance must exist between the heat losses and gains for any given body of water. The heat gain may be from radiation, conduction, and condensation of large and short-wave waves. Direct and reflected radiation, conduction, advection, and evaporation may be responsible for heat losses. In other words, the first law of thermodynamics describes this process.

*(Inflow – Outflow) = (change in storage).*

Heating caused by chemical and biological processes, heat transfer by conduction through the bottom, and kinetic energy conversion into thermal energy were neglected in this system. The energy budget methods are reliable in theory and 14 suitable for research purposes only in small areas, because of their requirements for detailed metrological data, such as net radiation and sensible heat. So, this method is restricted to be only used in small areas. An expression for the energy budget given by Harbeck et al. (1958) as follows:

$$Q_A = Q_s - Q_r + Q_{LW} - Q_{rLW} - Q_{LWe} - Q_h + Q_v - Q_E - Q_w$$

Where $Q_A$ is defined as the increase in energy stored by water body (J), $Q_s$ is defined as the solar radiation incident to the water surface (J) , $Q_r$ is defined as the reflected solar radiation(J), $Q_{LW}$ is defined as the incoming longwave radiation from the atmosphere(J), $Q_{rLW}$ is defined as the reflected longwave radiation(J), $Q_{LWe}$ is defined as the longwave radiation emitted by the water body (J), $Q_h$ is defined as the energy conducted from the body of water due to the temperature difference between that surface and air as sensible heat(J), $Q_V$ is defined as the net energy advected into the water body (J), $Q_E$ is latent energy carried away by the evaporated water (J) , and $Q_W$ is defined as the energy advected by the evaporated water as sensible heat (J) . A schematic diagram for the Energy Budget Method is shown in figure 10.[7]
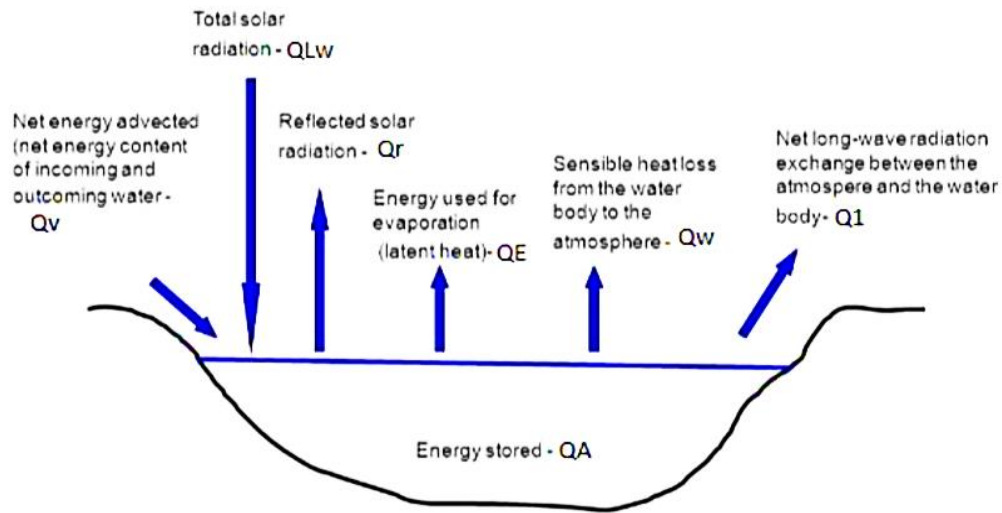


*Figure 10: A Schematic Diagram of the Energy Budget Method*

The following correlations are used to evaluate the evaporation rate formula:

$$Q_E = \rho_g E_v h_{fg}; \quad Q_h = B_r Q_E; \quad Q_W = \rho_g c_p E_v (T_{v,s} - T_{v,\infty})$$

Mass of water evaporated $E_m$ becomes as the following equation:

$$E_m = \rho_g E_v = \frac{(R_n + Q_v - Q_A)}{(h_{fg}(1 + B_r) + c_p(T_{v,s} - T_{v,\infty}))}$$

Where $E_m$ is the mass of evaporated water, and $R_n$ is net radiation input to the storage,

$$R_n = Q_s - Q_r + Q_{LW} - Q_{rLW} - Q_{LWe}z$$

Bowen ratio equation is:

$$B_r = \frac{Q_h}{Q_E} = \gamma \frac{\Delta T}{\Delta e} = 0.46 \frac{(T_{v,s} - T_{v,\infty})P_g}{(P_{v,s} - P_{v,\infty})760}$$

Where $\gamma$ is psychrometric constant, $T_{v,\infty}$ and $P_{v,\infty}$ are defined as the original temperature and vapor pressure of the air passing over the lake (°C,mm of mercury), respectively. $T_{v,s}$ and $P_{v,s}$ are defined as the corresponding quantities for the layer of air in contact with the water surface(°C,mm of mercury), respectively. $P_g$ is defined as the total atmospheric pressure(mm of mercury). [7]

### C. Mass-Transfer Method (Aerodynamic Method)

This approach uses the principle of eddy motion transfer of water vapor from the evaporating surface to the atmosphere. Dalton (1802) established a basic law on evaporation from a free water surface. His standard evaporation formula is as follows:

$$E = C(P_{v,s} - P_{v,\infty})$$

Where E is defined as the evaporation rate from the free water surface, $P_{v,s}$ is defined as the saturation vapor pressure at the temperature of the water surface, $P_{v,\infty}$ is defined as the vapor pressure in the air, and C is defined as the aerodynamic conductance dependent on the barometric pressure.
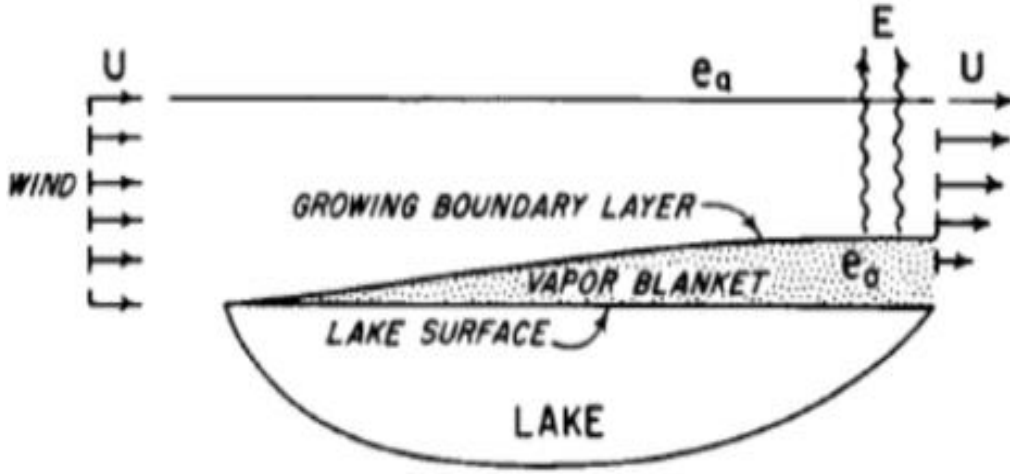
*Figure 11: A Schematic Diagram for Mass-Transfer Method*

$$E = \frac{(A + BV)(\mathrm{P_{v,s}} - \emptyset\mathrm{P_{v,\infty}})}{h_{fg}}$$

A and B are unknown constants, $\emptyset$ is defined as the relative humidity, $h_{fg}$ is defined as the latent heat of vaporization of water, V is defined as wind velocity.

### D. Combined Method

Combined models use a simultaneous solution of the mass transfer method and the energy budget method or other method to boost the precision of the results by reducing the reliance on metrological factors such as temperature and relative humidity.

$$E_p = \frac{\Delta}{\Delta + \gamma}(r_n + A_h) + \frac{\gamma}{\Delta + \gamma}\frac{6.43(1 + 0.5362V_2)(\mathrm{P_{v,s}} - \emptyset\mathrm{P_{v,\infty}})}{h_{fg}}$$

$E_p$ is defined as the potential evaporation rate $(\frac{kg}{m^2*sec})$, $\Delta$ is defined as the slope of saturation vapor pressure versus temperature curve at temperature $T(\frac{Kpa}{°C})$, $\gamma$ is defined as a psychrometric constant $(\frac{Kpa}{°C})$ , rn is defined as a net radiation exchange for the water surface$(\frac{m}{day})$ , Ah is defined as any significant energy advected into the water body $(\frac{m}{day})$, V2 is the wind speed at 2m height above the water surface, $(\mathrm{P_{v,s}} - \emptyset\mathrm{P_{v,\infty}})$ is defined as the vapor pressure differential $(Pa)$, and $(h_{fg})$ is defined as the latent heat of vaporization $(\frac{J}{kg})$.

### iii. Empirical Evaporation Correlations Experimental Results-Based

| Reference | Case | n | Proposed Correlation | Notes |
|---|---|---|---|---|
| Dalton - (1802) | Still air | 1 | $E = C(P_{v,s} - P_{v,\infty})^n$ | Doesn't address all the phenomena involved |
| Carrier (1918) | Still & Moving air | 1 | $E = (0.089 + 0.0782V)\dfrac{(P_{v,s} - \emptyset P_{v,\infty})^n}{h_{fg}}$ | $0 \leq V \leq 0.7$ Didn't describe the experimental apparatus or procedures used to obtain the data. Yield 15% higher than expected |
| Smith et al. (1993) | Still & Moving air | 1 | $E = 0.76(0.089 + 0.0782V)\dfrac{(P_{v,s} - \emptyset P_{v,\infty})^n}{h_{fg}}$ | Modified the Carrier formula. $51 \leq \emptyset \leq 73$ $21.7 \leq T_a \leq 27.8$ $T_w = 28.3$ |
| Shah 2002,2012 | Natural convection under turbulent airflow | | $E = C(P_{v,s} - P_{v,\infty})^{\frac{1}{3}}(\omega_{v,s} - \omega_{v,\infty})$ $C = 35$ for $(P_{v,s} - P_{v,\infty}) > 0.02$ $C = 40$ for $(P_{v,s} - P_{v,\infty}) \leq 0.02$ | Based on similarity method $7°C < T_w < 94°C$ $6°C < T_a < 35°C$ $28\% < \emptyset < 95\%$ |
| Raimundo et al. (2014) | Forced convection under turbulent air flow | 1 | 1) $E = 1*10^{-9}(37.17 + 32.19V)(P_{v,s} - P_{v,\infty})^n$ <br> 2) $E = 1*10^{-3}(1.05 + 10.32V)(m_{v,s} - m_{v,\infty})$ <br> 3) $E = 1*10^{-6}(22.77 + 215.85V - 23.59\emptyset - 219.05\emptyset V + 13.95\emptyset V(T_{v,s} - T_{v,\infty}))$ | 1- experimental $2475 \leq Re \leq 17326$ $0.101 \leq V \leq 0.697 m/s$ $1850 \leq P_{v,s} - P_{v,\infty} \leq 8751$ Pa 2- Numerical 3- Numerical V (0.1- 2 m/sec) |

| | | | | |
|---|---|---|---|---|
| Pauken (1999) | Mixed convection Under turbulent air flow | | 1) $E = 1*10^{-6}*A(1*10^{-3}(P_{v,s} - \emptyset P_{v,\infty})^n$ <br><br> $A = 20.56 + 27.21V + 6.92V^2$ <br> $n = 1.22 - 0.19V + 0.038V^2$ <br> 2) $Sh_{mixed} = Sh_n[1 + f(\frac{Gr_m}{Re^2})]$ <br> $f = 0.543 - 0.408(ln(\frac{Gr_m}{Re^2}))$ <br> $+ 0.0826((\frac{Gr_m}{Re^2}))^2$ | 1- Modified Dalton's law <br> 2- Similarity Method <br><br> $0.33 \leq V \leq 1.45$ <br> $25°C \leq T_w \leq 50°C$ <br> $T_a = 20°C, \emptyset = 50\%$ <br> $0.1 < \frac{Gr_m}{Re^2} < 10$ |
| Mehmet et al. (2017) | Natural and Forced convection | 0.695 | $E = (0.280 + 0.0782V)\frac{(P_{v,s} - \emptyset P_{v,\infty})^{n=0.695}}{h_{fg}}$ | $16°C \leq T_a \leq 26°C$ <br> $14°C \leq T_w \leq 24°C$ <br> $\%50 \leq \emptyset \leq \%70$ <br> $0.20 m/sec \leq V \leq 0.38 m/sec$ |

*Table 4: Empirical Evaporation Correlations*

## What is (n) ?

Some researchers showed that the evaporation rate is not linearly proportional to the vapor pressure difference and may be related to the power less than unity. While other researchers concluded to write the exponent (n) as a higher degree polynomial function of airflow velocity to produce a good, proposed model, and this is carried out for mixed turbulent conditions an for mixed and forced turbulent conditions. These correlations were obtained at the lower range of water surface temperature is up to 55°C and the vapor pressure difference is up to 11 Kpa.

## The differences between the Evaporation Correlations

The Dalton based models don't consider into account the effect of vapor density difference, and this can explain why Carrier's expression greatly overpredicted evaporation rate than that expected. Smith et al. (1993) evaluated the rate of evaporation by applying the energy budget method to the swimming pools. The evaporation rate was calculated based on the difference between the total energy supplied to the water and sensible heat gained by the water. In their work, they ignored the evaporation from the wet deck and the wet bodies of the swimmers. Thus, Smith et al. (1993) modified Carrier's formula for indoor and outdoor swimming pools, and they recommended that the results of Carrier's correlation should be multiplied by 0.76. [7]

## 2.3. Boiling

When evaporation occurs at a solid–liquid interface, it is termed boiling. Boiling is the rapid vaporization of a liquid, which occurs when a liquid is heated to its boiling point or the temperature at which the vapor pressure of the liquid is equal to the pressure exerted on the liquid by the surrounding atmosphere. At sea level the boiling point of water is 100 °C or 212 °F but at higher altitudes it drops to correspond with decreasing atmospheric pressures.

Boiling water is also used in several cooking methods including boiling, steaming and poaching. [8]

Pool boiling has been used for cooling in numerous thermal energy dissipation systems, such as high-power electronics, heat exchangers, and nuclear reactors. The advantage of pool boiling is that a high heat flux can be removed passively while maintaining a low superheat compared with natural/forced convection without phase change. However, the heat removal capacity is limited by the upper limit of cooling, i.e., the critical heat flux (CHF), where the heat transfer coefficient decreases dramatically because the boiling regime is changed from nucleate boiling to film boiling. Therefore, the CHF enhancement is of great interest to engineers and researchers. Studies on CHF enhancement by surface modification in saturated pool boiling have generally considered porous coatings (uniform or modulated) or/and structures of various sizes fabricated/ installed on the heated surface. In general, CHF enhancement in saturated pool boiling is a result of the effects of

      (a) extended surface area,

      (b) nucleation site density,

      (c) wettability,

      (d) capillary wicking, and

      (e) wavelength decrease based on the modified Zuber hydrodynamic stability model.

The exact contribution of each effect has not yet been clarified. A number of combined techniques for CHF enhancement have been proposed.

Gambill and Lienhard showed the theoretical upper limit of cooling for evaporation, neglecting condensation on the liquid vapor interface. The theoretical maximum heat flux is given by where qv, hlg, R, Tv, and M are the density of the vapor, the latent heat of evaporation, the universal gas constant, the saturation temperature, and the molecular mass, respectively. The theoretical maximum heat flux for water is 223.2 MW/m2 and for FC-72 is 46.7 MW/m2 under atmospheric pressure condition. In general, the achievable CHF for a plain surface without using external power is smaller than the theoretical upper limit for evaporation by one or two

orders of magnitude, which indicates that CHF enhancement may be possible.

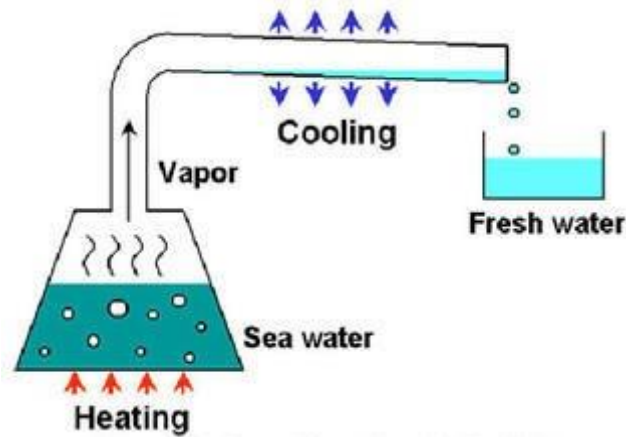$$q''_{max} = \rho_v h_{lg} \sqrt{\frac{RT_v}{2\pi M}}$$

[9]



*Figure 12 : Thermal Desalination Principle for Boiling*

## **Why was heat transfer fluid chosen?**

A heat transfer fluid is a gas or liquid involved in heat transfer by acting as an intermediary in cooling, transport and storage of thermal energy on one side of a process and heating on the other side of a process. Heat transfer fluids are used in many applications and industrial processes that require heating or cooling, typically in closed loop and continuous loops. For example, the coolant cools an engine, while the heating water in a hydronic heating system heats the radiator in a room. Water is the most common heat transfer fluid due to its economy, high heat capacity and favorable transport properties. However, the useful temperature range is limited to freezing below 0 °C and boiling at high temperatures, depending on the system pressure. Antifreeze additives can alleviate the freezing problem to some extent. However, many other heat transfer fluids have been developed and used in a wide variety of applications. For higher temperatures, oil or synthetic hydrocarbon or silicone based fluids offer lower vapor pressure. Gases such as water vapor, nitrogen, argon, helium and hydrogen have been used as heat transfer fluids where liquids are not suitable. For gases, pressure typically needs to be increased to facilitate higher flow rates with lower pumping power.

They generally have a high boiling point and high heat capacity. Its high boiling point prevents heat transfer fluids from evaporating at high temperatures. The high heat capacity allows a small amount of refrigerant to transfer a large amount of heat very efficiently.

The heat transfer fluids used do not have low boiling points. This is because its low boiling point causes the liquid to evaporate at low temperatures when used in heat exchange with hot substances. This will produce vapors of the liquid in the machine itself where it is used.

## 2.4. Condensation

Condensation may be a phenomena frequently encountered in nature, defined as the change of the physical state of matter from the gas phase into the liquid phase, and is the reverse of vaporization.[10] In industrial equipment, the process commonly results from contact between the vapor and a cool surface. The latent energy of the vapor is released, heat is transferred to the surface, and the condensate is formed. Other common modes are homogeneous condensation. This could occur on a solid surface whose temperature is below the saturation temperature of the vapor. Within the latter case the vapor temperature itself could also be either at saturation or superheated. In any case, condensation requires a particular amount of subcooling. During the physical change process energy within the kind of the heat must be far from the region of condensation, either by convection, diffusion, or radiation.

A pressure decrease occurs within the region where condensation is happening, as a result mass diffuses toward this region. The condensation phenomenon is often classified as:

1) Bulk condensation
2) Surface condensation

Bulk condensation takes place within the majority of the vapor removed from any solid or liquid boundaries. Surface condensation is the condensation going down on a subcooled solid surface when exposed to vapor. due to its wide application in industry, it's the foremost important one from the engineering point of view. Surface condensation is classified further as either dropwise or filmwise condensation. Depending upon the characteristics of the condenser surface employed, either one or both of those can occur on a surface.

Filmwise condensation is the most generally observed mode, and occurs if the liquid wets the condenser surface, leading to the coverage of the surface by a liquid condensate film. This film is aloof from the surface under the action of the gravity, acceleration or other body forces and/or shear stresses thanks to vapor flow.

Dropwise condensation occurs if the condensate doesn't wet the condenser surface. During this sort of condensation vapor in reality with a subcooled surface form microscopic droplets on the surface, which then grow by the direct condensation on the droplets and by coalescences

between the droplets, until a particular size is reached. The drops then leave the surface by the action of body forces and/or vapor shear. It's been noted that the warmth transfer coefficient with dropwise condensation is an order of magnitude larger than that with filmwise condensation. This might seem to form dropwise condensation, a really attractive mechanism for industrial applications.

No satisfactory means of sustaining dropwise condensation over an extended period of your time may well be found, which has hindered industrial applications of this efficient heat transfer mechanism. Film condensation occurs when the liquid wets the surface, and also the condenser surface is blanketed by a condensate film. This film represents a thermal resistance to heat transfer and a gradient exists within the film.

Dropwise condensation occurs on a surface which is coated with a substance that inhibits wetting. Heat transfer rates in dropwise condensation is also ten times beyond that in film condensation. Since very high heat transfer rates are obtained, it's desired to possess dropwise condensation in applications. it's possible to scale back the warmth transfer area half or less in a very condenser system by using dropwise condensation. [10]

Various surface coatings, like gold, silicones, and Teflon, are employed in the industry to take care of dropwise condensation but one in all these methods has reached any considerable success. The effectiveness of such coatings gradually decreases thanks to oxidation and fouling, and film condensation occurs after a period of your time. one more reason for losing the effectiveness of dropwise condensation is the accumulation of droplets on the condenser surface. Heat transfer rate sharply decreases due to the accumulated droplets. Therefore, most condensers are designed on the belief that film condensation will happen on the surface. Unlike filmwise condensation, the physical processes going down in dropwise condensation are complex and random when viewed on a close scale. Moreover, the parameters affecting dropwise condensation are tougher to regulate (e. g. the amount of nucleation sites, and non-condensable gases). The most important portion of the warmth transfer with dropwise condensation takes place on droplets of microscopic sizes. In early studies the bulk of research workers produced dropwise condensation by means of chemical promoters. Recent studies showed that coating the condenser surface with noble metals, particularly gold, could also be the last word solution of the matter of sustaining dropwise condensation over long periods of your time. It's been suggested that an optimum coating thickness, thick enough to get dropwise

condensation and at the identical time thin enough to stay the coating expenses to a minimum, will be found.

Dropwise condensation is actually a cyclic process. the various droplets that cover the surface labor under the identical cycle of subprocesses. A drop cycle begins with the nucleation of single droplets at preferred nucleation sites. These droplets grow by direct condensation only, up to a size on the order of magnitude of the space between neighboring nucleation sites. Beyond this time coalescences between neighboring drops can occur and therefore the subsequent growth of the drops could also be considered to occur by the mix of direct condensation and by coalescence. As a result of the coalescence, the quantity of droplets per unit area decreases because the drop sizes increase, while the condensing area covered by these drops increases. Coalescences between droplets provide a continual source of nucleation sites since the movement of the droplets expose bare areas on which these sites may exist. When a drop reaches a size at which the body forces exceed the physical phenomenon forces holding the drop to the solid surface, the drop departs and sweeps the surface clear, permitting new nucleation sites to become available within the sweeping path.

The understanding and outline of dropwise condensation thus depends upon a careful analysis of the cyclic subprocesses which begin with the nucleation of droplets, continues with growth and seemingly random coalescences, and ends with the drop departing and sweeping the surface.

The size at which drops are aloof from the surface is termed the departure size. The departure size is a vital parameter in dropwise condensation: By intuition it will be concluded that a decrease within the departure size ends up in a rise in heat transfer coefficients. Since the departure size is related to the drop size distribution and therefore the sweeping frequency, a study of the influence of departure size on dropwise condensation heat transfer is expected to boost the understanding of this phenomenon. [11]

# 3. Design and Calculation

## 3.1. Design

For this project, it is assumed that there is one evaporator and one condenser. Also the heating oil and cold water is used. The calculations made regarding to this project design. The referenced examples were used from the book.

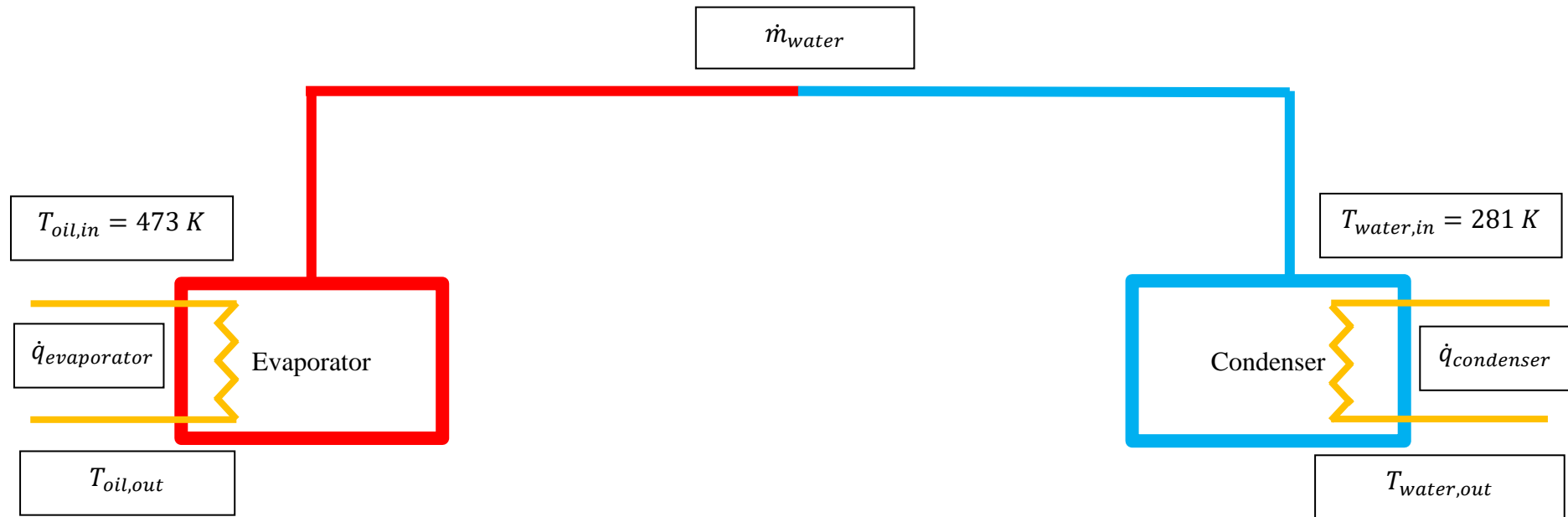

*Figure 13 : Design of Project*

In the figure, the following labels appear: $\dot{m}_{water}$, $T_{oil,in} = 473\ K$, $T_{water,in} = 281\ K$, $\dot{q}_{evaporator}$, Evaporator, Condenser, $\dot{q}_{condenser}$, $T_{oil,out}$, $T_{water,out}$.

## 3.2. Calculation

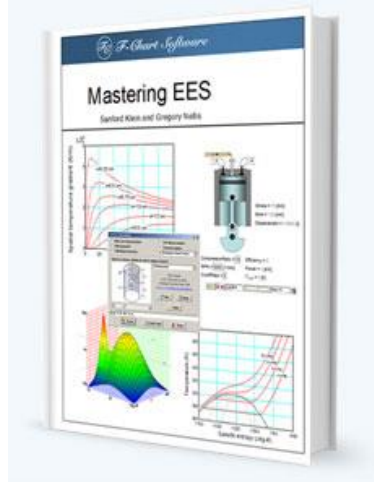For calculation part, the Engineering Equation Solver (EES) were used.



*Figure 14 : Book for EES*

Engineering Equation Solver (EES) is a commercial software package used for solution of systems of simultaneous non-linear equations. It provides many useful specialized functions and equations for the solution of thermodynamics and heat transfer problems, making it a useful and widely used program for mechanical engineers working in these fields. EES stores thermodynamic properties, which eliminates iterative problem solving by hand through the use of code that calls properties at the specified thermodynamic properties. EES performs the iterative solving, eliminating the tedious and time-consuming task of acquiring thermodynamic properties with its built-in functions. [12]

There are two major differences between EES and existing numerical equation-solving programs. First, EES automatically identifies and groups equations which must be solved simultaneously. This feature simplifies the process for the user and ensures that the solver will always operate at optimum efficiency. Second, EES provides many built-in mathematical and thermophysical property functions useful for engineering calculations. For example, the steam tables are implemented such that any thermodynamic property can be obtained from a built-in function call in terms of any two other properties. Similar capability is provided for most organic refrigerants, ammonia, methane, carbon dioxide and many other fluids. Air tables are built-in, as are psychrometric functions and JANAF table data for many common gases. Transport properties are also provided for most of these substances.
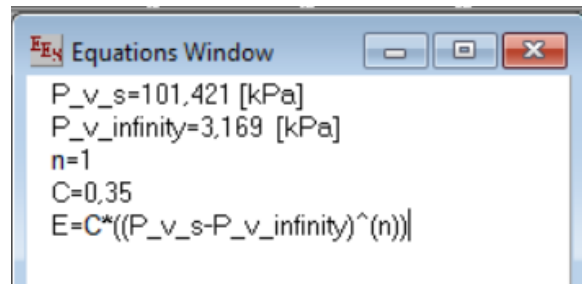


*Figure 15 : Logo of EES*

The reason that EES has chosen for this thesis' calculation process is to determine necessary thermodynamic variable without using tables in the book.[13]

Firstly, calculation started with empirical formulas for evaporation to see basic results. The formula which has been referenced by Dalton in 1802 for still air has been the most basic one.

$$E = C(P_{v,s} - P_{v,\infty})$$
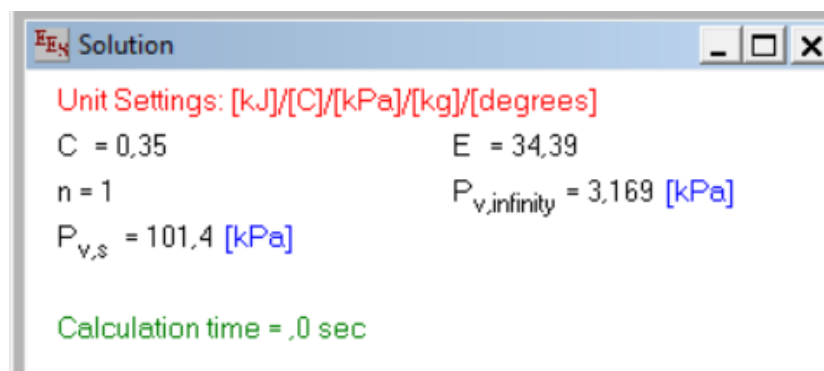
- **The code has written as empirical formula in evaporation:**



*Figure 16 : Code of Dalton's Empirical Formula*

- **Results:**



*Figure 17 : Result of First Equation*

The formula referenced by Dalton has been the most basic one since there is no temperature reference. For this reason, it is not possible to create parametric data, draw graphics and make a comparison. The "C" value is a fixed value, not a variable, but no clear value is specified in the sources. For this reason, comparisons were made for possible C values.
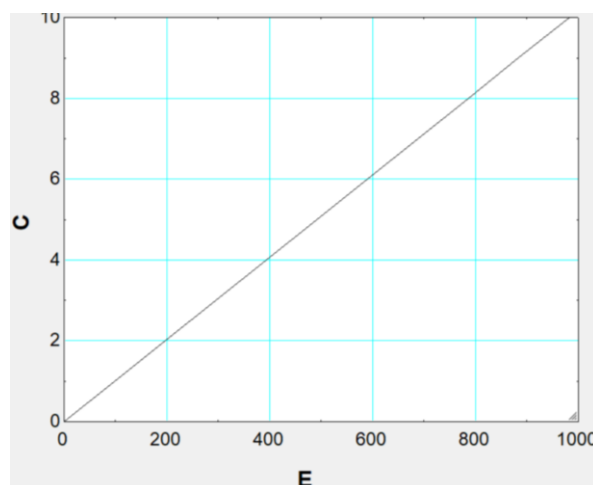


*Graph 1 : Graph of First Equation*

34

After that calculations, the formula has changed due to it does not address all the phenomena involved. The formula which has been referenced by Carrier in 1918 for still and moving air were the Best-Known and used empirical correlation for water evaporation rate. It were based on conventional Dalton's law. The first Yield found by Carrier 15% higher than expected. Carrier's proposed correlation has been chosen for the first trial. Where E is defined as the evaporation rate per unit area($\frac{kg}{m^2 sec}$), V defined as the velocity parallel to the water surface($\frac{m}{sec}$), Pv,s described as the saturated vapor pressure at surface water temperature (Pa), Pv,∞ defined as the saturated vapor pressure at air temperature (Pa), $h_{fg}(\frac{J}{kg})$ described as the latent heat of vaporization , n=1 defined as the exponent coefficient and Ø defined as the air relative humidity. This equation can be used for air velocities between (0 and 0.7),

$$E = (0.089 + 0.0782V)\frac{(P_{v,s} - ØP_{v,\infty})^n}{h_{fg}}$$

- **The code has written as empirical formula in evaporation:**

```
T_1=100 [C]
P_1=101,325 [kPa]
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169 [kPa]
V=0,35
n=1
E=((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg
```

*Figure 18 : Code of Carrier's Empirical Formula*
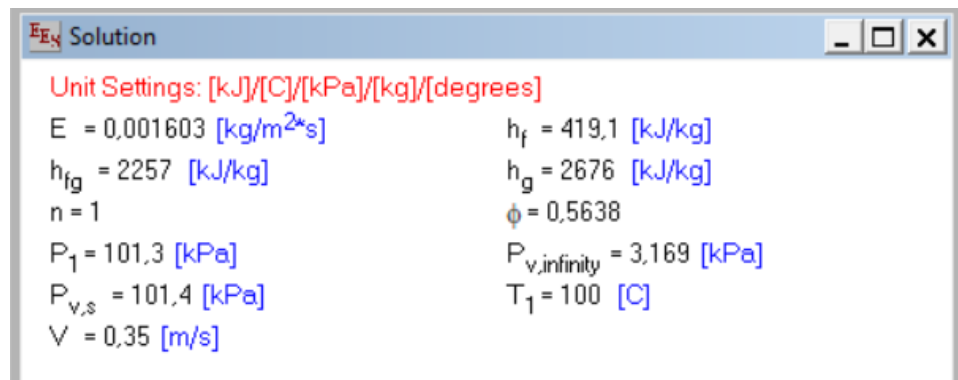
- **Results:**



*Figure 19 : Result of Second Equation*

For these conditions, the result for evaporation rate came as 0.001603.
After this process and the result, the main values in the formula were made variable in order

to make a comparison.

First of all, the fixed value of the velocity parallel to the water made as variable.

```
T_1=100 [C]
P_1=101,325 [kPa]
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169 [kPa]
n=1
"V=0, 35 [m/s]"
E=((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg
```

For to see the graph of the effect of velocity changes, parametric table which contains velocity and evaporation rate has made.

| | E [kg/m2*s] | V [m/s] |
|---|---|---|
| Run 1 | 0,0003926 | 0 |
| Run 2 | 0,0006617 | 0,07778 |
| Run 3 | 0,0009307 | 0,1556 |
| Run 4 | 0,0012 | 0,2333 |
| Run 5 | 0,001469 | 0,3111 |
| Run 6 | 0,001738 | 0,3889 |
| Run 7 | 0,002007 | 0,4667 |
| Run 8 | 0,002276 | 0,5444 |
| Run 9 | 0,002545 | 0,6222 |
| Run 10 | 0,002814 | 0,7 |

*Table 5 : Change in Evaporation Rate Due to Velocity*
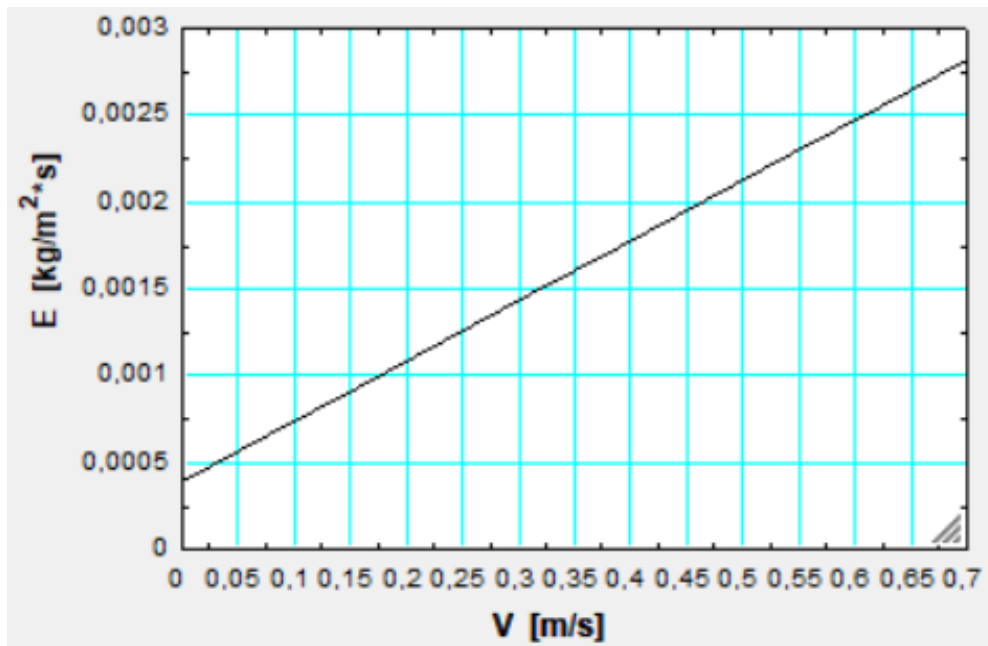


*Graph 2 : Graph of Evaporation Rate vs. Velocity*

It can be seen from the graph that the velocity and the evaporation rate are directly proportional. As the speed increases, the evaporation rate also increases.

Then, the fixed value of the temperature of the water made as variable.

---
"T_1=100 [C]"
P_1=101,325 [kPa]
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169 [kPa]
n=1
V=0, 35 [m/s]
E=((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg
---

For to see the graph of the effect of Temperature changes, parametric table which contains Temperature 1 and evaporation rate has made

| | E [kg/m²*s] | T$_1$ [C] |
|---|---|---|
| Run 1 | 0,001512 | 75 |
| Run 2 | 0,001534 | 80 |
| Run 3 | 0,001554 | 85 |
| Run 4 | 0,001572 | 90 |
| Run 5 | 0,001588 | 95 |
| Run 6 | 0,001603 | 100 |
| Run 7 | 0,001618 | 105 |
| Run 8 | 0,001631 | 110 |
| Run 9 | 0,001645 | 115 |
| Run 10 | 0,001658 | 120 |

*Table 6 : Parametric Table of E vs T1*



*Graph 3 : Graph of E vs T1*

It can be seen from the graph that there is a polynomial ratio between the velocity and the evaporation rate. As the velocity increases, the evaporation rate increases polynomially accordingly. The reason of this relation can be explained as the temperature not used in the equation directly but used for defining enthalpy values.

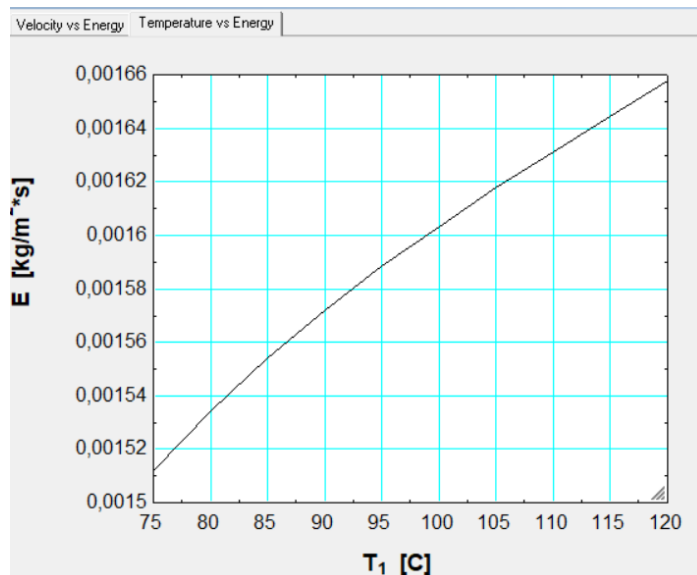Then, the fixed value of the temperature of the water made as variable.

```
T_1=100  [C]
"P_1=101,325 [kPa]"
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169  [kPa]
n=1
V=0, 35 [m/s]
E=((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg
```

| Pressure Changes | E [kg/m2*s] | $P_1$ [kPa] |
|---|---|---|
| Run 1 | 0,001605 | 96 |
| Run 2 | 0,001605 | 96,8 |
| Run 3 | 0,001604 | 97,6 |
| Run 4 | 0,001604 | 98,4 |
| Run 5 | 0,001604 | 99,2 |
| Run 6 | 0,001604 | 100 |
| Run 7 | 0,001604 | 100,8 |
| Run 8 | 0,001603 | 101,6 |
| Run 9 | 0,001603 | 102,4 |
| Run 10 | 0,001603 | 103,2 |
| Run 11 | 0,001603 | 104 |

*Table 7 : Parametric Table of E vs P1*
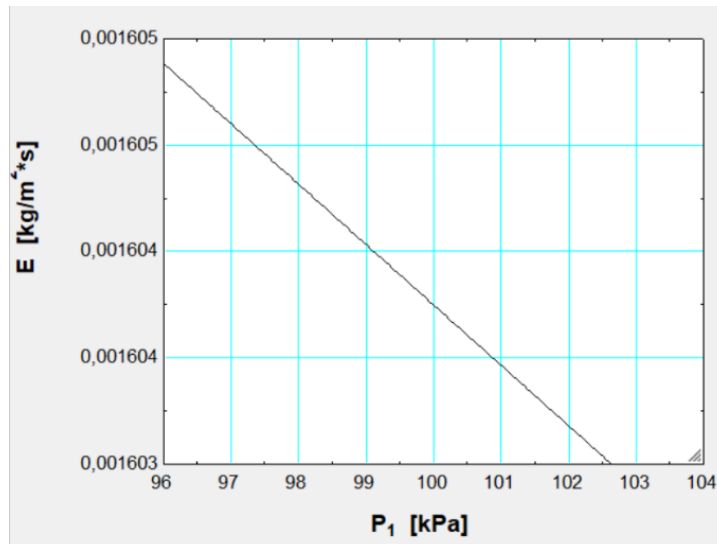


*Graph 4 : Graph of E vs P1*

It can be seen from the graph that the pressure and the evaporation rate are inversely proportional. As the pressure decreases, the evaporation rate increases.
The Dalton based models don't consider into account the effect of vapor density difference, and this can explain why Carrier's expression greatly overpredicted evaporation rate than that expected.

After the calculations for Dalton and Carrier, there has to made more proportional calculations needed. Thus, the third empirical equation were used.

Smith et al. (1993) evaluated the rate of evaporation by applying the energy budget method to the swimming pools. The evaporation rate was calculated based on the difference between the total energy supplied to the water and sensible heat gained by the water. In their work, they ignored the evaporation from the wet deck and the wet bodies of the swimmers. Smith et al. (1993) modified Carrier's formula for indoor and outdoor swimming pools, and they recommended that the results of Carrier's correlation should be multiplied by 0.76.

$$E = 0.76(0.089 + 0.0782V)\frac{(P_{v,s} - \emptyset P_{v,\infty})^n}{h_{fg}}$$

- **The Code:**

```
T_1=100 [C]
P_1=101,325 [kPa]
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169 [kPa]
n=1
V=0, 35 [m/s]
E=0,76*((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg
```

*Figure 20 : Code of Smiths Empirical Formula*

- **Result**:

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

| | | |
|---|---|---|
| $E = 0.001219$ [kg/m$^2$*s] | $h_f = 419.1$ [kJ/kg] | $h_{fg} = 2257$ [kJ/kg] |
| $h_g = 2676$ [kJ/kg] | $n = 1$ | $\phi = 0.5638$ |
| $P_1 = 101.3$ [kPa] | $P_{v,infinity} = 3.169$ [kPa] | $P_{v,s} = 101.4$ [kPa] |
| $T_1 = 100$ [C] | $V = 0.35$ [m/s] | |

*Figure 21 : Result of Smith's Equation*

For these conditions, the result for evaporation rate came as 0.001219.
After this process and the result, the main values in the formula were made variable in order to make a comparison.

First of all, the fixed value of the velocity parallel to the water made as variable.

T_1=100  [C]
P_1=101,325 [kPa]
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169  [kPa]
n=1
"V=0, 35 [m/s]"
E=0,76*((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg

| Velocity Changes(copy) | E [kg/m²*s] | V [m/s] |
|---|---|---|
| Run 1 | 0,0002984 | 0 |
| Run 2 | 0,0005029 | 0,07778 |
| Run 3 | 0,0007074 | 0,1556 |
| Run 4 | 0,0009118 | 0,2333 |
| Run 5 | 0,001116 | 0,3111 |
| Run 6 | 0,001321 | 0,3889 |
| Run 7 | 0,001525 | 0,4667 |
| Run 8 | 0,00173 | 0,5444 |
| Run 9 | 0,001934 | 0,6222 |
| Run 10 | 0,002139 | 0,7 |

*Table 8 : Parametric Table of E vs V*



*Graph 5 : Graph of E vs V*

It can be seen from the graph that the velocity and the evaporation rate are directly proportional. As the speed increases, the evaporation rate also increases.
Then, the fixed value of the temperature of the water made as variable.

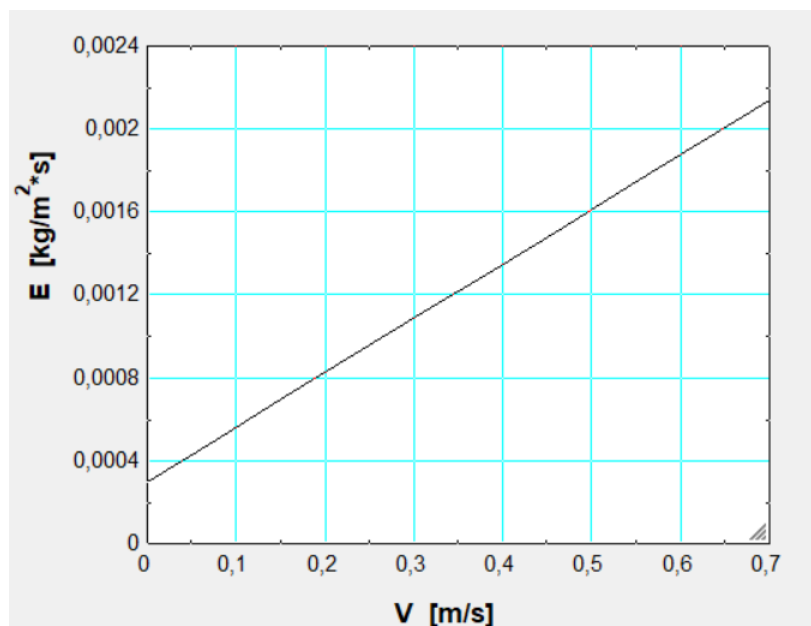After that, the fixed value of the temperature made as variable.

---

"T_1=100  [C]"
P_1=101,325 [kPa]
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169  [kPa]
n=1
V=0, 35 [m/s]
E=0,76*((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg

---

| 1 (1..10) | E [kg/m2*s] | $T_1$ [C] |
|---|---|---|
| Run 1 | 0,001214 | 98 |
| Run 2 | 0,001215 | 98,5 |
| Run 3 | 0,001216 | 99 |
| Run 4 | 0,001217 | 99,5 |
| Run 5 | 0,001219 | 100 |
| Run 6 | 0,00122 | 100,5 |
| Run 7 | 0,001221 | 101 |
| Run 8 | 0,001222 | 101,5 |
| Run 9 | 0,001223 | 102 |
| Run 10 | 0,001224 | 102,5 |

*Table 9 : Parametric Table of E vs T1*



*Graph 6 : Graph of E vs T1*

It can be seen from the graph that there is a polynomial ratio between the velocity and the evaporation rate. As the velocity increases, the evaporation rate increases polynomially accordingly. The reason of this relation can be explained as the temperature not used in the equation directly but used for defining enthalpy values.

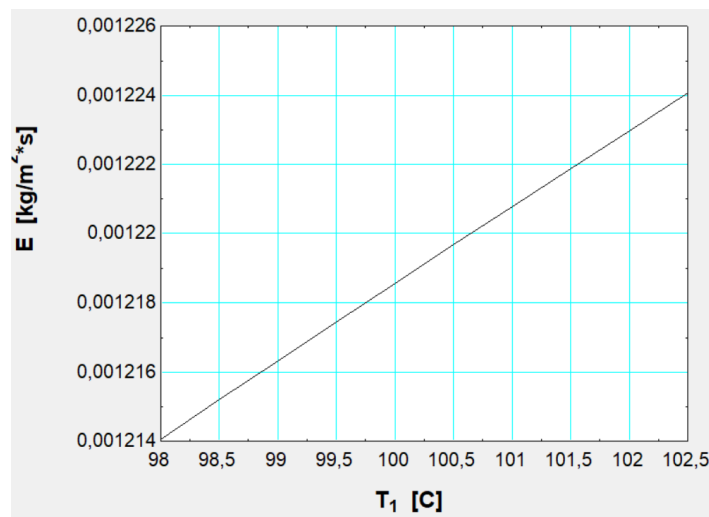Then, the fixed value of the pressure of the water made as variable.

T_1=100 [C]
"P_1=101,325 [kPa]"
h_f=ENTHALPY(Water;x=0;T=T_1)
h_g=ENTHALPY(water;x=1;T=T_1)
h_fg=h_g-h_f
phi=relhum(AirH2O;T=T_1;P=P_1;h=h_fg)
P_v_s=101,421 [kPa]
P_v_infinity=3,169 [kPa]
n=1
V=0, 35 [m/s]
E=0,76*((0,008893+(0,07835*V))*((P_v_s-(phi*P_v_infinity))^n))/h_fg

Pressure Changes(copy)

| 1..11 | E [kg/m2*s] | P₁ [kPa] |
|---|---|---|
| Run 1 | 0,001219 | 99 |
| Run 2 | 0,001219 | 99,4 |
| Run 3 | 0,001219 | 99,8 |
| Run 4 | 0,001219 | 100,2 |
| Run 5 | 0,001219 | 100,6 |
| Run 6 | 0,001219 | 101 |
| Run 7 | 0,001219 | 101,4 |
| Run 8 | 0,001218 | 101,8 |
| Run 9 | 0,001218 | 102,2 |
| Run 10 | 0,001218 | 102,6 |
| Run 11 | 0,001218 | 103 |

*Table 10 : Parametric Table of E vs P2*
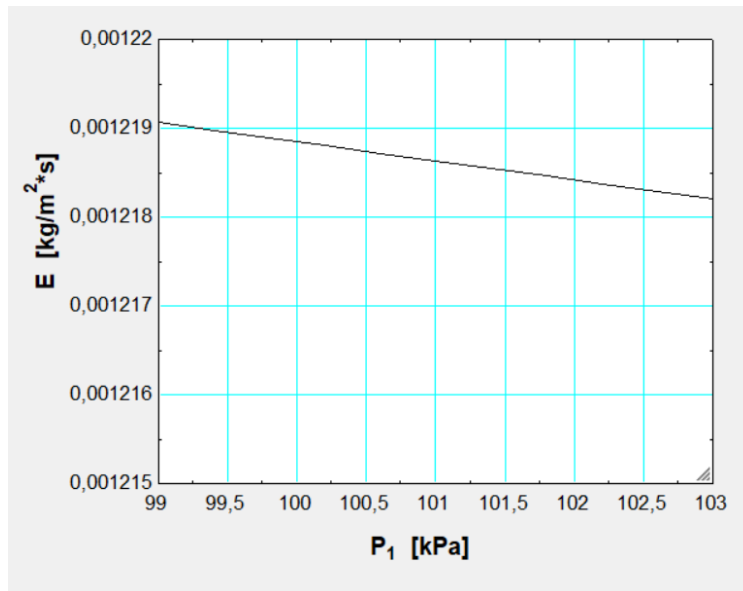


*Graph 7 : Graph of E vs P1*

Since it is recognized that the evaporation formulas and calculations were not capable for the aim it has been decided to try boiling methods. When evaporation occurs at a solid–liquid interface, it is termed boiling. The formulas for boiling are taken from the referenced book.

## Boiling Calculation

The formulas used for boiling calculations are as follows:

$T_{sat}$ saturation temperature of water boiling at 1 atm and the temperature of the heated copper surface $T_s$, the excess temperature $\Delta T_e$

$$\Delta T_e = T_s - T_{sat}$$

$$q_s'' = \mu_l * h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \left(\frac{c_{p,l}\Delta T_e}{C_{s,f}h_{f,g}Pr_l^n}\right)^3$$

Boiling heat transfer rate

$$q_s = q_s'' * A = q_s'' * \frac{\pi * D^2}{4} \, (kW)$$

$$q_s = \dot{m}_b h_{fg}$$

$\dot{m}_b$ is the rate at which water evaporates from the free surface to the room

$$\dot{m}_b = \frac{q_s}{h_{fg}}$$

The assumptions are as follows:
- Steady-state condition.
- Water exposed to standard atmospheric pressure, 1.01 bar.
- Water at uniform temperature $T_{sat} = 100\,°C$
- Large pan bottom surface of polished copper.
- Negligible losses from heater to surroundings.

Other thermodynamics properties are recognized in EES.
- **The code has written**

```
T_sat=373 [K]
P_ath=1,01 [bar]
V_sat=volume(Water;T=T_sat;P=P_ath)
rho_sat=density(Water;T=T_sat;P=P_ath)
rho_vapor=density(Water;T=T_sat;x=1)
C_p_sat=SpecHeat(Water;T=T_sat;P=P_ath)
mu_sat=viscosity(Water;T=T_sat;P=P_ath)
Pr_sat=Prandtl(Water;T=T_sat;P=P_ath)
h_f=ENTHALPY(Water;x=0;T=T_sat)
h_g=ENTHALPY(Water;x=1;T=T_sat)
h_fg=h_g-h_f
sigma=58,9*(10^(-3))
T_s=391 [K]
delta_T=T_s-T_sat
g=9,81 [m/s^2]
C_s_f=0,0128
n=1
q_ddot_s=mu_sat*h_fg*(((g/sigma)*(rho_sat-rho_vapor))^(1/2))*(((c_p_sat*delta_t)/(c_s_f*h_fg*Pr_sat^n))^3)
Area=1
q_s=q_ddot_s*Area
m_dot=q_s/h_fg

{ANSWERS}
Aq_dot=q_s*3600*24
Am_dot=(m_dot*3600*24)/Area
T_water=293 [K]
AQ=Am_dot*C_p_sat*(T_sat-T_water)*Area
```

*Figure 22 : Code for Boiling Calculation*

- **Results:**



*Figure 23 : Results of Boiling Calculation*

The boiling heat transfer rate came as $6,95*10^7$ kJ/day and the rate of the water came as 30803 kg/day-m$^2$.
Answers used in other calculations also. The boiling heat transfer rate used for calculating heat transfer oil output temperature and the mass transfer rate used for evopariton stage to try to make less differences between two rates.

## Heat Transfer Oil Calculation

The formulas used for boiling oil calculations are as follows:

Average heat coefficient

$$\bar{h} = \frac{\dot{m}c_p}{\pi DL} * \frac{(T_{m,o} - T_{m,i})}{\Delta T_{lm}} (\frac{W}{m^2 K})$$

Finding the $T_{out\_oil}$

$$\Delta T_{lm} = \frac{(T_s - T_{m,o}) - (T_s - T_{m,i})}{ln[\frac{(T_s - T_{m,o})}{(T_s - T_{m,i})}]}$$

The assumptions are as follows:
- $T_{oil,in} = 200\,°C$
- Diameter for the tube = 0.05 m
- Length of tube = 6 m
- Velocity of fluid = 0.01 m/s
- Surface temperature of tube = 300 K

Other thermodynamics properties are recognized in EES. It is planned to find out temperature of oil

- **The code has written**



```
FROM BOILING|CALCULATIONS}
Am_dot= 30803 [kg/day-m^2]
C_p_sat=4,217 [kJ/kg-K]
T_sat=373 [k]
Area= 1 [m^2]

{From Water Output}
T_water=293 [K]
AQ=Am_dot*C_p_sat*(T_sat-T_water)*Area
x=86400 [s/day]
Q_dot=AQ/x

T_s=573 [K]
T_oil_in=473 [K]
D=0,06 [m]
V=0,01 [m/s]
L=6 [m]
C_p_oil=2,57 [kJ/kg-K]

A_oil=pi*(D^2)/4
mu=0,00152 [kg/m-s]
rho=921 [kg/m^3]
reynolds= rho*V*D/mu
m_dot_oil=rho*A_oil*V
h_bar=((m_dot_oil*C_p_oil*1000)/(pi*D*L))*((T_oil_in-T_oil_out)/delta_T_lm)
delta_T_lm=((T_s-T_oil_out)-(T_s-T_oil_in))/f
f=(ln((T_s-T_oil_out))/(T_s-T_oil_in))

Q_dot=h_bar*(T_oil_in-T_oil_out)*(2*pi*(D/2)*L)
```

*Figure 24 : Code for Heating Oil*

- **Results:**



Unit Settings: [kJ]/[K]/[kPa]/[kg]/[degrees]

$\dot{Am}$ = 30803 [kg/day-m$^2$]    AQ = 1,039E+07 [kJ/day]    Area = 1 [m$^2$]

$A_{oil}$ = 0,002827 [m$^2$]    $C_{p,oil}$ = 2,57 [kJ/kg-K]    $C_{p,sat}$ = 4,217 [kJ/kg-K]

D = 0,06 [m]    $\delta_{T,lm}$ = 743,4 [K]    f = 0,04917

$\bar{h}$ = 2,909 [kW/m$^2$-K]    L = 6 [m]    $\mu$ = 0,00152 [kg/m-s]

$\dot{m}_{oil}$ = 0,02604 [kg/s]    $\dot{Q}$ = 120,3 [kJ/s]    reynolds = 363,6

$\rho$ = 921 [kg/m$^3$]    $T_{oil,in}$ = 473 [K]    $T_{oil,out}$ = 436,4

$T_s$ = 573 [K]    $T_{sat}$ = 373 [K]    $T_{water}$ = 293 [K]

V = 0,01 [m/s]    x = 86400 [s/day]

*Figure 25 : Result of Heating Oil Calculation*

It has been tried to find what should the output temperature will be. It came as 436,4 K. When it compares with the referenced example, it makes sense.

## Condensation Calculation

The formulas used for boiling calculations are as follows:

Convection coefficient for the top, unfinned tube which is of the form

$$\overline{h_D} = C \left[ \frac{p_l * g * (p_l - p_v) * k_l^3 * h_{fg}'}{\mu_l * (T_{sat} - T_s) * D} \right]^{1/4}$$
$$C = 0.729 \; for \; a \; tube$$

$$h_{fg}' = h_{fg} + 0.68 * c_p * (T_{sat} - T_s)$$

Array-averaged convection coefficient

$$\overline{h_{D,N}} = \overline{h_D} N^n$$

Condensation rate per unit length of tubing

$$\dot{m}_{uft}' = N * N \frac{\overline{h_{D,N}}(\pi D)(T_{sat} - T_s)}{h_{fg}'}$$

Total heat transfer to the surface obtained with Newton's law of cooling

$$q = \overline{h_L}(\pi D L)(T_{sat} - T_s)$$

The assumptions are as follows:
- Spatially uniform cylinder and fin temperature.
- Negligible concentration of noncondensable gases in the steam.
- Average heat transfer coefficient varies with tube row with n= -1/6(empirical value).
- Water exposed to standard atmospheric pressure, 1.01 bar.
- Saturation temperature $T_{sat} = 54 \; ^\circ C$
- Temperature of fluid (water) = $T_f = 39,5 \; ^\circ C$
- Surface Temperature $T_s = 25 \; ^\circ C$
- Length of cylinder = 1 m
- Diameter of cylinder = 6 mm

Other thermodynamics properties are recognized in EES.

- **The code has written**

```
T_sat=327 [K]
P_ath=1,01 [bar]
V_g=volume(Water;T=T_sat;P=P_ath)
rho_v=density(Water;T=T_sat;x=1)
h_f=ENTHALPY(Water;x=0;T=T_sat)
h_g=ENTHALPY(Water;x=1;T=T_sat)
h_fg=h_g-h_f
sigma=0,0671 [N/m]
T_f= 312,5 [K]
V_l=volume(Steam;T=T_f;P=P_ath)
rho_l=density(Steam;T=T_f;P=P_ath)
mu_l=viscosity(Water;T=T_f;x=0)
k_l=conductivity(Water;T=T_f;x=0)
C_p_l=SpecHeat(Water;T=T_f;x=0)
g=9,81 [m/s^2]
T_s=298 [K]
h_dot_fg=h_fg+0,68*c_p_l*(T_sat-T_s)
C=0,729
D=6*(10^(-3))
h_bar_D=C*(((rho_l*g*(rho_l-rho_v)*(k_l^3)*(h_dot_fg*10^3))/(mu_l*D*(T_sat-T_s)))^(0,25)
N=16
h_bar_D_N=h_bar_D*N^((-1)/6)
m_dot_uft=N*N*(h_bar_D_N*(pi*D)*(T_sat-T_s))/(h_dot_fg)
L= 1 [m]
q=h_bar_D*(pi*D*L)*(T_sat-T_s)

{Answer}
Answer_q=q*3600*24
AnswerM_dot=m_dot_uft*24*3600/1000
```

*Figure 26 : Code for Condensation Calculation*

- **Results:**
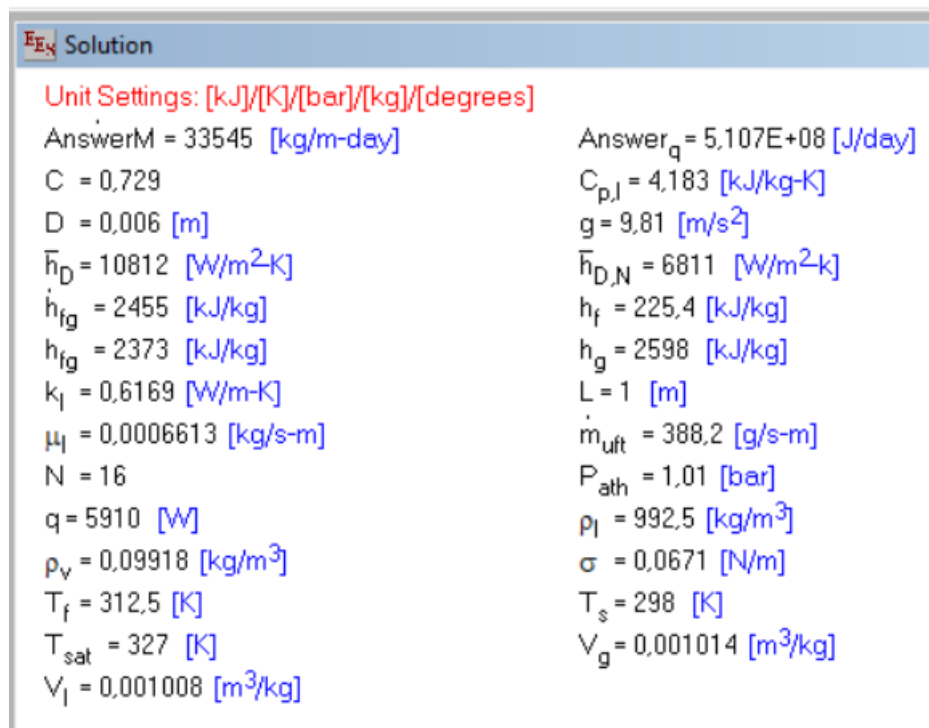


*Figure 27 : Results of Condensation Calculation*

Mass transfer rate came near to the boiling stage. It can be said that this makes logical. The heat transfer rate result used for calculations of cooling oil.

## Cooling Water Calculation

The formulas used for cooling water calculations are as follows:

Average heat coefficient

$$\bar{h} = \frac{\dot{m}c_p}{\pi DL} * \frac{(T_{m,o} - T_{m,i})}{\Delta T_{lm}} \left(\frac{W}{m^2 K}\right)$$

Finding the $T_{out\_water}$

$$\Delta T_{lm} = \frac{(T_s - T_{m,o}) - (T_s - T_{m,i})}{ln[\frac{(T_s - T_{m,o})}{(T_s - T_{m,i})}]}$$

The assumptions are as follows:
- $T_{water,in} = 20\,°C$
- Diameter for the tube = 0.007 m
- Length of tube = 6 m
- Velocity of fluid = 0.01 m/s
- Surface temperature of tube = 303 K

Other thermodynamics properties are recognized in EES. It is planned to find out temperature of oil

- **The code has written**

```
AQ=5,107E+08 [J/day]
x=86400 [s/day]
y=1000 [J/kJ]
Q_dot=AQ/(x*y)
T_water_in=293 [K]
V=0,01 [m/s]
D=0,007 [m]
L=6 [m]
C_water=4,12 [kJ/kg-K]
T_s=303[K]

A_water=pi*(D^2)/4
mu= viscosity(water;T=T_s;x=0)
rho=997 [kg/m^3]
reynolds= rho*V*D/mu

m_dot_water=rho*A_water*V
h_bar=((m_dot_water*C_water*1000)/(pi*D*L))*((T_water_in-T_water_out)/delta_T_lm)
delta_T_lm=((T_s-T_water_out)-(T_s-T_water_in))/f
f=(ln((T_s-T_water_out))/(T_s-T_water_in))

Q_dot=h_bar*(T_water_in-T_water_out)*(2*pi*(D/2)*L)
```

*Figure 28 : Code for Cooling Water Calculation*

- **Results:**
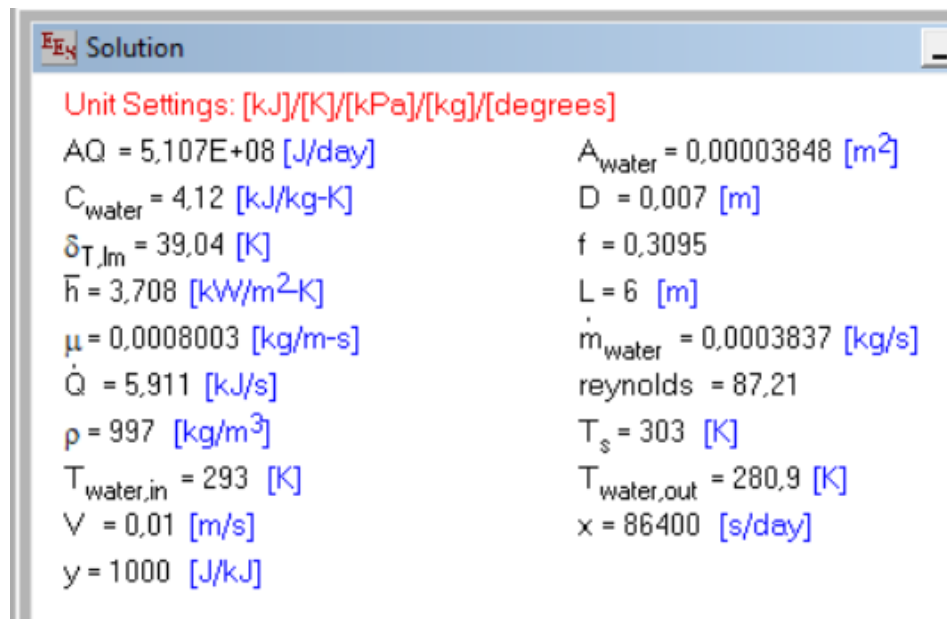


*Figure 29 : Result of Cooling Water*

It has been tried to find what should the output temperature will be. It came as 280,9 K. When it compares with the referenced example, it makes sense.

# 4.   COST ANALYSIS
## Boiler

$$Q= 6.952*10^7 \text{ kJ/day} = 804 \text{ kW} = 938 \text{ HP}$$



*Figure 30 : Product Display of Boiler*

**Quick Details**

| | | | |
|---|---|---|---|
| Applicable Industri... | Hotels, Garment Shops, Building Material Shops, Manufacturi... | After Warranty Serv... | Video technical support, Online support |
| Local Service Locat... | None | Showroom Location: | None |
| Video outgoing-ins... | Provided | Machinery Test Re... | Provided |
| Marketing Type: | Hot Product 2019 | Warranty of core co... | 1 Year |
| Core Components: | leway | Condition: | New |
| Type: | Natural Circulation | Usage: | Industrial, Steam Outputing |
| Structure: | Fire Tube | Pressure: | Low Pressure |
| Steam Production: | Max. 20t/h | Style: | Horizontal |
| Fuel: | Gas, Oil | Place of Origin: | Henan, China |
| Brand Name: | LEWAY | Output: | Steam |
| Dimension(L*W*H): | Consult customer-service staff | Weight: | Consult customer-service staff |
| Certification: | SGS, ISO, OHSAS | Warranty: | 2 years |
| After-sales Service ... | Engineers available to service machinery overseas | Key Selling Points: | Easy to Operate |
| Product Name: | Industrial Steam Boiler | Fuel Type: | Gas, Oil |
| Boiler Power: | 30-1300HP | Steam Capacity: | 0.5-20tons of steam per hour |
| Working Pressure: | ≤1.25MPa | Steam Temperature: | ≤194°C |
| Thermal Efficiency: | 95% | Operation: | Intelligent PLC Control |

*Figure 31 : Overview of Boiler*

*Figure 32 : Scheme of Boiler*



[14]

**Total Price = $125,000**

# Evaporator

Q=5,107*10$^8$ J/day= 5.910 kW = 7.919 HP



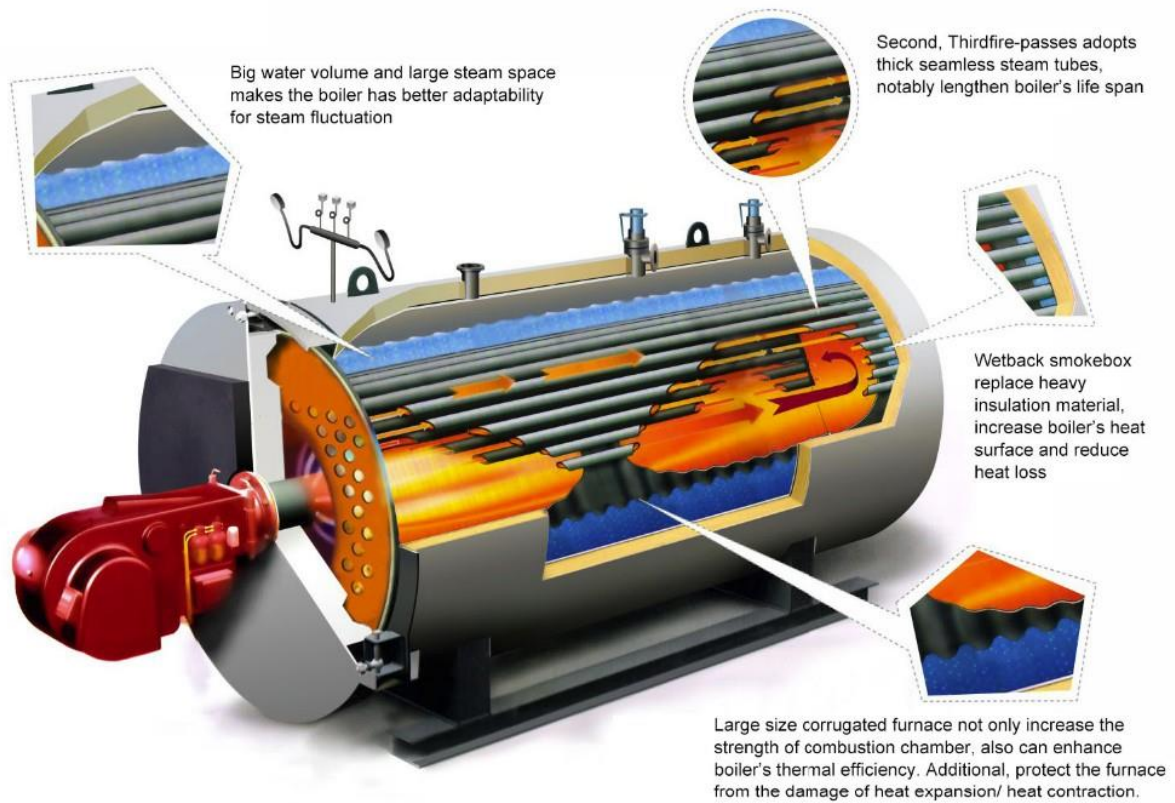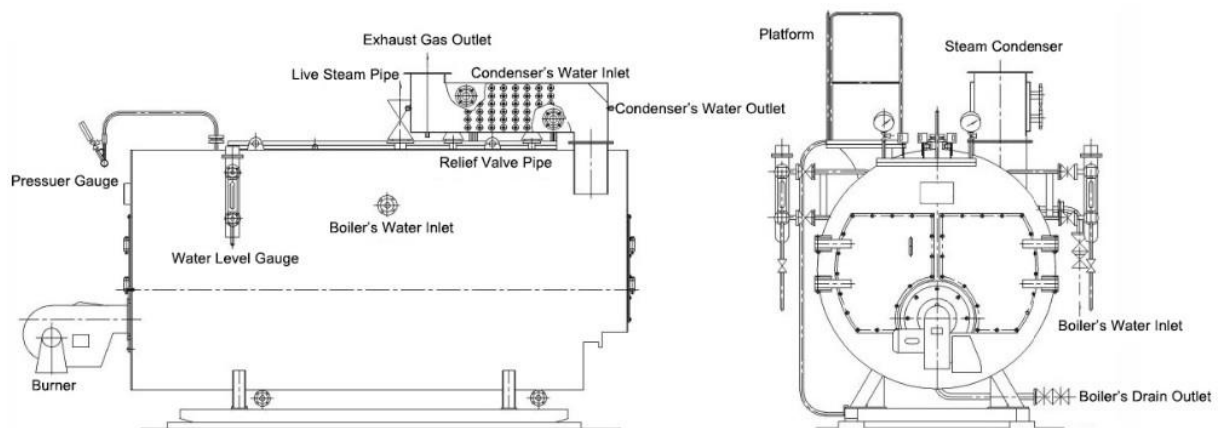*Figure 33 : Some Examples of Evaporator Design*



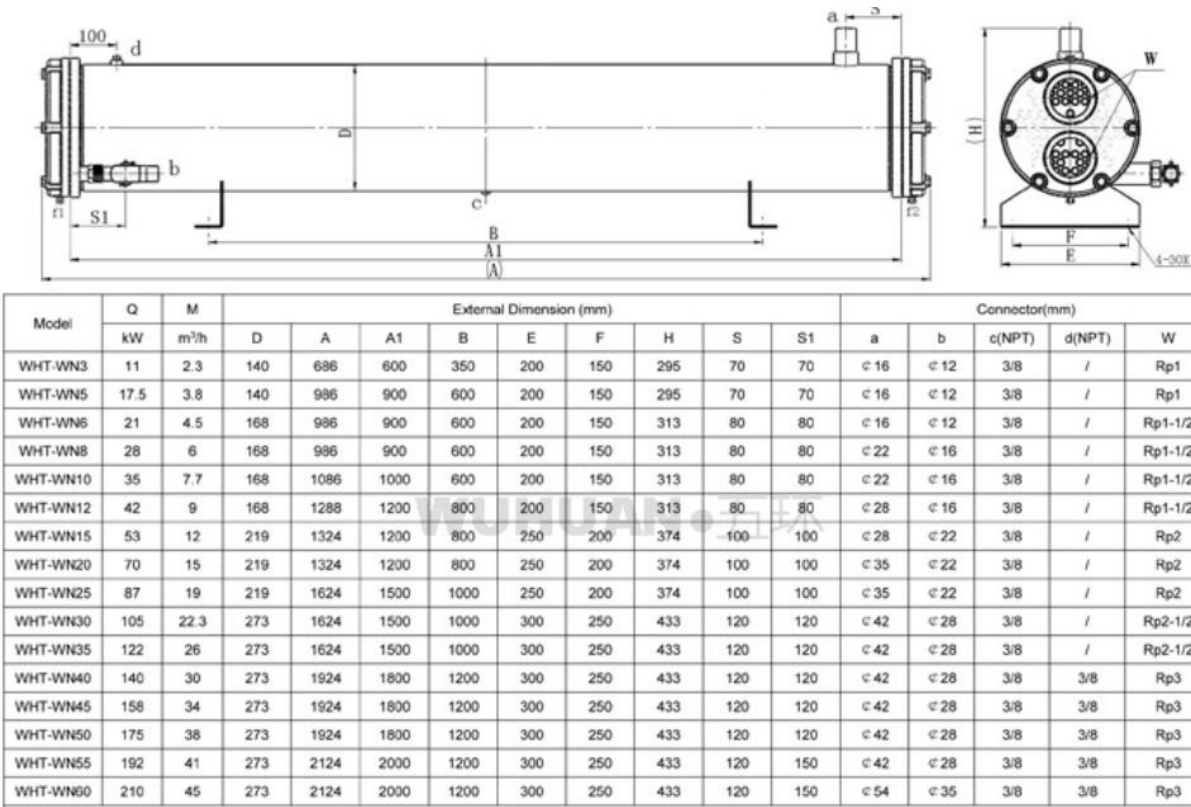| Model | Q | M | External Dimension (mm) | | | | | | | | | Connector(mm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kW | m³/h | D | A | A1 | B | E | F | H | S | S1 | a | b | c(NPT) | d(NPT) | W |
| WHT-WN3 | 11 | 2.3 | 140 | 686 | 600 | 350 | 200 | 150 | 295 | 70 | 70 | ¢16 | ¢12 | 3/8 | / | Rp1 |
| WHT-WN5 | 17.5 | 3.8 | 140 | 986 | 900 | 600 | 200 | 150 | 295 | 70 | 70 | ¢16 | ¢12 | 3/8 | / | Rp1 |
| WHT-WN6 | 21 | 4.5 | 168 | 986 | 900 | 600 | 200 | 150 | 313 | 80 | 80 | ¢16 | ¢12 | 3/8 | / | Rp1-1/2 |
| WHT-WN8 | 28 | 6 | 168 | 986 | 900 | 600 | 200 | 150 | 313 | 80 | 80 | ¢22 | ¢16 | 3/8 | / | Rp1-1/2 |
| WHT-WN10 | 35 | 7.7 | 168 | 1086 | 1000 | 600 | 200 | 150 | 313 | 80 | 80 | ¢22 | ¢16 | 3/8 | / | Rp1-1/2 |
| WHT-WN12 | 42 | 9 | 168 | 1288 | 1200 | 800 | 200 | 150 | 313 | 80 | 80 | ¢28 | ¢16 | 3/8 | / | Rp1-1/2 |
| WHT-WN15 | 53 | 12 | 219 | 1324 | 1200 | 800 | 250 | 200 | 374 | 100 | 100 | ¢28 | ¢22 | 3/8 | / | Rp2 |
| WHT-WN20 | 70 | 15 | 219 | 1324 | 1200 | 800 | 250 | 200 | 374 | 100 | 100 | ¢35 | ¢22 | 3/8 | / | Rp2 |
| WHT-WN25 | 87 | 19 | 219 | 1624 | 1500 | 1000 | 250 | 200 | 374 | 100 | 100 | ¢35 | ¢22 | 3/8 | / | Rp2 |
| WHT-WN30 | 105 | 22.3 | 273 | 1624 | 1500 | 1000 | 300 | 250 | 433 | 120 | 120 | ¢42 | ¢28 | 3/8 | / | Rp2-1/2 |
| WHT-WN35 | 122 | 26 | 273 | 1624 | 1500 | 1000 | 300 | 250 | 433 | 120 | 120 | ¢42 | ¢28 | 3/8 | / | Rp2-1/2 |
| WHT-WN40 | 140 | 30 | 273 | 1924 | 1800 | 1200 | 300 | 250 | 433 | 120 | 120 | ¢42 | ¢28 | 3/8 | 3/8 | Rp3 |
| WHT-WN45 | 158 | 34 | 273 | 1924 | 1800 | 1200 | 300 | 250 | 433 | 120 | 120 | ¢42 | ¢28 | 3/8 | 3/8 | Rp3 |
| WHT-WN50 | 175 | 38 | 273 | 1924 | 1800 | 1200 | 300 | 250 | 433 | 120 | 120 | ¢42 | ¢28 | 3/8 | 3/8 | Rp3 |
| WHT-WN55 | 192 | 41 | 273 | 2124 | 2000 | 1200 | 300 | 250 | 433 | 120 | 150 | ¢42 | ¢28 | 3/8 | 3/8 | Rp3 |
| WHT-WN60 | 210 | 45 | 273 | 2124 | 2000 | 1200 | 300 | 250 | 433 | 120 | 150 | ¢54 | ¢35 | 3/8 | 3/8 | Rp3 |

*Table 11 : Design Table of Evaporator*

**Total price = $1000** [15]

# 5.  Discussion and Conclusion

## Discussion

In this study, the results of condensation and evaporation are investigated and analyzed by using empirical formulas. First of all, evaporation methods were tried in order to establish a desalination system. However, since these methods do not give us the necessary values when it comes to condensation, which is the opposite, it was decided to do this with the boiling method. Help was received from heating oil while heating the water with boiler.

Empirical methods were not completely conclusive, so the transition to precise methods was made. The project was originally intended to be tried in a workplace or a factory environment, but it was left in the design phase due to the corona. Smaller radius but longer tubes were preferred to reduce the energy used. Thus, both the speed of the water decreased and a more laminar result was obtained.

As a result, a treatment system was designed by boiling and cooling the water in this project. Efficiency and cost analysis were also important issues in the design. Calculations were carried out with maximum efficiency and reducing the carbon footprint.

## Conclusion

Waste heat energy is produced as a mandatory by-product as a result of machines and processes that use energy. The need to extract heat as a by-product of many systems is the basis of the laws of thermodynamics. Waste heat energy has a lower utility (low exergy or high entropy in the thermodynamics dictionary) than the original energy source. All kinds of human activities, natural systems and all organisms are sources of waste heat. Unnecessary cold (as in a heat pump) output is also a form of waste heat.

Instead of being released into the environment, sometimes the waste heat can be used in another process, or if the missing heat is added to the system, some of the waste heat energy will be used for the same process (as in heat recovery ventilation).

Water treatment is any process that improves water quality to make it more acceptable for a particular end use. End use can be many other uses, including drinking water, industrial water supply, irrigation, river flow maintenance, water recreation or its safe return to the environment. Water treatment removes or reduces the concentration of contaminants and unwanted components, ensuring that the water is suitable for the desired end use. There is also wastewater treatment, which is the treatment of water after it has been used for domestic or industrial purposes.

Water quality refers to the chemical, physical, biological and radiological properties of water. It is a measure of water status relative to the requirements of one or more biotic species or any human need or purpose. Generally, the values obtained by treating the water will be used as a set of standards by which to evaluate. The most common standards used for water treatment relate to the health of systems, the maintenance of human health and drinking water.

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