MATLAB BASED MODELING OF AN OTEC AMMONIA POWER PLANT

A Project

Presented to the

Faculty of

California State Polytechnic University, Pomona

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

In

Mechanical Engineering

By

Aaron Siow

2020

SIGNATURE PAGE

PROJECT: MATLAB BASED MODELING OF AN OTEC AMMONIA POWER PLANT

AUTHORS: Aaron Siow

DATE SUBMITTED: Fall 2020
Department of Mechanical Engineering

Dr. Kevin R. Anderson
Thesis Committee Chair
Mechanical Engineering ______________________________

Dr. Henry Xue
Professor
Mechanical Engineering ______________________________

Dr. Maryam Shafahi
Professor
Mechanical Engineering ______________________________

ACKNOWLEDGEMENTS

I would like to thank Dr. Kevin R. Anderson for the opportunity to assist him in conducting research and examination on the subject of ocean thermal energy conversion. My experience has been both interesting and enlightening. I am grateful and thankful for his counsel on this project as I conclude my studies.

ABSTRACT

A MATLAB based analysis was carried out to model an ammonia-based ocean thermal energy conversion (OTEC) power plant. This project presents an analysis using ammonia (NH_3) or R-717 as the primary working fluid in a closed cycle system, also known as the Anderson cycle. The goal of the system is to produce 100 kW of gross power. Parameters such as turbine and pump efficiency are varied in order to assess impact on overall system efficiency and performance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

$\dot{Q}_E$	heat transfer at evaporator
$\dot{Q}_C$	heat transfer at condenser
$\dot{m}_{wf}$	mass flow rate of working fluid
h	enthalpy
$\dot{m}_{ws}$	mass flow rate of warm seawater
T_{wsi}	temperature of warm seawater, in
T_{wso}	temperature of warm seawater, out
$\dot{m}_{cs}$	mass flow rate of cold seawater
T_{cso}	temperature of cold seawater, out
T_{csi}	temperature of cold seawater, in
$\dot{W}^{\leftarrow}_{P,wf}$	work, working fluid pump
v	specific gravity
g	gravitational constant
ΔH	water elevation head
$\eta_{P,sw}$	temperature of cold seawater, in
$\dot{W}_N$	net work
$\dot{W}_{T-G}$	work, turbine generator
$\dot{W}_{P,wf}$	work, working fluid pump
$\dot{W}_{P,ws}$	work, warm seawater pump

NOMENCLATURE (CONTINUED)

$\dot{W}_{P,cs}$	work, cold seawater pump
η_{th}	system thermal efficiency

1 CHAPTER: INTRODUCTION

1.1 INTRODUCTION TO OCEAN THERMAL ENERGY CONVERSION (OTEC)

The ocean thermal energy conversion (OTEC) concept is an active and on-going area of renewable energy technology research and development. The OTEC power plant is an attractive method for producing energy that has the potential to provide clean, renewable energy without negatively impacting the environment. Based on the cycle type design utilized, an ancillary benefit of OTEC power plants is water condensate that may be used be utilized for multiple applications such as potable water, irrigation, and alternative applications [1]. Large OTEC systems are currently in developmental and planned phases around the world from applications ranging from the supply of electricity to providing water for island communities [2].

The OTEC system employs the temperature difference between cooler, deep and warmer, shallow surface seawaters to run a heat engine and produce useful work, usually in the form of electricity. A higher system efficiency is achieved when the temperature differential between the cooler, deep seawaters and the warmer, shallow surface seawaters is large. There are currently three types of power cycles utilized in OTEC: closed, open, and hybrid. They hybrid cycle utilizes principles of both closed and open cycles. A generalized illustration of the OTEC concept is found in **FIGURE 1**. The closed cycle, also Anderson cycle, concept is modeled herein as it is the most common type of cycle being developed and planned due to its inherent simplicity, ease of constructability, and required capital costs.

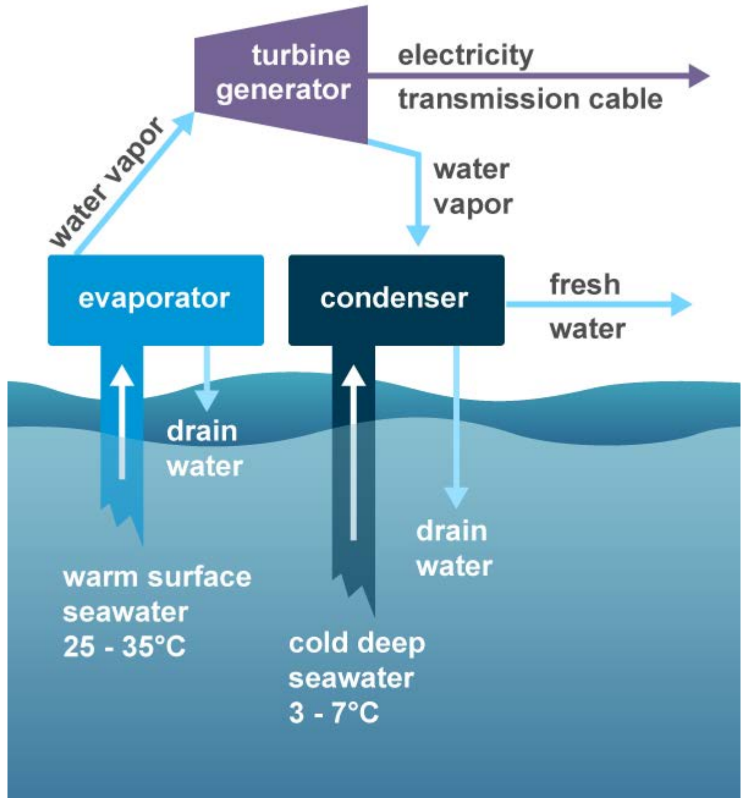


FIGURE 1: *OCEAN THERMAL CONVERSION SYSTEM [2]*

1.2 CLOSED CYCLE

Closed cycle OTEC systems is a Rankine-type cycle similar to a conventional power plant system. One difference is that the working fluid is never superheated more than a few degrees. Due to viscous effects, the working fluid pressure drops in both the evaporator and condenser [3]. An illustration of a closed cycle OTEC system can be found in **FIGURE 2.**

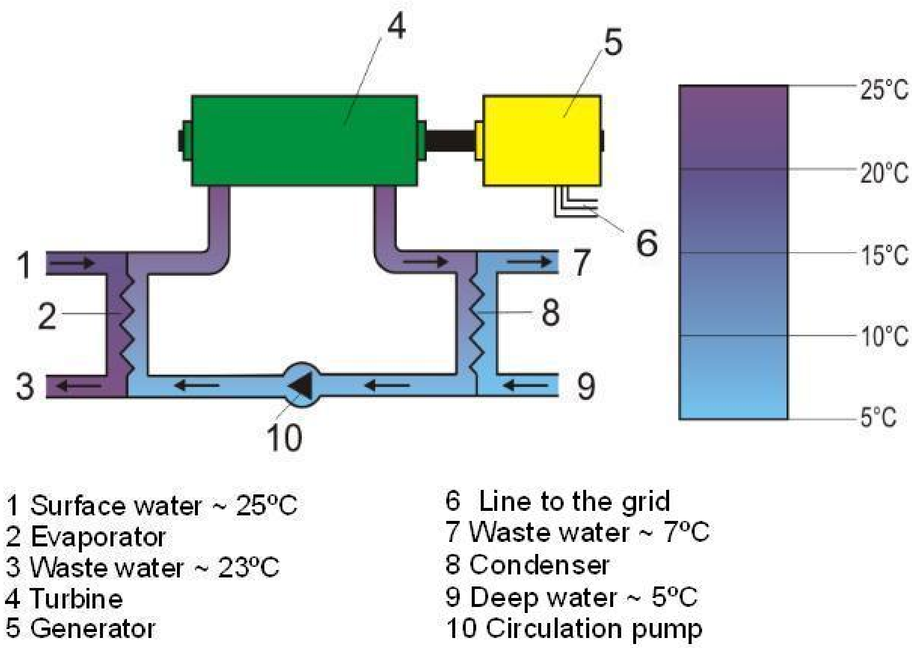


***FIGURE 2**: DIAGRAM OF A CLOSED CYCLE OTEC POWER PLANT [4]*

1.3 OPEN CYCLE

Open cycle OTEC systems, also known as Claude cycle systems, utilize warm surface water to produce electricity. When warm ocean water is placed in a low-pressure container, it boils. The expanding steam is then used to drive a low-pressure turbine attached to an electrical generator. The steam, which has left its salt and contaminants behind in the low-pressure container, is pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep, colder ocean water. Open cycle systems have the advantage of producing desalinized fresh water suitable for drinking or irrigation [5]. An illustration of an open cycle OTEC system can be found in **FIGURE 3.**

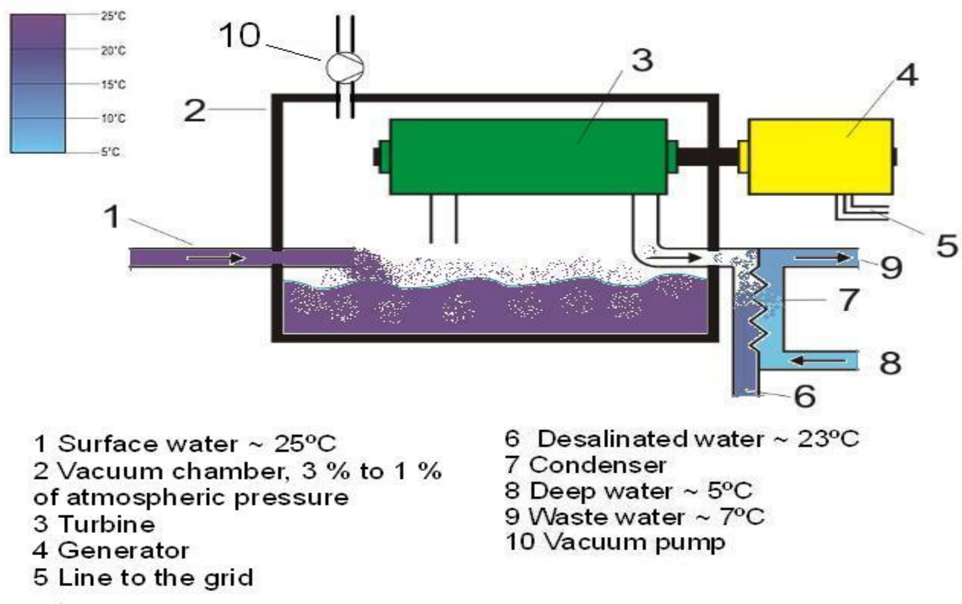


***FIGURE 3:** DIAGRAM OF AN OPEN CYCLE OTEC POWER PLANT [4]*

1.4 LITERATURE REVIEW

In the study by Wu, Zhixiang, et. al [6], it was concluded that R-717 (NH_3), R-507a, and R-1234yf used as working fluids appear to be the most suitable for OTEC applications. The study by Lee, C.J., et. al [7] examined refrigerants R-1234yf, R-410a, R-134a, R-290 and R-32. The work by Halimi, B., et. al [8] presented an analysis of an OTEC power plant using butane as the working fluid. In the work by Halimi, B., et. al, it is reported that a thermal efficiency of 6% can be obtained using butane as the OTEC working fluid.

Yoon, Jung-In, et. al [9] presents the performance characteristics for various wet refrigerants used in an OTEC power cycle. Performance characteristics show a direct correlation between system efficiency and evaporating temperature, and an inverse correlation between system efficiency and condensing temperature. Additionally, Yoon, Jung-In, et. al [9] presents the performance characteristics for various wet refrigerants used in an OTEC power cycle with varying turbine efficiencies. Varying turbine efficiency is shown to have a greater effect on system efficiency when compared to varying pump efficiency.

According to Masutani, S.M., et. al, Carnot efficiencies of OTEC systems range from 6% - 8%. This compares to the theoretical Carnot efficiencies of 60% or more for steam power cycles utilizing state-of-the-art combustion technology. In terms of thermodynamic efficiency, the best efficiency that can be achieved for OTEC systems lies in the range of 3 - 5%. Masutani, et. al also states that 90% of the energy extracted from warm surface seawaters is rejected back to the environment [10]. OTEC closed cycle analyzed herein follows the schematic of **FIGURE 4**.

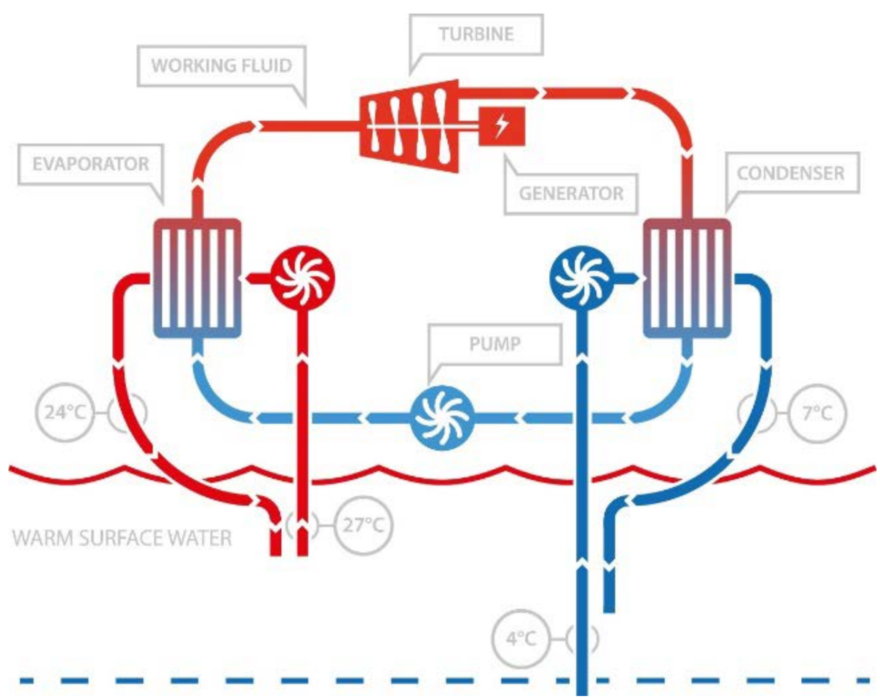
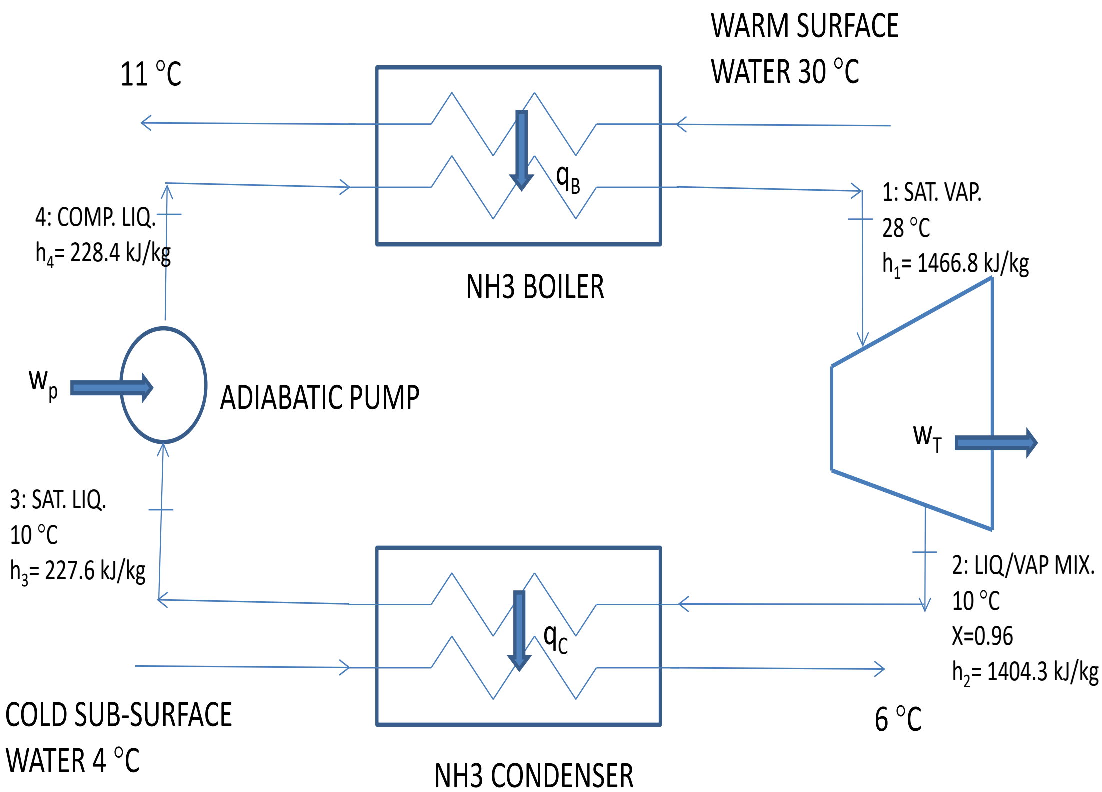


FIGURE 4: *WORKING PRINCIPLE OF CLOSED OTEC PLANT [11]*

Preliminary manual calculations in **FIGURE 5** shows an efficiency on the order of 5% for an OTEC NH_3 power plant due to the passive design and characteristics of the power plant relying solely on the geographical location and the temperature gradient form in the ocean.



$$\dot{W}_T - \dot{W}_P = 100kW \qquad \text{(EQ-1)}$$

$$\dot{W}_T = \dot{m}(h_1 - h_2) \qquad \text{(EQ-2)}$$

$$\dot{W}_P = \dot{m}(h_4 - h_3) \qquad \text{(EQ-3)}$$

$$\dot{m}[(h_1 - h_2) - (h_4 - h_3)] = 100\ kW \quad \text{(EQ-4)}$$

$$\dot{m} = \frac{100kW}{1466.8 - 1404.3 - 228.4 + 227.6} = 1.621\ kg/sec \quad \text{(EQ-5)}$$

$$\eta_{th} = \frac{\dot{W}_T - \dot{W}_P}{\dot{Q}_B} = \frac{\dot{m}[(h_1 - h_2) - (h_4 - h_3)]}{\dot{m}[(h_1 - h_4)]} = \frac{[(h_1 - h_2) - (h_4 - h_3)]}{[(h_1 - h_4)]} \text{ (EQ-6)}$$

$$\eta_{th} = \frac{(1466.8 - 1404.3 - 228.4 + 227.6)}{(1466.8 - 228.4)} = 5\% \text{ (EQ-7)}$$

FIGURE 5: *MANUAL CALCULATIONS OF THERMAL EFFICIENCY FOR NH_3 OTEC SYSTEM*

The system of **FIGURE 5** is shown on a temperature-volume (T-v) thermodynamic phase diagram in **FIGURE 6**.

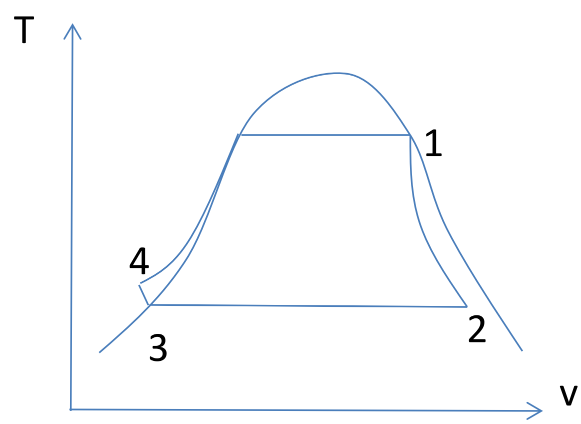


FIGURE 6: *NH_3 OTEC SYSTEM ON THERMODYNAMIC T-v PHASE DIAGRAM*

With a high side temperature of 38 °C, and a low side temperature of 10 °C, for an output of 100 kW, the flow rate of the working fluid is 1.62 kg/sec. Efficiency was determined to be 5%. The next section of the paper describes the MATLAB modeling of the NH_3 OTEC power plant.

2 CHAPTER: MATLAB ANALYSIS MODELING METHODOLOGY

2.1 DESIGN PARAMETERS AND ASSUMPTIONS

Design conditions and assumptions used in the thermodynamic analysis are shown in **TABLE 1**. The analysis herein is based on a steady-state, steady-flow of the OTEC power plant components. A gross power generation of 100 kW is desired. Seawater temperatures were assumed to be constant. Properties for refrigerants utilized in the analysis were obtained from the National Institute of Standards and Technology (NIST) Reference Fluid Thermodynamic and Transport Properties database and also data sheets readily available from TEGA [12]. The state points used for the OTEC analysis are shown in **FIGURE 7.**

TABLE 1: *EQUATION PARAMETERS FOR THERMODYNAMIC ANLAYSIS*

Property Description	**Symbol**	**Value**
Warm Seawater Temperature at Inlet (°C)	T_{wsi}	26
Cold Seawater at Inlet (°C)	T_{csi}	5
Pinch Point Temperature Difference (°C)		
At the Evaporator	ΔT_e	2
At the Condenser	ΔT_c	1.8
Efficiency of Components (%)		
Turbine	η_T	90
Generator	η_G	95
Pump Used for Working Fluid	$\eta_{P,wf}$	80
Pump Used for Seawater	$\eta_{P,sw}$	80
Specific Heat Capacity of Seawater (kJ/kg K)	c_p	4.025
Density of Seawater (kg/m³)	ρ	1025

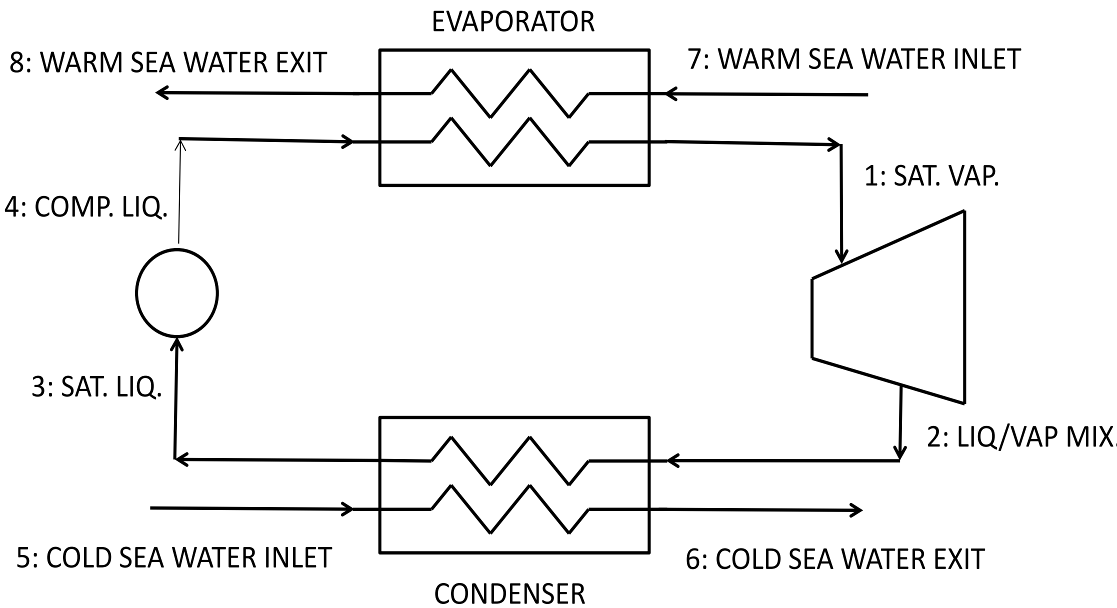


FIGURE 7: *OTEC CLOSED CYCLE STATEPOINTS*

2.2 GOVERNING PHYSICAL PHENOMENA

2.2.1 HEAT EXCHANGERS

The energy balance equations can be written as follows for the evaporator:

$$\dot{Q}_E = \dot{m}_{wf}(h_1 - h_4) = \dot{m}_{ws}c_p(T_{wsi} - T_{wso}) \qquad \text{(EQ-8)}$$

Similarly, the energy balance equation for condenser is the same as the evaporator, and can be written as follows:

$$\dot{Q}_C = \dot{m}_{wf}(h_2 - h_3) = \dot{m}_{Cs}c_p(T_{cso} - T_{csi}) \qquad \text{(EQ-9)}$$

2.2.2 PUMPS

The work required to run working fluid can be written as follows:

$$\dot{W}_{P,wf} = \frac{\dot{m}_{wf}v_4(P_4 - P_3)}{\eta_{P,wf}} \qquad \text{(EQ-10)}$$

The work required to run seawater can be written as follows:

$$\dot{W}_{P,ws(cs)} = \frac{\dot{m}_{ws(cs)} g \Delta H}{\eta_{P,sw}} \qquad \text{(EQ-11)}$$

2.2.3 TURBINE

The net power of the system can be written as follows:

$$\dot{W}_N = \dot{W}_{T-G} + \dot{W}_{P,wf} + \dot{W}_{P,ws} + \dot{W}_{P,cs} \qquad \text{(EQ-12)}$$

2.3 THERMAL EFFICIENCY

The system thermal efficiency can be written as follows:

$$\eta_{th} = \frac{\dot{W}_N}{\dot{Q}_E} \qquad \text{(EQ-13)}$$

2.4 EXERGY

An exergy analysis is also completed as part of the thermodynamic analysis. Exergy is the amount of work obtainable when matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible processes [13]. **FIGURE 8** shows that exergy is the maximum work obtainable between the system state and reference states. In other words, exergy is the maximum amount of work that can be obtained from a system in reference to the environment at standard conditions, T_0, P_0. The following standard reference values were used in the analysis: T_0 = 298.2 ^oK, P_0 = 101.3 kPa [14].

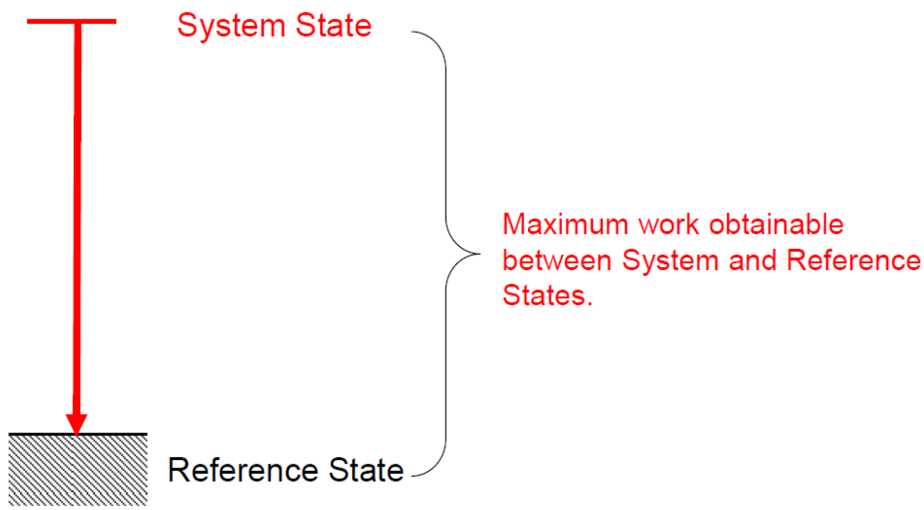


***FIGURE 8**: DEFINITION OF EXERGY [13]*

Traditionally, the availability (also exergy) is defined as:

$$a = (H - TS) \qquad \text{(EQ-14)}$$

The MATLAB program designed and developed utilizes the governing equations previously described to complete the analysis of the working fluid used for a closed cycle OTEC system. The program consists of two main files. The MATLAB file “Main.m” contains input parameters while “OTEC.m” contains the governing equations used in the analysis. Executing the program “Main.m” will provide the user output parameters and results. In order to execute “Main.m,” thermodynamic and physical properties of the working fluid are be entered to the program. **APPENDIX A** provides both set of codes and contains the input parameters for NH_3 (ammonia). A flowchart illustrating the computational process is illustrated in **FIGURE 9**. A list of descriptions for the nomenclature used in this flow chart can be found in the beginning of this report on **pages *ix-x***.

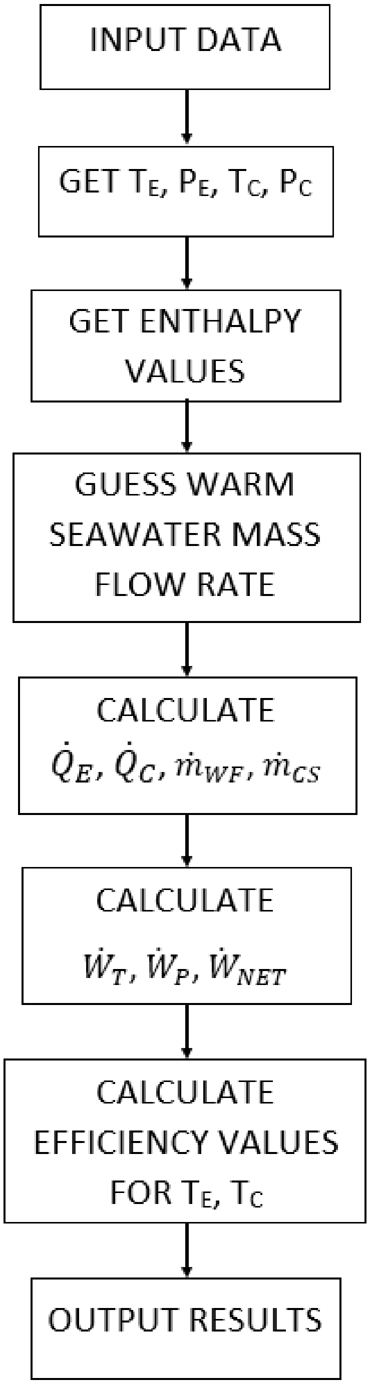


FIGURE 9: *MATLAB CODE FLOW CHART*

3 CHAPTER: RESULTS AND DISCUSSION

FIGURE 10 through **FIGURE 13** are plots of system efficiency versus evaporating temperatures and condensing temperatures for the refrigerant NH_3. The turbine efficiency were varied from 80% and 60%, with a constant pump efficiency of 80%.

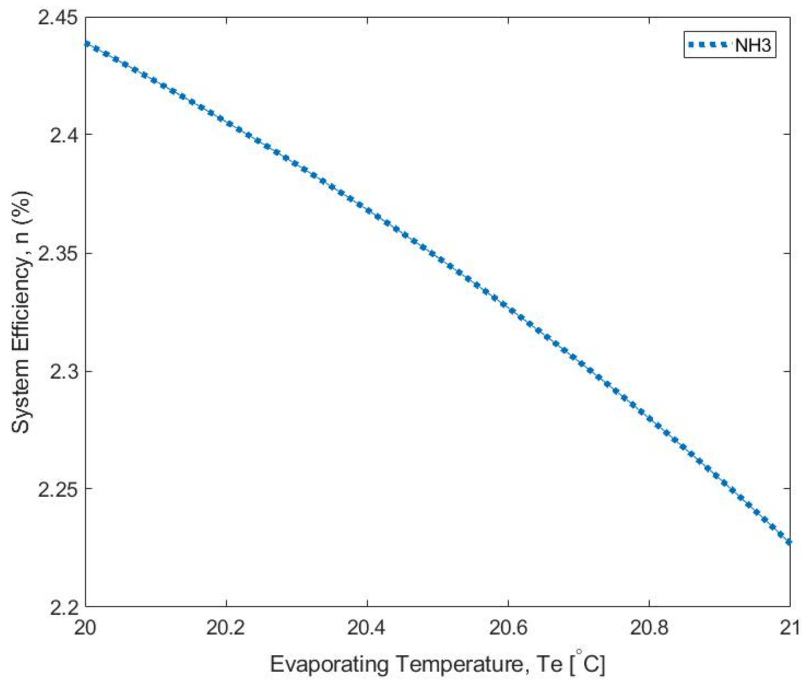


***FIGURE 10**: SYSTEM EFFICIENCY VS. EVAPORATING TEMPERATURE AT 80% TURBINE EFFICIENCY*

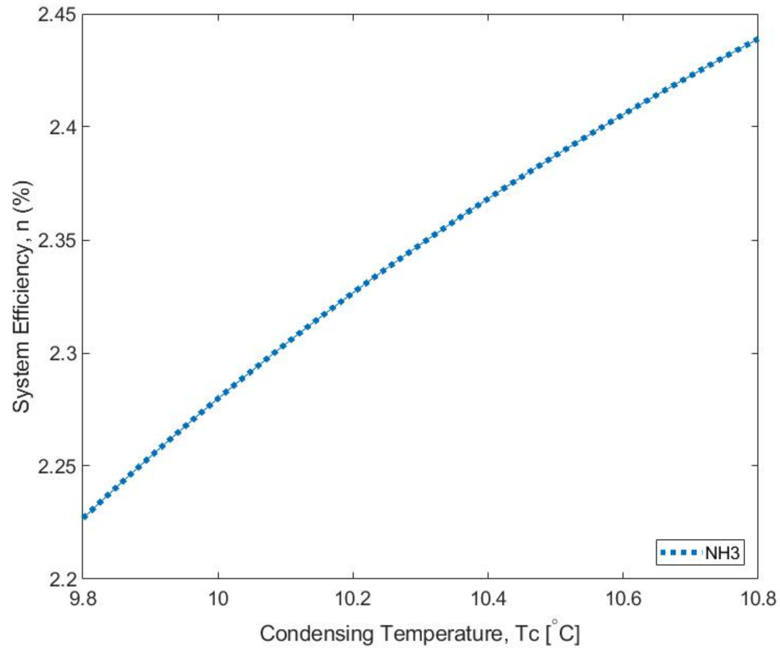


FIGURE 11: *SYSTEM EFFICIENCY VS. CONDENSING TEMPERATURE AT 80% TURBINE EFFICIENCY*

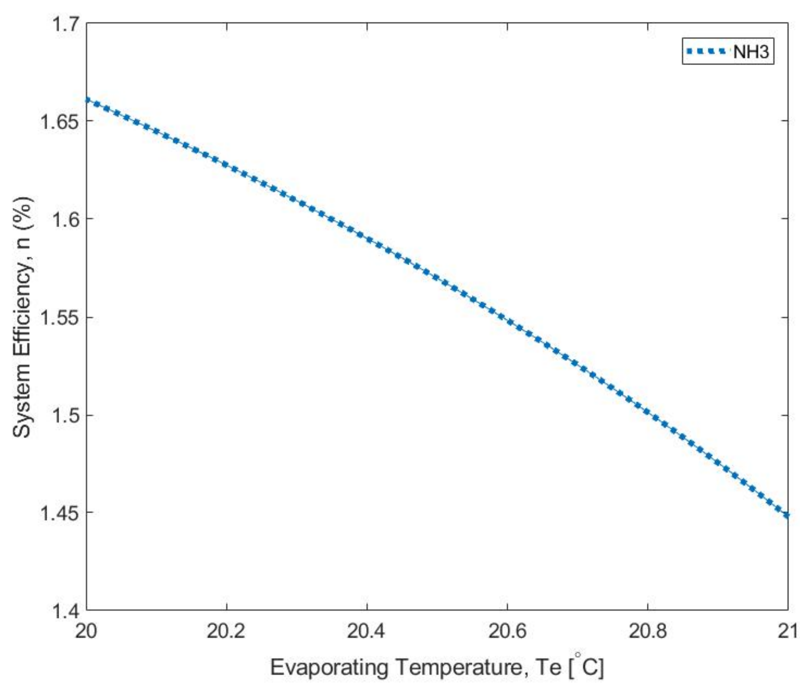


FIGURE 12: *SYSTEM EFFICIENCY VS. EVAPORATING TEMPERATURE AT 60% TURBINE EFFICIENCY*

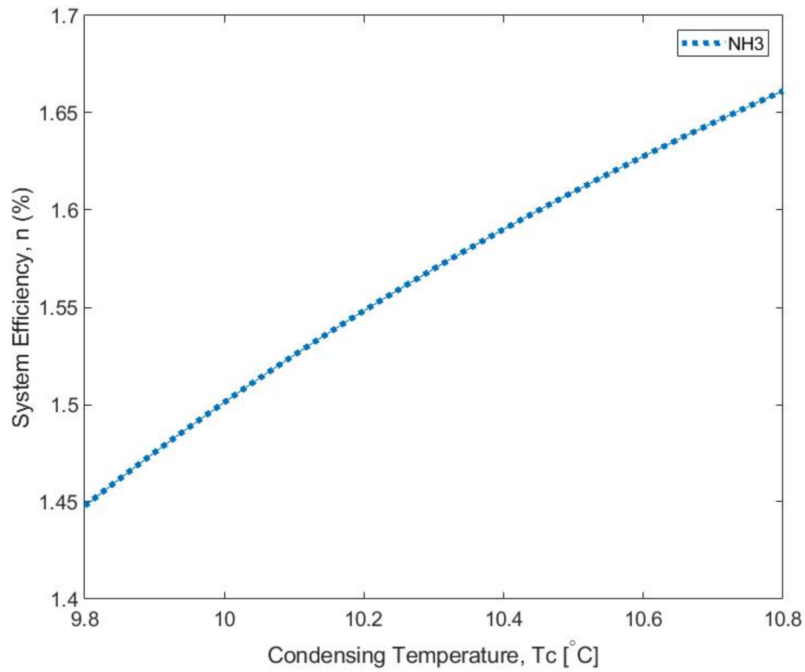


***FIGURE 13:** SYSTEM EFFICIENCY VS. CONDENSING TEMPERATURE AT 60% TURBINE EFFICIENCY*

FIGURE 10 and **FIGURE 12** indicates an inverse correlation between system efficiency and evaporating temperature. However, a direct correlation is indicated between system efficiency and condensing temperature as shown in **FIGURE 11** and **FIGURE 13**. These correlations are consistent with similar data gathered from Yoon, Jung-In, et. al [6]. Additionally, it can be seen from **FIGURE 10** and **FIGURE 12** that system efficiencies are also consistent with the MATLAB model for that of the heritage working fluid R-717 (NH_3). As previously noted, Masutani, S.M., et. al, stated Carnot the best efficiency that can be achieved for OTEC systems lies in the range of 3 - 5%.

The results of the availability analysis carried out for the OTEC cycle will now be presented. **TABLE 2** shows the exergy values for the NH_3 working fluid at each of the state points of the OTEC cycle. As previously noted, the dead state for the availability analysis taken was as $T_o = 298.15$ K, $P_o = 101.325$ kPa. The exergy values listed in table shows the work potential for the NH_3 working fluid. The state-points listed corresponds to those of **FIGURE 7**. Analysis and results in **TABLE 2** assumes pump and turbine efficiencies of 80% and 90%, respectively.

TABLE 2: *EXERGY ANALYSIS OF OTEC CYCLE*

Statepoint	**1** **Turbine Inlet**	**2** **Turbine Exit**	**3** **NH_3 Pump Inlet**	**4** **NH_3 Pump Exit**
Availability (kJ/kg)	116.27	633.28	98.93	99.92

From **TABLE 2**, the change in availability across the turbine is 517 kJ/kg, for R-717 (NH_3). Hence the heritage NH_3 working fluid has the potential of supplying 517 kJ per kilogram of NH_3 flowing in the system.

4 CHAPTER: CONCLUSION

This study has presented the development of a MATLAB based code for analysis of an ammonia based OTEC power plant. Trendlines showing the impact to turbine and pump efficiencies on system level thermodynamic efficiency have been presented as well as an availability study for the power plant.

Based on the modeling analysis, evaporating and condensing temperatures, seawater temperature variances, and component efficiencies all effect the overall performance of an OTEC plant. There is a direct relationship between evaporating and condensing temperatures to system efficiency. The system efficiency is found to be directly proportional to the turbine's efficiency and inversely proportional to the amount of heat the evaporator needed to supply to the refrigerant. The findings are consistent with previous literature and this MATLAB program can now be used to study other candidate working fluids.

Even though at present a large amount of capital and incentives are required to make OTEC energy economically viable, the future of OTEC remains promising as the technology improves and costs continue to decrease as experience in the industry matures. OTEC power plants can serve as an attractive form of carbon-neutral form of energy much like wind, solar, and hydropower.

5 REFERENCES

1. OTEC. (n.d.). Retrieved February 05, 2021, from https://tethys-engineering.pnnl.gov/technology/otec#:~:text=Capturing%20energy%20using%20temperature%20gradients%20across%20water%20depths.&text=Both%20the%20open%2Dcycle%20and,agriculture%20and%20potable%20drinking%20water

2. U.S. energy Information administration - eia - independent statistics and analysis. (n.d.). Retrieved February 01, 2021, from https://www.eia.gov/energyexplained/hydropower/ocean-thermal-energy-conversion.php

3. Iqbal, K. Z., & Starling, K. E. (n.d.). *Use of Mixtures As Working Fluids in Ocean Thermal Energy Conversion Cycles* (Tech.).

4. Wikipedia contributors. (2020, November 29). Ocean thermal energy conversion. In *Wikipedia, The Free Encyclopedia*. Retrieved 16:05, December 13, 2020, from https://en.wikipedia.org/w/index.php?title=Ocean_thermal_energy_conversion&oldid=991348910

5. M., T. S., Harikrishnan, T., & Aswathanarayana, U. (2010). *Green Energy: Technology, Economics and Policy*. Boca Raton, FL: CRC Press.

6. Wu, Zhixiang, Huijun Feng, Lingen Chen, and Yanlin Ge. "Performance Optimization of a Condenser in Ocean Thermal Energy Conversion (OTEC) System Based on Constructal Theory and a Multi-Objective Genetic Algorithm." Entropy 22, no. 6 (2020): 641.

7. Lee, C. J., F. H. Lim, J. A. Lim, Shariffah Mastura Noor Osman, Nurul Shakira Hamid, and MohdAdzwan MdNor. "Investigation into the Performance and Safety of Alternative Refrigerants to Ammonia for Integrated OTEC Application." In Offshore Technology Conference Asia. Offshore Technology Conference, 2018.

8. Halimi, B., and R. Y. Atolah. "Analysis of 100 kW ocean thermal power plant with butene as working fluid." In IOP Conference Series: Earth and Environmental Science, vol. 339, no. 1, p. 012039. IOP Publishing, 2019.

9. Yoon, J., Son, C., Baek, S., Kim, H., & Lee, H. (2014). *Efficiency comparison of subcritical OTEC power cycle using various working fluids* (Tech.). Springer-Verlag. doi:10.1007/s00231-014-1310-8

10. Masutani, S., & Takahashi, P. (n.d.). Technology, Instrumentation. In *Ocean Thermal Energy Conversion (OTEC)* (3rd ed., Vol. 5, pp. 641-647). Elsevier.

11. Ferreira, D. (n.d.). Thermal Gradient (OTEC). Retrieved December 5, 2020, from https://www.tudelft.nl/en/ocean-energy/research/thermal-gradient-otec/

12. T. (n.d.). Downloads. Retrieved November 1, 2020, from https://www.tega.de/en/service/downloads?categoryfilter%5B%5D=4#c148

13. Szargut, J. (1988). Energy and exergy analysis of the preheating of combustion reactants.

14. Gutowski, T. G. (2014). Introduction to the exergy concept.

6 APPENDICES

6.1 APPENDIX A: MATLAB CODE FOR THERMODYNAMIC MODELING

In order to run the program follow the steps below:

(1) Put Main.m and OTEC.m docs in same folder. Run both of them.

(2) Main.m is our main program, Click run on MATLAB for the results.

The following code provided can be found in the MATLAB file "OTEC.m."

```
% This function defines the equations are used to calculate Closed Cycle
% Ocean Thermal Energy Conversions system. Run main1.m program to see the results.

function [n,N,T2,T1]= OTEC(Twsi,Tcsi,P1,h1,s1,P2,h3,s2f,s2g,hf,hg,rho)

Tcso = Tcsi + (3:0.01:4);
Twso = Twsi - (3:0.01:4);

%Pinch point temperature difference taken 2(C) for Evaporator and 1.8(C)
%for condenser
T1 = Twso - 2; %Evaporation Temperature
T2 = Tcso + 1.8; %Condensation Temperature



%Evaporator

P4 = P1; %constant pressure

%Condenser
```

```
T3 = T2; %constant temperature
P3 = P2; %constant pressure

%Turbine

hfg = hg-hf;
x2s = (s1 - s2f)./(s2g - s2f); %entropy @2 is same as @1
h2s = hf + (x2s .* hfg); %ideal enthalpy at turbine exit
h2 = h1 - .90 * (h1 - h2s); %actual enthalpy
T4=25; %Temperature at pump exit
Cp=4; %(kJ/kg)

%Pump
v = 1/rho; %Specific Volume of the liquid
wp = v * (P4 - P3)/.8; %Pump work (pump efficiency is 80%)
h4 = h3 + wp; %enthalpy at pump exit
mdot = 150 : 0.1 :500; %mass flow rate of warm sea water. Mass flow rate of the sea water
% was taken from 'SEAWATER FLOW RATE REGULATION OF OTEC PLANT USING
%UEHARA CYCLE BY CONSIDERING WARM SEAWATER TEMPERATURE VARIATION (ICIC International
%c 2017 ISSN 1349-4198)'


%Evaporator
N = length(mdot);
for i = 1:N
Qedot(i,:) = mdot(i).*Cp.*(Twsi - Twso); %Heat transfer from sea water to working fluid
end
```

```
mdotwf = Qedot./(h1-h4); %mass flow rate of the working fluid

%Power

Wt = mdotwf.*(h1-h2).*(.95); %Turbine work rate (95% generator efficiency)
Qcdot = mdotwf.*(h2-h3); %Heat transfer rate from the working fluid to cold seawater
Wp = mdotwf.*wp; %Pump work rate
for i = 1:N
mdotcs(i,:) = Qcdot(i,:)./(Cp*(Tcso-Tcsi)); %Cold seawater mass flow rate
end

%Seawater Pumps

rhowater = 1025;
Dhws = 2.5; %differential head for warm sea water pump, constant
Dhcs = 6; %differential head for cold sea water pump, constant
g = 9.81;
Wdotpump1 = mdot.*g.*Dhws/0.8/1000; %warm seawater pump work
Wdotpump2 = mdotcs.*g.*Dhcs/0.8/1000; %cold seawater pump work
NN = length(T1);
for j = 1:NN
Wnet(:,j) = Wt(:,j) - Wp(:,j) - Wdotpump1' - Wdotpump2(:,j); %Net power of the system
end

%Calculating efficiency of the system

n =abs( Wnet./Qedot)*100;

end
```

The following code provided can be found in the MATLAB file “Main.m.”

```
%% SI UNITS
clc; clear all;
Twsi = 26; %(C) Warm Sea Water Temperature
Tcsi = 5;  %(C) Cold Sea Water Temperature
%%
%%   NH3(R717) Values
P1=[ 885.24]; % Saturation pressure(kPA) @Evaporator Temperature (T1)
h1 = [1624];% Enthalpy(kJ/kg)  @Evaporator Temperature (T1)
s1 = [5.8359];% Entropy(kJ/kg.K) @Evaporator Temperature (T1)

P2 = [636.57]; %Pressure (kPa) @Condensation Temperature (T2)
h3 = [394.41];% Enthalpy(kJ/kg) @Condensation Temperature (T2)

%Values @Turbine

s2f = [ 1.6544];% Liquid Entropy @ T2, P2
s2g = [5.954];% Vapor Entropy @ T2, P2
hf = [394.41];% Liquid Enthalpy @ T2, P2
hg = [1616.2];% Vapor Entalpy @T2, P2
x2s = (s1 - s2f)./(s2g - s2f);
s2= s2f+(s2g.*x2s);
s3= [1.6544];
s4 = [1.8804];
h4 = [460.82];
%Density Values for the working fluids @Pump
hfg = hg-hf;
x2s = (s1 - s2f)./(s2g - s2f); %entropy @2 is same as @1
```

```
h2s = hf + (x2s .* hfg); %ideal enthalpy at turbine exit
h2 = h1 - .80 * (h1 - h2s); %actual entalpy
rho = [1138];%Working Fluid Density (kg/m^3) @ P3

T0=298.2;
B=abs(h2-T0.*s2);

% OTEC(Twsi,Tcsi,P1,h1,s1,P2,h3,s2f,s2g,hf,hg,rho,T4)
figure(2)
hold on
for i=1:length(P1)
[n,N,T2,T1]=OTEC(Twsi,Tcsi,P1(i),h1(i),s1(i),P2(i),h3(i),s2f(i),s2g(i),hf(i),hg(i),rho(i));
for i = 1:N %Plotting vectors corresponding to each mass flow rate
plot(T2,n(i,:));
%  set(gca,'ylim',[0 0.2],'XLimMode','Manual');

grid on
end
end
%Plotting System Efficiency/Condensing Temp (Tc)
xlabel('Condensing Temperature, Tc [^\circC]');ylabel('System Efficiency, n (%)')
legend ('NH3')
hold off
figure(3)
hold on
for i=1:length(P1)
[n,N,T2]=OTEC(Twsi,Tcsi,P1(i),h1(i),s1(i),P2(i),h3(i),s2f(i),s2g(i),hf(i),hg(i),rho(i));
for i = 1:N %Plotting vectors corresponding to each mass flow rate
plot(T1,n(i,:));
```

```
grid on
end
end
%Plotting System Efficiency(n)/Evaporating Temp (Te)
xlabel('Evaporating Temperature, Te [^\circC]');ylabel('System Efficiency, n (%)')

legend ('NH3')
hold off
```