OCEAN THERMAL ENERGY CONVERSION(OTEC) OPTIMIZATION

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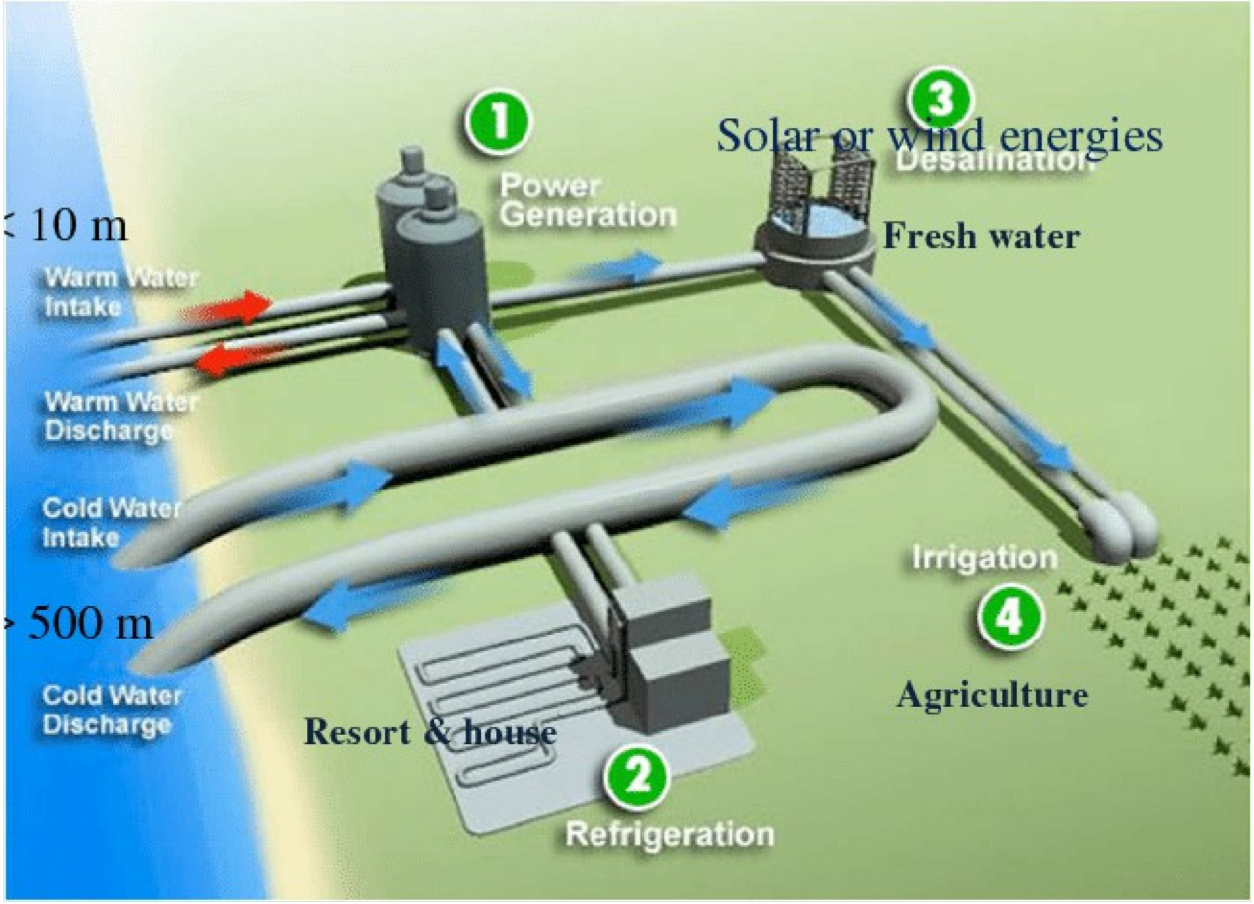
Subject: MAE-3524 Thermal Fluids Design
Due Date: December 8th,2023



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ABSTRACT:

In this report, the design of the Ocean Thermal Energy Conversion (OTEC) will be conveyed, in conjunction to furthering the exploration of computations pertaining to MATLAB modeling. The contents within the MATLAB modeling will include the accumulation of fundamental concepts that were learned in MAE-3524 Thermal Fluids Design course such as Thermodynamic cycles, Laws, Heat Transfer of certain components, Piping systems, and Refrigeration cycles. The application of engineering principles will be retrieved in this project. The contents of this report will aim towards the optimization of the OTEC power cycle design to produce a net power output of 20MW. The OTEC open cycle will take into account a dual-purpose of converting the temperature gradient of the seawater and transmute it into electricity and desalinated water(freshwater) to island in the Pacific Ocean.The usage of deep cold water to augment the refrigeration cycle will provide desalinated water for consumption. In turn, the economic feasibility will be unearthed in this report based upon the evaluation of the results provided from the simulation and modeling in this report. Also, the inclusion of the three configurations will be proposed and evaluated in the Mechanical Vapor Compression(MVC) cycles. The objective is to design an OTEC plant that can maximize its profit in the least amount of years that includes the different configurations of the Vapor Compressions cycles being implemented. The parameters of the project include:

1. The economic impact is calculated based on an electricity price of $0.47 per kWh and a desalinated water price of $2.00 per cubic meter.
2. The warm surface water temperature is assumed to be 27 degrees Celsius.
3. The cold deep-ocean water temperature is assumed to be 4 degrees Celsius.
4. The pipe length is 600 meters, the pipe diameter is to be met with the most economical price.
5. No heat losses in all pipes.
6. The terminal temperature difference in the condenser can be assumed to be 3 degrees Celsius
7. The industrial cooling load required temperature is 0 degrees Celsius.
8. The annual base cooling electrical loading is 25kWh of energy per square foot and total area is 500,000 square feet.
9. Assume the compressor to be isentropic efficiency to be 85%.
10. The ambient temperature is 30 degrees Celsius.
11. The powerplant’s initial cost could be assumed to be $10,000/kWnet.
12. Adding the stainless-steel pipe cost showing your calculation for choosing the most economical pipe diameter.

BACKGROUND:

INTRODUCTION:

With certain speculations and conjectures pertaining to the macro-change in the climate across the globe, there has been an outburst of innovative notions and developments over the past years coming into fruition such as the highly debatable topic of renewable energy sources. Renewable energy sources can be problematic for certain civilizations around the globe due to a myriad of factors or impedances constituting to why it would not be optimal. Ultimately, it could be difficult for residents to attain a sustainable energy source especially for island residents. The introduction of Ocean Thermal Energy Conversion(OTEC) could be an optimal solution for the civilizations near bodies of water to harness electricity, and purified drinkable water. The premise is to design an OTEC plant that can be a financially and multi-faceted self-sustainable power plant.

The fundamental conceptualization of the OTEC plan is to generate electricity while subsequently providing desalinated water and providing cooling to a warehouse approximately 500,000 ft^2. The transmutation of energy will derive from steam in the turbine. The desalinated water will be condensed from the steam exiting the turbine, and the cold-deep ocean water will go into the warehouse to provide annual cooling. The implementation of this power plant will lead to the procurement of a continual source of the electricity and desalinated water which will negate other costly expenditures such as other alternative energy sources.

In this report, the analysis of the OTEC power plant will be assessed by the fundamental conceptualizations from thermodynamics, heat transfer, and fluid mechanics. The use of the idealistic ranking cycle, refrigeration cycles, and piping systems will be taken into account when making calculations to ensure the plant is economically viable for its lifespan.

OBJECTIVES:

1. The ability to formulate and solve engineering problems pertaining to the OTEC experimentation by the application of fundamental engineering principles.
2. Designing and conducting computations of the performance of an OTEC system.
3. To formulate conclusions and avenues to optimize the design of the OTEC system.
4. Calculate the net work of the power plant and prove the design(operating pressures and mass flow rates can deliver 20MW.
5. Calculate the pumping power for the condenser cold water pump and the surface warm water pump. Show the most economical cold water pipe diameter.
6. For the three different MVC configurations, calculate the COP for each configuration.
7. Calculation of the reduction in annual operating cost of the two new designs comprated to the base load($/year).

ENGINEERING PROBLEM STATEMENT:

Within the given parameters and assumptions will provide the efficient amount of information to optimize an OTEC open cycle. An island in the Pacific Ocean is scouring to acquire and develop a sustainable and efficient energy system. The ability to harness the ocean's thermal gradient will provide power generation, drinkable water, and refrigeration in a single system with the constraint of it being economically viable and environmentally conducive. The design of an Ocean Thermal Energy Conversion open cycle system will be utilized with the net power output to be 20MW. The design will take into account a dual application of the system's freshwater supply and the use of the cold deep water to augmentation of the refrigeration cycle of an industrial cooling load.

Under the given parametrics of this outline, the computations of the economic feasibility will be taken under scrutiny in conjunction with the performance of the entire open cycle OTEC system. Monetarily, it will determine the overall impact of the implementation of the OTEC power plant. The goal of designing a OTEC power plant is to provide an adequate amount of desalination water and electricity so it may be transmuted into income and eventually have the investment pay for itself in a minimal amount of years and begin an epoch of bringing profit to the island.

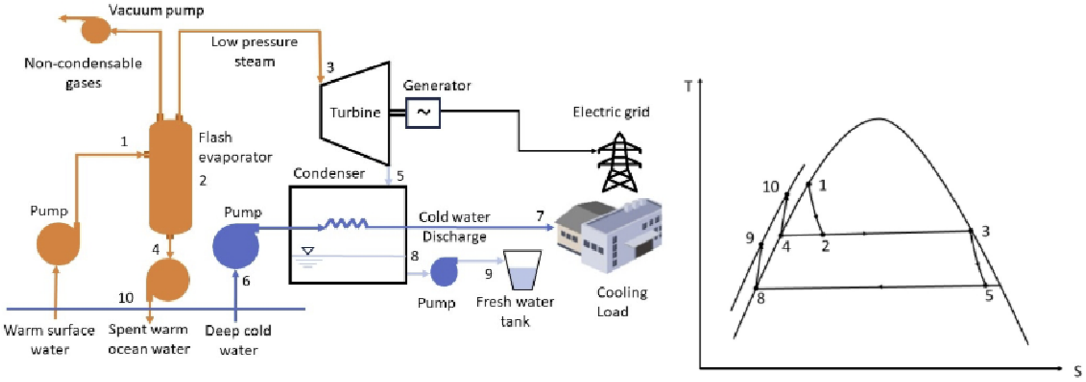


Figure 1: Schematic of OTEC Power Plant and the T-S Diagram

OPEN CYCLE OTEC:

There are few different variations of an OTEC power plant such as the open-cycle, closed cycle and hybrid. In this report, the analysis of the open cycle OTEC will be under scrutiny because of certain economic advantages it has such as the production of electricity and desalinated water. The open cycle is composed of four main components which are a pump(s), Heat exchanger(s) specifically a flash evaporator and a condenser and finally the turbine. The open cycle alludes to the notion of the system being open where it pumps water in and pumps water out. The warm surface water going through the power plant will constitute its physical properties to be changed at various points. Fundamentally, the warm surface water will flashed to steam then will produce electricity. Finally, the steam will go through the condenser to condense back into a fluid which is drinkable, and it will be sold for a profit. The cold-deep ocean water after it is utilized to cool the steam will be directed to the warehouse to serve as coolant for the HVAC system to cool the warehouse. Figure 1 above depicts a visual presentation of the process water will be used.

GIVENS:

T_SW =27; % Celsius (Temperature of the warm surface water)
P_SW = 1; % atm (Pressure of warm surface water)
T6 = 4; % Celsius (Temperature of the cold deep water)
x1 = 0; % dimensionless (quality)
TTD = 3; % Celsius (Terminal Temperature Difference)
P_net = 20; % MW (total net power output of the OTEC power cycle system)
C_p = 4.18; % (kJ/kg*K)
zeta = 0.9; % Dimensionless (Efficiency of the work generator)

```
rho3 = 1000; % kg/m^3 (Density of Water)
T1 = 28; % Celsius
T2 = 20; % Celsius (Temperature of the Flash Evaporator)
T3 = T2;
T4 = T2;
T_CW = 2; % Celsius
T7 = T6 + TTD; % Celsius
p_eff = 0.64; % Dimensionless unit (Assuming the pump efficiency of all pumps to be equivalent)
T_load = 0; % Celsius (Required Cooling Load Temperature)
L_annual = 25; % (kWh/ft^2) (Annual Base Cooling Electric Load)
A_tot = 500000; % ft^2 (Total Area of the cooling load)
zeta_c = 0.85; % dimensionless (Compressor Isentropic Efficiency)
T_ambient = 30; % Celsius (Ambient Temperature)
hrs = 24 * 365; % hrs/year
pi = 3.141592653589793238462643; % pi constant
rho6 = 999.97; % (kg/m^3) (Density of Water at 4 C from engineeringtoolbox.com)
rho1 = 996.53; % (kg/m^3) (Density of Water at 27 C from engineeringtoolbox.com)
g = 9.81; %  (Gravitational Constant in meters per seconds squared)
D_p1 = 12; % inches (Diameter of  cold deep ocean water pipe)(Assumed value from engineering toolbox.com)
D_p2 = 8; % inches (Diameter of pipe warm surface water pipe)(Assumed value from engineering toolbox.com)
D_p3 = 6; % inches (Diameter of the fresh water pipe)(Assumed value from engineering toolbox.com)
z2 = 600;% Meters (Pipe Length of the cold water deep ocean)
Z2 = 5; % Meters (Pipe Length of the warm surface water)
Mu= 1.5705*(10^-3); % (Pa*s) (Dynamic Viscosity of Seawater at 4 degrees Celsius from engineeringtoolbox.com)
R_p = 0.002; % (mm) (Relative Roughness Factor from
Vi = 0; % m/s
z1 = 0; % m
Price_electricity = 0.47; % $/kWh (Price of electricity)
Price_desalinated = 2.00; % $/m^3 (Price of desalinated water)
Cost_initial = 10000; % $/kWnet (Powerplant's initial costs)
M_pipe = 49.55; % lbf/ft (T4-12 ratio of weight per foot of Schedule 40 Stainless Steel Pipe from metalsdepot.com)
Cost_steel = 36.86; % $/m (Cost of steel pipe depending on pipe diameter)
```

ASSUMPTIONS:

1. Isentropic Process
2. The efficiency all of the pumps is equivalent to one another
3. The Mechanical Vapor Compression configurations will be Air, Water, and Ammonia
4. The Net Power Output is equivalent to 20 MW or in range from 19.5MW to 21.0MW
5. No Heat Losses in all pipes
6. The initial cost for all equipment is $10,000

THERMODYNAMIC/ FLUID ANALYSIS:

The major tool for the application of this experiment and simulation was from utilization of MATLAB coding. Within the contents of the code describes all of the given that are categorical to the applicable calculations. Also, modules such as XSteam and CoolProp were used to ascertain certain values such as enthalpy and entropy to verify that the OTEC power plant can produce 20 MW in conjunction with proving the Mechanical Vapor Compression cycles will impact the OTEC plant. Also, the H-Q curves and P-H Diagrams were plotted using Matlab. The code below will ascertain the results.

MATLAB CODE:

```
%givens
T_SW =27; % Celsius (Temperature of the warm surface water)
P_SW = 1; % atm (Pressure of warm surface water)
T6 = 4; % Celsius (Temperature of the cold deep water)
x1 = 0; % dimensionless (quality)
TTD = 3; % Celsius (Terminal Temperature Difference)
P_net = 20; % MW (total net power output of the OTEC power cycle system)
C_p = 4.18; % (kJ/kg*K)
zeta = 0.9; % Dimensionless (Efficiency of the work generator)
rho3 = 1000; % kg/m^3 (Density of Water)

% Asssumed Givens:
T1 = 28; % Celsius
T2 = 20; % Celsius (Temperature of the Flash Evaporator)
T3 = T2;
```

```
T4 = T2;
T_CW = 2; % Celsius
T7 = T6 + TTD; % Celsius
p_eff = 0.64; % Dimensionless unit (Assuming the pump efficiency of all pumps to be
equivalent)

%givens for piping system
pi = 3.14159265358979323846264 3; % pi constant
rho6 = 999.97; % (kg/m^3) (Density of Water at 4 C from engineeringtoolbox.com)
rho1 = 996.53; % (kg/m^3) (Density of Water at 27 C from engineeringtoolbox.com)
g = 9.81; %  (Gravitational Constant in meters per seconds squared)
D_p1 = 12; % inches (Diameter of  cold deep ocean water pipe)(Assumed value from
engineering toolbox.com)
D_p2 = 8; % inches (Diameter of pipe warm surface water pipe)(Assumed value from
engineering toolbox.com)
D_p3 = 6; % inches (Diameter of the fresh water pipe)(Assumed value from engineering
toolbox.com)
z2 = 600;% Meters (Pipe Length of the cold water deep ocean)
Z2 = 5; % Meters (Pipe Length of the warm surface water)
Mu= 1.5705*(10^-3); % (Pa*s) (Dynamic Viscosity of Seawater at 4 degrees Celsius from
engineeringtoolbox.com)
R_p = 0.002; % (mm) (Relative Roughness Factor from
Vi = 0; % m/s
z1 = 0; % m
L_pipes1 = Z2;
L_pipes2 = z2;
K_l = 0;

% Givens for the Industrial Cooling load:
T_load = 0; % Celsius (Required Cooling Load Temperature)
L_annual = 25; % (kWh/ft^2) (Annual Base Cooling Electric Load)
A_tot = 500000; % ft^2 (Total Area of the cooling load)
zeta_c = 0.85; % dimensionless (Compressor Isentropic Efficiency)
T_ambient = 30; % Celsius (Ambient Temperature)
hrs = 24 * 365; % hrs/year
% Financial Givens:
Price_electricity = 0.47; % $/kWh (Price of electricity)
Price_desalinated = 2.00; % $/m^3 (Price of desalinated water)
Cost_initial = 10000; % $/kWnet (Powerplant's initial costs)
M_pipe = 49.55; % lbf/ft (T4-12 ratio of weight per foot of Schedule 40 Stainless
Steel Pipe from metalsdepot.com)
Cost_steel = 36.86; % $/m (Cost of steel pipe depending on pipe diameter)

%Solution:
%Conversions:
W_net = P_net * 1000; % kW -MW to kW (Total Work of the OTEC Plant)
D_pipes1 = D_p1 / 39.3700787; % m -inches to meters (Diameter of the pipe for Cold
water pump)
```

```
D_pipes2 = D_p2 / 39.3700787; % m -inches to meters (Diameter of the pipes for Warm surface water pump)
D_pipes3 = D_p3 / 39.3700787; % m -inches to meters (Diameter of the pipe for the freshwater)
R_pipes = R_p / 1000; % m - millimeters to meters (Relative Roughness of stainless steel pipe)
Mp = (M_pipe * 2.2) / (3.2808399); % kg/m -pounds to kilograms, -feet to meters (Weight of the T4-12 per foot)

% Solution to find all of the OTEC's Enthalpy:
hSW = XSteam('hL_T', T_SW);
h1 = XSteam('hL_T', T1);
h2 = h1;
h2f = XSteam('hL_T', T2);
P2= XSteam('psat_T',T2);
P3 = P2;
h4 = h2f;
h2g = XSteam('hV_T', T2);
h3 = h2g;
x2= (h2-h2f)/(h2g-h2f);
T5 = T7 + TTD; % Celsius
T8 = T5;
h5f = XSteam('hL_T', T5);
h5g = XSteam('hV_T', T5);
s3 = XSteam('sV_T', T3);
s5s = s3;
P5 = XSteam('psat_T',T5);
s5f = XSteam('sL_T', T5);
s5g = XSteam('sV_T', T5);
x5 = (s5s-s5f)/(s5g-s5f);
h5s = h5f + x5*(h5g-h5f);
h5 = zeta * h5g;
h8 = h5f;
hCW = XSteam('hL_T', T_CW);
h6 = XSteam('hL_T', T6);
s8 = XSteam('sL_T', T8);
s9 = s8;
h9 = XSteam('h_ps',P5, s9);
h4 = XSteam('hL_p', P5);
s2f = XSteam('sL_T', T4);
s4 = s2f;
h10 = XSteam('h_ps',P5, s4);
h7 = XSteam('hL_T', T7);

% Solving for Turbine efficiency:
zeta_t = (h3 - h5s) / (h3 - h5); % dimensionless

% Solving for m_dot_3:
```

```
m_dot_3 = ((W_net) / (zeta*zeta_t*(h3 - h5s)));

% Solving for the remaining m_dots except m_dot_6:
m_dot_SW = m_dot_3 / x2; % (kg/s)
m_dot_4 = m_dot_SW - m_dot_3; % (kg/s)
m_dot_5 = m_dot_3; % (kg/s)
m_dot_8 = m_dot_5; % (kg/s)
m_dot_9 = m_dot_8; % (kg/s)

% Solving for m_dot_6 and m_dot_7:
W_turb = m_dot_3*(h3-h5s);
% Q_condenser = W_turb --> substitute in the equation below
% Q_condenser = m_dot_6*Cp*(T7 - T6) --> rearranging the equation to solve
% for m_dot_6
% m_dot_6 = (Q_condenser / (Cp*(T7-T6)))
Q_condenser = m_dot_3*(h3 - h5); % kW
m_dot_6 = (Q_condenser / (C_p*(T7-T6))); % (kg/s)
m_dot_7 = m_dot_6; % (kg/s)

% Solving for Work of Turbine:
W_turb = m_dot_3*(h3-h5s); % kW

% Solving for the Pressure Difference of the pipe:

% Tabulating for area of the pipe:
% A = (pi/4)*(D^2)
A1 = (pi/4)*(D_pipes1^2); % m^2 (Area of Pipe for the deep cold water pump)
A2 = (pi/4)*(D_pipes2^2); % m^2 (Area of Pipe for the surface water pump)
A3 = (pi/4)*(D_pipes3^2); % m^2 (Area of Pipe for the Freshwater)

% Tabulating the Volumetric Flow rate of Pumps 1 and 3:
% m_dot = V_dot*rho
V_dot_1 = m_dot_SW / rho1;% (m^3/s) (Volumetric Flow Rate for the surface water pump)
V_dot_6 = m_dot_6 / rho6; % (m^3/s) (Volumetric Flow Rate for the cold deep water
pump)
V_dot_8 = m_dot_8 / rho3; % (m^3/s) (Volumetric Flow Rate for the Freshwater pump)
V_dot_9 = V_dot_8

% Tabulating the velocity of Pumps 1 and 3:
% V_dot = A*V
V1 = V_dot_1/A2; % m/s (Velocity for the surface water pump)
V6 = V_dot_6/A1; % m/s (Velocity for the cold deep water pump)

% Calculation of Reynold's Number:
% Re = ((rho*V*D)/Mu)
Re1 = ((rho1*V1*D_pipes2)/Mu); % Dimensionless Unit
Re6 = ((rho6*V6*D_pipes1)/Mu); % Dimensionless Unit
```

```
% Finding the Relative Roughness:
releps1 = R_pipes/D_pipes2; % dimensionless unit
releps6 = R_pipes/D_pipes1; % dimensionless unit

% Finding the Friction Factor:
f1=Haaland(releps1, Re1);
f2=Haaland(releps6, Re6);

% Finding the Major Head Losses of the Pipes:
% H_major_loss=((f*L*(V^2))/(D*2*g)
H_major_loss1 = (f1*L_pipes1*(V1^2) / (D_pipes1 * 2 *g)); % m
H_major_loss2 = (f2*L_pipes2*(V6^2) / (D_pipes2 * 2 *g)); % m

% Finding the Pressure difference:
% deltaP = P1 - P2
deltaP1 = P_SW - P2; % Pa (Pressure difference of the surface water pump)
deltaP3 = P_SW; % Pa (Pressure difference for the cold deep surface water pump)

% Finding the Head Losses:
% (P1/(rho*g))+((V1^2)/(2*g)+z1=(P2/(rho*g))+((V2^2)/(2*g))+z2+H_major_loss+H_minor_loss;z1=0,H_major_loss=((f*L*(V1^2))/(D_pipes*2*g),H_minor_loss=K_L*.5*rho*(V1^2)=0
% Solve for H
% H = ((V1^2)-(V2^2)/(2g)) + ((deltaP)/(rho*g)) + (z1 - z2)
H_loss1 = (((V1^2)-(Vi^2)) / (2*g)) + ((deltaP1)/(rho1*g)) + (z2 - z1); % m (Head loss of the pipe of the surface water)
H_loss2 = (((V6^2)-(Vi^2))/ (2*g)) + ((deltaP3)/(rho6*g)) + (Z2 - z1); % m (Head loss of the pipe of the surface water)

% Finding C for the equation H=C*V_dot^2
% C =(Sum(K_l) + f*(L/d)*)*(2*g*(A^2))Q^2
C_warm = ((K_l) + f1*(L_pipes1/D_pipes1))*(2*g*(A2^2));
C_cold = ((K_l) + f2*(L_pipes2/D_pipes2))*(2*g*(A1^2));

%Graphing H-Q Curve for Warm Surface Pump
Q = 0:1:25;
H = C_warm*Q.^2;
figure
plot(Q,H);, xlabel('Flow Rate(Q) (m^3/s)'), ylabel('Head(H) (m)'), title('Warm Surface Pump H-Q Curve'), grid on

%Graphing H-Q Curve for Cold-Deep Water Pump
Q = 0:1:25;
H = C_cold*Q.^2;
figure
plot(Q,H);, xlabel('Flow Rate(Q) (m^3/s)'), ylabel('Head(H) (m)'), title('Cold Deep Pump H-Q Curve'), grid on
```

```
% Solving for Work of Turbine:
W_turb = m_dot_3*(h3-h5s) % kW

% Solving for the Work of all pumps:
W_pump1 =  p_eff * ((deltaP1 * V_dot_1) * 1000)  % kW
W_pump2 =  p_eff * (m_dot_4*((P_SW/rho3) - (P2/rho3))) % kw
W_pump3 =  p_eff * ((deltaP3 * V_dot_6) * 1000) % kW
W_pump4 =  p_eff * (m_dot_8*(P_SW/rho3) - (P5/rho3)) % kW

% Verification of the OTEC Power Plant power output is 20MW:
Wnet = W_turb - (W_pump1 + W_pump2 + W_pump3 + W_pump4) % kW

% Finding the Compressor Power:
W_compressor = ((L_annual * A_tot) / hrs); % kW

% Mechanical Vapor Cycle Configuration 1: Air Cooled
TTD1 = 1; % Celsius
gas = 'Air';
TH = T_ambient + 273.15; % K (Conversion from Celsius to Kelvin)
TC = T_load + 273.15; % K (Conversion from Celsius to Kelvin)
% Carnot Coefficient of Performance;
% COP = ((TC) / (TH-TC)) Dimensionless unit
COP1 = ((TC) / (TH-TC));
L_load1 = COP1 * (zeta_c *W_compressor); % kW

% Mechanical Vapor Cycle Configuration 2: Water Cooled before the condensor
% of the OTEC
gas = 'Water';
TH = T6 + TTD; % Celsius
T1= TH +273.15; % Kelvin
P1=py.CoolProp.CoolProp.PropsSI('P','T',T1,'Q',1,gas);
h1=py.CoolProp.CoolProp.PropsSI('H','T',T1,'Q',1,gas);
s1=py.CoolProp.CoolProp.PropsSI('S','T',T1,'Q',1,gas);
P2=10e6; % Pa
beta=P2/P1;
s2is=s1;
h2is=py.CoolProp.CoolProp.PropsSI('H','P',P2,'S',s2is,gas);
eta_is=0.8;
h2=(h2is-h1)/eta_is+h1;
T2=py.CoolProp.CoolProp.PropsSI('T','H',h2,'P',P2,gas);
s2=py.CoolProp.CoolProp.PropsSI('S','H',h2,'P',P2,gas);
T3=(T_ambient + TTD) +273.15;
P3=P2;
h3=py.CoolProp.CoolProp.PropsSI('H','T',T3,'P',P3,gas);
s3=py.CoolProp.CoolProp.PropsSI('S','T',T3,'P',P3,gas);
s4=s3;
P4 = P1;
h4=py.CoolProp.CoolProp.PropsSI('H','S',s4,'P',P1,gas);
```

```
T4=py.CoolProp.CoolProp.PropsSI('T','S',s4,'P',P1,gas);
Q4=py.CoolProp.CoolProp.PropsSI('Q','S',s4,'P',P1,gas);
COP2 = (h2-h3)/(h2-h1)
L_load2 = COP2 * (zeta_c *W_compressor)  % kW

% Plot P-h diagram
figure;
plot([h1, h2, h3, h4, h1], [P1, P2, P3, P4, P1], '-o');
xlabel('Enthalpy (h)');
ylabel('Pressure (P)');
title('P-h Diagram');
legend('Cycle', 'Location', 'Best');
grid on;

% Mechanical Vapor Cycle Configuration 2: Ammonia Cooled after the condensor
% of the OTEC
gas = 'Ammonia';
TH = T7 + TTD; % Celsius
T1= TH +273.15; % Kelvin
P1=py.CoolProp.CoolProp.PropsSI('P','T',T1,'Q',1,gas);
h1=py.CoolProp.CoolProp.PropsSI('H','T',T1,'Q',1,gas);
s1=py.CoolProp.CoolProp.PropsSI('S','T',T1,'Q',1,gas);
P2=10e6; % Pa
beta=P2/P1;
s2is=s1;
h2is=py.CoolProp.CoolProp.PropsSI('H','P',P2,'S',s2is,gas);
eta_is=0.8;
h2=(h2is-h1)/eta_is+h1;
T2=py.CoolProp.CoolProp.PropsSI('T','H',h2,'P',P2,gas);
s2=py.CoolProp.CoolProp.PropsSI('S','H',h2,'P',P2,gas);
T3=(T_ambient + TTD) +273.15;
P3=P2;
h3=py.CoolProp.CoolProp.PropsSI('H','T',T3,'P',P3,gas);
s3=py.CoolProp.CoolProp.PropsSI('S','T',T3,'P',P3,gas);
s4=s3;
P4 = P1;
h4=py.CoolProp.CoolProp.PropsSI('H','S',s4,'P',P1,gas);
T4=py.CoolProp.CoolProp.PropsSI('T','S',s4,'P',P1,gas);
Q4=py.CoolProp.CoolProp.PropsSI('Q','S',s4,'P',P1,gas);
COP3 = (h2-h3)/(h2-h1)
L_load3 = COP3 * (zeta_c *W_compressor) % kW

% Plot P-h diagram
figure;
plot([h1, h2, h3, h4, h1], [P1, P2, P3, P4, P1], '-o');
xlabel('Enthalpy (h)');
ylabel('Pressure (P)');
title('P-h Diagram');
```

```
legend('Cycle', 'Location', 'Best');
grid on;

% Economic Analysis:

% Income generated from the OTEC Power Plant
Income1 = Price_electricity * Wnet; % $/hour
Income_1 = Income1 * hrs % $/year (Income of the electricity per Year)
Income2 = Price_desalinated * V_dot_9 % $/s (Income of Desalinated water per second)
Income_2 = Income2 * (3600 * 24 * 365) % $/year (Income of Desalinated water per
year)

% Cost from Each MVC configurations:
Load_base_cost1 = (L_load1 * Price_electricity) * hrs % $/year
Load_base_cost2 = (L_load2 * Price_electricity) * hrs % $/year
Load_base_cost3 = (L_load3 * Price_electricity) * hrs % $/year

% Savings comparing each MVC configuration:
Savings2 = Load_base_cost2 - Load_base_cost1 % $/year
Savings3 = Load_base_cost3 - Load_base_cost1 % $/year

% Total Income and Saving of the OTEC power plant per year:
Total_Revenue1 = Income_1 + Income_2 % $/year
Total_Revenue2 = Income_1 + Income_2 + Savings2 % $/year
Total_Revenue3 = Income_1 + Income_2 + Savings3; % $/year

% Total Cost of the OTEC Power Plant:
% Total Cost of Material
Wt_total= Mp*(L_pipes1 + L_pipes2); % kg
Total_cost= Wt_total*Cost_steel; % $
Operation_cost = Cost_initial * 10000 * 20; % $/year
Total_expenditures1 = Operation_cost + Total_cost + Load_base_cost1; % $/year
Total_expenditures2 = Operation_cost + Total_cost + Load_base_cost2; % $/year
Total_expenditures3 = Operation_cost + Total_cost + Load_base_cost3; % $/year

% Total profit of otec
Profit1 = Total_Revenue1 - Total_expenditures1 % $/year
Profit2 = Total_Revenue2 - Total_expenditures2 % $/year
Profit3 = Total_Revenue3 - Total_expenditures3 % $/year

%plot income vs expenditure graph
x = 0:1:25
y1 = Total_Revenue1*x - Total_expenditures1
y2 = Total_Revenue2*x - Total_expenditures2
y3 = Total_Revenue3*x - Total_expenditures3
y4 = Total_expenditures1
figure
```

```
plot(x, y1, x, y2, x, y3, x, y4), xlabel('Years'), ylabel('Dollars'), title('Income per Year')

% Determining the most economical pipe diameter

function f=Haaland(releps, Re)
answer=-1.8*log10((releps/3.7)^1.11+6.9/Re);
f= (1/answer)^2;
end
```

PUBLICATION:
file:///C:/Users/jpasc/OneDrive/Documents/MAE-3524%20Thermal%20Fluids%20Design/html/Project2Matlabcode.html

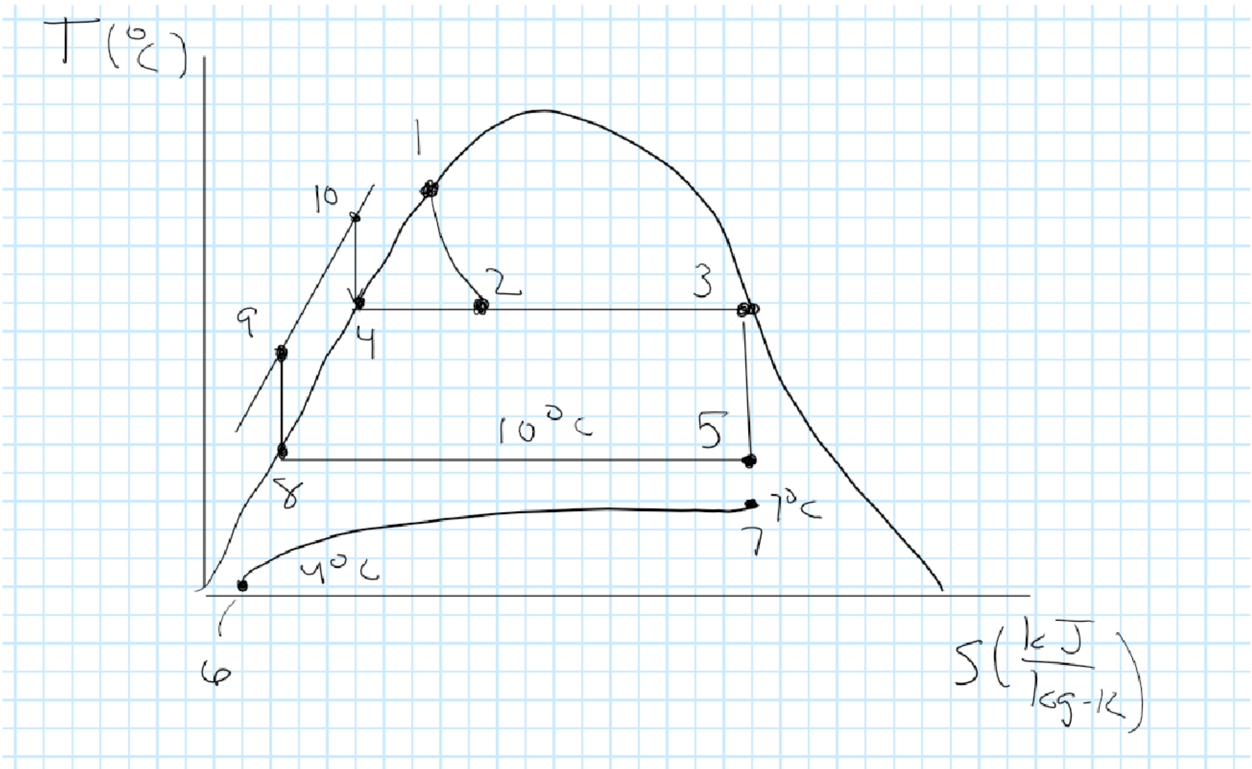
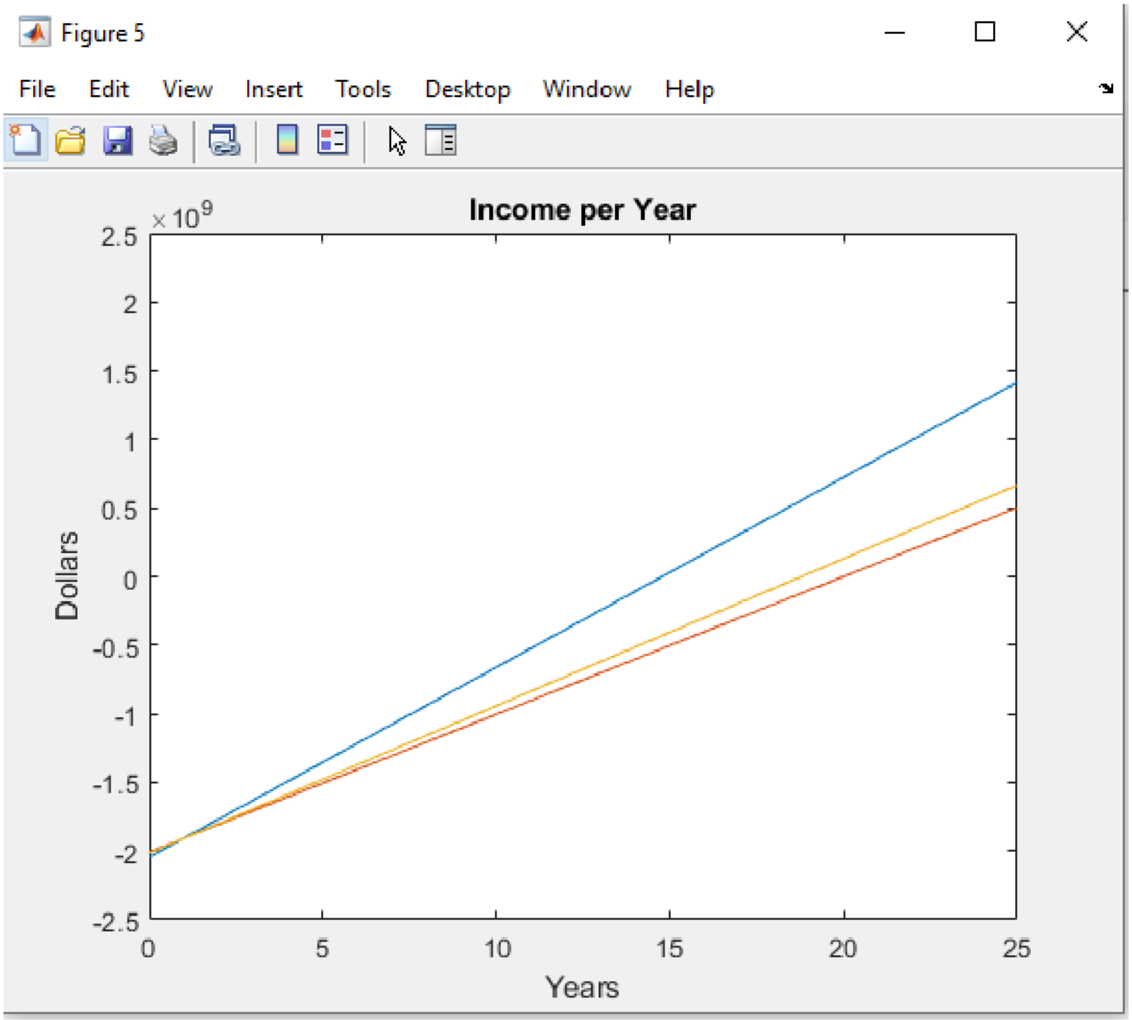


Figure 2: T-S Diagram including the temperatures of the condenser at 6 and 7

In Figure 2, it resembles figure 1 of the T-S diagram, but it demonstrates the cold deep ocean water entering the condenser at point 6 and exiting at point 7. The terminal temperature difference is 3 degrees Celsius.

ECONOMIC ANALYSIS:

In analysis of the economic feasibility of the OTEC power plant there were multiple forms of income that could proliferate the proficiency of the power plant. There are three different forms of income produced from the power plant which are the 20 MW of electricity which is the net power after all other components have been powered such as the pumps and the compressor of the mechanical vapor compression cycle. When conducting the economical impact of the power plant the initial design costs were taken into account, and the annual operational cost were negligible for this simulation. The total initial cost of the power plant would approximately be 200 million dollars just in start-up costs which include the piping system, cost of the components. The incorporation of a refrigeration cycle would demonstrate the significance in savings annually. The objective is to tabulate the total income of the power plant through its lifespan which would be defined as 25 years. The graph below that was designed and generated from the Matlab code shows a linear relationship of the income generated per year from the OTEC plant.



Graph 1: The comparisons of Income over 25 years with each MVC

The blue line is the representation of just the OTEC power plant where the warehouse's cooling process is through the electricity. The yellow linear line shows the MVC being cooled by water before the water is entering the condenser. Finally, the red line is an illustration of the MVC with the usage of Ammonia being the refrigerant to cool the deep ocean water after it comes out of the condenser. Based upon the results it seems as if the most optimal result economically would be the use of not implementing a MVC. However, the total initial expenditures of the industrial cooling load scenario has a higher initial expenditures, and the cooling load costs way more. Also the break even year would take 16 years of 25 years for the

OTEC power plant to and by year 25 the modification of the electric cooled would have a total profit of 1.4156*10^9.

Line	Total Revenue ($/year)	Total Initial Expenditures ($/year)	Break Even Year (Year)	Total Profit ($)	Cooling load cost ($/year)	ROI(Return on Investment) %
Blue(Air)	1.3845*10^8	2.0457*10^9	16	1.4156*10^9	4.5468*10^7	0.6920
Yellow(Water)	1.0039*10^8	2.0076*10^9	21	5.022*10^8	7.4094*10^6	0.2501
Red(Ammonia)	1.0723*10^8	2.0145*10^9	20	6.663*10^8	1.4248*10^7	0.3308

Table 1: Economics of Each MVC and the break even year.

The results of table 1 convey the dichotomies of the each adjusted OTEC power plant modification. The most economical variant of the OTEC plant would have the warehouse be cooled electrically, but it costs significantly more than the water cooled and ammonia cooled MVC. Also, the electrically cooled OTEC power plant has the best return on investment with the quickest payoff period.

1st Mechanical Vapor Compression Cycle: Electrically Cooled

As far as the implementation of the adding a mechanical vapor compression cycle, the first configuration would have no adjustments to be taken into account. The warehouse would be cooled electrically. The ambient of the temperature year is 30 degrees Celsius and the necessitated operating temperature would be 0 degrees Celsius of which would be cooled from the electricity produced from the turbine where the coefficient of the performance of the cycle would be 9.1050 and the total power of the cooling load would be 11034 kW. The figure below shows the pressure and enthalpy diagram of the MVC cycles. Also, there would have been a P-H diagram for the air designed in Matlab, but it was difficult to compute.

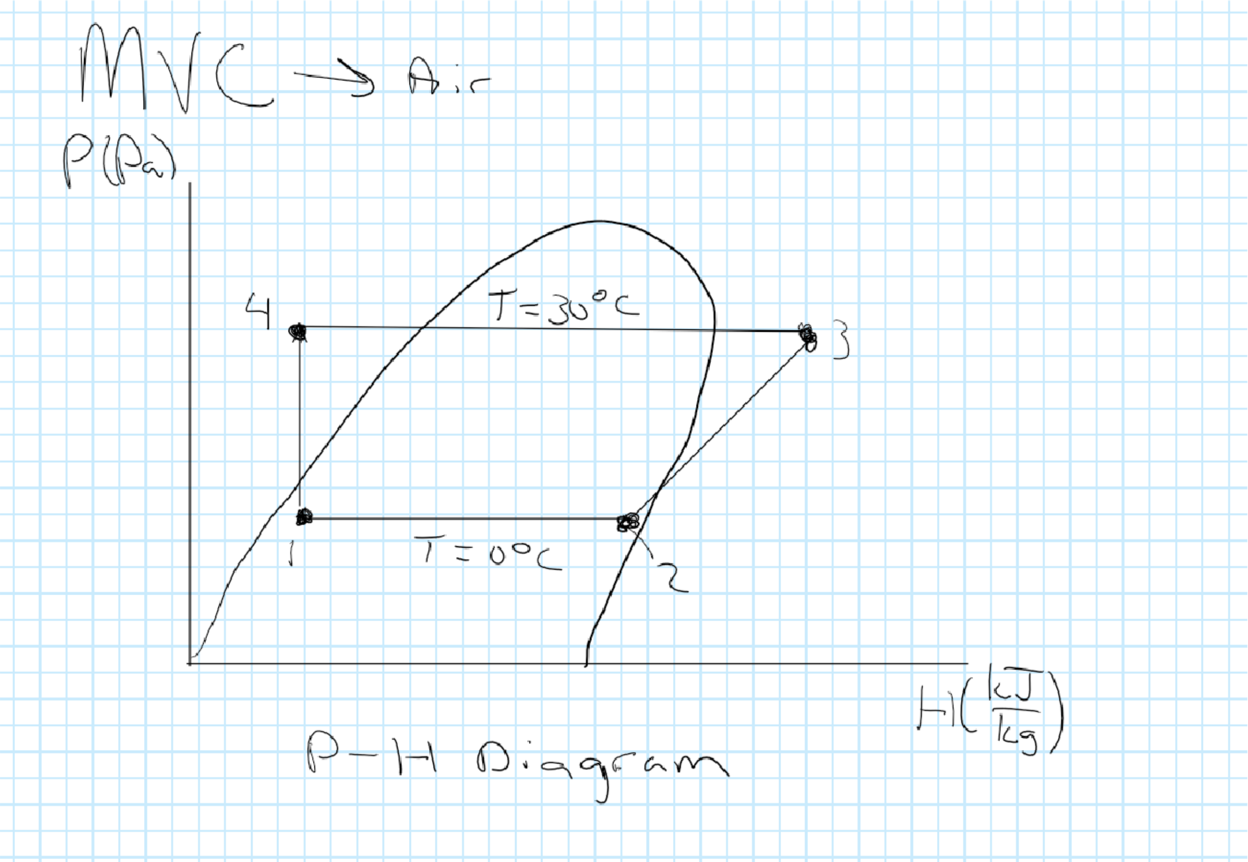


Figure :P-H Diagram

2nd Mechanical Vapor Compression Cycle: Water

The second configuration of the mechanical vapor compression cycle would be the implementation of the water as the coolant in the refrigeration cycle that would be placed before the deep cold ocean water would enter the condenser. The coefficient of performance is significantly lower in comparison to the electrically cooled MVC, it has a value of 1.4837. The cooling load is 1799.6 kW which is significantly lower, and it would be more effective on implementing the MVC because it takes less to power the warehouse, this would constitute towards the lower operating temperatures. The terminal temperature difference is 2 or 3 degrees cooler than the standard operating temperature.

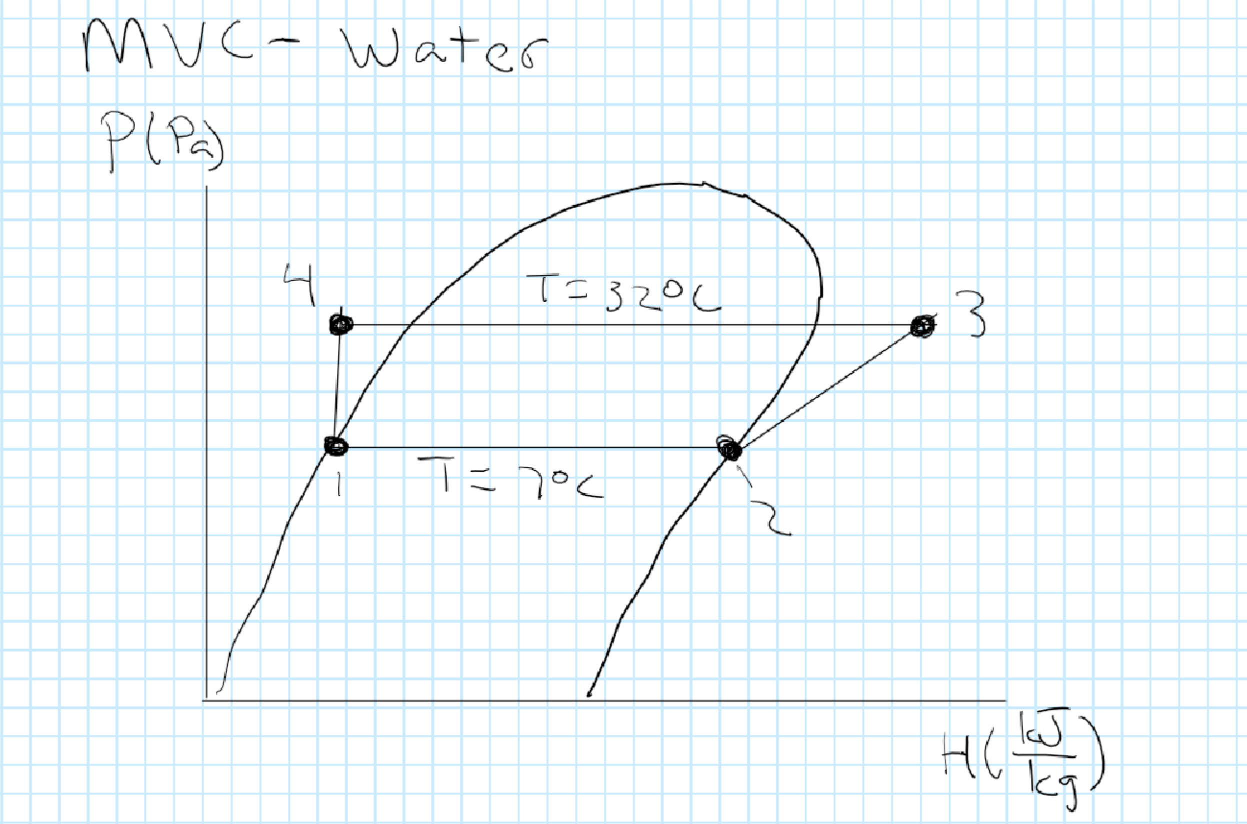


Figure : P-H Diagram of the water before the condenser

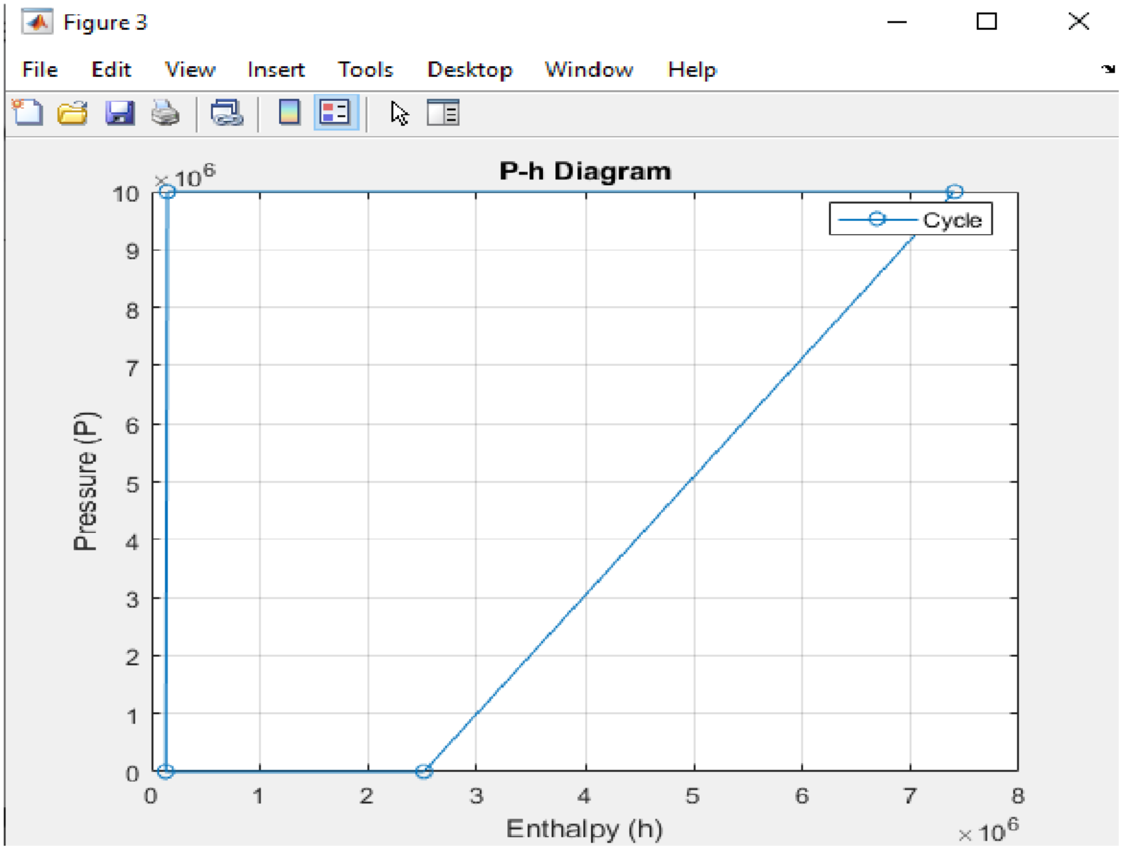


Figure : P-H Diagram generated from the Matlab for Water before the condenser.

3rd Mechanical Vapor Compression Cycle: Ammonia

The third configuration that was taken under scrutiny was the use of the refrigerant: Ammonia. The third configuration would be placed after the condenser so it could cool the deep-ocean water before it would go into the warehouse. Where the operating temperature high is 32 degrees Celsius and the minimal cooling temperature is 10 degrees Celsius. The coefficient of performance is 2.8531 and the total cooling load is 3460.6 kW.

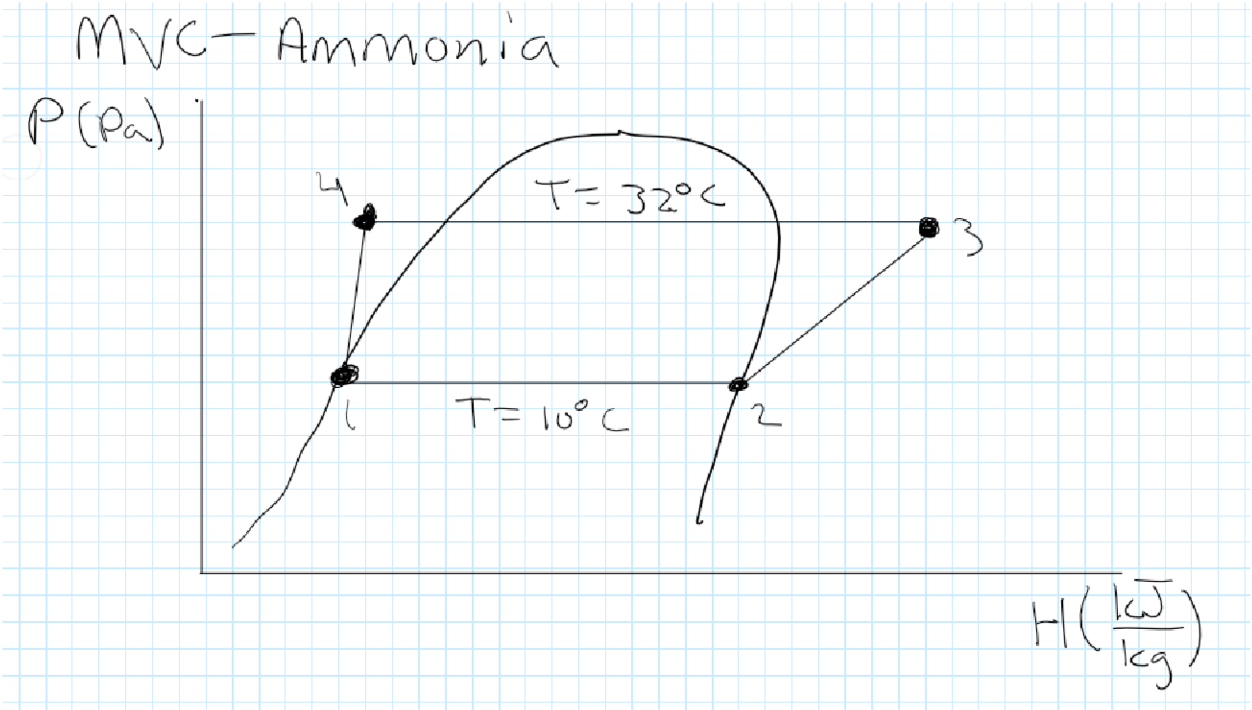


Figure : P-H Diagram of Ammonia after the condenser

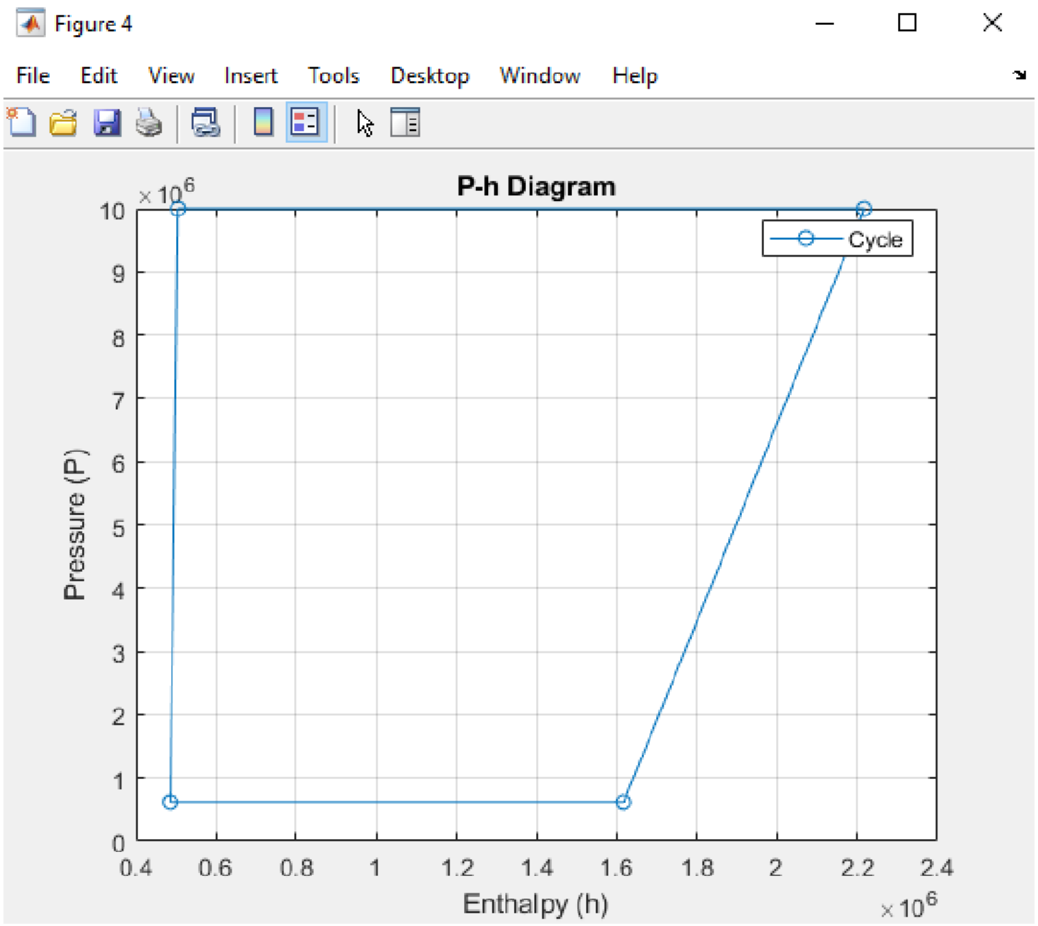


Figure : P-H Diagram of the Ammonia generated in Matlab

Type	COP	Cooling Load (kW)
Air(electric)	9.1050	11043
Water	1.4837	1799.6
Ammonia	2.8531	3460.6

Table 2: Configurations and their perspective cooling load and the COP

OPTIMIZATION/DISCUSSION:

The optimization of the OTEC would be the inclusion of picking the most economical pipe diameter of which in the Table below demonstrates the total price of the piping system for the warm surface water pipe and the cold deep ocean water pipe. The diameter of the pipe was run through the matlab code and these are the values that came into fruition. However, the observation of there being a discrepancy with the code or there being a bug in the code could be implied. The reasoning for this is because the use of the equation Wpump1, 3 = Pressure*the Volume metric flow rate. The pressure difference of the pipe and the Volumetric flow rate should impact the total power of the power plant because the pumps are powered by the turbine.

The pipes were all assumed to be Stainless steel Schedule 40 pipe to simplify the analysis of the total production of power and financial cost for the pipes. Schedule 40 was selected for the reasoning of there being a great pressure difference and it would be sustainable and optimal for the long-term.

Diameter (in)	Work Net (kWh)	Work Turbine (kWh)	Pump 1 (kWh)	Pump 2 (kWh)	Pump 3 (kWh)	Pump 4 (kWh)	Total cost of pipe at 605 m ($)
12	20722	71118	38741	38.0804	11616	0.5392	740960
10	20722	71118	38741	38.0804	11616	0.5392	358840
8	20722	71118	38741	38.0804	11616	0.5392	213930

Table 3: Comparisons of Pipe Diameters

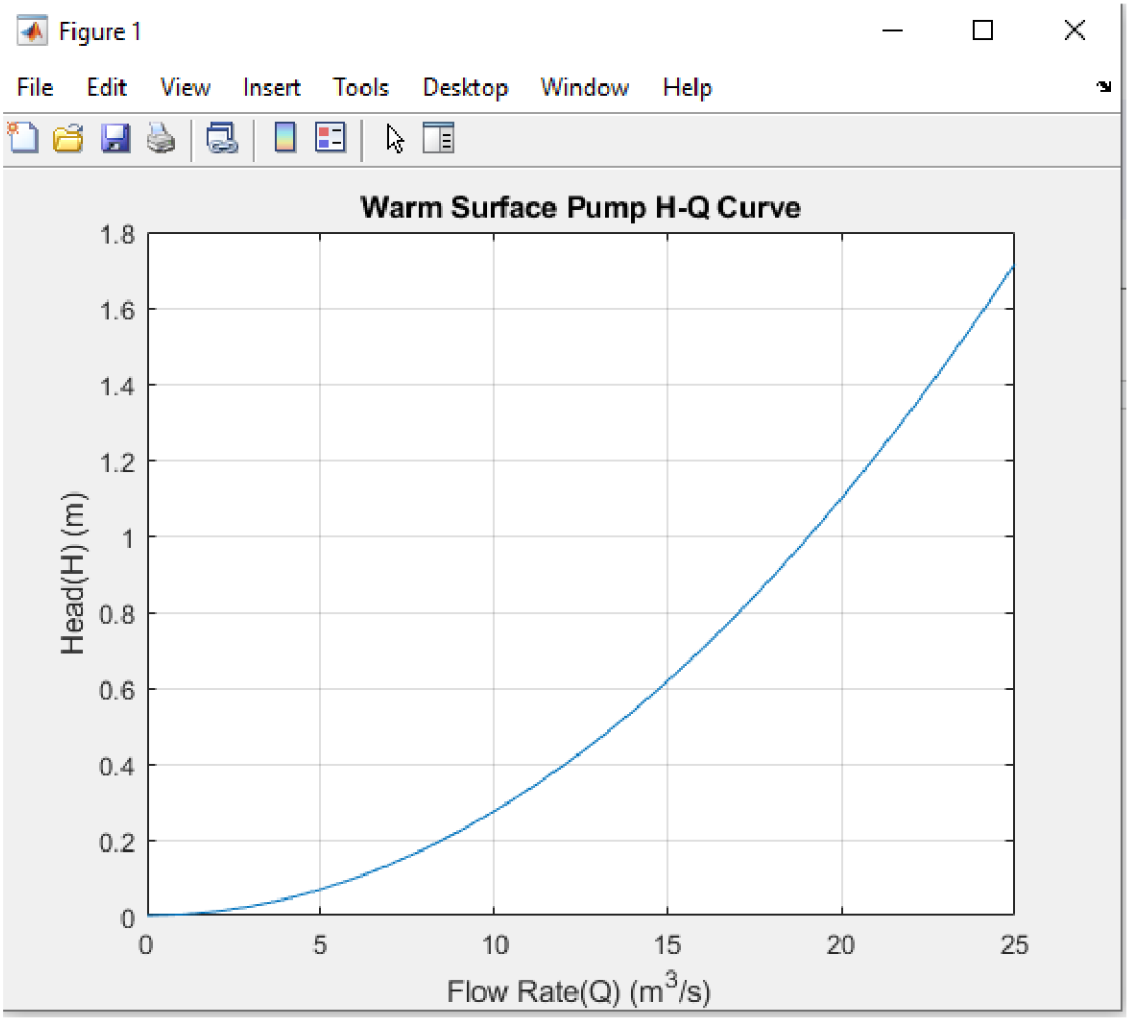


Figure : H-Q Curve of the warm surface water pump

The Head vs Volumetric flow rate of the warm surface water pump shows that the head loss is proportional to the flow rate. The curve was solved in matlab by presuming the diameter of the pipe was 8 inches for the outer diameter, and the material used for the pipe is stainless steel.

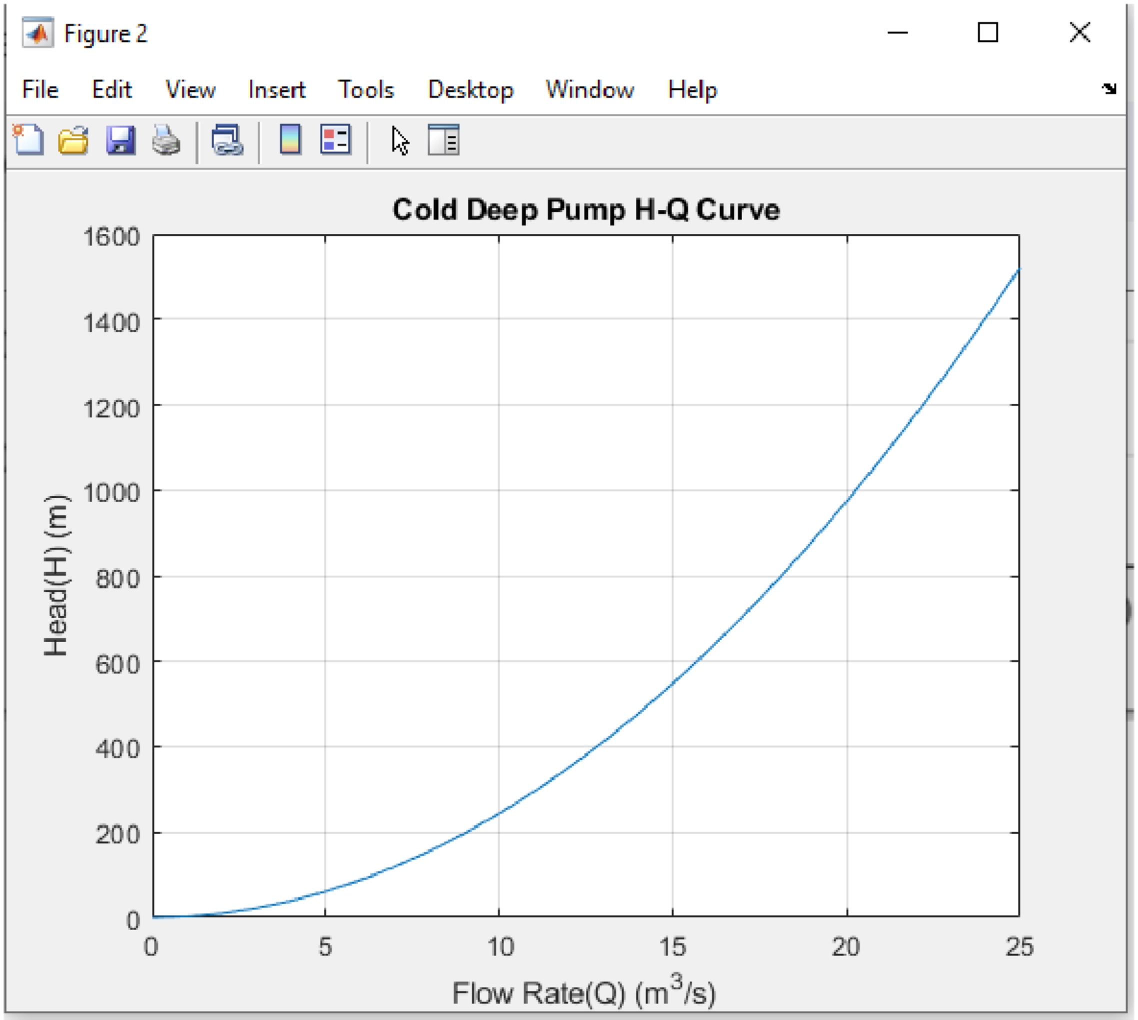


Figure :H-Q Curve of the Cold-Deep Ocean Water

The figure above shows the Head vs Volumetric Flow Rate of the cold deep ocean water where the head loss is proportional to each other. The outer diameter of the pipe is 12 inches and the material used is stainless steel pipe. The curve was computed in Matlab, please see the code in order to see how the equation was computed.

Other Considerations for Optimizations:

Throughout the project there were many uncertainties that were needed to ascertain, and one of the major impacts is the amount of power the first and third pumps are consuming in comparison to pumps 2 and 4. If the pumps power consumption could be lowered which would contribute to adjusting the certain properties such as the temperature of the cold-deep ocean water and placement of the MVC with a further dive into optimizing the refrigerant would be beneficial and economical.

CONCLUSION:

Based upon the results of the OTEC power plant simulation the ability to produce a 20 MegaWatt power plant was obtained along with the implementation of different mechanical vapor compressions of air, water, and ammonia. The results show that if the power plant was to have no MVC cycle it would be the most optimal configuration, yet it costs the most and the industrial cooling load annual is the highest out of all three configurations. The main challenge of this report was to ascertain the unknowns and navigating Matlab, but the code came out to be over 300 lines long and it was beneficial.

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