THERMODYNAMIC ANALYSIS OF SOLAR OCEAN THERMAL ENERGY CONVERSION SYSTEM

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ABSTRACT

M. Sc. Thesis

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Ocean thermal energy conversion (OTEC) is a way to use ocean energy to generate electricity by exploiting the temperature difference between the ocean surface and depth. This system, which uses ammonia as the working fluid, generates energy by pumping cold water from a depth of 1000 m and hot water from a depth of 35 m. In order for this system to work efficiently, there must be a temperature difference of at least 20 °C between the surface and depth temperatures. This temperature difference cannot be reached during the cold seasons when the air temperature and solar radiation decrease. Another reason for not being able to reach this temperature difference is that in systems established near shallow sea coasts, sufficient cold water cannot be obtained due to the low depth. Achieving this required temperature difference continuously for a year is possible with the system called solar ocean thermal energy conversion (SOTEC), which uses solar panels. In this research, it is thermodynamically investigated how the inlet temperature of the evaporator used in the SOTEC system is increased by solar panels and thus the amount of energy that can be obtained and the efficiency of the system are increased. The optimum value of the mass flow rate of the working fluid ammonia, which will maximize the efficiency of the system, has been calculated. In this study, thermodynamic calculations were made by using the sea water 2020 temperature values near Alanya, Turkey, as input in the computer package program called TRNSYS. For this 120 kW SOTEC system, it has been calculated that the solar panel surface area to be used should be 5000 m^2. It was determined that the optimum ammonia mass flow rate, which maximizes the efficiency of the system, is 1.9 kg/s. The maximum value of the efficiency of the system was calculated as 78%. This value is 1.4 times the OTEC system efficiency. In conclusion, this study shows that the use of solar panels is an effective way to improve system performance.

Key Words : Solar collector, ammonia, NH_3, OTEC, SOTEC, TRNSYS software.
Science Code : 91441

ÖZET

Yüksek Lisans Tezi

GÜNEŞ ENERJİSİYLE GÜÇLENDİRİLMİŞ OKYANUS ISIL ENERJİ DÖNÜŞÜM SİSTEMİNİN TERMODİNAMİK ANALİZİ

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Okyanus ısıl enerji dönüşümü (OTEC), okyanus yüzeyi ve derinliği arasındaki sıcaklık farkından yararlanarak elektrik üretmek için okyanus enerjisini kullanmanın bir yoludur. Çalışma akışkanı olarak amonyağı kullanan bu sistem, 1000 m derinlikten soğuk su ve 35 m derinlikten sıcak su pompalayarak enerji üretiyor. Bu sistemin verimli çalışabilmesi için yüzey ve derinlik sıcaklıkları arasında en az 20 °C sıcaklık farkı olması gerekir. Bu sıcaklık farkına, hava sıcaklığının ve güneş ışınımının azaldığı soğuk mevsimlerde ulaşılamamaktadır. Bu sıcaklık farkına ulaşamamanın diğer bir nedeni de, sığ deniz kıyılarına yakın yerlerde kurulan sistemlerde, az derinlikten dolayı yeterli soğuklukta suyun elde edilememesidir. Bu gerekli sıcaklık farkının bir yıl boyunca sürekli olarak elde edilebilmesi, güneş panelleri kullanan güneş enerjili okyanus ısıl enerji dönüşümü (SOTEC), adlı sistem ile mümkün olabilmektedir. Bu araştırmada, SOTEC sisteminde kullanılan evaporatörün giriş sıcaklığının, güneş panelleriyle artırılması ve böylece elde edilebilecek enerji miktarının ve sistem veriminin nasıl arttırıldığı termodinamik açıdan incelenmiştir. Sistemin verimini maksimum yapacak, çalışma akışkanı amonyağın kütlesel debisinin optimum değeri hesaplanmıştır. Bu çalışmada, Türkiye Alanya yakınıdaki deniz suyu 2020 sıcaklık değerleri, TRNSYS adlı bilgisayar paket programında girdi olarak kullanılarak termodinamik hesaplamalar yapılmıştır. 120 kW gücündeki bu SOTEC sistemi için, kullanılması gereken güneş panel yüzey alanının 5000 m^2 olması gerektiği hesaplanmıştır. Sistemin verimini maksimum yapan optimum amonyak kütlesel debisinin 1,9 kg/s olduğu belirlenmiştir. Sistemin veriminn maksimum değeri, %78 olarak hesaplanmıştır. Bu değer, OTEC sistem veriminin 1,4 katıdır. Sonuç olarak, bu çalışma güneş panellerinin kullanımının sistem performansını iyileştirmede etkili bir yol olduğunu göstermektedir.

Anahtar Kelimeler **:** Güneş kollektörü, amonyak, NH_3, OTEC, SOTEC, TRNSYS yazılımı.

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CONTENTS

Page

Page

Page

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

SYMBOLS AND ABBREVIATIONS INDEX

SYMBOLS

A_c	: Collector surface area.
d_{ws}	: Warm seawater inner pipe.
D_{eq}	: Equivalent diameter.
F_R	: Heat removal factor.
I_t	: Total incident radiation.
L_{WS}	: Length of the warm seawater pipe.
m_{wf}	: Working fluid mass flow rate.
m_{ws}	: Warm seawater mass flow rate.
m_{cs}	: Cold seawater mass flow rate.
t	: Time
T_{ex}	: Inlet temperature of fluid of collector.
U_c	: Collector overall heat loss coefficient.
v_{ws}	: Velocity of warm seawater.
W_N	: Net power output from the system.
$W_{P,cs}$	: Pump power of cold seawater.
$W_{P,wf}$	: Pump power of working fluid.
$W_{P, ws}$	: Pump power of warm seawater.
$W_{T\text{-}G}$	: Turbine power.
W_{cs}	: Pumping power of cold seawater.
ρ_{CS}	: Density cold deep seawater.
ρ_{WS}	: Density warm seawater surface.
Q_u	: Rate of useful the total incident radiation energy gain.
Q_{TL}	: Rate of energy loss from the storage tank.
Q_1	: Heating load supplied by solar energy via the load heat exchanger.
λ_E	: Friction loss coefficient.
σ	: Clearance.

η_c	: Collector efficiency.
η_{wsp}	: Efficiency cold seawater pump.
η_{th}	: Net cycle efficiency.
$(\tau\alpha)_n$	: Transmissivity - absorptivity product.
ΔH_{cs}	: Total head loss of cold seawater piping.
ΔH_{ws}	: Total head difference of the warm seawater piping
$(\Delta H_{ws})_B$	: Friction loss due to bending pipe.
$(\Delta Hws)_E$	: Pressure difference of warm seawater in the evaporator.
$(\Delta H_{ws})_P$	: Pump head of the warm seawater pipe due to friction.
$(\Delta H_{ws})_{sp}$	: Friction loss in the straight pipe.

ABBREVIATIONS

CC	: Closed cycle.
CWP	: Condenser water pump.
DCC	: Direct-contact condenser.
FGP	: Fiberglass piping.
IPCC	: Intergovernmental panel on climate change.
OC	: Open cycle.
OST	: Ocean surface temperature.
OTEC	: Ocean thermal energy conversion.
SDC	: Seawater district cooling.
SOTEC	: Solar Ocean thermal energy conversion.

PART 1

INTRODUCTION AND LITERATURE REVIEW

Our planet is in desperate need of energy due to a significant increase in demand. Instead of concentrating on energy sources that contribute to significant ecological problems and environmental contamination, attention should be given to those that are environmentally beneficial as well as warming the earth. Ocean thermal energy conversion (OTEC) is one of the important energy resources that may be very important in the future. French physicist Jacques Picard came up with the idea for this technique in his book Arsene. Then, Dr. Georges in Cuba had Claude put it into use in 1930 as a workable method (Matanzas Bay). Several research institutions carried out a number of development projects between the years of 1950 and 1960 that are also related to research publications. On the other hand, because nuclear energy was not only more attractive than other energy sources at the time but also because the price of oil fell in the latter half of the 20th century, it appears that governments did not find OTEC to be desirable in the 1990s. To be more precise, without taking into mind the environment's future, renewable energy had been overlooked in recent years. Oil prices rose by more than 1400% a barrel at the start of the 20th century, while global warming gained importance and heightened the threat to the environment. Consequently, renewable energy has reemerged and is now considered a very valuable resource. It makes sense to use this natural resource to meet the need for energy because the oceans account for the largest percentage of the earth’s surface (70%). The technology for renewable energy is known as OTEC. Since it receives its heated energy from the sun, it is a significant source of solar energy. It takes advantage of the difference in temperature between the cooler deep ocean point and the warmer ocean surface water that is heated by the sun at a depth of roughly 800-1000 m to produce energy. For the OTEC system to function, a differential temperature of 20 °C is required. Depending on whether it is built on land (a land-based OTEC power plant) or is floating in the water (a power plant), there are two different types of OTEC power plant construction.

Both their materials and their functions are comparable. On the other hand, the land-based power plant is more expensive than the floating power plant since the cold-water pipe needs to be slanted in order to reach the cold water. Since it has a vertical cold-water pipe, it must therefore be longer than in the floating power plant. On the other hand, using cold water as an air conditioning fluid for a land-based power plant is more advantageous because it doesn't require additional transportation expenses. Additionally, because it doesn't have to sail into the ocean, maintenance is simpler [1, 2].

1.1. INTRODUCTION FOR OTEC

Especially because of the strength disaster of the 1970s, studies in addition to improvements have picked up pace toward developing sustainable strength, which is associated with ideally inexperienced strength. Whenever oil expenses went up, pursuits in renewable energy and technology increased. On an average day, tropical seas on Earth absorb a quantity of strength from solar radiation equal to the warmth content of 200 billion barrels of oil. OTEC is a technique that targets the use of that loose strength. OTEC, which stands for Ocean Thermal Energy Conversion, is a type of renewable energy technology that generates power by harnessing the temperature difference that exists between the surface of the earth and the depths of the ocean and transferring that temperature difference to a low-strain turbine. Under the influence of sunshine, the ground temperature may rise to between 25-29 °C in tropical regions. In addition, the temperature is falling with increasing severity, which is related to temperatures of around 4-6 °C on a mark one thousand meters below floor level. In the year 1881, the French physicist D'Arsonval proposed the idea of using the warm surface seawater that is common in tropical regions in order to vaporize an operating fluid (ammonia) with the help of an evaporator and then pressurize a turbine generator with the ammonia vapor that was obtained in order to produce electricity. D'Arsonval's proposal was based on the idea that using the warm surface seawater would be more efficient than this theory, when combined with the concept of the Rankine cycle and applied to steam engines and power plants, may be expected to contribute to the overall performance of both types of facilities. As a result of the fact that the operating fluid in this concept is contained inside a closed loop, OTEC has classified it as a 'closed cycle' system. This technology had not been brought to life until 1930, when D'Arsonval's mentee, a French engineer who is also affiliated with the inventor Georges Claude, developed the first prototype plant in Cuba. Prior to that time, it had not been used. Claude's cycle, on the other hand, was not the same as the concept of a closed cycle because, in this particular example, floor seawater was flash-evaporated by using a vacuum chamber and bloodless seawater was used to condense the vapor. This caused Claude's cycle to be distinct from the concept of a closed cycle. This concept was given the moniker 'open cycle' OTEC since the operating fluid simply circulated once all the way through the system. The temperature difference between the two locations was just 14 °C, yet Claude was able to generate 22 kW over the course of 10 days. The use of an open-cycle OTEC system also makes it possible to produce desalinated water as a byproduct. 1979 saw the construction of a modest OTEC plant that was built on a barge about a mile off the coast of Hawaii by the state of Hawaii. Gross energy production at this plant was slightly more than 50 kW, while the facility's internet energy technology could reach as high as 18 kW. Since that time, OTEC technology has been a focus of endeavor in terms of research, primarily garnering the interest of industrialized islands in addition to countries located in the tropics [3]. Flowchart for how an OTEC system operates in a closed cycle is shown in Figure 1.1.

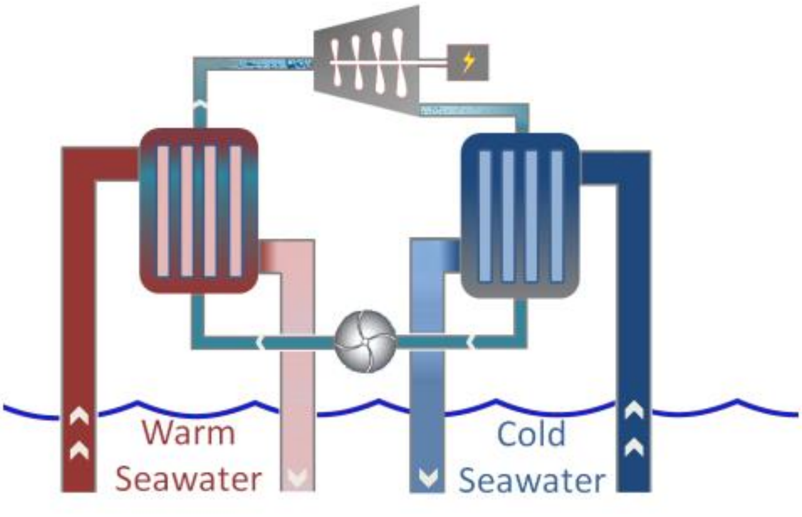

Figure 1.1. Flowchart showing how an OTEC system operates in a closed cycle [4].

1.2. BACKGROUND

On a yearly basis, it is estimated that the amount of solar power received by the seas is at least four thousand times that which is now given to people. It's possible that we'd only need a tiny fraction of this renewable energy if OTEC could convert ocean thermal electricity to power at a performance level of 3 percent. Even if we thought that collecting such a small amount of ocean solar energy no longer hurt the environment, we would still need to choose and improve ways to get it to the consumer in a way that they could use it. The idea of using the heat of the ocean to make electricity was first written about in Jules Verne's 'Twenty Thousand Leagues Under the Sea.' The film 'The Sea Monsters' (1870) popularized the idea. Eleven years later, Jules Verne and D'Arsonval came up with the idea of using a heat exchanger, like an evaporator, to turn pressurized ammonia into vapor and then using the vapor to pressurize a turbine generator. Condensing the ammonia vapor could be done with any heat exchanger, like a condenser, on the seafloor, which was between 800 m and 1000 m deep and had temperatures between 4-8 °C from the sterile ocean water that was forced (upwelled) to the surface. The Rankine cycle, a tool of thermodynamics, backs up his theory by showing how the energy landscape of steam (vapor) can be broken down. This is because of the notion of a closed-cycle OTEC, in which ammonia flows in a closed cycle (CC-OTEC). In 1979, a Mini-OTEC plant shown in Figure 1.2. a tiny plant installed on a barge off the coast of Hawaii, put the concept to the test by generating 50 kW of gross energy and 18 kW of internet output. After that, a group of Japanese companies ran a land-based plant with a gross output of 100 kW on the island of Nauru. This plant was cared for over a period of time so that it could be used as an illustration. Size systems for industrial applications could not be applied to them [3].

Figure 1.2. Mini-OTEC 1979 [5].

Forty years after D'Arsonval, another French inventor named Georges Claude suggested utilizing saltwater as the working fluid. The water from the floor is evaporated swiftly in a vacuum chamber in Claude's cycle. A turbine generator is then driven by the low-strain steam. After the turbine, the steam is cooled by being cooled by deep saltwater, which is linked to much cooler water. Because of this, the cycle may also generate desalinated water in addition to electricity. Because of its open nature, Claude's cycle is also known as open-cycle OTEC (OC-OTEC). The operating fluid does not make several circuits through the system. In 1930, he developed this cycle at his modest land-based facility in Cuba, which included an instantaneous touch condenser direct contact condenser (DCC). This eliminates the need for product-based desalination processes. The plant's inability to generate internet-based power may be traced back to a mismatch between the electrical and saltwater systems, as well as to unsatisfactory website options like thermal resources. However, operation of the facility was maintained for weeks. Using a 2.2 structure allows for this realization to be made easier. floating ice-making equipment with a 2000-ton capacity, generating up to 2000 MW for Rio de Janeiro (this arises before the widespread availability of household refrigerators). About a hundred miles out to sea, Claude positioned his floating power plant (a plant ship, for instance). Despite his best efforts, he was never able to successfully erect the vertical, long pipe necessary to convey deep ocean water to the cold-water pipe (CWP), and his firm was dissolved in 1935 [6]. Not having access to modern ocean engineering expertise is another possible reason for his failure. This time period saw the decline of the offshore business. The installation of a CWP while at sea proved to be his most difficult technical challenge. When compared to other scenarios, this one stands out since it involves experimental actions in which a confirmed file may be contained within a setup of many pipes. The next step toward fixing problems with running OTEC plants is to build a modest, land-based, very experimental facility in Hawaii. This facility was developed and managed by the author's group. The new target for the turbine-heat generator's output is 210 kW per 26 °C of floor water. 210 kW OC-OTEC experimental plant 1993-1998 is shown in Figure 1.3 This is the equivalent of a deep-water temperature of 6 °C. In order to create desalinated water, 10% of the steam created is sent to a floor condenser. The trial plant operated for six years without incident. Besides that, the maximum production rates reached 255 kW (gross), which is equal to 103 kW of internet power and 0.04 l s^{-1} of desalinated water. The data from OTEC may be interpreted as global in scale.

Figure 1.3. 210 kW OC-OTEC experimental plant 1993-1998 [5].

The author and his colleagues have developed a two-stage OTEC hybrid cycle, where power is created in a first-degree closed cycle with the aid of water manufacturing in a third-degree open cycle to make the most of the thermal assistance available to provide water and electricity. An OTEC plant's waste saltwater is desalinated on the second level using a flash evaporator and a floor condenser, resulting in a temperature differential of 12 °C (basically, an open cycle without a turbine generator). When an additional degree is applied, water output in an open-cycle plant double. Chiller fluid formed from bloodless deep water has been proposed for use in air conditioning (AC) systems. It has been calculated that these buildings' potential to save large quantities of energy without relying on OTEC might have major cost ramifications. For example, 5800 tons (about equal to 5800 rooms) of air cooling may be supplied by only one (m^3 /s) of deep ocean water at 7 °C. Standard alternating current (AC) devices need 5000 kW of power, whereas pumping systems only require 360 kW. It is expected that the financial payoff would take place over a period of three to four years. Several other combinations of OTEC flora were proposed. These concepts include anything from towers erected on the shelf and linked to different offshore constructions to floating plants and trees to plants grown on dry ground. The floating plant, situated near land and sending power to shore through a submarine power line, seems to be the best choice for an industrial length flora cable.

1.3. OTEC AND THE ENVIRONMENT

OTEC is one of the greenest methods of energy generation since it uses just flowing fluid to handle potentially dangerous substances like ammonia. In addition, there are no harmful waste products created. OTEC needs to get seawater from the mixed layer. In addition, this process, which involves bringing water from the deep ocean and returning it to the mixed layer near the thermocline, may be accomplished with minimum ecological impact. Less than one percent of the nearly 700 metric tons of carbon dioxide that are discharged into the sky annually by open cycle OC-OTEC plants is derived from ocean water. The amount of substance discharged by gasoline-oil power plants is expressed as a mass in grams per kilowatt hour. The fee is lower even if a closed cycle CC-OTEC power plant is built. For instance, sea floor temperature anomalies due to bio stimulation in the euphotic area should be perpetuated if recurrent events within the combined layer and the deep ocean's nutrient-rich, bacteria-free water are maintained. The euphotic zone is the uppermost layer of the water where there is potentially enough light for photosynthesis to occur. This has been taken to indicate about 120 m in Hawaiian waters, which is the 1 percent-mild penetration intensity. For most biological activity, the radiation levels needed are at least 10% greater than those found on the ocean bottom; therefore, this degree of caution is unnecessary. Since the depth at which mild penetrates decreases exponentially with intensity, 10 percent mild penetration is equivalent to, say, 60 m in the waters off the Hawaiian Islands. According to analyses of various OTEC designs, mixing seawater at depths of 60 m results in a dilution coefficient of 4 (i.e., 1 part of OTEC effluent is blended with 3 parts of the ambient seawater) and equilibrium (impartial buoyancy) depths beneath the combined layer at various times of the year. The intensity of the water returning to the surface is another indicator of vertical separation. In addition, the need to prevent re-injection into the plant is linked to the pleasant water consumption levels seen at around 20 m. The price will change according to the condition of the water. As a result, there can no longer be any continuous sea floor temperature anomalies, and the marine food supply should have little to no effect. These findings may be shown using real-world data from the pre-industrial plant described. In order to have a functional heat switch, protecting the heat exchangers from biofouling is essential. It has been established that biofouling only develops in OTEC heat exchangers when they are submerged in saltwater. Thus, it is of the utmost importance to safeguard the evaporators at CC-OTEC. In addition to chlorine, several mechanical approaches have been devised chlorine (Cl_2). Plus, depending on the evaporator type, any chemical that may be used in a mechanical process can be used. To protect marine life, the United States Environmental Protection Agency (EPA) sets a limit on Cl_2 discharge of 0.5 mg l-1, which is equivalent to an average of 0.1 mg l-1. CC-OTEC plants prefer to use Cl_2 concentrations much below the ten percent threshold set by the EPA. The upgrades to the energy plant will gradually leak trace quantities of working fluid during operation. Discharges to the ocean are affected by a number of factors, including the working fluid, biocides, consumption rate, and release configuration. There is a chain of causation connecting the developmental phase to subsequent, most likely system-wide issues. The challenges here are identical to those encountered in the construction of any power plant, shipyard, or similar endeavor. The energy plant expansions, which will take place on and around offshore platforms, will leak only trace quantities of working fluid into the environment. OTEC is the only technology that can transfer saltwater streams with transit costs equivalent to rivers and then return those streams to the ocean after passing them through the OTEC additives. The use of biocides, which are associated with ammonia, is also analogous to a wide range of human activities. Operating fluid and biocide emissions from an industrial facility should be too low to be detected outside of the plant locations, with the possible exception of anhydrous ammonia, which is related to chlorine, if occupational fitness and protection policies such as those in effect inside the USA are followed. Depending on their proximity, plant workers and nearby residents might be put in harm's way by a large leak of operating fluid or biocide. Since ammonia and chlorine are both corrosive to the eyes, skin, and respiratory system, the mucous membranes in those areas may also prevent adequate breathing. In the event of an accident, the dangers associated with either method are the same as those associated with other commercial programs, including those drugs. Ammonia is utilized as a fertilizer in addition to its application in ice skating rink refrigeration systems. Chlorine is employed in both steam power plants and municipal water treatment plants. Chlorine may be manufactured on-site; therefore, significant quantities are rarely needed for storage [7]. Threatening organisms are deterred at the OTEC plant's intake displays. If an organism gets impaled, it will die. In addition, the plant attracts a connection as it goes by. Organisms that get imprisoned may be subjected to biocides, temperature fluctuations, and mechanical stress. Working fluid, which is related to organisms entrapped in the system, may also expose entrapped organisms to other components (such as metals as well as oil or grease). It is recommended that intakes have a low inlet glide speed to lessen the chances of entrainment and impingement. The inlets need to be hydrodynamically adjusted so that withdrawal doesn't trigger turbulence or other unfavorable side effects. The recirculation zones are situated within the immediate vicinity of the facility. Most of the creatures that are impinged on or entangled by the devouring waters may be killed or annihilated. Studies show that phytoplankton and zooplankton carried across warm water would have a high death rate; nevertheless, consumption may be much lower than 100%; in reality, only a fraction of the phytoplankton plants at the bottom may be destroyed by entrainment. For the purposes of valuation, common sense dictates that all persons apprehended would perish instantly and that all those apprehended would be killed, unless evidence to the contrary is provided. Elements of the structure made of metal, such as heat exchangers, pump impellers, and steel pipelines that have been corroded or deteriorated by saltwater, would add hint factors to the effluent. It's not easy to tell how metals emitted from a plant will affect the nearby biota. Corrosion resistance is also linked to the toxicity of trace components, which might vary. Species found in the tropics and subtropics have received very little research. Further, with enough water circulating throughout the system, any trace metals emitted by OTEC vegetation may be swiftly eliminated. In contrast, the entire OTEC length may be thought of as the distance between the beginning and end of the device. Some species should benefit in the long run from the mix of clue components released from the plant or redistributed from natural reseeds, as shown by the plant flow device. The building of OTEC facilities and its associated activities may have repercussions on commercial and recreational fishing. There might be juvenile fish in the area, making the plant an attractive food source for the fish [8]. The redistribution of vitamins may increase output, which in turn boosts fishing. However, inshore fish populations may also be impacted by the loss of fish eggs, larvae, and juveniles as a result of impingement and entrainment, as well as losses associated with the discharge of biocides. The total impact of OTEC operations on aquatic lifestyles will be determined by the stability maintained among diverse impacts. If the area around an OTEC site is well planned and the local community is involved, the available recreational opportunities may be greatly enhanced. Other potential threats stem from the OTEC energy device's use of compressed gases and huge material-handling equipment, as well as the protective difficulties inherent to steam-electric-driven energy technology devices (electric dangers, spinning gears, etc.). Operating as a low-temperature, low-stress Rankine cycle, the CC-OTEC energy plant is safer for both the working population and the surrounding community than your standard fossil-gas plant. It is vital to test and assess all possible critical difficulties for each page and design in order to guarantee that OTEC is a safe and secure alternative to traditional energy technology. Researchers believe that OTEC plants can be designed to have less of an impact on the environment [4].

1.4. GLOBAL WARMING

Changes in the modern climate are made up of the combined effects of global warming and its repercussions on the planet's weather. Although climate change has occurred before, the current period is unique in its rapidity and lack of a natural explanation for the shifts. For the most part, carbon dioxide (CO_2) is released with methane for this function, making it the primary greenhouse gas emitted. Most of these gases are produced when fossil fuels are burned to generate electricity. Forest loss is only one of many causes, and agriculture, steel manufacturing, cement manufacturing, and other related industries are also factors. Lack of snow cover, which normally reflects sunlight, is only one of several meteorological feedbacks that contribute to the amplification of the upward push of temperatures [9]. Surface land temperatures have increased at a rate almost double the global average. Heat waves, often linked to the spread of wildfires, are becoming more frequent, and so are deserts. Permafrost melting, glacier retreat, and sea ice loss are all effects of increased heat within the Arctic. In addition, higher temperatures are causing more intense storms, which are linked to several climatic extremes. Many animal and plant species are being pushed to new habitats or becoming extinct due to environmental changes in places like coral reefs, mountains, and the arctic. Food security is threatened by climate change's linked water shortages, increased floods, harsh heat, increased illness, and monetary loss. It may be used to fuel human migration as well. The World Health Organization has identified climate change as the twenty-first century's greatest opportunity for improving global health. Some effects will persist for generations even if attempts to control future warming are successful. The rise in sea levels and the warming, more acidic seas are examples of these. All of these factors have already had an impact on the current rate of warming, which is at an all-time high of 1.2 °C (2 °F). With further rises to 1.5 °C and beyond, the Intergovernmental Panel on Climate Change (IPCC) projects even more impacts. Tipping points, like the Greenland ice sheet melting, will become more of a concern as temperatures continue to rise. Adapting to these shifts is an important part of the solution, as is taking steps to reduce the amount of warming. Reducing greenhouse gas emissions and the costs involved with eradicating them from the environment may help slow future warming. As part of this effort, we will be using more renewable energy sources like wind and solar, gradually eliminating our reliance on coal, and improving our overall energy efficiency. Emissions may be reduced in other ways, too, such as by switching to electric cars and heat pumps for homes and commercial buildings. Reducing forest loss and enhancing existing forests are both effective strategies for reducing atmospheric CO_2. Better coastal protection, disaster management, and the development of more resistant crops are all ways in which communities might adjust to the effects of climate change. Even if such attempts to adapt succeed, they won't eliminate the risk of broad, long-lasting consequences [7]. For the sea surface temperature values used in this study, meteorological data taken from the Turkey-Alanya coast were used. Average surface air temperatures from 2011 to 2021 compared to the 1956–1976 average is shown in Figure 1.4.

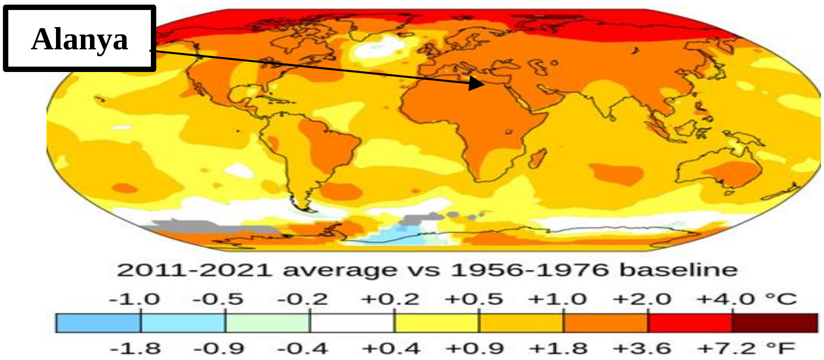

Figure 1.4. Average surface air temperatures from 2011 to 2021 compared to the 1956–1976 average [9].

1.5. OCEAN LAYERS

The ocean has three numbered layers. The layers are the floor layer (now and then called the blended layer), the thermocline, and the deep ocean. The floor layer is the topmost layer of the water. This layer is likewise called the 'blend layer', in addition to being associated with being nicely stirred by the wind as well as different forces. This pinnacle ocean layer is the warmest because solar heating occurs beneath the floor layer, which is the thermocline, the layer between heated floor water and the bloodless deep ocean. Its length varies primarily based entirely on range as well as that which is associated with season, but it will never rise deeper than 1000 m. Temperature changes have been hastily coupled with intensity changes in this layer [10]. This layer frequently coincides with the halocline, the place in which salinity modifications sharply increase in intensity under the thermocline, in the deep ocean. Right now, the water is both bloodless and dense. Temperature and salinity are generally very consistent beneath the thermocline [11]. The layers of ocean are shown in Figure 1.5.

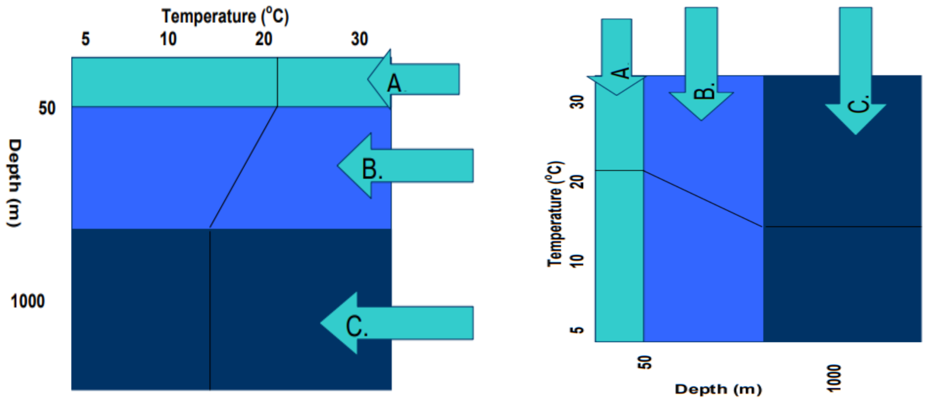

Figure 1.5. The layers of ocean (a) horizontal direction (b) vertical direction [11].

A: surface or mixed zone (or layer)

B: thermocline

C: deep ocean

The OST is often about 20 °C, yet it may be as high as 30 °C in the tropics and as low as 0 °C in the arctic. In the majority of the ocean, the temperature of the water decreases with depth. The temperature of the ocean floor is less than 1 °C in certain locations, with a worldwide average of roughly 2.5 °C at 1000 m. The average annual rise in ocean surface temperature (OST) has been roughly 1 °C since 1910, or 0.1 °C each decade. Over the course of more than a century, OST has been tracked globally by ocean devices equipped with specialized sensors to record temperature fluctuations. The warming is slower below the sea surface roughly 0.01 °C every decade at 1000 m and historical data on temperature are much less common. In terms of climate physics, both the steady rise in OST and the overall warming of the water column are crucial. As the temperature at which heat is transferred between the ocean and the atmosphere, the ocean surface temperature plays a significant role in determining global average temperatures. 90% of the net energy absorbed by the Earth's climate system (air, ocean, land, and ice) is stored in the seas, making the average heat content across the entire water column critical. Seawater is able to absorb and retain much more heat than air does, and heat is transported from the ocean's surface to its depths by means of currents and mixing. About 0.5 W/m^2 of ocean surface area has been absorbed as thermal energy during the previous 50 years. This is equivalent to constantly shining a 100-watt light bulb across a 10-by-20-m section of Earth. If the average ocean surface temperature (OST) continues to rise at the same pace as it has over the previous century, it will take another several hundred years before it rises by more than a couple °C [11]. OST distribution through the world between 2003-2011 is shown in Figure 1.6.

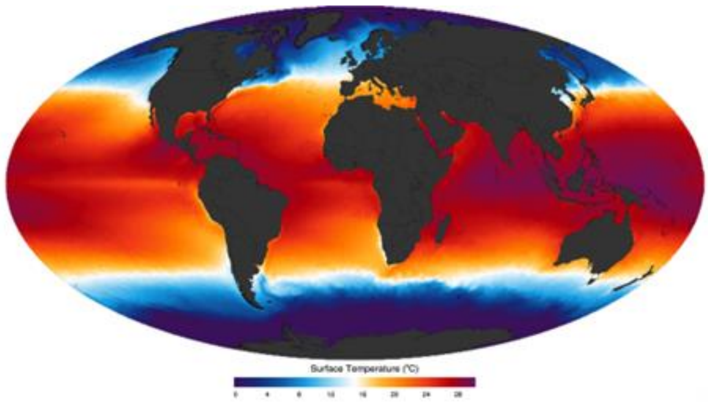

Figure 1.6. OST distribution through the world between 2003-2011 [12].

1.6. OTEC, SEAWATER UTILIZATION, AS WELL AS THE SUSTAINABLE DEVELOPMENT GOALS

In the first layer, seawater is used as a base resource by seawater utilization plants. The layers are the floor layer (now and then called the blended layer), the thermocline, and the deep ocean. The floor layer is the topmost layer of the water. This layer is likewise called the blended layer and is nicely stirred by the wind, in addition to being associated with diverse forces. This pinnacle ocean layer has a tendency to be the warmest layer because the thermocline, the layer among heated floor water in addition to which is associated with bloodless, is located beneath the floor layer. Deep ocean. Its length varies primarily with range and season; however, it will rarely go deeper than 1000 m. Temperature changes have been hastily coupled with intensity changes in this layer. This layer frequently coincides with the halocline, the place in which salinity modifications sharply increase in intensity under the thermocline, in the deep ocean. The water here is both bloodless and dense. Temperature and salinity generally tend to stay highly consistent under the Sustainable Development Goals (SDGs), such as:

- No poverty

- zero hunger
- good health as well as wellbeing
- quality education
- decent work as well as economic growth
- sustainable cities as well as communities can be promoted.

These are serious claims in addition which is associated with could now no longer arise without a notable deal of long-time period funding as well as effort, which is not assured on the time of publication. On the other hand, there's a proper imaginative in addition which is associated with prescient along the mere technical deployment of a 1 MW OTEC plant. If regionally primarily based totally agriculture/aquaculture industries develop, they are able to cope with the constrained eating regimen to be had to I-Kiribati people, selling sustainable meals assets in addition which is associated with healthful eating. The provision of fantastic schooling as well as education along regionally owned ancillary industries to OTEC will cope with the regions of poverty, nice livelihoods, in addition, which is associated with schooling opportunities. The increase of new, inexperienced techy-primarily based totally enterprise can make contributions toward respectable work, monetary increase, in addition which is associated with sustainable cities/ communities. Of course, none of this may arise without longer-time period funding as well as planning [5].

1.7. FACTORS AFFECTING THE TEMPERATURE DISTRIBUTION

The amount of heat absorbed by the ocean from the sun is just one component in the surface's temperature and how it is distributed. The seas are great heat sinks, so they absorb a lot of the solar energy that reaches the planet's surface. Some of this heat is absorbed near the surface, but it does so primarily after a prolonged late-night journey to deeper waters. The seas can absorb tremendous quantities of heat energy with just a little rise in temperature because water has a considerably larger heat capacity than air. In the afternoon, the sun's rays heat the water, raising the temperature of the ocean by one or more degrees Celsius. In the tropics, this heat-up happens on around 5% of days. Roughly 2% of Earth's surface is taken up by seas. Oceanic temperature profiles in the vertical the photic zone goes far below the surface, up to around 200 m. Ample sunlight reaches the photic zone [7]. There is an area of the water, beginning at a depth of about 200 m, called the photic zone, which is poorly illuminated due to insufficient solar radiation. Temperature layout of the OST layer of the ocean is shown in Figure 1.7.

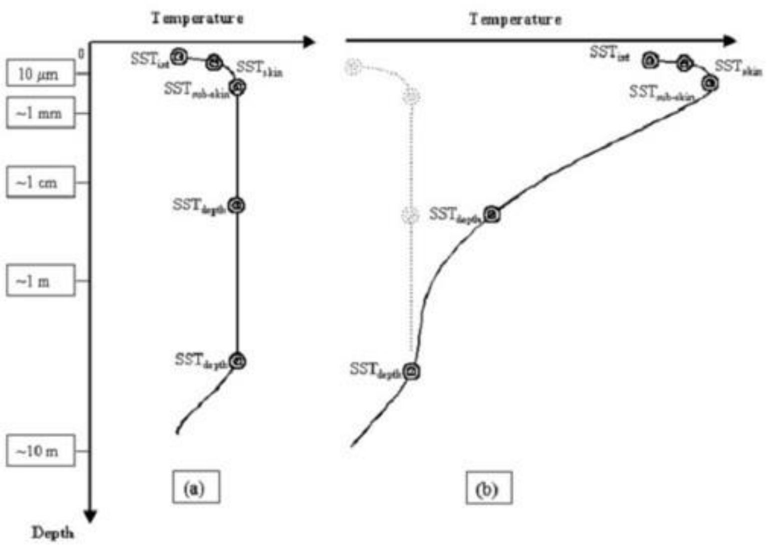

Figure 1.7. Temperature layout of the OST layer of the ocean (a) at night (b) during a day [11].

Where The OST distribution is affected in the horizontal direction The average OST is about 27 °C and it gradually decreases from the equator towards the poles. The rate of decreasing of temperature with increasing latitude is generally 0.5 °C per latitude. Sea surface temperature on December 2013 is shown in Figure 1.8.

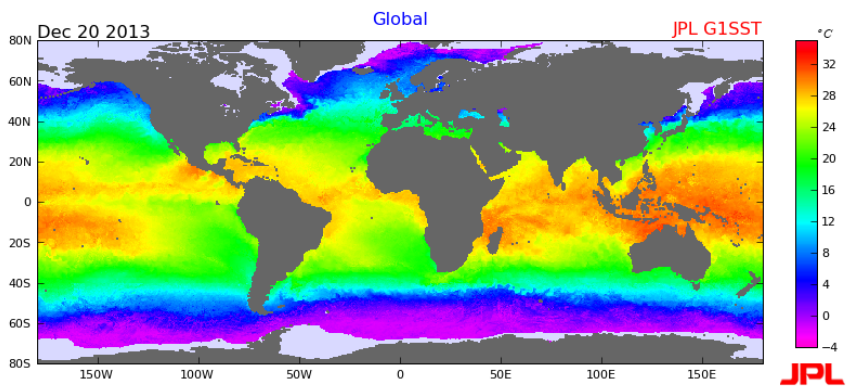

Figure 1.8. Sea surface temperature on December 2013 [5].

1.8. AIM OF THE STUDY

The aim of the study can be defined as:

- To develop a validated simulation model for a SOTEC system.
- To study the effect of operational parameters on the thermodynamic performance of a SOTEC cycle.
- To identify the optimal design and operating parameters for 120 kW SOTEC system.

1.9. SCOPE OF THE STUDY

This study's scope may be split into many segments, which are stated below:

- The proposed SOTEC system is based on a mathematical and simulation analysis conducted with the TRNSYS software system.
- The SOTEC cycle's reference power output is 120 kW.
- The analysis goals are based on thermodynamics and design considerations such as the lowest warm seawater flow rate and optimal solar collector area to create 120 kW of turbine power.
- Ammonia will be chosen as the working fluid.
- The study will be conducted based on the available solar data in Alanya, Turkey.

1.10. VALUE OF THE RESEARCH

With the growing need for power, it is important to use technology that is both advanced and good for the environment. The performance of SOTEC is being studied as one of the solutions to meet the need for power in our everyday lives. OTEC cycle uses the difference in temperature between the warm salt water on the surface and the cold water 1000 m deep. Based on research done in the past on the OTEC cycle, the goal of installing a solar collector is to raise the surface temperature of the warm seawater and make the temperature difference bigger. This improves thermodynamic performance, such as net power generation and net Rankine efficiency.

PART 2

POWER CYCLES AND LOCATIONS

OTEC power systems function as cyclic warming engines. They generate heat by re-heating sun-warmed groundwater, and they may also use this heat to generate electricity. The second law of thermodynamics prohibits the entire process of converting thermal energy into electrical energy. In order to make use of a cooler thermal sink, some of the heat absorbed by the pleasant and warm seawater must be wasted. Seawater pumped up from the ocean floor through a submerged tube serves as the thermal sink for OTEC buildings. The net energy generated by the engine must be conserved in order to meet the requirements of a steady-state control quantity power analysis. The temperature gradient runs from warm and pleasant, associated with warm floor water, to cold and lifeless deep water [13]. For instance, the restrictions on the potential calorific strength conversion performance of a cyclic warmth engine scale with the temperatures at which such warmth transfers take place. Temperature is also used to make this difference for OTEC, which may be fairly minor, leading to subpar performance. When compared to modern combustion steam energy cycles, which use much hotter energy sources, viable OTEC systems with combustion efficiencies of 6–8% can convert nearly 60% of the extracted thermal energy into electricity. More than 90% of the thermal strength obtained from the ocean bottom is also wasted due to OTEC's weak strength conversion capacity; hence, deep sea water must be rejected. Power output is so low that massive heat exchangers and seawater flow rates are needed. However inefficient it may be, OTEC at least makes use of a renewable resource and reduces environmental damage compared to traditional fossil fuel construction. Increased use of nutrient-rich, deep OTEC seawater sustains marine organism populations, which reduces atmospheric CO_2, protects corals, and reduces typhoon damage by preventing the ocean's surface temperature from rising due to energy extraction. These are all examples of how widespread use of OTEC could have real environmental benefits. Excellent heating engines are the only ones for which the

Carnot performance criterion holds. If real-world technology systems are irreversible, the system as a whole will be less efficient. Due to its low theoretical performance, OTEC strength technology requires meticulous engineering to reduce irreversibility. Despite OTEC's use of a relatively abundant resource, poor thermodynamic overall performance will reduce the quantity of power available on the market and, in turn, reduce the economic viability of an OTEC plant. Both the original inventor of OTEC, the French engineer D'Arsonval, and his former student, Claude, came up with practical designs for OTEC heat engines. The terms 'open cycle' and 'closed cycle' refer to the various constructions [14].

In this thesis, OTEC system was improved by using solar energy. The thesis flow chart is given by Figure 2.1.

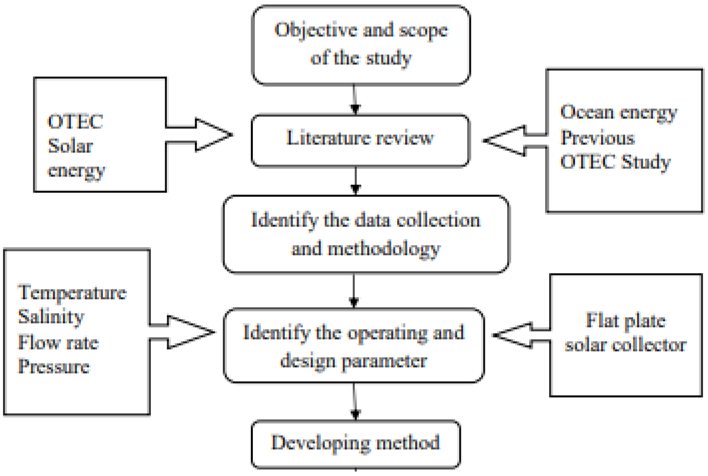

Figure 2.1. Thesis flow chart [13].

2.1. CLOSED CYCLE OTEC

Closed Cycle OTEC D'Arsonval's original concept employed a pure working fluid that would evaporate at the temperature of warm sea water [15]. The vapor would subsequently expand and do work before being condensed by the cold seawater. This series of steps would be repeated continuously with the same working fluid, whose flow path and thermodynamic process representation constituted closed loops, hence the name 'closed cycle'. In closed-cycle OTEC, ammonia is filled inside the closed loop of the pipeline and is chosen because of its low boiling point. (-33 °C or 28 °F) and has higher efficiency due to its high sensible heat. The specific process adopted for closed cycle OTEC is the Rankine, or vapor power, cycle. Figure 2.2 shows a simplified schematic diagram of a closed-cycle OTEC system. The principal components are the evaporator, condenser, turbine, and pump. There are additional devices not included such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply the working fluid lost through leaks or contamination. In this system, heat is transferred from warm surfaces to water occurs in the evaporator, producing a saturated vapor from the working fluid. Electricity is generated when this gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the cold sea water in the condenser and the resulting liquid is pressurized with a pump to repeat the cycle.

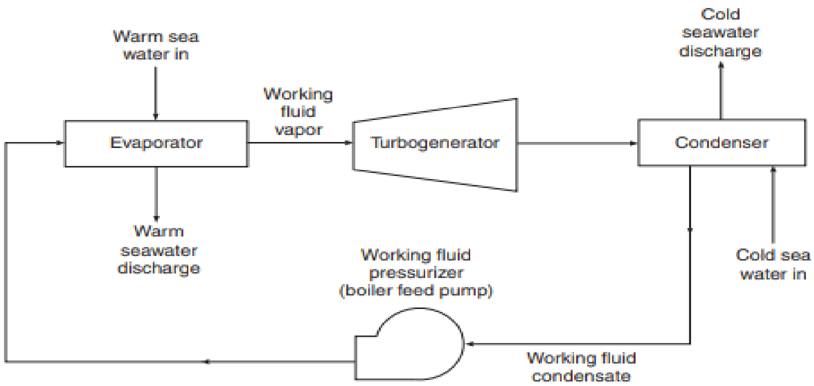

Figure 2.2. Schematic diagram of a closed-cycle OTEC system [16].

2.2. OPEN CYCLE OTEC

The working principle of open-cycle OTEC is very similar to that of closed-cycle OTEC. Its only difference is that an open cycle does not use intermediate fluid or working fluid. Figure 2.3 shows the schematic diagram of an open-cycle OTEC system whereby seawater itself is used to provide the thermodynamic fluid. Warm seawater is expanded rapidly into low-pressure vapor in a partially evacuated chamber, where some of its 'flashes' to steam. This steam is then used to drive a steam turbine. The vapor produced by flashing warm seawater is at a relatively low pressure, so it requires a very large turbine to operate effectively. Then, the expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt behind in the low-pressure container, is almost pure fresh water. From the exhaust of the turbine, the vapor is condensed back into a liquid by exposure to the cold temperatures of deep-ocean water [13].

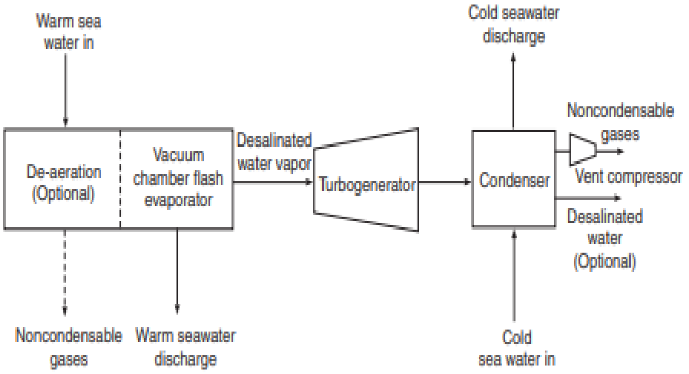

Figure 2.3. Schematic diagram of an open-cycle OTEC system [16].

2.3. HYBRID CYCLE OTEC

Some research on marketing says that OTEC structures that can provide both energy and water can get into the market just as easily as plants that are only used to make energy. As a result of those studies, OTEC was born. Hybrid cycles combine the open-cycle OTEC's ability to produce potable water with the closed cycle's ability to generate large amounts of energy. Several hybrid cycle variants were proposed. Typically, heat-floor seawater is sucked out and evaporated in a partial vacuum, as in the Claude cycle. This low-pressure steam then enters a heat exchanger, where it is utilized to evaporate a low-boiling-factor solvent, such as ammonia, that has been compressed. During this procedure, the vast majority of the steam condenses, resulting in purified water that has been isolated from any salt. Ammonia vapor is condensed with cold saltwater in a straightforward closed-cycle power loop. Additionally, the liquid ammonia coming out of the ammonia condenser, or the cold sea water, may be used to further chill the uncondensed steam associated with other gases departing the ammonia evaporator. Compressing the non-condensable and releasing them into the atmosphere follows. The possibility for biofouling within the ammonia evaporator has reduced significantly in recent years due to the use of steam as an intermediate warm temperature transfer medium and its association with pleasant sea water and ammonia. Removing the turbine from the steam route is another benefit of the hybrid cycle for freshwater generation. This allows for condensation to take place at much higher pressures than in an open-cycle OTEC condenser. As a consequence, the cost of the compressed gas and the cost of discharging the tool's non-condensable gases might be reduced. The resource of using the more labor-intensive closed-cycle ammonia pump cancels out these savings (in contrast to a clean Claude cycle generating energy and water). The hybrid cycle has the drawback that electricity generation and water production are intimately coupled, which is a significant issue. When one of these systems is disrupted, it might have a domino effect on the others. The utilization of an ammonia leak also poses a threat of contaminating the drinkable water supply. Some have suggested a hybrid cycle as a solution, one that uses decoupled electricity and is connected to water production mechanisms [17]. A hybrid-cycle OTEC system is shown in Figure 2.4. This idea rests on the observation that the temperature of saltwater leaving a closed-cycle evaporator stays high enough and the temperature of seawater leaving a closed-cycle condenser remains low enough to sustain a completely autonomous freshwater production process. The proposed hybrid cycle consists of upstream sash evaporation-based 100% desalination equipment and an upstream traditional closed-cycle OTEC power generation tool. There is also the option of adjusting water production apart from power generation, and both systems can function in the event that one component needs maintenance or replacement. The ammonia evaporator's principal drawbacks are that it utilizes a large quantity of warm saltwater at once and that it is prone to biofouling. In addition, the cost of capital increases because of the need for additional equipment, such as the potable water ground condenser [18].

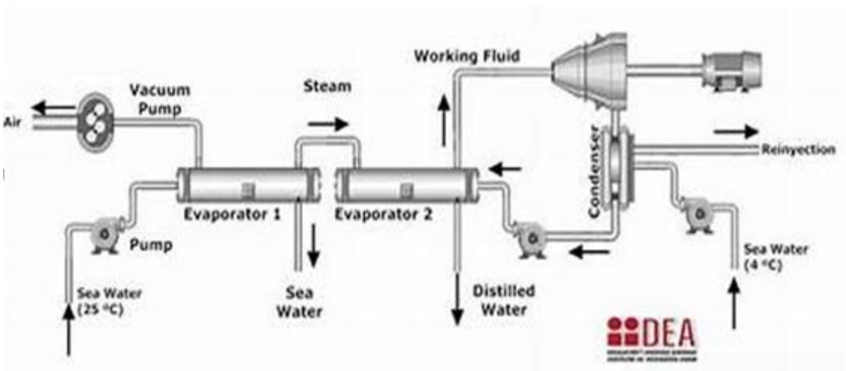

Figure 2.4. Schematic diagram of a hybrid-cycle OTEC system [17].

2.4. CLOSED-CYCLE SOTEC

SOTEC is an energy-generation technique that takes advantage of small temperature differences between the surface and deep water, which are associated with warm ocean floor water. They describe the overall performance simulation effects of an OTEC plant that now uses less effective heat sources such as ocean thermal strength and sun thermal strength. It has been found that the thermal performance of gadgets, which is related to how much electricity they produce, will go up as the working temperature goes up. Increasing the temperature of the turbine's inlet also improves the turbine's performance and the work it can do. Performance is also linked to the rise in electricity output and the rise in the ratio of the float rates of hot water to cold water. A solar collector is applied to offer auxiliary warmth to the gadget. In addition, the additional sun is set up to pre-heat the cooling, which is associated with getting the seawater into the evaporator earlier. The warmth absorbed from the sun collector by using heated seawater will then warm the running fluid, causing the enthalpy to drop throughout the turbine expansion because the sun source does not devour exhaustible power sources, such as fossil fuels. They all use the closed-cycle Rankine cycle; the only difference is whether they use ammonia or hydrogen as a fluid [19]. A closed-cycle SOTEC system is shown in Figure 2.5.

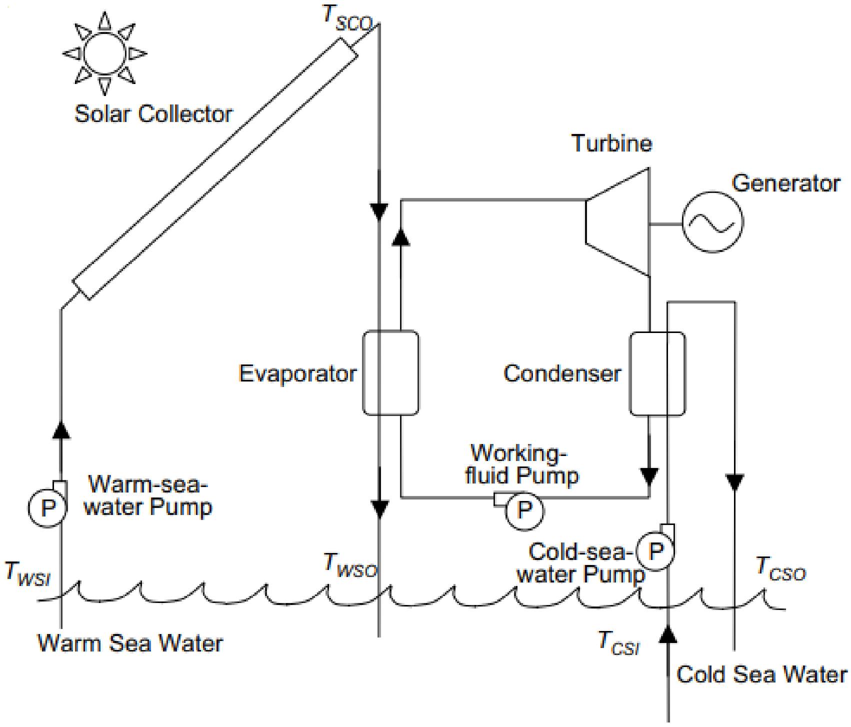

Figure 2.5. Schematic diagram of a closed-cycle SOTEC system [19].

2.5. COMPLEMENTARY OTEC PRODUCTS

As mentioned earlier, An OTEC plant can produce treasured complementary merchandise together with desalinated water similarly to producing power. The bloodless seawater may be used for culturing marine lifestyles, in addition, which is associated with for refrigeration as well as air conditioning. These doubtlessly synergistic sports might also additionally make OTEC structures appealing to enterprise and island groups even supposing the charge of oil stays low. Some of the goods and offerings that might be made from an incorporated OTEC gadget are shown in Figure 2.6.

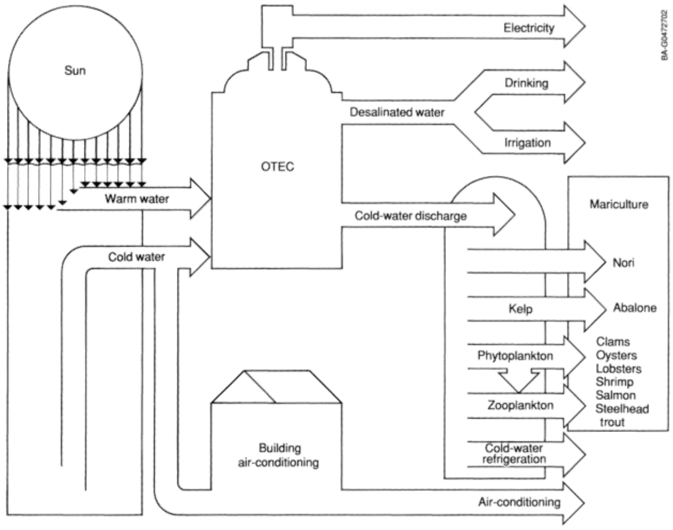

Figure 2.6. A multiple product/application integrated OTEC plant [16].

2.6. PLANT DESIGN AND LOCATION

Studies indicate that commercial OTEC facilities could be located on land or near the shore, on platforms attached to the continental shelf, or on moored or free-floating facilities in deep ocean water.

Basic considerations for plant design as well as location include:

- A stable environment for system operation
- A constant source of both warm, in addition, which is associated with cold water with a minimum temperature difference 20 °C
- A cost-effective way to deliver power as well as complementary products.

Land based as well as near shore facilities are currently considered the most probable for OTEC market penetration also early development.

2.6.1. Land Based and Near Shore Facilities

Land-based and close-to-shore centers provide three primary blessings over those placed in deep water. Plants built on or close to land will now no longer require state-of-the-art mooring, prolonged energy cables, or the greater widespread renovation related to open ocean environments. They can be built in sheltered areas so that they are safe from storms, high seas, electricity, and desalinated water. Additionally, because it is associated with nutrient-rich, bloodless seawater, it can be transmitted from near-shore centers via trestle bridges or causeways. Furthermore, land-based sites that are completely or nearly completely webbed could allow OTEC flowers to perform with associated industries such as mariculture or people who require desalinated water; these plants could be built using current technology with only minor modifications. Favored locations have slender shelves, steep (15˚–20˚) offshore slopes, and are associated with relatively clean sea floors. These webbed sites might limit the duration of the bloodless-water consumption pipe [16]. A land-based total plant could be built well inland from the shore, providing greater storm protection, or at the seashore, where the pipes could be shorter. In both cases, the ease of access for creation, in addition to that associated with operation, may help reduce the cost of OTEC-generated electricity. As previously stated, this land, which is primarily based on completely or nearly entirely shore webbed sites, can guide mariculture. Mariculture tanks or lagoons constructed on shore permit employees to display and, in addition, manipulate miniature marine environments. Mariculture products may be introduced to the marketplace with relative ease through railroads or highways. One downside of land-based surf centers arises from the turbulent wave movement within the surf area. Unless the OTEC plant's water delivery system, which is associated with discharge pipes, is buried in protecting trenches, there will be difficulty with intense pressure at some stage in storms and extended durations of heavy seas. Furthermore, the combined discharge of bloodless and heated seawater may have to be carried several hundred meters offshore to achieve the proper intensity before being released. This association might require an extra fee for creation and maintenance. OTEC structures can keep away from a number of the issues and costs of working in a surf area if they are simply constructed offshore in water depths ranging from 10 to 30 m. This sort of plant might have a shorter (and consequently much less costly) consumption, in addition to being associated with discharge pipes, which might keep away from the risks of turbulent surf. On the other hand, the plant itself might require safety from the marine environment, which includes smash waters and, in addition, is associated with erosion-resistant foundations, as well as the plant's output, which might want to be transported to shore. Experience has shown that the capability issues associated with near-shore or land-based completely web sites no longer preclude OTEC development. The Japanese successfully tested a land-based, entirely electronic device in the Republic of Nauru. This 100 kW (gross) plant, illustrated in Figure 2.7 demonstrated that shore-based, completely closed-cycle technology can generate internet power. The authentic seawater delivery system of the land-based, totally integrated seacoast test facility (STF) has been running nearly constantly since 1982.

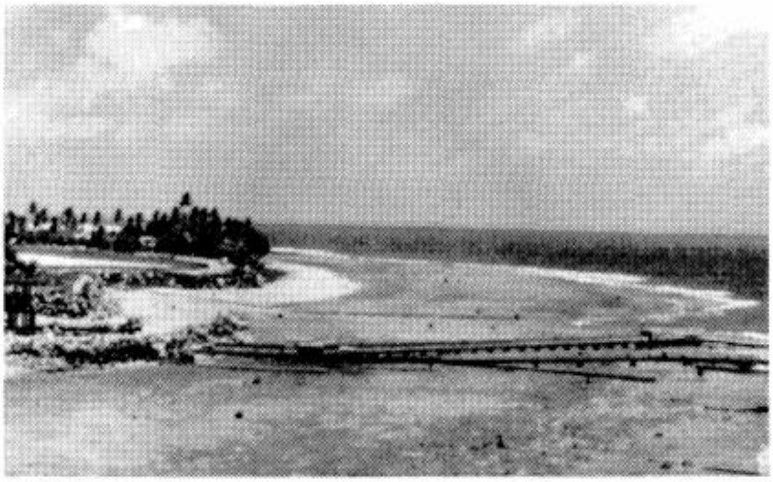

Figure 2.7. The land-based 100kW OTEC plant at Nauru, Tokyo [16].

2.6.2. Shelf-Mounted Facilities

To avoid the turbulent surf region in addition to have nearer get entry to the cold-water resource, OTEC plant life may be hooked up to the continental shelf at depths of as much as 100 m. A shelf hooked up plant will be constructed in a shipyard, towed to its site, and glued to the ocean bottom. This form of production is already used for offshore oilrigs. The extra troubles of working an OTEC plant in deeper water, on the other hand, may also make shelf looked up centers much less suited, in addition, which is associated with greater steeply-priced than their land-primarily based totally counterparts. Problems with shelf hooked up plant life consist of the strain of open ocean situations as well as greater tough product transport. Having to don't forget robust ocean currents, in addition, which is associated with massive waves creates extra engineering as well as production expense. Platforms require enormous pilings to hold a solid base for OTEC operation. Power transport can also end up high-priced due to the lengthy underwater cables required to attain land. For those reasons, shelf hooked up plant life are much less appealing for close to time period OTEC development [16].

2.6.3. Floating Facilities

Floating OTEC facilities could be designed to perform offshore. Although such a plant is conceptualized in distinguish 2.7 and although it is undeniably desirable for structures with massive energy capacities, floating centers present numerous challenges. This plant layout might be more difficult to stabilize, in addition, which is associated with its inability to moor in very deep water and creates issues with energy delivery. Cables connected to floating systems might be more susceptible to harm, particularly for the duration of storms. Cables at depths greater than 1000 m may be difficult to maintain and repair. Riser cables, which span the space among the seabed and are associated with the plant, will want to be built to withstand entanglement. As with the shelf-established flora, floating flora will want a strong base for non-stop OTEC operation. Major storms, in addition, which are associated with heavy seas, can wreck the vertically suspended bloodless water pipe as well as interrupt the consumption of hot water. Pipes can be made from extremely bendy polyethylene and connected to the bottom of the platform, which is also associated with gimbaled joints or collars, to help solve and save you those issues, as became complete with OTEC. Pipes may also need to be disconnected from the plant to protect you from harm during storms. As an opportunity for a heat water pipe, floor water may be drawn immediately into the platform [16]. A floating 100 MW open-cycle OTEC is illustrated by Figure 2.8.

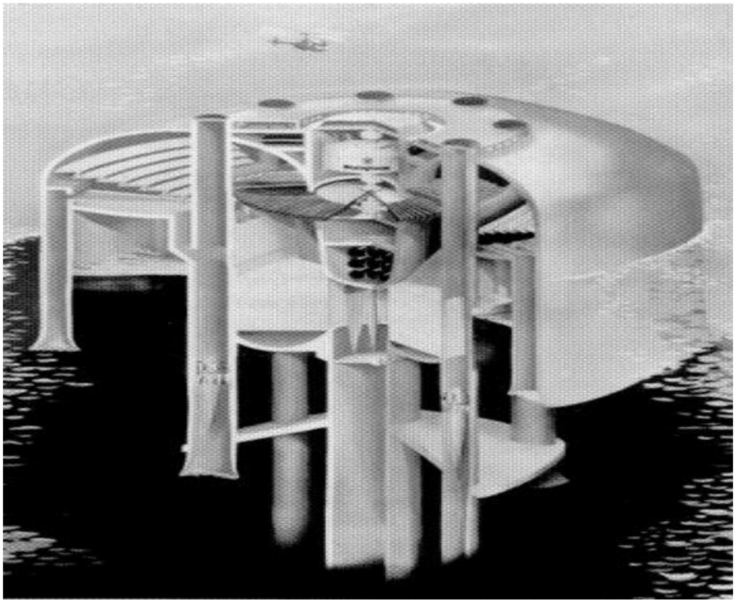

Figure 2.8. Design for a floating 100 MW open-cycle OTEC [16].

If a floating plant is linked to energy shipping cables, it will want to stay fantastically stationary. Mooring could be an appropriate method; on the other hand, modern-day mooring is restricted to depths of approximately 2000 m. Even at shallower depths, the cost of mooring may limit industrial OTEC ventures. An opportunity for deep water OTEC can be drifting or self-propelled plant ships. These ships could use their on-board internal energy to produce a wide range of products, including ammonia and hydrogen.

2.7. ADVANTAGES OF OTEC SYSTEM

OTEC is clean, renewable power that makes use of herbal sources to generate electricity. As a result, it is beyond doubt that it no longer plays a significant role in polluting the environment and producing carbon dioxide, even in the long run. According to America's Department of Energy (DOE), there is no negative impact on ocean water while it is miles applied, after which it is discharged into the sea once more at an intensity of greater than 70 m. Furthermore, it can generate electricity indefinitely throughout the virtual reality (VR) because it is based on not only inexhaustible resources but also significant resources that never deplete, in contrast to other power sources that rely on fossil fuels, which can disappear at any time and whose price has fluctuated over the previous numerous decades. It also outperforms other renewable energy sources such as wind and solar power, which generate electricity through claims that may or may not be available at all times. In addition to producing electricity, it can produce desalinated water for people who live on islands that may be affected by a water shortage. It can produce approximately 2.28 million liters of drinkable water in line with one megawatt of electricity, consistent with Magesh's study. Furthermore, bloodless ocean water can be harnessed and used in home cooling devices without consuming electricity [3].

2.8. DISADVANTAGES OF OTEC SYSTEM

One of the essential elements that must be paid attention to is the differential temperature, which must be at least 20 °C to make the OTEC machine profitable. It is normally difficult to find a location close enough to the shore to reach this temperature. Moreover, OTEC plant performance is fairly low, for the reason that it must be built on a relatively large scale to provide an acceptable quantity of strength production. As a result, building a large-scale OTEC plant machine requires a lot of money, especially if it's far from the land, because its production requires more materials, such as pipes, as well as long-term maintenance. It is plain that to gain the bloodless water from ocean depths, the duration of pipes must be around 1 km; additionally, to provide 10 MW, for instance, they must be extensive enough (as much as 7 m) to carry large volumes of bloodless water. As a result, they'll have an effect on not only the shape of a coast but also marine existence, due to the fact that it's far more difficult to put in these internal oceanic environments and then maintain them.

2.9. MULTI-FUNCTIONALITY OF OTEC SYSTEM

Besides electricity production, OTEC plant life may be utilized to assist air-conditioning, seawater district cooling (SDC), or aquaculture purposes. OTEC plant life can also produce clean water. Clean water can be obtained from the evaporated seawater after it has passed through the turbine in open-cycle OTEC plant life, and it can also be obtained from the discharged seawater used to condense the vapor fluid in hybrid-cycle OTEC plant life. Another choice is to mix the use of electricity with the manufacturing of desalinated water. In this case, OTEC's electricity production can be used to provide energy for a reverse osmosis desalination plant. According to Magesh (2010), each megawatt of electricity generated by a hybrid OTEC system can provide nearly 2.28 million liters of desalinated water per day. The manufacturing of clean water along with energy manufacturing is specifically applicable for nations with water shortages as well as those in which water is produced with the aid of the desalination process. Clean water is also necessary for island countries with a tourism industry to help with water intake in hotels. Based on a case study in the Bahamas, we estimated that an OTEC plant could produce freshwater for around USD 0.89 per gallon. Large-scale seawater desalination costs range from USD 2.6 per gallon to USD 4.0 per gallon. Given that deep seawater is frequently free of pathogens, in addition to being associated with contaminants and being rich in nutrients (nitrogen, phosphates, etc.), land-based structures may also want to benefit from the use of deep seawater for parallel applications, which include cooling for homes in addition to being associated with infrastructure, chilled soil, or seawater-cooled greenhouses for agriculture, as well as more decentralized applications. Utilizing deep seawater to chill homes in district cooling configurations can offer a big and green opportunity for a universal energy discount in coastal areas, supporting the stability of the high energy needs in addition to the universal energy demand.

2.10. ATMOSPHERIC INTERACTIONS

OTEC facilities emit no additional heat and significantly less carbon dioxide than comparable-sized traditional fossil-fuel energy plants. These advantages may also become more important in the future if predictions regarding international climate change are correct and energy plants are required to significantly reduce carbon dioxide production. Changes in ocean floor temperatures should cause dramatic changes in continental climate patterns. However, the dimensions, which are associated with a wide variety of OTEC vegetation that may be projected in a location for the foreseeable future, will make a significant contribution to the effect. For overall performance reasons, it is best to keep away from the reinjection of cool discharge water. This discharge can be directed deep into the sea, where it would have a minimum impact on floor temperature. Researchers expect that the small quantity of water delivered to the floor via means of neighborhood blending can no longer lower temperatures sufficiently to have an effect on weather methods.

2.11. CURRENT ACTIVITIES IN ENVIRONMENTAL ASSESSMENT

The operating permit necessities of the diverse county, country as well as federal corporations with oversight at Natural Energy Laboratory of Hawaii (NELH) name for an environmental tracking application so that it will assist guard the specific sources with inside the Keahole factor vicinity. To compare long time results at the environment, effects of the tracking could be as compared with a baseline of groundwater, in addition, which is associated with offshore water excellent as well as offshore biota this is being mounted at NELH. The OTEC application is assisting a country attempt that includes reviewing archival information, in addition, which is associated with amassing web website online information to set up benchmark situations at Keahole factor, that's possibly to be the vicinity for OTEC improvement withinside the close to future. The application is likewise offering technical, in addition, which is associated with monetary aid for dealing with the environmental excellent at the site.

PART 3

MATHEMATICAL MODELING

3.1. MODELING OF THE SOLAR OCEAN THERMAL ENERGY CONVERSION (SOTEC)

Modeling of the solar ocean thermal energy conversion the performance required to generate the electricity depends on a group of parameters, in addition to conditions, namely the criteria that govern how the system operates, the surroundings, and the available space. For the study of the relationship between the aforementioned factors on the basis of design, control techniques, and performance analysis, the development of a model is an essential tool. The simulation of the conversion of solar ocean thermal energy to Figure 3.1 refers actually to the integration of models of individual components of the system (turbine, evaporator, condenser Solar collector, storage tank). Diverse positions of the system as these are defined in Figure 3.2 and Figure 3.3 (T-s) diagram for a single stage in SOTEC system and Table 3.1 describe the specification in each point of system.

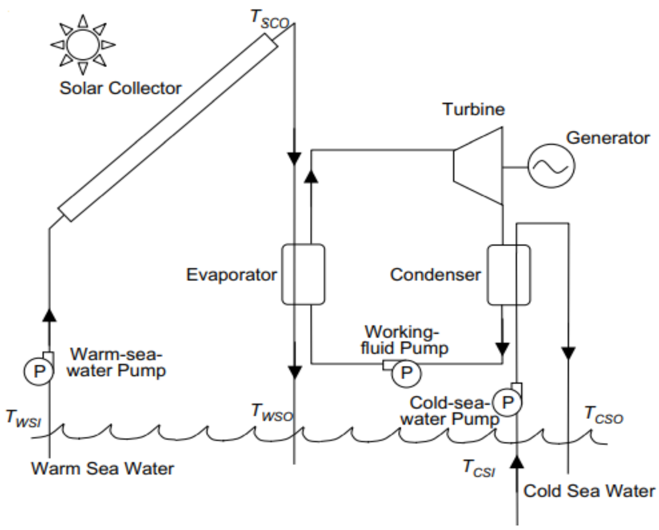

Figure 3.1. Schematic of a SOTEC system [19].

Several assumptions will be considered to simplify this study; the following are the most important:

- The heat condenser as well as the evaporative effectiveness are 95% and 86%, respectively.
- The energy input for the water pump is neglected in the cycle analysis.
- The turbine as well as the pump are isentropic processes; their efficiency is 85%, 86%.
- Both the OTEC and SOTEC thermodynamic cycles are perfect saturated Rankine cycles that use pure ammonia as the working fluid. The efficiency of the turbine and the efficiency of the pump are specifically stated.
- The heat losses caused by pipework and other auxiliary components are negligible.

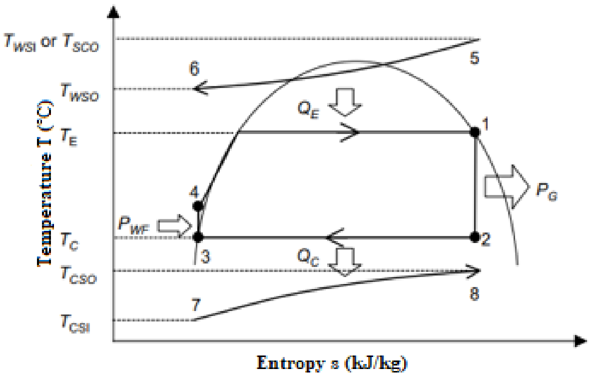

Figure 3.2. Cycle temperature-entropy (*T-s*) diagram for a single stage in SOTEC Rankine closed cycle [20].

Table 3.1. Shows specification in each point of system [20].

Point number	Specification
1	Saturated Vapor coming turbine
2	Saturated ammonia entering condenser
3	Saturated liquid entering working fluid pump
4	Liquid ammonia exiting working fluid pump
5	Warm water entering evaporator
6	Warm water exiting evaporator to ocean
7	Cold water entering condenser
8	Cold water exiting condenser to ocean

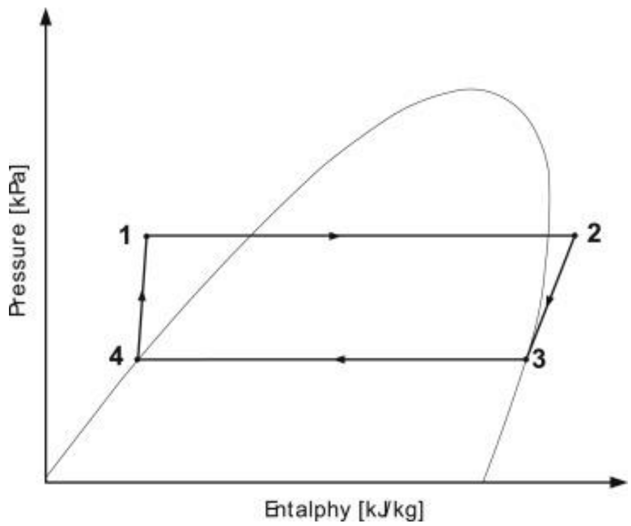

Figure 3.3. *P-h* representation of the SOTEC Rankine closed cycle [20].

3.1.1. Turbines

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be utilized for generating electrical power when combined with a generator. A turbine is a turbomachine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move, which is associated with imparting rotational energy to the rotor. Types of the turbine:

- Steam turbine
- Water turbine
- Wind turbine
- Gas turbine

Table 3.2. Classification of steam turbines.

Shaft position	Horizontal or vertical
Method of drive	Direct connected or geared
Action of the steam	Impulse or reaction
Exhaust pressure	Non-condensing, condensing, extraction

Operation Theory

A working fluid contains potential energy (pressure head) and kinetic energy (velocity head). The fluid may be compressible or incompressible. Several physical principles are employed by turbines to collect this energy [18].

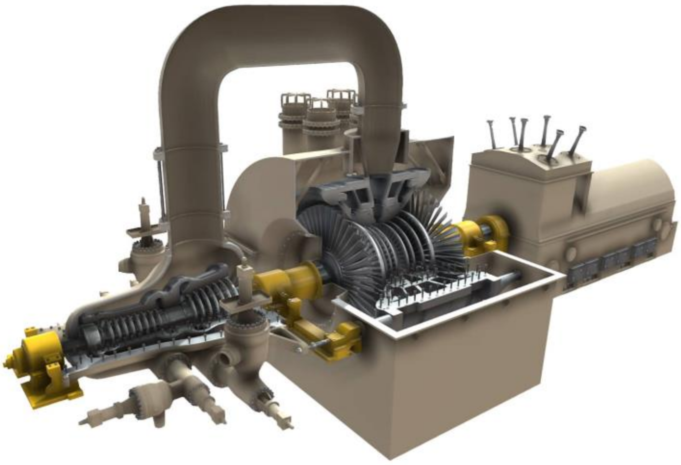

Figure 3.4. Schematic of a steam turbines [18].

Turbine Generator Power

Product of the adiabatic heat loss across the turbine and the mass working fluid flow rate, m_{wf}, yields the turbine generator. Here is the formula:

$$W_{TG} = \dot{m}_{wf} \eta_T \eta_G (h_2 - h_1) \tag{3.1}$$

3.1.2. Pumps

Pumps are put to use to move liquids by transferring the energy contained in their revolution to the energy contained in the fluid's motion. Motors, both internal combustion and electric, are common sources of rotational energy. They belong to the class of work-absorbing dynamics that rotate around an axis. In turbomachinery, the fluid is pumped into the impeller along or near the axis of rotation, where it is accelerated before exiting the pump via a diffuser or volute chamber (casing) located at a radial distance from the impeller. The pumping of water, sewage, agricultural, petroleum, and petrochemical products is commonplace. Since centrifugal pumps can handle high flow rates, are safe to use with abrasive solutions, have excellent mixing capabilities, and are relatively easy to construct, they are often used [21]. A centrifugal pump is illustrated in Figure 3.5.

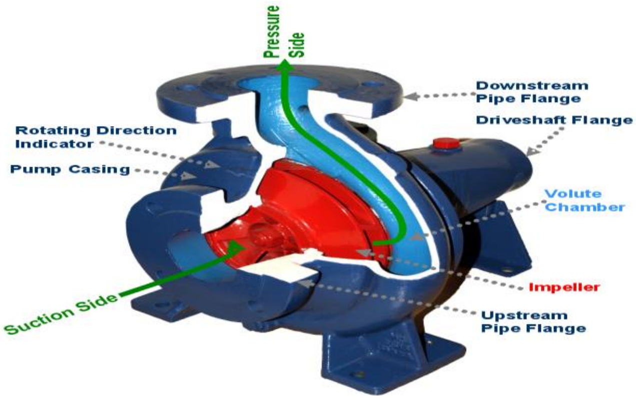

Figure 3.5. Schematic of centrifugal pump [21].

Warm Seawater Pumping Power

The warm seawater pumping power can be defined as follows [22]:

$$W_{ws} = \frac{\dot{m}_{ws}\ \Delta H_{ws}\ g}{\eta_{wsp}} \tag{3.2}$$

$$\Delta H_{ws} = (\Delta H_{ws})_P + (\Delta H_{ws})_E \tag{3.3}$$

$$(\Delta H_{ws})_P = (\Delta H_{ws})_{sp} + (\Delta H_{ws})_B \tag{3.4}$$

$$(\Delta H_{ws})_{sp} = 6.82 \frac{L_{ws}}{d_{ws}^{1.17}} \left(\frac{V_{ws}}{100}\right)^{1.85} \tag{3.5}$$

$$(\Delta H_{ws})_B = \sum \lambda_m \frac{V_{ws}^2}{2g} \tag{3.6}$$

$$(\Delta H_{ws})_E = \lambda_E \frac{V_{ws}^2}{2g}\ \frac{L_E}{(Deq)_w} \tag{3.7}$$

$D_{eq} = 2\sigma$ (3.8)

Cold Seawater Pumping Power

The pumping power of cold seawater can be expressed as [22]:

$$W_{cs} = \frac{\dot{m}_{cs}\, \Delta H_{cs}\, g}{\eta_{csp}} \quad (3.9)$$

$$\Delta H_{cs} = (\Delta H_{cs})_p + (\Delta H_{cs})_c + (\Delta H_{cs})_d \quad (3.10)$$

$$(\Delta H_{cs})_P = (\Delta H_{cs})_{sp} + (\Delta H_{cs})_B \quad (3.11)$$

$$(\Delta H_{cs})_c = \lambda_c \frac{V_{cs}^2}{2g} \frac{L_c}{(Deq)_c} \quad (3.12)$$

Below is a calculation of the pressure differential brought on by the density difference between the warmer surface water and the colder deep water [22]:

$$(\Delta H_{CS}) = L_{CS} - \frac{1}{\rho_{CS}} [0.5(\rho_{WS} + \rho_{CS}) L_{CS}] \quad (3.13)$$

3.1.3. Condenser

The exhaust steam from the steam turbine is condensed in a device called a 'steam condenser' by passing it through a cooling water system. Exhaust steam may be condensed by eliminating its thermal energy through cooling water circulation. Condensation is the phase transition from vapor to liquid that occurs when the working material (steam) rejects latent heat. A condenser's principal function is to keep the pressure on the exhaust side of a steam turbine's rotor low. In turn, this allows the steam to expand to a higher degree, increasing the amount of energy that can be converted into mechanical labor. The condensed steam that is released from the condenser and collected in a hot well may be reused as feed water for the boiler, which is the secondary purpose of the condenser. An electric power plant's efficiency may be increased with the use of a condenser by reducing the steam's exhaust pressure below atmospheric levels. In addition to reducing the water softening capacity, the condenser's clean feed water has a boiler side effect [20]. A schematic of the condenser is illustrated in Figure 3.6. Basically, the energy balance equation for the condenser written as [22]:

$$Q_C = \dot{m}_{cs} c_p (T_{cso} - T_{csi}) = \dot{m}_{wf}(h_2 - h_3) \quad (3.14)$$

The heat transfer area of the condenser can be defined as below [22]:

$$Q_c = U_c \, A_c \, \Delta T_{lm,c} \quad (3.15)$$

The logarithmic mean temperature difference across the evaporator and condenser is correlated as below [22]:

$$\Delta T_{lm,c} = \frac{T_{cso} - T_{csi}}{ln\frac{T_c - T_{csi}}{T_c - T_{cso}}} \quad (3.16)$$

$$Q_C = \dot{m}_{wf}(h_2 - h_3) \quad (3.17)$$

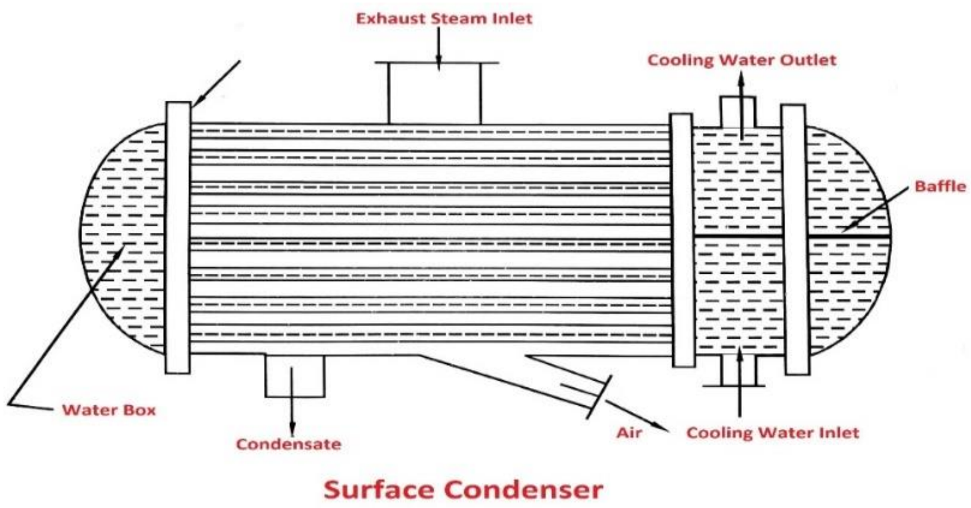

Figure 3.6. Schematic of condenser [23].

3.1.4. Evaporator

Evaporation may be performed to remove a liquid from a solution, suspension, or emulsion. Therefore, this is a kind of thermal separation or thermal concentration. Here, we use the term 'evaporation process' to refer to a procedure in which a liquid input is converted into a more concentrated, but still liquid and pumpable, concentration. Though we won't go into detail, there are a few scenarios in which the evaporated volatile component is the primary end result. It is usually crucial that the product suffer as little thermal deterioration as possible throughout the evaporation process; therefore, it is important to limit both the temperature and the length of time it is exposed to heat. There is a wide variety of evaporator types because of these and other needs arising from the physical features of the substance being processed. New plant topologies and cutting-edge machinery designs have resulted from the pressing need to cut down on energy consumption and environmental effects. Evaporation plants are often employed in the area of thermal separation and concentration technology for the concentration of liquids in the forms of solutions, suspensions, and emulsions. For evaporation technology to succeed, it must be able to keep liquids from degrading or becoming contaminated as they evaporate. To do this, the liquid may need to be subjected to a boiling temperature as low as feasible for as brief a time as possible. Because of this, as well as many other constraints, a large range of designs is now at your disposal. The product on the other side of an evaporator's heat transfer surface is heated by steam, the heating medium used in practically all evaporators. A working fluid is heated in an evaporator until it evaporates into a saturated vapor [24]. The energy balance equation at each side of the evaporator can be written as:

$$Q_E = \dot{m}_{ws} c_p (T_{wsi} - T_{wso}) = \dot{m}_{wf} (h_1 - h_4) \quad (3.18)$$

The average logarithmic temperature differential between the evaporator and condenser is connected with:

$$\Delta T_{lm,E} = \frac{T_{wsi} - T_{wso}}{ln \frac{T_{wsi} - T_E}{T_{wso} - T_E}} \quad (3.19)$$

$$Q_E = U_E\, A_E\, \Delta T_{lm,E} = \dot{m}_{wf}(h_1 - h_4) \tag{3.20}$$

3.1.5. Flat Plate Solar Collector

The normal solar collector utilized for sunlight-based water warming as part of homes, structures and sun powered space warming is a flat plate collector. An average flat plate collector is a protected metal box with a glass fiber or plastic spread (called the glazing) and a dark-colored absorber plate [25]. A schematic of flat plate collector is shown in Figure 3.7. The collector uses water as a working fluid. The type of the collector is flat plate. Area of the collector array is chosen to be 5000 m^2. Hottle-Whillier's equation gives a general expression for collector efficiency [22] as follows:

$$\eta_c = \frac{Q_u}{A_c\, I_t} = F_R(\tau\alpha)_n - F_R U_C \frac{(T_{ex} - T_1)}{I_t} \tag{3.21}$$

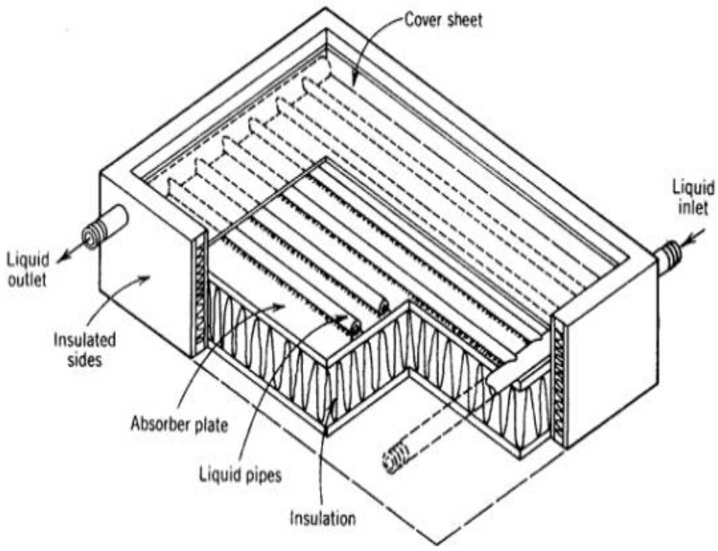

Figure 3.7. Schematic of flat plate collector [25].

The value of factors $F_R(\tau\alpha)_n$ and $F_R U_c$ depend on the type of the collectors, layer of the cover glass and selective material. Typical values of these factors are shown in Table (3.3).

Table 3.3. Values of $F_R\ (\tau\alpha)_n$ and $F_R U_c$ for some type of solar collectors [26].

Solar Collector Type	$F_R\ (\tau\alpha)_n$	$F_R U_c$
Flat-Plate, Single-Glass Cover	0.80(a)	5.00(a)
Flat-Plate, Selective-Surface, Double-Glass Cover	0.80(b)	3.50(b)
Evacuated Tubular Collectors	0.80(a)	Range 1-2(a)
Parabolic-Through Concentrating solar collector (PTC)	0.70(c)	2.5(c)

(a) from Fléchon, Lazzarin et al., 1999

(b) from Huang, Chang et al., 1998

(c) average data from Table 3.3 in Henning, 2004

Q_u can be expressed considering the collector energy balance [22].

$$Q_u = F_R A_c\,[I_t(\tau\alpha)_n - U_C(T_{ex} - T_1)] \tag{3.22}$$

3.1.6. Global Solar Radiation in Turkey

Solar radiation is the energy or radiation that we get from the sun. It is sometimes referred to as short-wave radiation and can take the form of visible light, radio waves, heat (infrared), x-rays, and ultraviolet rays. Solar radiation measurements are typically greater on bright, sunny days and lower on gloomy days. Solar radiation is 0 when the sun is set or there are strong clouds covering the sun. The monthly mean daily values of global sun radiation in Turkey are shown in Table 3.4. and Figure 3.8 [27].

Table 3.4. Monthly mean daily values of global sun radiation in Turkey [27].

Months	Monthly average solar energy (kWh/m^2) month	Sunshine duration (h/month)
January	51.75	103.0
February	63.27	115.0
March	96.65	165.0
April	122.23	197.0
May	153.86	273.0
June	168.75	325.0
July	175.38	365.0
August	158.40	343.0
September	123.28	280.0
October	89.90	214.0
November	60.82	157.0

December	46.87	103.0
Total	1,311	2,640
Average	3.6 (kWh/m^2) day	7.2 h/day

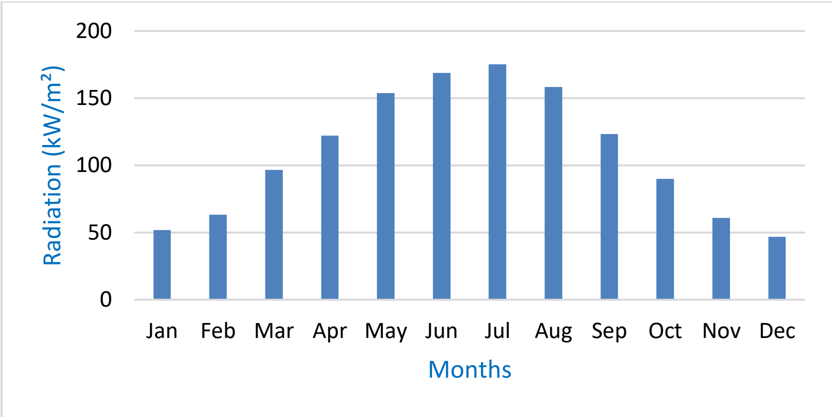

Figure 3.8. Monthly average of solar radiation [27].

3.1.7. Storage Tank

The storage tank used is of the fully mixed type. The load flow enters at the bottom of the tank, and the hot source stream enters at the top of the tank. The tank is well insulated. The water in the storage tank is assumed to be unstratified at a uniform time dependent temperature resulting from the well mixing of hot water from the collector and cool water back from the heat exchanger [28]. A schematic of storage tank type fully mixed is illustrated in Figure 3.9.

Figure 3.9. Schematic of storage tank type fully mixed [28].

3.1.8. Pipes

Most businesses choose to utilize fiberglass piping (FGP) because it is corrosion-resistant. The high-quality resins used in fiberglass pipe systems make them resistant to acids, caustics, and solvents, making them ideal for use in vent and liquid applications operating in the temperature range of -57 °C to 150 °C. The inner surface liner of pipes may be made with abrasion-resistant materials to increase their durability when exposed to abrasive slurries [29]. The photograph of Fiberglass pipes is shown in Figure. 3.10.

Figure 3.10. The Fiberglass pipes [29].

3.1.9. Net Power Generation

The net power output from the system be calculated based on this equation [22]:

$$W_N = W_{T\text{-}G} - W_{P,wf} - W_{P,ws} - W_{P,cs} \quad (3.23)$$

By considering turbine power and pump powers, the obtained net power allows the calculation of the net thermal efficiency [22]:

$$\eta_{th} = \frac{W_N}{Q_E} \quad (3.24)$$

Based on the definition of cycle efficiency, net cycle efficiency should be defined as the following expression [22]:

$$\eta_{net} = \frac{W_N}{W_T} \tag{3.25}$$

3.1.10. Ammonia As Working Fluid

Ammonia is one of the most widely manufactured synthetic compounds due to its importance in the production of fertilizers. In this essay, we trace the history of ammonia manufacturing and discuss its current ammonia (NH_3) has a very distinct odor, one that most people connect with cleaning products or smelling salts. However, the amount of ammonia used in these two products is negligible compared to the overall ammonia output, which was roughly 176 million metric tons in 2014 [30]. Worldwide ammonia production has steadily increased from 1946-2014. It is shown in Figure 3.11. Let's look back at our technological and industrial roots in order to better understand our present situation. The production of ammonia has rapidly risen to become a major economic force. Approximately two to three billion people would not be living on Earth now if food productivity hadn't been increased by ammonia-based fertilizers and pesticides. Since 1946, ammonia production has expanded and now, some facilities produce more than 300 Mt/day of NH_3, valuing the industry at over $100 billion annually.

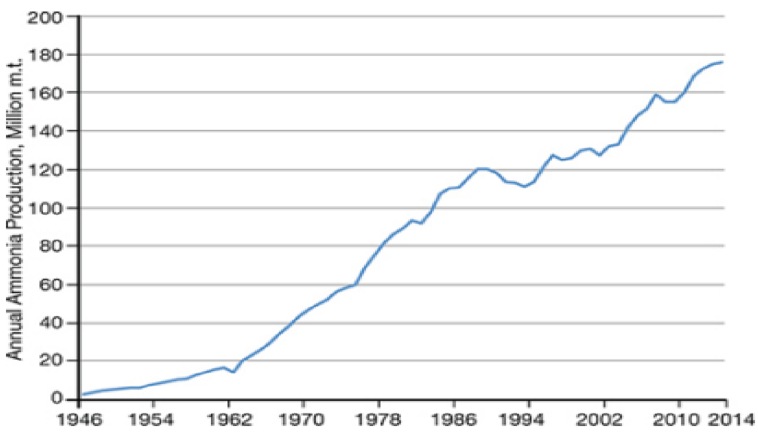

Figure 3.11. Worldwide ammonia production 1946-2014 [30].

3.1.10.1. Physical Properties

Based on the conditions, anhydrous ammonia may take the form of a colorless gas, a colorless liquid, or a white solid. It takes the form of a liquid or a gas in the vast majority of real-world contexts. At atmospheric pressure, the gas is less dense than air, and the liquid is less dense than water. Ammonia vapor diffuses easily in air, while ammonia liquid is highly soluble in water, both of which cause a release of heat. As long as both the vapor and liquid phases are present, ammonia displays traditional saturation equations in which pressure and temperature are directly connected. There is a crucial pressure and temperature for it. The equilibrium temperature of a closed container containing ammonia at atmospheric pressure is -28 °F (-33 °C). However, according to the law of partial pressures, a pool of boiling liquid ammonia that has been discharged into the environment at room temperature will be substantially colder than -28 °F (the partial pressure of the ammonia vapor in the air near the liquid surface will be less than atmospheric pressure). A few of ammonia's key physical features are included in the table below [30]. Physical properties of ammonia are given in Table 3.5.

Table 3.5. Physical properties of ammonia [30].

Property	Condition	Value (SI)
Molecular weight		17.03
Color		None
Physical state	Room Temp	Gas
Freezing point	P=1 atm	–78 °C
Boiling point	P=1 atm	–33.3 °C
Critical Temp		133°C
Critical pressure		11.410 kPa
Specific volume	32 °F/1 atm/vap	1.30 m^3/kg
Specific gravity	32 °F/1 atm/vap	0.596
Specific gravity	60 °F/liquid	0.62
Odor threshold		5–50 ppm
Upper flam lim		25–28%
Lower flam lim		15–16%
Ignition Temp	No Catalyst	651 °C

3.2. TRNSYS SOFTWARE

When it comes to transient modeling of systems, including multi-zone structures, TRNSYS offers an all-inclusive and expandable simulation platform. From domestic hot water systems to the design and simulation of entire buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaic, and hydrogen systems), and so on, it is used by engineers and researchers all over the world to verify novel energy concepts. TRNSYS success over the last 35 years may be attributed in large part to its open, modular design. Users are given access to both the kernel and component models' source code. This makes it far less complicated to adapt preexisting models to individual requirements. The DLL-based design makes it simple for users and third-party developers to plug in their own unique component models in any of the commonly-used programming languages (C, C++, PASCAL, FORTRAN, etc.). In addition, TRNSYS may be linked to a wide variety of different applications for use in simulation preparation, postprocessing, and interactive calling (e.g., Microsoft Excel, MATLAB, COMIS, etc.)

TRNSYS Applications İnclude:

- Solar systems (solar thermal and PV)
- Low energy buildings and HVAC systems with advanced design features (natural ventilation, slab heating/cooling, etc.)
- Renewable energy systems
- Cogeneration, fuel cells
- Anything requiring dynamic simulation, such as cogeneration or fuel cells.

3.2.1. The TRNSYS Simulation Studio

The TRNSYS Simulation Studio is the primary visual interface. You can then create projects by dragging and dropping components into the workspace, connecting them, and configuring the global simulation parameters. The project information is saved in a TRNSYS Project File by the Simulation Studio. The Studio generates a TRNSYS input file when you run a simulation (text file that contains all the information on the simulation). The simulation Studio also includes an output manager where you can control which variables are integrated, printed, and/or plotted, as well as a log/error manager where you can examine what happened during a simulation in detail. You can also use the Simulation Studio to generate projects using the 'New Project Wizard' create a skeleton for new components using the Fortran Wizard, view and edit component proformas (a proforma is a component's input/output/parameters description), view output files, and so on [31]. The TRNSYS windows example is illustrated in Figure 3.12.

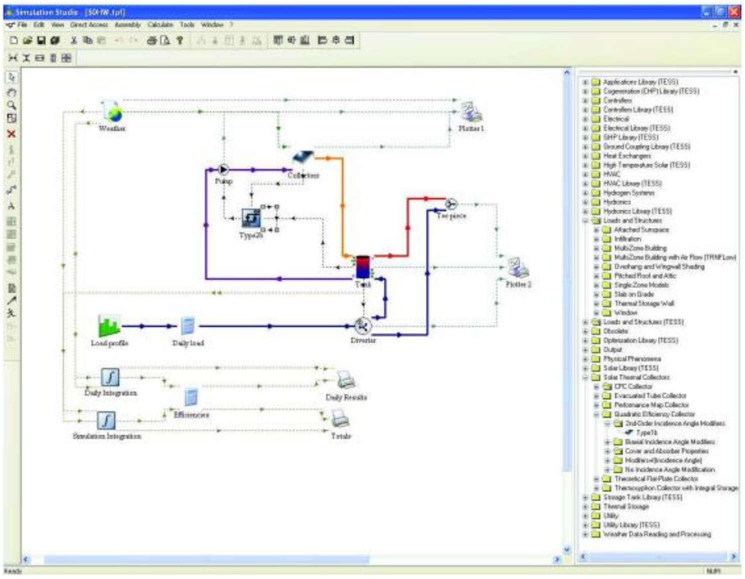

Figure 3.12. The TRNSYS simulation studio [31].

3.2.2. The Online Plotter

While running, a simulation may show an online plot if it has at least one 'online plotter' component. Several tools to help you analyze simulation results in real time and thereafter are included into the online plotter. The 'Calculation/Stop' and 'Calculation/Resume' menu items, as well as a right-click anywhere on the plot, allow you to pause and restart the simulation at any time. Diagnosing issues that arise at a certain point in a simulation is another benefit of using the 'Pause at' command. After the simulation has completed, you may use the 'Plot settings' menu to alter the plot in a number of ways, including changing the background color from black to white and increasing the line thickness. Furthermore, the left and right Y-axis boundaries may be adjusted directly by clicking on the axes themselves to open a dialogue box. Please note that if you make any modifications to those bounds and then run the simulation again, your changes will be discarded. Modifying the simulation's online plotter settings yields lasting results (double-click on the online plotter icon). You may toggle the visibility of each variable in the plot by clicking on its name in the legend boxes. Online plotter in a paused simulation with Y-axis control box is shown in Figure 3.13.

Figure 3.13. Online plotter in a paused simulation with Y-axis control box [31].

3.3. CREATING A TRNSYS PROJECT

Starting with a physical description of the system to be represented, this section will construct the 'Begin' example from scratch.

3.3.1. System Description

Figure 3.14 depicts the simulated system. It is a straightforward solar thermal application in which solar collectors are used to warm water in an industrial process.

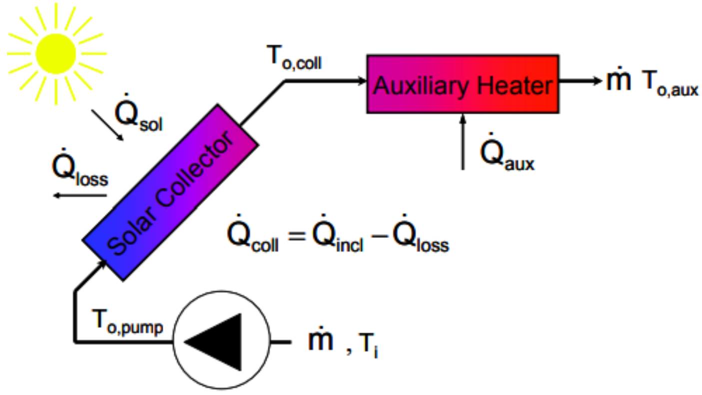

Figure 3.14. Solar collectors are used to heat water in a simple solar thermal application [31].

3.3.2. Modeling Approach

Before we begin working in the Simulation Studio, we must first investigate the simulated system, determine which factors will be of interest, and identify the components that will be used in the simulation.

PART 4

RESULTS AND DISCUSSION

With the goal of lowering SOTEC's overall cost, a number of possible thermodynamic cycles have been explored. Among these is the Rankine cycle, which is well-known to scientists. For the time being, we are only able to perform analysis on the closed Rankine cycle due to this being standard practice in the engineering community. Though other fluids, including propylene and other refrigerants, have been explored in the literature, ammonia is still the fluid of choice for OTEC closed-cycle systems. Here, we examine electricity grids where ammonia is used as the driving force. Ammonia and seawater heat exchangers have a large amount of experimental data for boiling and condensation at SOTEC conditions. The system of SOTEC by using TRNSYS software is illustrated in Figure 4.1.

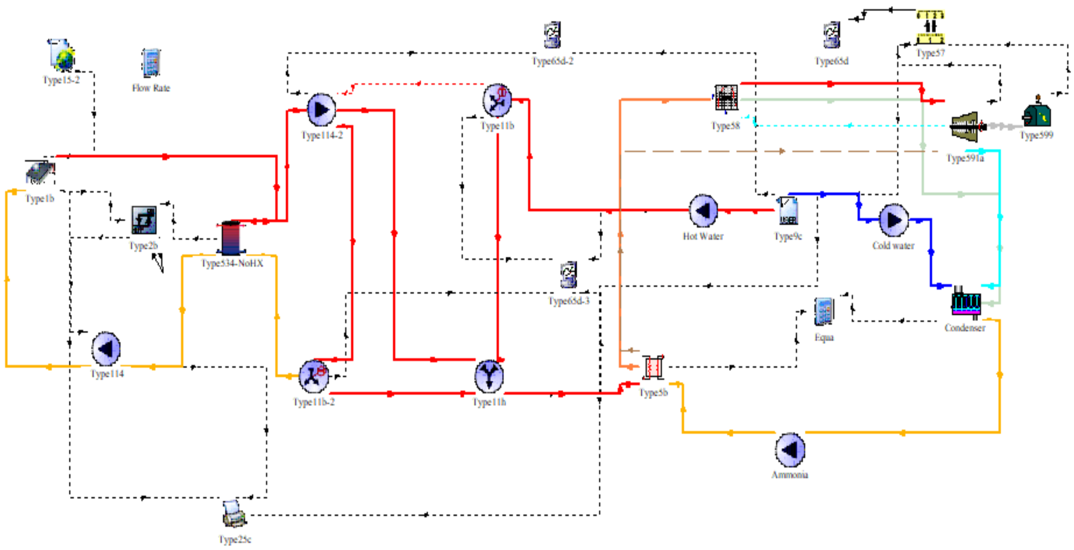

Figure 4.1. The system of SOTEC by using TRNSYS software.

All components of the system were modeled using commercially available software TRNSYS 17.2 ammonia flow rate and the evaporator and condenser pressures were varied to arrive at maximum power production for the system. Initial conditions for the simulation are given in Table 4.1. SOTEC flow conditions are given detail in Figure 4.2.

Table 4.1 Initial conditions for the simulation

Turbine generator power W_G	120	kW
Efficiency of pumps η_p	85	%
Turbine efficiency η_T	86	%
Evaporator Overall heat transfer coefficient	4.0	kW/(m² K)
Condenser Overall heat transfer coefficient	3.5	kW/(m² K)
Collector efficiency	63	%
Collector area	5000	m^2
Flat plat collector Tilt Angle	40	°
Solar radiation	3.6	(kWh/m²) day
Ambient temperature	27	°C
Temperature of sea water		
Warm sea water surface temp	28	°C
Cold deep sea water temp	5	°C

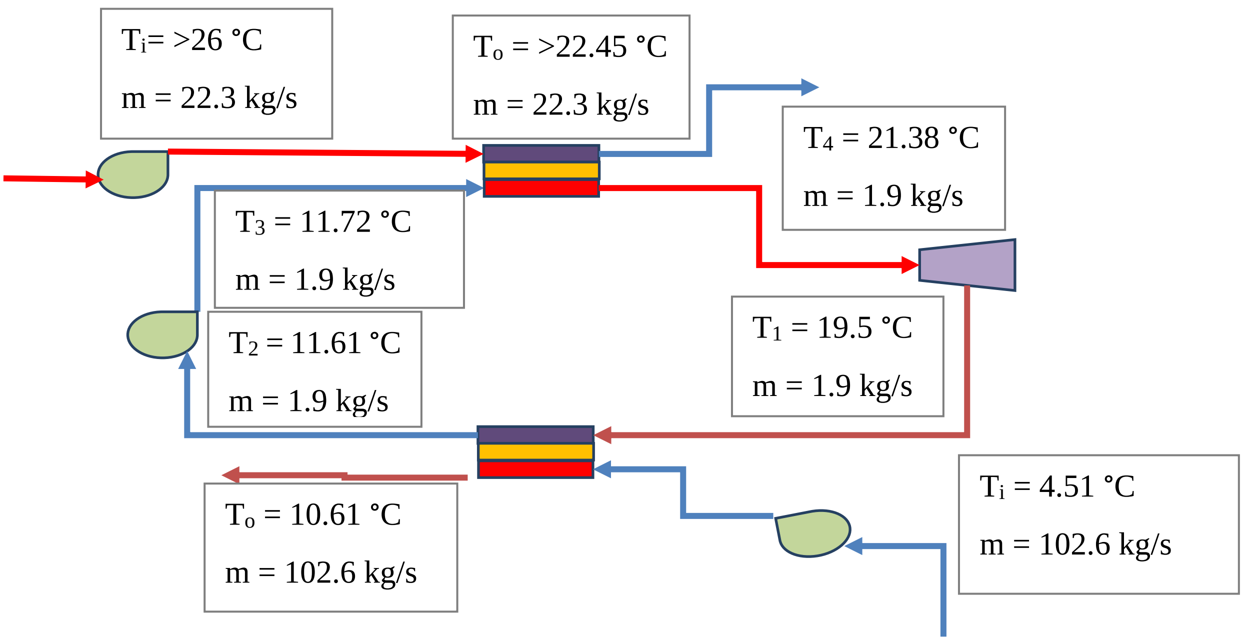

Figure 4.2. SOTEC flow conditions in detail.

The process starts with steam being expanded and sent to the condenser in the entering turbine. There, the condenser restores the working fluid to a liquid state by transferring heat from the working fluid to deep saltwater pumped up from the depths of the ocean. This is seen in the preceding picture. The evaporator raises the temperature of the working fluid, which causes it to transform from a liquid to a vapor state (steam). In order for the sea to be navigable, the surface water temperature must be higher than 26 °C. In the event that the water temperature at the surface of the ocean is not high enough, we use a secondary system consisting of solar collectors to heat the working fluid before it enters the turbine to generate electricity.

As shown in Figure 4.3 the variation of water solar collector temperature with time in SOTEC is due to the amount of solar radiation, which causes the temperature to change continuously all the time. The solar water temperature increases on clear days and decreases significantly on cloudy days. That is, the changing temperature of the water in the solar collector affects both the system's efficiency and the amount of net power generated. Figure 4.3. shows Variation of water solar collector temperature with time in SOTEC for Alanya, Turkey.

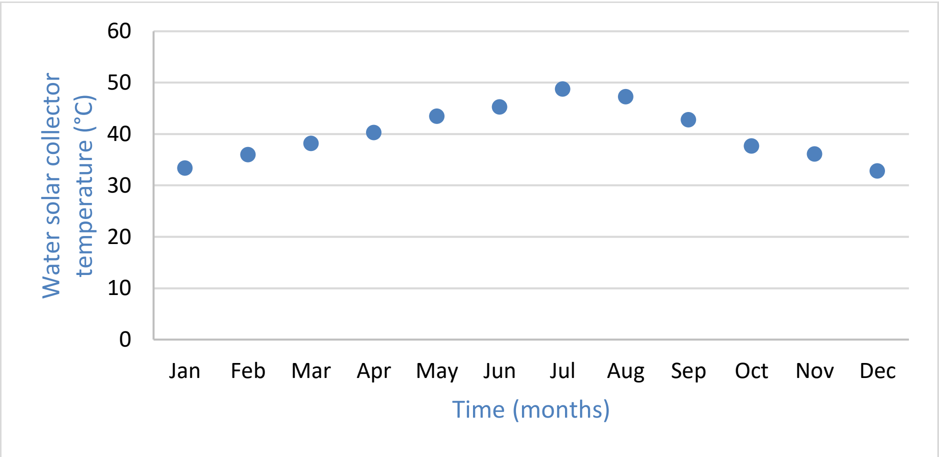

Figure 4.3. Variation of water solar collector temperature with time in SOTEC for Alanya, Turkey.

Figure 4.4 shows the variation of seawater surface temperature with time in Alanya, Turkey. Surface seawater changes every day because it depends on ambient conditions.

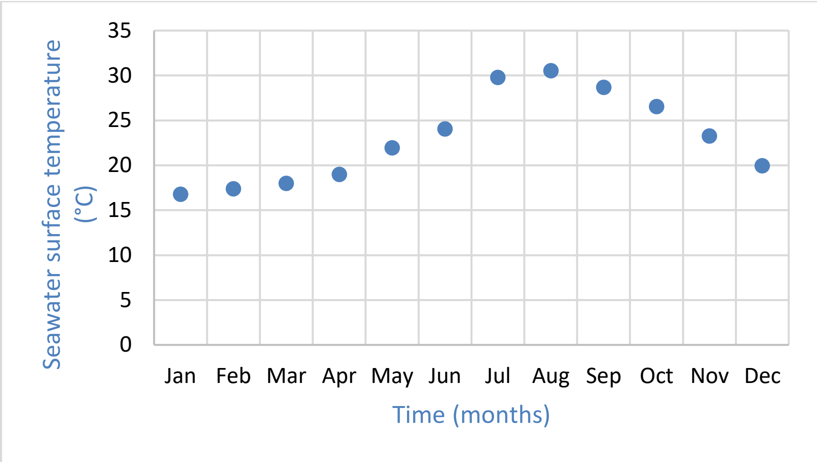

Figure 4.4. Variation of seawater surface temperature with time in Alanya, Turkey.

As shown in Figure 4.5 the result of ammonia working fluid temperature of SOTEC, the temperature of ammonia changes in each component of the system, absorbing heat in the heat exchanger and decreasing the temperature in condenser and losing part of its temperature during its cycle, also depended of solar temperature where it affects directly of ammonia.

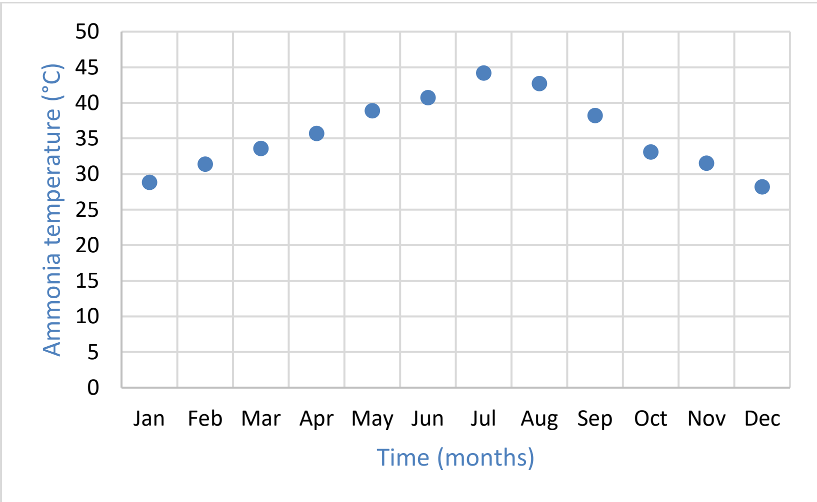

Figure 4.5. Variation of ammonia temperature of SOTEC.

As shown in Figure 4.6, the results of simulating the turbine output generation of OTEC and SOTEC systems show that the turbine is designed to generate 120 kW, but as shown, there are some losses in generating. We can consider these losses as operating losses and frictions and longevity of turbines. There is also a difference in net power generation between the two systems, depending on the operating conditions.

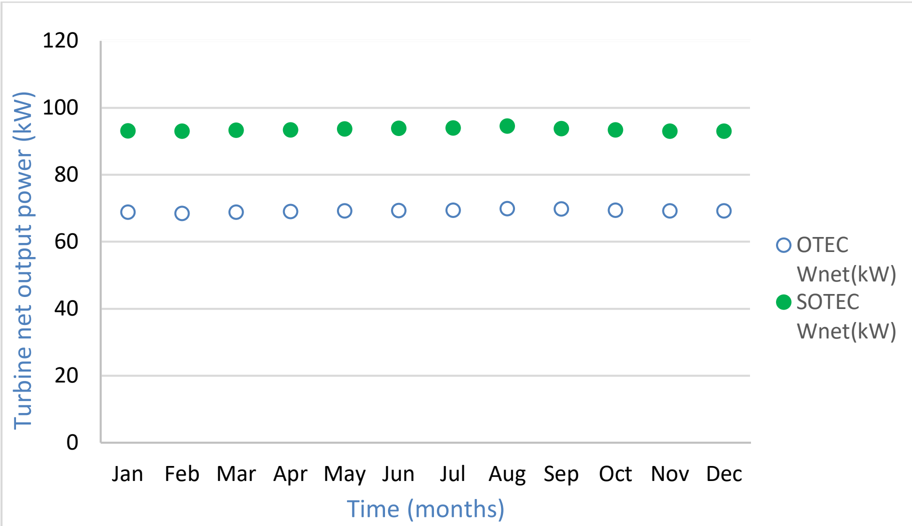

Figure 4.6. Result of turbine net output power of OTEC and SOTEC.

The ammonia mass flow rate in the system indicates the capacity of the system, which was designed with a production capacity of 120 kW, and it appears in Figure 4.7, which shows the critical point of the design for the SOTEC system that we can reach in terms of net output power at 93.3 kW with an ammonia flow rate of about 1.9 kg/s.

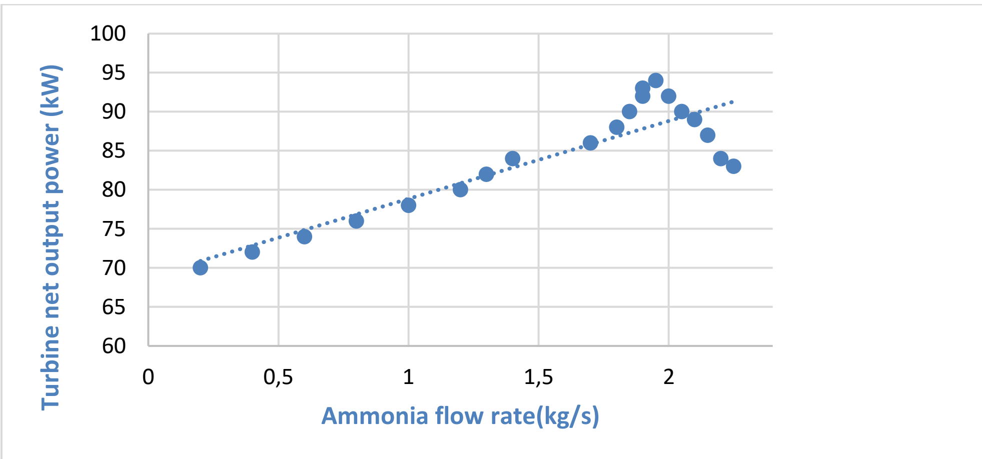

Figure 4.7. Variation of net power versus ammonia circulation rate.

Figure 4.8 shows the relation between output power of turbine and solar water temperature this mean that output of turbine and increases of water solar collector temperature is direct proportion, that gives an indication that the addition of solar collector was beneficial.

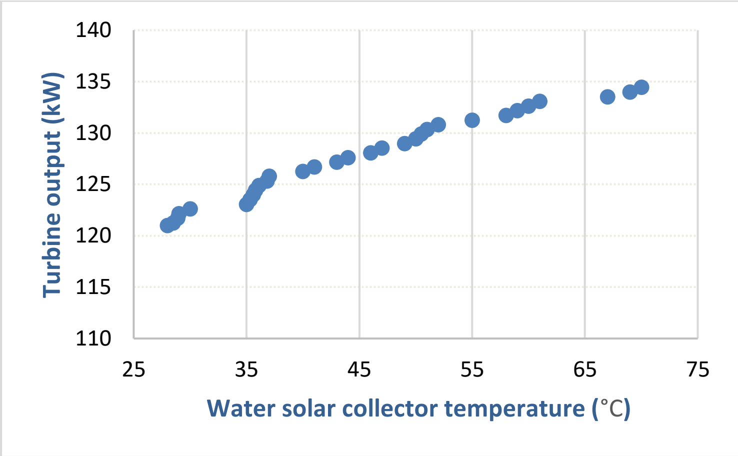

Figure 4.8. Relation between turbine output and solar water temperature.

Figure 4.9 shows the relation between efficiency of SOTEC and increasing of warm seawater temperature from diagram the increasing of warm seawater will see the efficiency of SOTEC is depending of warm water this meaning when warm seawater increasing the efficiency will increase and vice versa.

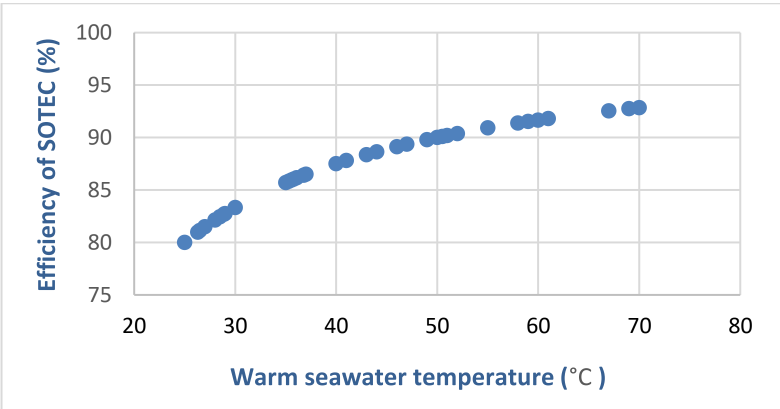

Figure 4.9. Effectiveness of the increasing of seawater temperatures on SOTEC efficiency.

In Figure 4.10 the efficiency curve of the solar collector is plotted against the amount of incident solar radiation, where solar radiation is a basic factor raising and lowering the efficiency of the collector, meaning that the relationship between solar radiation and the efficiency of the solar collector is a direct one.

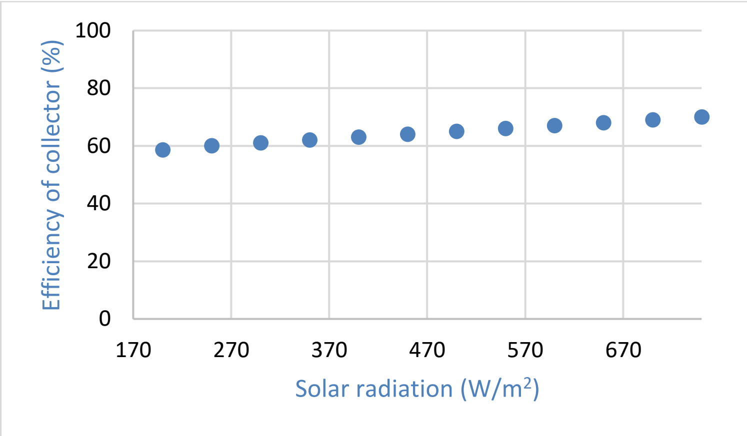

Figure 4.10. Variation of efficiency of the collector with solar radiation.

4.1. SIMULATION MODEL

TRNSYS programming was used to run numerical tests with a turbine-generator power of 120 kW to compare how well OTEC and 120 kW solar SOTEC of work. The equations for each part were found using an iterative process, starting with the idea that the output would be warm seawater and the output would be cold seawater. Due to this research, we now know what the evaporator and condenser pinch point temperatures should be. The evaporator and condenser temperatures were then used to figure out the saturation pressure and temperature of the working fluid. Once all the values at each place have been calculated, the energy values at the evaporator, condenser, and heater can be found. Following that, the mass warm seawater flow rate, cold seawater flow rate, and working fluid flow rate were calculated. Once the flow rates of warm and cold seawater were known, the pumping powers of warm and cold seawater were calculated. Figures 4.11 and 4.12 show diagrams of the traditional closed-Rankine OTEC cycle and the proposed solar-boosted SOTEC cycle. These pictures show how the heat exchangers, pumps, pipes, turbine generator, and solar collector are set up in general. In Figure 12, a solar collector is used to give the system some extra heat. Before the warm seawater goes into the evaporator, it is warmed up by the solar add-on. The warm seawater will take the heat from the solar collector and heat the working fluid. This will make the enthalpy drop across the turbine go up. A simulation of a 120 kW SOTEC plant is run to see how well it works, and then the results are compared to those of a traditional OTEC plant. Ammonia has a big advantage because it can be made without pollution, which makes it more likely that an OTEC plant system could be built. The results of the simulations are shown to compare how well the system is doing in terms of its net thermal efficiency, net power output, and solar collector area [22].

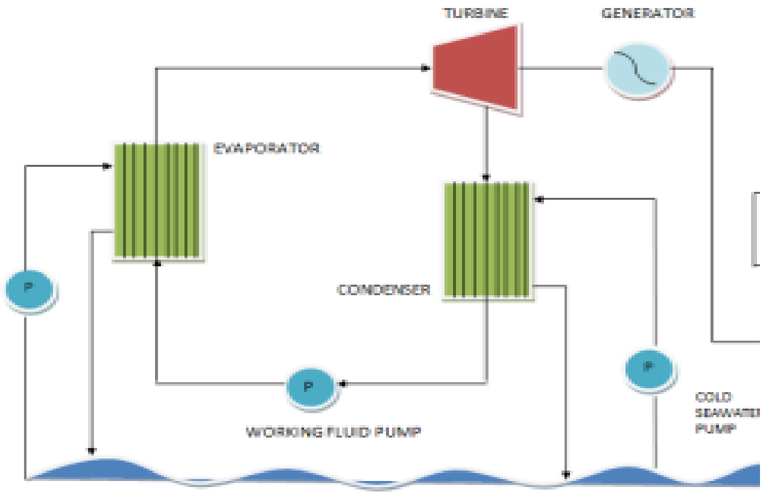

Figure 4.11. Schematic diagram of conventional OTEC cycle [22].

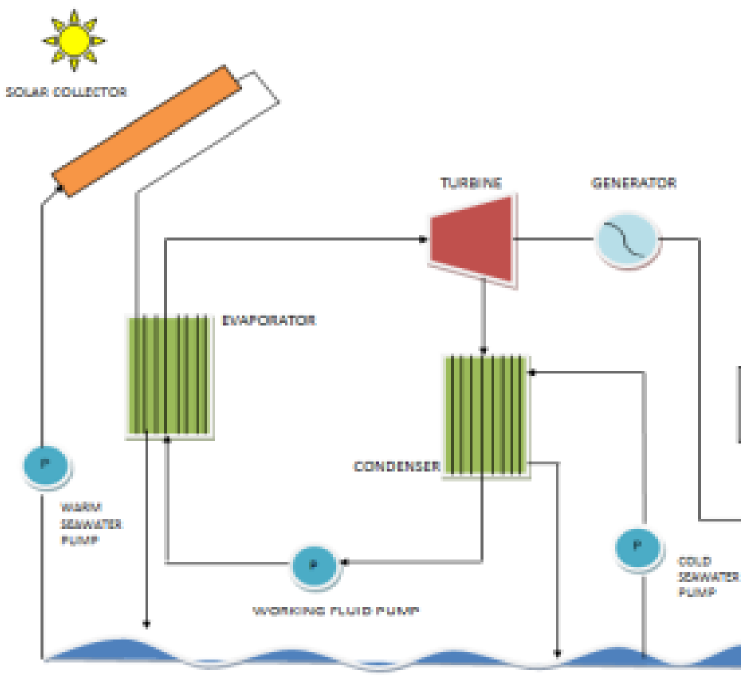

Figure 4.12. Schematic diagram of solar boosted SOTEC cycle [22].

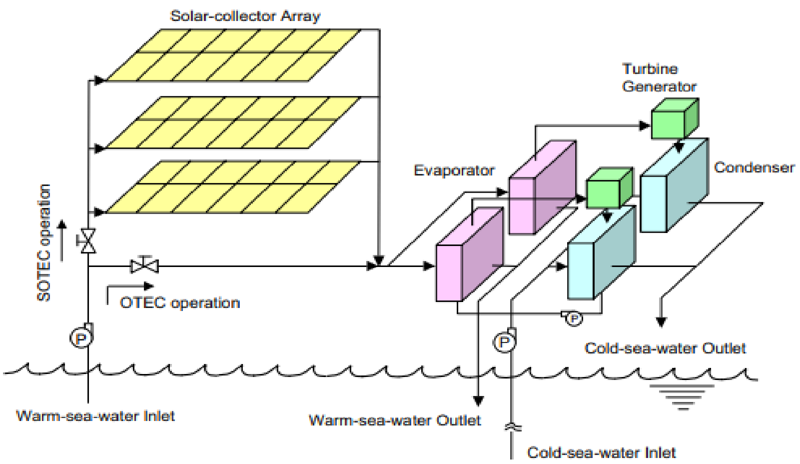

Figure 4.13. The SOTEC plant's piping diagram [19].

Figure 4.13 depicts the proposed SOTEC plant's piping diagram. Its operation was alternately switched from OTEC to SOTEC via valve control. By controlling valves, the heat transfer areas of the evaporator and condenser were also optimally controlled for optimal heat exchange efficiency. The simulations piping conditions are given in Table 4.4. The program flow chart is given in Figure 4.14.

Table 4.2. The simulations piping conditions.

Warm seawater pipe	
Diameter	0.7 m
Length	50 m
Cold seawater pipe	
Diameter	0.7 m
Length	1000 m

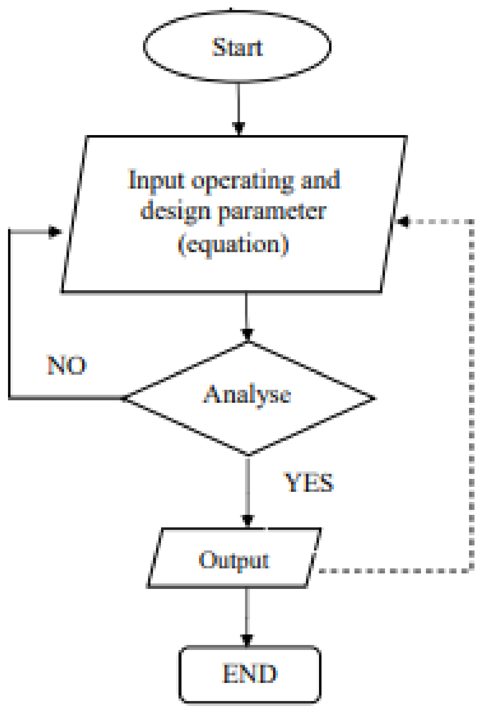

Figure 4.14. Program flow chart [13].

4.2. SUMMARY OF RESULTS

This thesis presents an investigation of the thermodynamic effects of a closed-cycle SOTEC system. For this purpose, a closed-cycle SOTEC system capable of generating 120 kW of total power has been designed. This system formed the basic OTEC system to be thermodynamically optimized, added to, and improved. SOTEC, designed with ammonia as the working fluid, was capable of producing 93 kW of net power with a net thermal efficiency and a net cycle efficiency of 78%. Simulation results show an improvement in net power generation of up to 20–25% from the addition of the preheater. This indicates that adding a flat-plate solar system to the system enables it to increase net thermal efficiency and reduce the working flow rate by 1.9 kg/s by compensating for the loss of pumping power. The parameters and outcomes were identical to those listed in Tables 4.3 and 4.4, respectively. A storage tank was also added to the system to provide warm water during evening periods when the sun is absent in order to enhance the system with warm water and maintain production capacity. This type of storage tank is fully mixed with SOTEC system, which is expected to enhance system performance while improving its thermodynamic performance. In preheated SOTEC, a solar collector is installed at the inlet of the evaporator with the function of preheating and providing additional heat to warm the sea water before it enters the evaporator. The SOTEC system consists of the pipes and pumps needed to supply SOTEC with cold and warm ocean water. These pipes are made of fiberglass, which is characterized by its light weight and low price. Cold water piping through a tray and error from 0.7 m to depths of up to 1000 m and warm seawater intake from 35 to 50 m depth are designed. On the other hand, in this case, the maximum temperature of the ammonia working fluid is 67.9 °C.

Figure 4.15 shows the monthly fluctuation in the daytime net Rankine cycle efficiency of OTEC operation vs SOTEC operation. SOTEC's efficiency is typically 1.4 times greater than OTEC's efficiency. Figure 4.16. shows Monthly variation of efficiency improvement due to SOTEC.

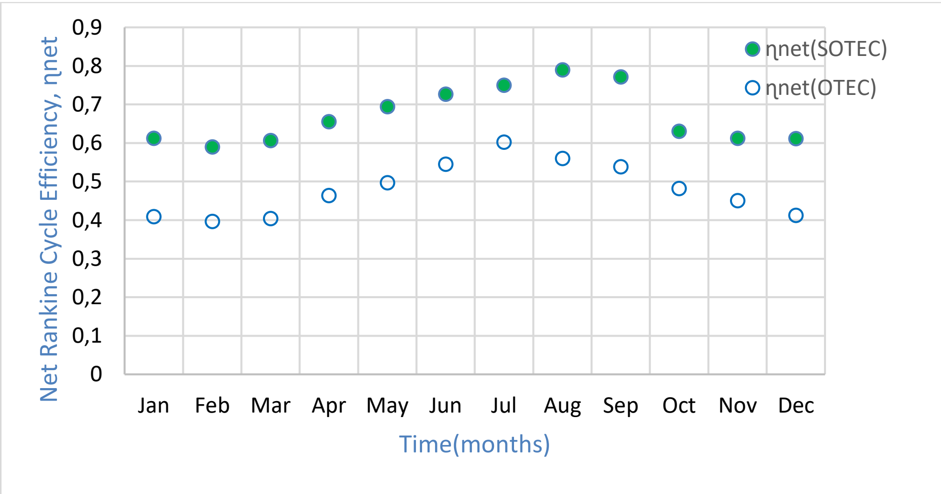

Figure 4.15. Monthly variation of net Rankine-cycle efficiency of OTEC and SOTEC operation at Alanya, Turkey.

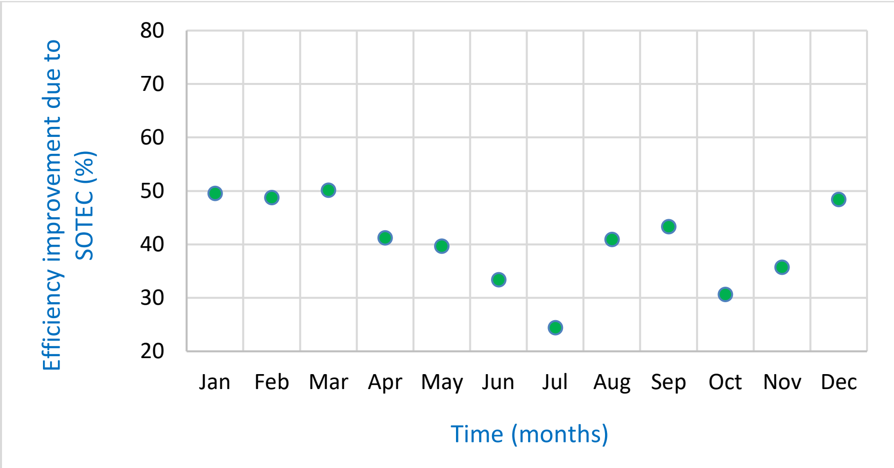

Figure 4.16. Monthly variation of efficiency improvement due to SOTEC.

Table 4.3 shows the thermodynamic properties of both the SOTEC and OTEC systems at each component of the system. Table 4.4 shows the most important results from simulating the systems with the TRNSYS program. It shows the mass flow rates of hot and cold water as well as the working flow rate. And the net power generation and net efficiency of each of the systems.

Table 4.3. The optimal state parameters of OTEC and SOTEC.

Point	**Pressure (KPa)**	**Temperature (°C)**	**Enthalpy (KJ/kg)**	**Phase**
OTEC				
1	631.09	19.7	1461	Super-heated
2	435.78	10.7	1451.78	S. Vapor
3	435.78	10.98	1425.03	S. liquid
4	631.09	20.6	1461.75	Subcooled
SOTEC				
1	1553.7	21.3	2858.9	Super-heated
2	1000.7	11.6	2778	S. Vapor
3	1000.7	11.8	2778	S. liquid
4	1553.7	24.5	2858.9	Subcooled

Table 4.4. Simulation results of 120 kW OTEC and SOTEC.

	OTEC (120 kW)	**SOTEC (120 kW)**
Warm seawater	18.5 – 26 °C	18.5 – 31 °C
Cold seawater	4.5 – 7 °C	4.5 – 6.5 °C
Solar collector		27 – 75 °C
Flow rate		
Warm seawater	500 kg/s	22.3 kg/s
Cold seawater	285 kg/s	102.6 kg/s
Working fluid	4.8 kg/s	1.9 kg/s
Net power	69.9 kW	93.3 kW
Cold seawater pump	25.8 kW	15.5 kW
Warm seawater pump	21.1 kW	8.8 kW
Working fluid pump	3.2 kW	2.4 kW
Net Rankine-cycle-efficiency	58.3%	78.15%
Heat transfer area of condenser	478 m²	360 m²
Heat transfer area of evaporator	514 m²	285 m²

4.3. VALIDATION PROCESS

The validation is based on the usage of software, fluid properties and comparison study of previous research that was conducted by Yamada [29].

4.3.1. Program Validation

To test the program that will be used in this study, the starting and piping conditions are assumed to be the same as in the book Performance Simulation of SOTEC Cycle. When a solar flat plate collector is incorporated as an extra component, the intended OTEC system is regarded as an exemplary base system that permits the thermodynamic study of its off-design operation. The TRNSYS software was used to do a numerical design-point study of the SOTEC system, which produced turbine-generator power of 120 kW. As a consequence, the acquired results were compared to those of Yamada [29]. The primary findings of this study are consistent with those of Yamada et al., who built the same scale SOTEC system. It is noticeable that the area of the evaporator and condenser is slightly different due to the different overall heat transfer coefficient of the heat exchanger, which is not stated in the study conducted by Yamada. Table 4.5 shows the results of the quantity states for 120 kW SOTEC.

Table 4.5. Comparison study.

	This study SOTEC (120 kW)	**Yamada SOTEC (100 kW)**
Warm seawater	18.5 – 31 °C	25.7 – 22.8 °C
Cold seawater	4.5 – 6.5 °C	4.4 – 8.5 °C
Solar collector	27 – 75 °C	25.7 – 45.7 °C
Flow rate		
Warm seawater	22.3 kg/s	16 kg/s
Cold seawater	102.6 kg/s	81.2 kg/s
Working fluid	1.9 kg/s	1.1 kg/s
Net power	93.3 kW	88.4 kW
Cold seawater pump	15.5 kW	5.7 kW
Warm seawater pump	8.8 kW	3.4 kW
Working fluid pump	2.4 kW	2.5 kW
Net Rankine-cycle-efficiency	78.15%	72 %
Heat transfer area of condenser	360 m²	299 m²
Heat transfer area of evaporator	285 m²	237 m²

PART 5

CONCLUSION

To sum up, renewable energy sources such as OTEC are viewed as one of the answers to supporting increased energy demand and reducing reliance on fossil fuels as the primary energy supply. The modest temperature difference, however, restricts OTEC's efficiency, and the focus should be on deep-ocean water with a minimum temperature differential of 20 °C. To supply the facility, a large amount of cold seawater flow rate taken from 1000 m depth may necessitate the construction of a lengthy pipeline. The potential of using renewable energy in Alanya, Turkey Aside from warm ocean surface water taken from 35–50 m below the surface, no ocean thermal energy could be cheaply captured. In the absence of the needed depth, a flat plate collector was used to raise the ocean surface temperature and maintain the required temperature differential. The current study reports on the optimization of a 120 kW of SOTEC to achieve a 40 °C increase in intake temperature. A simulation study method based on numerically based issue design is given to figure out the best results. The warm and cold seawater flow rates required to create a gross power of 120 kW SOTEC in shallow seawater are 22.3 kg/s and 102.6 kg/s, respectively, where the optimum mass working fluid for SOTEC is 1.9 kg/sec. Using the yearly solar radiation value (360 W/m^2), the solar collector area required to raise the temperature to 40 °C is 5000 m^2. Using this best design, the monthly net power distribution indicates an excellent result of roughly 93.3 kW throughout the year. With long-term price increases and the depletion of fossil resources, the development of an upgraded SOTEC system will become more relevant and promising.

5.1. RECOMMENDATIONS FOR FURTHER RESEARCH

By improving collector design or using a different heat transfer fluid with a higher solar absorption coefficient, the collector area required for preheating and superheating in OTEC could be significantly reduced. Previous research has shown that incorporating nanoparticles into fluids can boost light absorption to nearly 100% above a certain nanoparticle concentration [20, 24, 32]. This increase in light absorption has a direct impact on solar collector efficiency; for example, there is a 10% increase in efficiency when aluminum nanoparticles are suspended in water. Increasing the collector's efficiency would increase the combined system's overall thermal efficiency while also lowering production costs. To that end, investigating various shapes and configurations of plasmonic nanoparticles, as well as considering a solar thermal collection system with strong light absorption across a broad spectrum from visible to near-infrared, would be worthwhile.

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APPENDIX A

TEMPERATURE OF SURFACE SEAWATER FOR ALANYA IN 2020 (ID:17310,2021120825D9)

January			February			March		
Day	Hours	Temperature °C	Day	Hours	Temperature °C	Day	Hours	Temperature °C
1	5	18.5	1	5	16.7	1	5	16.6
1	6	18.5	1	6	16.7	1	6	16.6
1	12	18.5	1	12	16.7	1	12	16.6
1	19	18.5	1	19	16.7	1	19	16.6
2	5	19.1	2	5	17.5	2	5	16.9
2	6	19.1	2	6	17.5	2	6	16.9
2	12	19.1	2	12	17.5	2	12	16.9
2	19	19.1	2	19	17.5	2	19	16.9
3	5	19.3	3	5	17.7	3	5	17.2
3	6	19.3	3	6	17.7	3	6	17.2
3	12	19.3	3	12	17.7	3	12	17.2
3	19	19.3	3	19	17.7	3	19	17.2
4	5	18.8	4	5	17.8	4	5	17.6
4	6	18.8	4	6	17.8	4	6	17.6
4	12	18.8	4	12	17.8	4	12	17.6
4	19	18.8	4	19	17.8	4	19	17.6
5	5	19.0	5	5	17.7	5	5	17.6
5	6	19.0	5	6	17.7	5	6	17.6
5	12	19.0	5	12	17.7	5	12	17.6
5	19	19.0	5	19	17.7	5	19	17.6
6	5	18.1	6	5	17.0	6	5	17.1
6	6	18.1	6	6	17.0	6	6	17.1
6	12	18.1	6	12	17.0	6	12	17.1
6	19	18.1	6	19	17.0	6	19	17.1
7	5	17.9	7	5	17.2	7	5	17.4
7	6	17.9	7	6	17.2	7	6	17.4
7	12	17.9	7	12	17.2	7	12	17.4
7	19	17.9	7	19	17.2	7	19	17.4
8	5	17.8	8	5	16.5	8	5	17.3
8	6	17.8	8	6	16.5	8	6	17.3
8	12	17.8	8	12	16.5	8	12	17.3
8	19	17.8	8	19	16.5	8	19	17.3
9	5	18.3	9	5	15.4	9	5	17.9
9	6	18.3	9	6	15.4	9	6	17.9
9	12	18.3	9	12	15.4	9	12	17.9
9	19	18.3	9	19	15.4	9	19	17.9
10	5	19.1	10	5	15.7	10	5	17.0
10	6	19.1	10	6	15.7	10	6	17.0
10	12	19.1	10	12	15.7	10	12	17.0
10	19	19.1	10	19	15.7	10	19	17.0
11	5	17.4	11	5	16.7	11	5	17.3
11	6	17.4	11	6	16.7	11	6	17.3
11	12	17.4	11	12	16.7	11	12	17.3
11	19	17.4	11	19	16.7	11	19	17.3
12	5	18.1	12	5	16.7	12	5	17.8
12	6	18.1	12	6	16.7	12	6	17.8
12	12	18.1	12	12	16.7	12	12	17.8
12	19	18.1	12	19	16.7	12	19	17.8

13	5	17.7	13	5	16.2	13	5	17.5
13	6	17.7	13	6	16.2	13	6	17.5
13	12	17.7	13	12	16.2	13	12	17.5
13	19	17.7	13	19	16.2	13	19	17.5
14	5	18.5	14	5	16.5	14	5	17.5
14	6	18.5	14	6	16.5	14	6	17.5
14	12	18.5	14	12	16.5	14	12	17.5
14	19	18.5	14	19	16.5	14	19	17.5
15	5	18.1	15	5	16.7	15	5	18.0
15	6	18.1	15	6	16.7	15	6	18.0
15	12	18.1	15	12	16.7	15	12	18.0
15	19	18.1	15	19	16.7	15	19	18.0
16	5	17.8	16	5	17.2	16	5	17.7
16	6	17.8	16	6	17.2	16	6	17.7
16	12	17.8	16	12	17.2	16	12	17.7
16	19	17.8	16	19	17.2	16	19	17.7
17	5	18.7	17	5	17.2	17	5	18.2
17	6	18.7	17	6	17.2	17	6	18.2
17	12	18.7	17	12	17.2	17	12	18.2
17	19	18.7	17	19	17.2	17	19	18.2
18	5	18.5	18	5	17.3	18	5	18.0
18	6	18.5	18	6	17.3	18	6	18.0
18	12	18.5	18	12	17.3	18	12	18.0
18	19	18.5	18	19	17.3	18	19	18.0
19	5	18.4	19	5	16.9	19	5	18.2
19	6	18.4	19	6	16.9	19	6	18.2
19	12	18.4	19	12	16.9	19	12	18.2
19	19	18.4	19	19	16.9	19	19	18.2
20	5	18.2	20	5	16.8	20	5	17.1
20	6	18.2	20	6	16.8	20	6	17.1
20	12	18.2	20	12	16.8	20	12	17.1
20	19	18.2	20	19	16.8	20	19	17.1
21	5	17.8	21	5	16.6	21	5	17.0
21	6	17.8	21	6	16.6	21	6	17.0
21	12	17.8	21	12	16.6	21	12	17.0
21	19	17.8	21	19	16.6	21	19	17.0
22	5	17.2	22	5	15.4	22	5	16.8
22	6	17.2	22	6	15.4	22	6	16.8
22	12	17.2	22	12	15.4	22	12	16.8
22	19	17.2	22	19	15.4	22	19	16.8
23	5	17.0	23	5	16.9	23	5	17.3
23	6	17.0	23	6	16.9	23	6	17.3
23	12	17.0	23	12	16.9	23	12	17.3
23	19	17.0	23	19	16.9	23	19	17.3
24	5	17.5	24	5	16.4	24	5	18.2
24	6	17.5	24	6	16.4	24	6	18.2
24	12	17.5	24	12	16.4	24	12	18.2
24	19	17.5	24	19	16.4	24	19	18.2
25	5	17.0	25	5	16.8	25	5	17.2
25	6	17.0	25	6	16.8	25	6	17.2
25	12	17.0	25	12	16.8	25	12	17.2

25	19	17.0	25	19	16.8	25	19	17.2
26	5	16.5	26	5	16.8	26	5	16.8
26	6	16.5	26	6	16.8	26	6	16.8
26	12	16.5	26	12	16.8	26	12	16.8
26	19	16.5	26	19	16.8	26	19	16.8
27	5	16.9	27	5	17.4	27	5	17.8
27	6	16.9	27	6	17.4	27	6	17.8
27	12	16.9	27	12	17.4	27	12	17.8
27	19	16.9	27	19	17.4	27	19	17.8
28	5	17.2	28	5	17.6	28	5	17.4
28	6	17.2	28	6	17.6	28	6	17.4
28	12	17.2	28	12	17.6	28	12	17.4
28	19	17.2	28	19	17.6	28	19	17.4
29	5	17.0	29	5	17.3	29	5	17.5
29	6	17.0	29	6	17.3	29	6	17.5
29	12	17.0	29	12	17.3	29	12	17.5
29	19	17.0	29	19	17.3	29	19	17.5
30	5	16.9				30	5	17.4
30	6	16.9				30	6	17.4
30	12	16.9				30	12	17.4
30	19	16.9				30	19	17.4
31	5	17.5				31	5	17.9
31	6	17.5				31	6	17.9
31	12	17.5				31	12	17.9
31	19	17.5				31	19	17.9
April			**May**			**June**		
Day	Hours	Temperature °C	Day	Hours	Temperature °C	Day	Hours	Temperature °C
1	5	21.8	1	5	20.6	1	5	21.8
1	6	21.8	1	6	20.6	1	6	21.8
1	12	21.8	1	12	20.6	1	12	21.8
1	19	21.8	1	19	20.6	1	19	21.8
2	5	22.4	2	5	20.6	2	5	22.4
2	6	22.4	2	6	20.6	2	6	22.4
2	12	22.4	2	12	20.6	2	12	22.4
2	19	22.4	2	19	20.6	2	19	22.4
3	5	21.5	3	5	21.1	3	5	21.5
3	6	21.5	3	6	21.1	3	6	21.5
3	12	21.5	3	12	21.1	3	12	21.5
3	19	21.5	3	19	21.1	3	19	21.5
4	5	21.8	4	5	20.3	4	5	21.8
4	6	21.8	4	6	20.3	4	6	21.8
4	12	21.8	4	12	20.3	4	12	21.8
4	19	21.8	4	19	20.3	4	19	21.8
5	5	22.0	5	5	20.3	5	5	22.0
5	6	22.0	5	6	20.3	5	6	22.0
5	12	22.0	5	12	20.3	5	12	22.0
5	19	22.0	5	19	20.3	5	19	22.0
6	5	23.2	6	5	20.3	6	5	23.2
6	6	23.2	6	6	20.3	6	6	23.2
6	12	23.2	6	12	20.3	6	12	23.2

6	19	23.2	6	19	20.3	6	19	23.2
7	5	22.2	7	5	20.0	7	5	22.2
7	6	22.2	7	6	20.0	7	6	22.2
7	12	22.2	7	12	20.0	7	12	22.2
7	19	22.2	7	19	20.0	7	19	22.2
8	5	22.2	8	5	20.2	8	5	22.2
8	6	22.2	8	6	20.2	8	6	22.2
8	12	22.2	8	12	20.2	8	12	22.2
8	19	22.2	8	19	20.2	8	19	22.2
9	5	23.0	9	5	20.0	9	5	23.0
9	6	23.0	9	6	20.0	9	6	23.0
9	12	23.0	9	12	20.0	9	12	23.0
9	19	23.0	9	19	20.0	9	19	23.0
10	5	23.0	10	5	20.6	10	5	23.0
10	6	23.0	10	6	20.6	10	6	23.0
10	12	23.0	10	12	20.6	10	12	23.0
10	19	23.0	10	19	20.6	10	19	23.0
11	5	23.7	11	5	21.2	11	5	23.7
11	6	23.7	11	6	21.2	11	6	23.7
11	12	23.7	11	12	21.2	11	12	23.7
11	19	23.7	11	19	21.2	11	19	23.7
12	5	23.9	12	5	21.5	12	5	23.9
12	6	23.9	12	6	21.5	12	6	23.9
12	12	23.9	12	12	21.5	12	12	23.9
12	19	23.9	12	19	21.5	12	19	23.9
13	5	23.7	13	5	21.7	13	5	23.7
13	6	23.7	13	6	21.7	13	6	23.7
13	12	23.7	13	12	21.7	13	12	23.7
13	19	23.7	13	19	21.7	13	19	23.7
14	5	24.0	14	5	21.6	14	5	24.0
14	6	24.0	14	6	21.6	14	6	24.0
14	12	24.0	14	12	21.6	14	12	24.0
14	19	24.0	14	19	21.6	14	19	24.0
15	5	24.7	15	5	21.9	15	5	24.7
15	6	24.7	15	6	21.9	15	6	24.7
15	12	24.7	15	12	21.9	15	12	24.7
15	19	24.7	15	19	21.9	15	19	24.7
16	5	24.2	16	5	22.9	16	5	24.2
16	6	24.2	16	6	22.9	16	6	24.2
16	12	24.2	16	12	22.9	16	12	24.2
16	19	24.2	16	19	22.9	16	19	24.2
17	5	24.9	17	5	23.8	17	5	24.9
17	6	24.9	17	6	23.8	17	6	24.9
17	12	24.9	17	12	23.8	17	12	24.9
17	19	24.9	17	19	23.8	17	19	24.9
18	5	24.9	18	5	24.4	18	5	24.9
18	6	24.9	18	6	24.4	18	6	24.9
18	12	24.9	18	12	24.4	18	12	24.9
18	19	24.9	18	19	24.4	18	19	24.9
19	5	25.0	19	5	24.1	19	5	25.0
19	6	25.0	19	6	24.1	19	6	25.0

19	12	25.0	19	12	24.1	19	12	25.0
19	19	25.0	19	19	24.1	19	19	25.0
20	5	25.0	20	5	24.7	20	5	25.0
20	6	25.0	20	6	24.7	20	6	25.0
20	12	25.0	20	12	24.7	20	12	25.0
20	19	25.0	20	19	24.7	20	19	25.0
21	5	25.9	21	5	25.0	21	5	25.9
21	6	25.9	21	6	25.0	21	6	25.9
21	12	25.9	21	12	25.0	21	12	25.9
21	19	25.9	21	19	25.0	21	19	25.9
22	5	26.0	22	5	25.2	22	5	26.0
22	6	26.0	22	6	25.2	22	6	26.0
22	12	26.0	22	12	25.2	22	12	26.0
22	19	26.0	22	19	25.2	22	19	26.0
23	5	25.6	23	5	24.3	23	5	25.6
23	6	25.6	23	6	24.3	23	6	25.6
23	12	25.6	23	12	24.3	23	12	25.6
23	19	25.6	23	19	24.3	23	19	25.6
24	5	25.3	24	5	25.2	24	5	25.3
24	6	25.3	24	6	25.2	24	6	25.3
24	12	25.3	24	12	25.2	24	12	25.3
24	19	25.3	24	19	25.2	24	19	25.3
25	5	25.0	25	5	24.0	25	5	25.0
25	6	25.0	25	6	24.0	25	6	25.0
25	12	25.0	25	12	24.0	25	12	25.0
25	19	25.0	25	19	24.0	25	19	25.0
26	5	25.4	26	5	22.8	26	5	25.4
26	6	25.4	26	6	22.8	26	6	25.4
26	12	25.4	26	12	22.8	26	12	25.4
26	19	25.4	26	19	22.8	26	19	25.4
27	5	26.1	27	5	22.1	27	5	26.1
27	6	26.1	27	6	22.1	27	6	26.1
27	12	26.1	27	12	22.1	27	12	26.1
27	19	26.1	27	19	22.1	27	19	26.1
28	5	25.6	28	5	21.7	28	5	25.6
28	6	25.6	28	6	21.7	28	6	25.6
28	12	25.6	28	12	21.7	28	12	25.6
28	19	25.6	28	19	21.7	28	19	25.6
29	5	25.6	29	5	21.0	29	5	25.6
29	6	25.6	29	6	21.0	29	6	25.6
29	12	25.6	29	12	21.0	29	12	25.6
29	19	25.6	29	19	21.0	29	19	25.6
30	5	26.0	30	5	21.2	30	5	26.0
30	6	26.0	30	6	21.2	30	6	26.0
30	12	26.0	30	12	21.2	30	12	26.0
30	19	26.0	30	19	21.2	30	19	26.0
			31	5	21.5			
			31	6	21.5			
			31	12	21.5			
			31	19	21.5			
July			**August**			**September**		

Day	Hours	Temperature °C	Day	Hours	Temperature °C	Day	Hours	Temperature °C
1	5	27.6	1	5	31.0	1	5	29.4
1	6	27.6	1	6	31.0	1	6	29.4
1	12	27.6	1	12	31.0	1	12	29.4
1	19	27.6	1	19	31.0	1	19	29.4
2	5	27.7	2	5	30.4	2	5	29.7
2	6	27.7	2	6	30.4	2	6	29.7
2	12	27.7	2	12	30.4	2	12	29.7
2	19	27.7	2	19	30.4	2	19	29.7
3	5	28.2	3	5	30.6	3	5	29.7
3	6	28.2	3	6	30.6	3	6	29.7
3	12	28.2	3	12	30.6	3	12	29.7
3	19	28.2	3	19	30.6	3	19	29.7
4	5	28.3	4	5	31.0	4	5	29.8
4	6	28.3	4	6	31.0	4	6	29.8
4	12	28.3	4	12	31.0	4	12	29.8
4	19	28.3	4	19	31.0	4	19	29.8
5	5	28.5	5	5	30.9	5	5	29.9
5	6	28.5	5	6	30.9	5	6	29.9
5	12	28.5	5	12	30.9	5	12	29.9
5	19	28.5	5	19	30.9	5	19	29.9
6	5	28.5	6	5	31.3	6	5	29.9
6	6	28.5	6	6	31.3	6	6	29.9
6	12	28.5	6	12	31.3	6	12	29.9
6	19	28.5	6	19	31.3	6	19	29.9
7	5	28.9	7	5	31.3	7	5	30.0
7	6	28.9	7	6	31.3	7	6	30.0
7	12	28.9	7	12	31.3	7	12	30.0
7	19	28.9	7	19	31.3	7	19	30.0
8	5	28.6	8	5	31.3	8	5	30.2
8	6	28.6	8	6	31.3	8	6	30.2
8	12	28.6	8	12	31.3	8	12	30.2
8	19	28.6	8	19	31.3	8	19	30.2
9	5	28.5	9	5	31.3	9	5	30.0
9	6	28.5	9	6	31.3	9	6	30.0
9	12	28.5	9	12	31.3	9	12	30.0
9	19	28.5	9	19	31.3	9	19	30.0
10	5	28.2	10	5	29.9	10	5	29.9
10	6	28.2	10	6	29.9	10	6	29.9
10	12	28.2	10	12	29.9	10	12	29.9
10	19	28.2	10	19	29.9	10	19	29.9
11	5	28.4	11	5	30.0	11	5	29.8
11	6	28.4	11	6	30.0	11	6	29.8
11	12	28.4	11	12	30.0	11	12	29.8
11	19	28.4	11	19	30.0	11	19	29.8
12	5	28.1	12	5	29.9	12	5	30.0
12	6	28.1	12	6	29.9	12	6	30.0
12	12	28.1	12	12	29.9	12	12	30.0
12	19	28.1	12	19	29.9	12	19	30.0
13	5	28.1	13	5	30.0	13	5	29.8

13	6	28.1	13	6	30.0	13	6	29.8
13	12	28.1	13	12	30.0	13	12	29.8
13	19	28.1	13	19	30.0	13	19	29.8
14	5	27.9	14	5	29.7	14	5	29.7
14	6	27.9	14	6	29.7	14	6	29.7
14	12	27.9	14	12	29.7	14	12	29.7
14	19	27.9	14	19	29.7	14	19	29.7
15	5	27.9	15	5	29.5	15	5	29.0
15	6	27.9	15	6	29.5	15	6	29.0
15	12	27.9	15	12	29.5	15	12	29.0
15	19	27.9	15	19	29.5	15	19	29.0
16	5	28.0	16	5	29.1	16	5	29.8
16	6	28.0	16	6	29.1	16	6	29.8
16	12	28.0	16	12	29.1	16	12	29.8
16	19	28.0	16	19	29.1	16	19	29.8
17	5	27.9	17	5	29.5	17	5	30.1
17	6	27.9	17	6	29.5	17	6	30.1
17	12	27.9	17	12	29.5	17	12	30.1
17	19	27.9	17	19	29.5	17	19	30.1
18	5	28.3	18	5	29.3	18	5	30.1
18	6	28.3	18	6	29.3	18	6	30.1
18	12	28.3	18	12	29.3	18	12	30.1
18	19	28.3	18	19	29.3	18	19	30.1
19	5	28.8	19	5	29.4	19	5	30.1
19	6	28.8	19	6	29.4	19	6	30.1
19	12	28.8	19	12	29.4	19	12	30.1
19	19	28.8	19	19	29.4	19	19	30.1
20	5	28.8	20	5	29.5	20	5	29.9
20	6	28.8	20	6	29.5	20	6	29.9
20	12	28.8	20	12	29.5	20	12	29.9
20	19	28.8	20	19	29.5	20	19	29.9
21	5	28.5	21	5	29.3	21	5	29.9
21	6	28.5	21	6	29.3	21	6	29.9
21	12	28.5	21	12	29.3	21	12	29.9
21	19	28.5	21	19	29.3	21	19	29.9
22	5	29.0	22	5	29.1	22	5	29.6
22	6	29.0	22	6	29.1	22	6	29.6
22	12	29.0	22	12	29.1	22	12	29.6
22	19	29.0	22	19	29.1	22	19	29.6
23	5	29.2	23	5	29.3	23	5	29.6
23	6	29.2	23	6	29.3	23	6	29.6
23	12	29.2	23	12	29.3	23	12	29.6
23	19	29.2	23	19	29.3	23	19	29.6
24	5	29.2	24	5	29.3	24	5	29.7
24	6	29.2	24	6	29.3	24	6	29.4
24	12	29.2	24	12	29.3	24	12	29.7
24	19	29.2	24	19	29.3	24	19	29.7
25	5	29.4	25	5	29.3	25	5	29.5
25	6	29.4	25	6	29.3	25	6	29.5
25	12	29.4	25	12	29.3	25	12	29.5
25	19	29.4	25	19	29.3	25	19	29.5

26	5	29.7	26	5	29.5	26	5	29.1
26	6	29.7	26	6	29.5	26	6	29.1
26	12	29.7	26	12	29.5	26	12	29.1
26	19	29.7	26	19	29.5	26	19	29.1
27	5	29.8	27	5	29.5	27	5	29.1
27	6	29.8	27	6	29.5	27	6	29.1
27	12	29.8	27	12	29.5	27	12	29.1
27	19	29.8	27	19	29.5	27	19	29.1
28	5	29.9	28	5	29.5	28	5	28.8
28	6	29.9	28	6	29.5	28	6	28.8
28	12	29.9	28	12	29.5	28	12	28.8
28	19	29.9	28	19	29.5	28	19	28.8
29	5	29.9	29	5	29.4	29	5	28.6
29	6	29.9	29	6	29.4	29	6	28.6
29	12	29.9	29	12	29.4	29	12	28.6
29	19	29.9	29	19	29.4	29	19	28.6
30	5	29.6	30	5	29.5	30	5	28.9
30	6	29.6	30	6	29.5	30	6	28.9
30	12	29.6	30	12	29.5	30	12	28.9
30	19	29.6	30	19	29.5	30	19	28.9
31	5	30.0	31	5	29.6			
31	6	30.0	31	6	29.6			
31	12	30.0	31	12	29.6			
31	19	30.0	31	19	29.6			
October			**November**			**December**		
Day	Hours	Temperature °C	Day	Hours	Temperature °C	Day	Hours	Temperature °C
1	5	28.5	1	5	25.1	1	5	20.6
1	6	28.5	1	6	25.1	1	12	20.6
1	12	28.5	1	12	25.1	1	19	20.6
1	19	28.5	1	19	25.1	2	5	21.1
2	5	28.6	2	5	25.1	2	6	21.1
2	6	28.6	2	6	25.1	2	12	21.1
2	12	28.6	2	12	25.1	2	19	21.1
2	19	28.6	2	19	25.1	3	5	21.0
3	5	28.0	3	5	25.1	3	6	21.0
3	6	28.0	3	6	25.1	3	12	21.0
3	12	28.0	3	12	25.1	3	19	21.0
3	19	28.0	3	19	25.1	4	5	21.4
4	5	27.9	4	5	24.3	4	6	21.4
4	6	27.9	4	6	24.3	4	12	21.4
4	12	27.9	4	12	24.3	4	19	21.4
4	19	27.9	4	19	24.3	5	5	21.4
5	5	27.6	5	5	23.9	5	6	21.4
5	6	27.6	5	6	23.9	5	12	21.4
5	12	27.6	5	12	23.9	5	19	21.4
5	19	27.6	5	19	23.9	6	5	21.1
6	5	27.8	6	5	24.3	6	6	21.1
6	6	27.8	6	6	24.3	6	12	21.1
6	12	27.8	6	12	24.3	6	19	21.1
6	19	27.8	6	19	24.3	7	5	21.1

7	5	27.6	7	5	24.5	7	6	21.1
7	6	27.6	7	6	24.5	7	12	21.1
7	12	27.6	7	12	24.5	7	19	21.1
7	19	27.6	7	19	24.5	8	5	20.8
8	5	27.6	8	5	24.4	8	6	20.8
8	6	27.6	8	6	24.4	8	12	20.8
8	12	27.6	8	12	24.4	8	19	20.8
8	19	27.6	8	19	24.4	9	5	20.2
9	5	28.0	9	5	24.1	9	6	20.2
9	6	28.0	9	6	24.1	9	12	20.2
9	12	28.0	9	12	24.1	9	19	20.2
9	19	28.0	9	19	24.1	10	5	20.2
10	5	27.5	10	5	24.0	10	6	20.2
10	6	27.5	10	6	24.0	10	12	20.2
10	12	27.5	10	12	24.0	10	19	20.2
10	19	27.5	10	19	24.0	11	5	20.5
11	5	27.2	11	5	24.4	11	6	20.5
11	6	27.2	11	6	24.4	11	12	20.5
11	12	27.2	11	12	24.4	11	19	20.5
11	19	27.2	11	19	24.4	12	5	21.0
12	5	27.0	12	5	24.1	12	6	21.0
12	6	27.0	12	6	24.1	12	12	21.0
12	12	27.0	12	12	24.1	12	19	21.0
12	19	27.0	12	19	24.1	13	5	19.8
13	5	27.0	13	5	23.8	13	6	19.8
13	6	27.0	13	6	23.8	13	12	19.8
13	12	27.0	13	12	23.8	13	19	19.8
13	19	27.0	13	19	23.8	14	5	20.0
14	5	26.8	14	5	23.8	14	12	20.0
14	6	26.8	14	6	23.8	14	19	20.0
14	12	26.8	14	12	23.8	15	5	19.4
14	19	26.8	14	19	23.8	15	6	19.4
15	5	26.4	15	5	22.9	15	12	19.4
15	6	26.4	15	6	22.9	15	19	19.4
15	12	26.4	15	12	22.9	16	5	19.6
15	19	26.4	15	19	22.9	16	6	19.6
16	5	26.6	16	5	23.3	16	12	19.6
16	6	26.6	16	6	23.3	16	19	19.6
16	12	26.6	16	12	23.3	17	5	19.8
16	19	26.6	16	19	23.3	17	6	19.8
17	5	26.5	17	5	23.7	17	12	19.8
17	6	26.5	17	6	23.7	17	19	19.8
17	12	26.5	17	12	23.7	18	5	19.8
17	19	26.5	17	19	23.7	18	6	19.8
18	5	26.7	18	5	23.7	18	12	19.8
18	6	26.7	18	6	23.7	18	19	19.8
18	12	26.7	18	12	23.7	19	5	19.7
18	19	26.7	18	19	23.7	19	6	19.7
19	5	26.5	19	5	23.7	19	12	19.7
19	6	26.5	19	6	23.7	19	19	19.7
19	12	26.5	19	12	23.7	20	6	19.6

19	19	26.5	19	19	23.7	21	5	19.8
20	5	26.8	20	5	23.2	21	12	19.8
20	6	26.8	20	6	23.2	21	19	19.8
20	12	26.8	20	12	23.2	22	5	19.6
20	19	26.8	20	19	23.2	22	6	19.6
21	5	26.6	21	5	22.0	22	12	19.6
21	6	26.6	21	6	22.0	22	19	19.6
21	12	26.6	21	12	22.0	23	5	19.6
21	19	26.6	21	19	22.0	23	6	19.6
22	5	26.4	22	5	21.9	23	12	19.6
22	6	26.4	22	6	21.9	23	19	19.6
22	12	26.4	22	12	21.9	24	5	19.6
22	19	26.4	22	19	21.9	24	12	19.6
23	5	26.2	23	5	22.9	24	19	19.6
23	6	26.2	23	6	22.9	25	5	18.9
23	12	26.2	23	12	22.9	25	6	18.9
23	19	26.2	23	19	22.9	25	12	18.9
24	5	26.4	24	5	22.9	25	19	18.9
24	6	26.4	24	6	22.9	26	5	18.9
24	12	26.4	24	12	22.9	26	6	18.9
24	19	26.4	24	19	22.9	26	12	18.9
25	5	25.6	25	5	22.7	26	19	18.9
25	6	25.6	25	6	22.7	27	5	18.8
25	12	25.6	25	12	22.7	27	6	18.8
25	19	25.6	25	19	22.7	27	12	18.8
26	5	25.7	26	5	22.8	27	19	18.8
26	6	25.7	26	6	22.8	28	5	19.1
26	12	25.7	26	12	22.8	28	6	19.1
26	19	25.7	26	19	22.8	28	12	19.1
27	5	25.8	27	5	22.4	28	19	19.1
27	6	25.8	27	6	22.4	29	5	19.0
27	12	25.8	27	12	22.4	29	6	19.0
27	19	25.8	27	19	22.4	29	12	19.0
28	5	25.6	28	5	22.3	29	19	19.0
28	6	25.6	28	6	22.3	30	5	18.9
28	12	25.6	28	12	22.3	30	6	18.9
28	19	25.6	28	19	22.3	30	12	18.9
29	5	25.3	29	5	22.0	30	19	18.9
29	6	25.3	29	6	22.0	31	5	18.7
29	12	25.3	29	12	22.0	31	6	18.7
29	19	25.3	29	19	22.0	31	12	18.7
30	5	25.1	30	5	21.8	31	19	18.7
30	6	25.1	30	6	21.8			
30	12	25.1	30	12	21.8			
30	19	25.1	30	19	21.8			
31	5	25.1						
31	6	25.1						
31	12	25.1						
31	19	25.1						

APPENDIX B.

TRNSYS - THE TRANSIENT SYSTEM SIMULATION PROGRAM OF SOTEC VERSION 17.2

* START, STOP and STEP

CONSTANTS 3

START=0

STOP=8760

STEP=1

SIMULATION START STOP STEP ! Start time End time Time step

TOLERANCES 0.001 0.001 ! Integration Convergence

LIMITS 30 500 50 ! Max iterations Max warnings Trace limit

DFQ 1 ! TRNSYS numerical integration solver method

WIDTH 80 ! TRNSYS output file width, number of characters

LIST ! NOLIST statement

! MAP statement

SOLVER 0 1 1 ! Solver statement Minimum relaxation factor Maximum relaxation factor

NAN_CHECK 0 ! Nan DEBUG statement

OVERWRITE_CHECK 0 ! Overwrite DEBUG statement

TIME_REPORT 0 ! disable time report

EQSOLVER 0 ! EQUATION SOLVER statement

* User defined CONSTANTS

* Model "Type591a" (Type 591)

*

UNIT 2 TYPE 591 Type591a

*$UNIT_NAME Type591a

*$MODEL.\Cogeneration (CHP) Library (TESS)\Steam Turbines\Efficiency as INPUT\Load Following\No Injections or Extraction Streams\Type591a.tmf

*$POSITION 1314 157

*$LAYER Main #

PARAMETERS 3

120,000000 ! 1 Capacity

0 ! 2 Number of Injection Ports

```
0                    ! 3 Number of Extraction Ports
INPUTS 8
4,1                  ! Type58:Temperature at state-1 ->Steam Inlet Temperature
13,4                 ! Type5b:Load side flow rate ->Steam Inlet Mass Flowrate
4,2                  ! Type58:Pressure at state-1 ->Steam Inlet Pressure
4,3                  ! Type58:Enthalpy at state-1 ->Steam Inlet Enthalpy
0,0                  ! [unconnected] Steam Exhaust Pressure
0,0                  ! [unconnected] Turbine Load
0,0                  ! [unconnected] Control Signal
0,0                  ! [unconnected] Isentropic Efficiency
*** INITIAL INPUT VALUES
225.0 18000,000000 1553.7 2858.9 647 120,000000 1.0 0.7
*------------------------------------------------------------------------------
* Model "Type9c" (Type 9)
UNIT 3 TYPE 9         Type9c
*$UNIT_NAME Type9c
*$MODEL .\Utility\Data Readers\Generic Data Files\Skip Lines to Start\Free Format\Type9c.tmf
*$POSITION 1080 255
*$LAYER Weather - Data Files #
PARAMETERS 14
5                    ! 1 Mode
1                    ! 2 Header Lines to Skip
2                    ! 3 No. of values to read
1.0                  ! 4 Time interval of data
1                    ! 5 Interpolate or not-1
1.0                  ! 6 Multiplication factor-1
0                    ! 7 Addition factor-1
1                    ! 8 Average or instantaneous value-1
1                    ! 9 Interpolate or not-2
1.0                  ! 10 Multiplication factor-2
0                    ! 11 Addition factor-2
1                    ! 12 Average or instantaneous value-2
```

```
30              ! 13 Logical unit for input file
-1              ! 14 Free format mode
*** External files
ASSIGN "C:\Trnsys17\MyProjects\2021\Libya\Temp Data\ocean temp_new.txt" 30
*|? Input file name |1000
*------------------------------------------------------------------------------
* Model "Type58" (Type 58)
UNIT 4 TYPE 58   Type58
*$UNIT_NAME Type58
*$MODEL .\Physical Phenomena\Thermodynamic Properties\Refrigerant and Steam Properties\Type58.tmf
*$POSITION 995 127
*$LAYER Main #
PARAMETERS 6
717             ! 1 Refrigerant for state-1
1               ! 2 1st property type for state-1
5               ! 3 2nd property type for state-1
717             ! 4 Refrigerant for state-2
2               ! 5 1st property type for state-2
3               ! 6 2nd property type for state-2
INPUTS 4
13,3            ! Type5b:Load side outlet temperature ->1st property for state-1
0,0             ! [unconnected] 2nd property for state-1
2,3             ! Type591a:Outlet Pressure ->1st property for state-2
2,4             ! Type591a:Outlet Steam Enthalpy ->2nd property for state-2
*** INITIAL INPUT VALUES
0.0 1 0.0 896
*------------------------------------------------------------------------------
* Model "Type599" (Type 599)
UNIT 5 TYPE 599   Type599
*$UNIT_NAME Type599
*$MODEL .\Cogeneration (CHP) Library (TESS)\Electrical Devices\Generator\Type599.tmf
```

```
*$POSITION 1413 138
*$LAYER Main #
PARAMETERS 3
1000,000000             ! 1 Capacity
31                  ! 2 Logical Unit for Data File
11                  ! 3 Number Points in Data File
INPUTS 1
2,6                 ! Type591a:Work Done ->Input Power
*** INITIAL INPUT VALUES
1800000.0
*** External files
ASSIGN "C:\Trnsys17\Tess Models\SampleCatalogData\CoGeneration\Electrical\Generators\Gen_Eff.Dat" 31
*|? Which file contains the efficiency data as a function of PLR for the generator? |1000
*------------------------------------------------------------------------------

* Model "Condenser" (Type 598)
UNIT 6 TYPE 598      Condenser
*$UNIT_NAME Condenser
*$MODEL .\Cogeneration (CHP) Library (TESS)\Steam System Components\Condenser\Floating Condensing Pressure\Type598.tmf
*$POSITION 1320 362
*$LAYER Main #
*$# Condenser for Steam Applications
PARAMETERS 6
6.5                 ! 1 Pinchpoint Temperature Difference
4.190               ! 2 Cooling Fluid Specific Heat
cp_NH3              ! 3 Specific Heat of Steam Condensate
1.2                 ! 4 Minimum Condensing Pressure
2.5                 ! 5 Degrees of Subcooling
1                   ! 6 Configuration
INPUTS 6
```

```
17,1            ! Cold water:Outlet fluid temperature ->Cooling Fluid Inlet Temperature
17,2            ! Cold water:Outlet flow rate ->Cooling Fluid Inlet Flowrate
4,8             ! Type58:Temperature at state-2 ->Steam Inlet Temperature
2,2             ! Type591a:Outlet Mass Flowrate ->Steam Inlet Flowrate
2,3             ! Type591a:Outlet Pressure ->Steam Inlet Pressure
2,4             ! Type591a:Outlet Steam Enthalpy ->Steam Inlet Enthalpy
*** INITIAL INPUT VALUES
25.0 1026000,000000 179.9 1026000,000000 1000.0 2778.0
*------------------------------------------------------------------------------
* EQUATIONS "Equa"
EQUATIONS 2
tk = (([13,3]+[6,3])/2)+274.15
cp_NH3 = 0.393 + 0.00037*tk*0.004187*1000
*$UNIT_NAME Equa
*$LAYER Main
*$POSITION 1130 372
*------------------------------------------------------------------------------
* Model "Type65d" (Type 65)
UNIT 8 TYPE 65     Type65d
*$UNIT_NAME Type65d
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 1139 52
*$LAYER Main #
PARAMETERS 12
2               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
200             ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
1000.0          ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
```

```
0                   ! 9 Shut off Online w/o removing
-1                  ! 10 Logical unit for output file
0                   ! 11 Output file units
0                   ! 12 Output file delimiter
INPUTS 4
9,1                 ! Type57:Turbine_kW ->Left axis variable-1
9,2                 ! Type57:Generator_kW ->Left axis variable-2
0,0                 ! [unconnected] Right axis variable-1
0,0                 ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES
Turbine_kW Generator_kW label label
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*------------------------------------------------------------------------------
* Model "Type57" (Type 57)
UNIT 9 TYPE 57       Type57
*$UNIT_NAME Type57
*$MODEL .\Utility\Unit Conversion Routine\Type57.tmf
*$POSITION 1271 42
*$LAYER Main #
PARAMETERS 6
12                  ! 1 Table Nb. for input-1
1                   ! 2 ID number from table for input -1
3                   ! 3 ID number from table for output-1
12                  ! 4 Table Nb. for input-2
1                   ! 5 ID number from table for input -2
3                   ! 6 ID number from table for output-2
INPUTS 2
2,6                 ! Type591a:Work Done ->Turbine
5,1                 ! Type599:Output Power ->Generator
*** INITIAL INPUT VALUES
```

```
0.0 0.0
*------------------------------------------------------------------------------
* Model "Type5b" (Type 5)
UNIT 13 TYPE 5       Type5b
*$UNIT_NAME Type5b
*$MODEL .\Heat Exchangers\Counter Flow\Type5b.tmf
*$POSITION 900 436
*$LAYER Main #
PARAMETERS 4
2               ! 1 Counter flow mode
4.19            ! 2 Specific heat of source side fluid
cp_NH3          ! 3 Specific heat of load side fluid
0               ! 4 Not used
INPUTS 5
26,1            ! Type11h:Outlet temperature ->Source side inlet temperature
26,2            ! Type11h:Outlet flow rate ->Source side flow rate
14,1            ! Ammonia:Outlet fluid temperature ->Load side inlet temperature
14,2            ! Ammonia:Outlet flow rate ->Load side flow rate
0,0             ! [unconnected] Overall heat transfer coefficient of exchanger
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0 100000
*------------------------------------------------------------------------------
* Model "Ammonia" (Type 114)
UNIT 14 TYPE 114    Ammonia
*$UNIT_NAME Ammonia
*$MODEL .\Hydronics\Pumps\Single Speed\Type114.tmf
*$POSITION 1083 532
*$LAYER Main #
*$# SINGLE-SPEED PUMP
PARAMETERS 4
MF_NH           ! 1 Rated flow rate
cp_NH3          ! 2 Fluid specific heat
2684.0          ! 3 Rated power
```

```
0.0             ! 4 Motor heat loss fraction
INPUTS 5
6,3             ! Condenser:Condensate Outlet Temperature ->Inlet fluid temperature
6,4             ! Condenser:Condensate Flowrate ->Inlet fluid flow rate
0,0             ! [unconnected] Control signal
0,0             ! [unconnected] Overall pump efficiency
0,0             ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 1000 1.0 0.6 0.9
*------------------------------------------------------------------------------
* Model "Hot Water" (Type 114)
UNIT 15 TYPE 114   Hot Water
*$UNIT_NAME Hot Water
*$MODEL .\Hydronics\Pumps\Single Speed\Type114.tmf
*$POSITION 968 255
*$LAYER Main #
*$# SINGLE-SPEED PUMP
PARAMETERS 4
MF_H_water          ! 1 Rated flow rate
4.19            ! 2 Fluid specific heat
2684.0          ! 3 Rated power
0.0             ! 4 Motor heat loss fraction
INPUTS 5
3,1             ! Type9c:Output 1 ->Inlet fluid temperature
0,0             ! [unconnected] Inlet fluid flow rate
0,0             ! [unconnected] Control signal
0,0             ! [unconnected] Overall pump efficiency
0,0             ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 1000 1.0 0.6 0.9
*------------------------------------------------------------------------------
* EQUATIONS "Flow Rate"
EQUATIONS 3
```

```
MF_NH = 20880 !                    flow_NH3= 5.8 kg / s
MF_C_water = 1026000  !             flow_water_cold =285 kg / s
MF_H_water = 1800000  !            flow_water_hot = 500 kg / s
*$UNIT_NAME Flow Rate
*$LAYER Main
*$POSITION 229 84
*------------------------------------------------------------------------------
* Model "Cold water" (Type 114)
UNIT 17 TYPE 114    Cold water
*$UNIT_NAME Cold water
*$MODEL .\Hydronics\Pumps\Single Speed\Type114.tmf
*$POSITION 1224 266
*$LAYER Main #
*$# SINGLE-SPEED PUMP
PARAMETERS 4
MF_C_water          ! 1 Rated flow rate
4.19                ! 2 Fluid specific heat
2684.0              ! 3 Rated power
0.0                 ! 4 Motor heat loss fraction
INPUTS 5
3,2                 ! Type9c:Output 2 ->Inlet fluid temperature
0,0                 ! [unconnected] Inlet fluid flow rate
0,0                 ! [unconnected] Control signal
0,0                 ! [unconnected] Overall pump efficiency
0,0                 ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 1000 1.0 0.6 0.9
*-----------------------------------------------------------------------------
* Model "Type15-2" (Type 15)
UNIT 19 TYPE 15      Type15-2
*$UNIT_NAME Type15-2
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type15-
2.tmf
```

*$POSITION 104 74

*$LAYER Weather - Data Files #

PARAMETERS 9

2 ! 1 File Type

33 ! 2 Logical unit

3 ! 3 Tilted Surface Radiation Mode

0.2 ! 4 Ground reflectance - no snow

0.7 ! 5 Ground reflectance - snow cover

1 ! 6 Number of surfaces

1 ! 7 Tracking mode

0.0 ! 8 Slope of surface

0 ! 9 Azimuth of surface

*** External files

ASSIGN "C:\Trnsys17\Weather\Meteonorm\Tripoli_Intl_Airp_-hour.tm2" 33

*|? Which file contains the TMY-2 weather data? |1000

*--

* Model "Type534-NoHX" (Type 534)

UNIT 18 TYPE 534 Type534-NoHX

*$UNIT_NAME Type534-NoHX

*$MODEL .\Storage Tank Library (TESS)\Cylindrical Storage Tank\Vertical Cylinder\Version without Plug-In\No HXs\Type534-NoHX.tmf

*$POSITION 333 287

*$LAYER Main #

*$# Cylindrical Storage Tank

PARAMETERS 33

-1 ! 1 LU for Data File

5 ! 2 Number of Tank Nodes

2 ! 3 Number of Ports

0 ! 4 Number of Immersed Heat Exchangers

1 ! 5 Number of Miscellaneous Heat Flows

2 ! 6 Tank Volume

1.5 ! 7 Tank Height

0 ! 8 Tank Fluid

```
4.19        ! 9 Fluid Specific Heat
1000        ! 10 Fluid Density
2.14        ! 11 Fluid Thermal Conductivity
3.21        ! 12 Fluid Viscosity
0.00026     ! 13 Fluid Thermal Expansion Coefficient
5.0         ! 14 Top Loss Coefficient
5.0         ! 15 Edge Loss Coefficient for Node-1
5.0         ! 16 Edge Loss Coefficient for Node-2
5.0         ! 17 Edge Loss Coefficient for Node-3
5.0         ! 18 Edge Loss Coefficient for Node-4
5.0         ! 19 Edge Loss Coefficient for Node-5
5.0         ! 20 Bottom Loss Coefficient
0           ! 21 Additional Thermal Conductivity
1           ! 22 Inlet Flow Mode-1
2           ! 23 Entry Node-1
4           ! 24 Exit Node-1
1           ! 25 Inlet Flow Mode-2
5           ! 26 Entry Node-2
1           ! 27 Exit Node-2
3.0         ! 28 Flue Overall Loss Coefficient for Node-1
3.0         ! 29 Flue Overall Loss Coefficient for Node-2
3.0         ! 30 Flue Overall Loss Coefficient for Node-3
3.0         ! 31 Flue Overall Loss Coefficient for Node-4
3.0         ! 32 Flue Overall Loss Coefficient for Node-5
1           ! 33 Node for Miscellaneous Heat Gain
INPUTS 19
28,1        ! Type1b:Outlet temperature ->Inlet Temperature for Port-1
28,2        ! Type1b:Outlet flowrate ->Inlet Flowrate for Port-1
27,1        ! Type11b-2:Temperature at outlet 1 ->Inlet Temperature for Port-2
27,2        ! Type11b-2:Flowrate at outlet 1 ->Inlet Flowrate for Port-2
0,0         ! [unconnected] Top Loss Temperature
0,0         ! [unconnected] Edge Loss Temperature for Node-1
0,0         ! [unconnected] Edge Loss Temperature for Node-2
```

```
0,0             ! [unconnected] Edge Loss Temperature for Node-3
0,0             ! [unconnected] Edge Loss Temperature for Node-4
0,0             ! [unconnected] Edge Loss Temperature for Node-5
0,0             ! [unconnected] Bottom Loss Temperature
0,0             ! [unconnected] Gas Flue Temperature
0,0             ! [unconnected] Inversion Mixing Flowrate
0,0             ! [unconnected] Auxiliary Heat Input for Node-1
0,0             ! [unconnected] Auxiliary Heat Input for Node-2
0,0             ! [unconnected] Auxiliary Heat Input for Node-3
0,0             ! [unconnected] Auxiliary Heat Input for Node-4
0,0             ! [unconnected] Auxiliary Heat Input for Node-5
0,0             ! [unconnected] Miscellaneous Heat Input
*** INITIAL INPUT VALUES
20.0 0.0 20.0 0.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 -100 0.0 0.0 0.0 0.0
0.0 0
DERIVATIVES 5
20.0            ! 1 Initial Tank Temperature-1
20.0            ! 2 Initial Tank Temperature-2
20.0            ! 3 Initial Tank Temperature-3
20.0            ! 4 Initial Tank Temperature-4
20.0            ! 5 Initial Tank Temperature-5
*------------------------------------------------------------------------------
* Model "Type114" (Type 114)
UNIT 21 TYPE 114    Type114
*$UNIT_NAME Type114
*$MODEL .\Hydronics\Pumps\Single Speed\Type114.tmf
*$POSITION 165 415
*$LAYER Main #
*$# SINGLE-SPEED PUMP
PARAMETERS 4
0,000000        ! 1 Rated flow rate
4.19            ! 2 Fluid specific heat
2684.0          ! 3 Rated power
```

```
0.0		! 4 Motor heat loss fraction
INPUTS 5
18,1		! Type534-NoHX:Temperature at Outlet-1 ->Inlet fluid temperature
18,2		! Type534-NoHX:Flowrate at Outlet-1 ->Inlet fluid flow rate
22,1		! Type2b:Output control function ->Control signal
0,0		! [unconnected] Overall pump efficiency
0,0		! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 1000 1.0 0.6 0.9
*------------------------------------------------------------------------------
* Model "Type2b" (Type 2)
UNIT 22 TYPE 2	 Type2b
*$UNIT_NAME Type2b
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0 (Successive Substitution) Control Strategy\Type2b.tmf
*$POSITION 216 266
*$LAYER Controls #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5		! 1 No. of oscillations
100.0		! 2 High limit cut-out
INPUTS 6
28,1		! Type1b:Outlet temperature ->Upper input temperature Th
18,3		! Type534-NoHX:Temperature at Outlet-2 ->Lower input temperature Tl
18,1		! Type534-NoHX:Temperature at Outlet-1 ->Monitoring temperature Tin
22,1		! Type2b:Output control function ->Input control function
0,0		! [unconnected] Upper dead band dT
0,0		! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
```

```
20.0 10.0 20.0 0 10.0 2.0
*------------------------------------------------------------------------------
* Model "Type114-2" (Type 114)
UNIT 24 TYPE 114    Type114-2
*$UNIT_NAME Type114-2
*$MODEL .\Hydronics\Pumps\Single Speed\Type114.tmf
*$POSITION 454 138
*$LAYER Main #
*$# SINGLE-SPEED PUMP
PARAMETERS 4
MF_H_water          ! 1 Rated flow rate
4.19                ! 2 Fluid specific heat
2684.0              ! 3 Rated power
0.0                 ! 4 Motor heat loss fraction
INPUTS 5
18,3                ! Type534-NoHX:Temperature at Outlet-2 ->Inlet fluid temperature
18,4                ! Type534-NoHX:Flowrate at Outlet-2 ->Inlet fluid flow rate
25,5                ! Type11b:Control function ->Control signal
0,0                 ! [unconnected] Overall pump efficiency
0,0                 ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 1000 1.0 0.6 0.9
*------------------------------------------------------------------------------
* Model "Type11b" (Type 11)
UNIT 25 TYPE 11     Type11b
*$UNIT_NAME Type11b
*$MODEL .\Hydronics\Tempering Valve\Other Fluids\Type11b.tmf
*$POSITION 690 127
*$LAYER Water Loop #
PARAMETERS 2
4                   ! 1 Tempering valve mode
7                   ! 2 Nb. of oscillations allowed
INPUTS 4
```

```
0,0             ! [unconnected] Inlet temperature
15,2            ! Hot Water:Outlet flow rate ->Inlet flow rate
15,1            ! Hot Water:Outlet fluid temperature ->Heat source temperature
0,0             ! [unconnected] Set point temperature
*** INITIAL INPUT VALUES
25 100.0 25 25
*------------------------------------------------------------------------------
* Model "Type11h" (Type 11)
UNIT 26 TYPE 11     Type11h
*$UNIT_NAME Type11h
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 679 447
*$LAYER Water Loop #
PARAMETERS 1
1               ! 1 Tee piece mode
INPUTS 4
0,0             ! [unconnected] Temperature at inlet 1
25,4            ! Type11b:Flow rate at outlet 2 ->Flow rate at inlet 1
24,1            ! Type114-2:Outlet fluid temperature ->Temperature at inlet 2
27,4            ! Type11b-2:Flow rate at outlet 2 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------
* Model "Type11b-2" (Type 11)
UNIT 27 TYPE 11     Type11b-2
*$UNIT_NAME Type11b-2
*$MODEL .\Hydronics\Tempering Valve\Other Fluids\Type11b.tmf
*$POSITION 444 447
*$LAYER Water Loop #
PARAMETERS 2
4               ! 1 Tempering valve mode
7               ! 2 Nb. of oscillations allowed
INPUTS 4
```

```
0,0             ! [unconnected] Inlet temperature
24,2            ! Type114-2:Outlet flow rate ->Inlet flow rate
24,1            ! Type114-2:Outlet fluid temperature ->Heat source temperature
0,0             ! [unconnected] Set point temperature
*** INITIAL INPUT VALUES
25.00001 100.0 25.00001 25.00001
*------------------------------------------------------------------------------
* Model "Type1b" (Type 1)
UNIT 28 TYPE 1    Type1b
*$UNIT_NAME Type1b
*$MODEL .\Solar Thermal Collectors\Quadratic Efficiency Collector\2nd-Order Incidence Angle Modifiers\Type1b.tmf
*$POSITION 77 212
*$LAYER Main #
PARAMETERS 11
1               ! 1 Number in series
10              ! 2 Collector area
4.190           ! 3 Fluid specific heat
1               ! 4 Efficiency mode
40.0            ! 5 Tested flow rate
0.80            ! 6 Intercept efficiency
9,000000        ! 7 Efficiency slope
0,000000        ! 8 Efficiency curvature
2               ! 9 Optical mode 2
0.2             ! 10 1st-order IAM
0.0             ! 11 2nd-order IAM
INPUTS 9
21,1            ! Type114:Outlet fluid temperature ->Inlet temperature
21,2            ! Type114:Outlet flow rate ->Inlet flowrate
19,1            ! Type15-2:Dry bulb temperature ->Ambient temperature
19,25           ! Type15-2:Beam radiation for surface ->Incident radiation
19,14           ! Type15-2:Global horizontal radiation (not interpolated) ->Total horizontal radiation
```

19,22 ! Type15-2:Total diffuse radiation on the horizontal ->Horizontal diffuse radiation
0,0 ! [unconnected] Ground reflectance
19,29 ! Type15-2:Angle of incidence for surface ->Incidence angle
0,0 ! [unconnected] Collector slope
*** INITIAL INPUT VALUES
20.0 100.0 10.0 0. 0.0 0.0 0.2 45.0 45
*---
* Model "Type65d-2" (Type 65)
UNIT 29 TYPE 65 Type65d-2
*$UNIT_NAME Type65d-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 764 52
*$LAYER Main #
PARAMETERS 12
2 ! 1 Nb. of left-axis variables
2 ! 2 Nb. of right-axis variables
0.0 ! 3 Left axis minimum
50 ! 4 Left axis maximum
0.0 ! 5 Right axis minimum
1000.0 ! 6 Right axis maximum
1 ! 7 Number of plots per simulation
12 ! 8 X-axis gridpoints
0 ! 9 Shut off Online w/o removing
-1 ! 10 Logical unit for output file
0 ! 11 Output file units
0 ! 12 Output file delimiter
INPUTS 4
24,1 ! Type114-2:Outlet fluid temperature ->Left axis variable-1
3,1 ! Type9c:Output 1 ->Left axis variable-2
0,0 ! [unconnected] Right axis variable-1
0,0 ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES

```
T_solar T_Ocean label label
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*-----------------------------------------------------------------------------
* Model "Type65d-3" (Type 65)
UNIT 30 TYPE 65     Type65d-3
*$UNIT_NAME Type65d-3
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 786 330
*$LAYER Main #
PARAMETERS 12
4               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
2000000         ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
1000.0          ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 6
15,2            ! Hot Water:Outlet flow rate ->Left axis variable-1
27,4            ! Type11b-2:Flow rate at outlet 2 ->Left axis variable-2
26,2            ! Type11h:Outlet flow rate ->Left axis variable-3
25,4            ! Type11b:Flow rate at outlet 2 ->Left axis variable-4
0,0             ! [unconnected] Right axis variable-1
0,0             ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES
```

```
MF_Ocean_T MF_solar MF_mix MF_Ocean_ok label label
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*------------------------------------------------------------------------------
* Model "Type25c" (Type 25)
*
UNIT 31 TYPE 25      Type25c
*$UNIT_NAME Type25c
*$MODEL .\Output\Printer\Unformatted\No Units\Type25c.tmf
*$POSITION 337 607
*$LAYER Outputs #
PARAMETERS 10
1               ! 1 Printing interval
START           ! 2 Start time
STOP            ! 3 Stop time
34              ! 4 Logical unit
0               ! 5 Units printing mode
0               ! 6 Relative or absolute start time
-1              ! 7 Overwrite or Append
-1              ! 8 Print header
0               ! 9 Delimiter
1               ! 10 Print labels
INPUTS 3
21,2            ! Type114:Outlet flow rate ->MF_solar_pumo\p
28,1            ! Type1b:Outlet temperature ->T-Solar
9,2             ! Type57:Generator_kW ->kW_generator
*** INITIAL INPUT VALUES
MF_solar T_solar Generator_kW
*** External files
ASSIGN "output\Ali.txt" 34
*|? Output file for printed results |1000
```

*---

END.

RESUME

Ali Yousuf ZIKRI graduated from Tripoli university department of mechanical and industrial engineering in 2019, I started working at the scientific research and technology corporation in Libya, then I came to turkey to continue studying, I started my master’s degree at karabük, university in 2021.