Modelling and Simulation of Combined Vapor Compression System and Organic Rankine Cycle Using Python

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1. ABSTRACT

Cogeneration systems refer to energy systems that have the ability to produce two useful commodities simultaneously. In practical terms, what cogeneration usually means is the use of what would otherwise be wasted heat (such as a manufacturing plant's exhaust) to produce additional energy benefit, such as to provide heat or electricity for the building in which it is operating. Cogeneration is great for the bottom line and also for the environment, as recycling the waste heat saves other fossil fuels from being burned.

For this project, we make use of the concept of cogeneration to recover heat liberated from the condenser of a vapour compression refrigeration cycle and transfer this heat to a boiler in an organic rankine cycle in order to produce steam which runs a turbine, thereby producing power.

To carry out this project we use a programming language such as python in order to generate the outputs such as COP, Power generated in the turbine, efficiencies, etc depending upon the user inputs.

2. ACKNOWLEDGEMENT

We take this opportunity to thank **Dr. R. KESHAVAMURTHY**, Head of the Department, Mechanical Engineering, DSCE, for his valuable support and guidance which has helped us complete our mini project.

We are deeply indebted to our guide and mentor **Dr. M.R Kamesh**, Associate Professor, Department of Mechanical Engineering, DSCE without whom this project would not have been successful, and whose technical knowledge helped us immensely throughout our project. His suggestions and instructions have served as a major contributor for the completion of the project. He with his immense experience also predicted the forthcoming practical problems and mentored us to face and solve these problems without any issues.

Also, we express our gratitude to all the teaching and non-teaching staff, who has directly/indirectly helped us to complete this mini project successfully.

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5. INTRODUCTION

Energy requirement is a fundamental need for human development. Energy can be considered as a key-element for promoting or improving base services such as lightning, drinking water access, health services, education or communications.

Taking thermodynamic cycles in general there is a lot of heat rejection from the cycle. This heat instead of going waste can be utilized effectively. This heat can be utilized to generate electricity. As population increases, demand for electricity also increases. Heat which when converted into electricity can be used to satisfy this demand.

Polygeneration System is a hot topic which could provide solutions to the above energy needs. This Polygeneration system could be implemented in various ways like Cogeneration, Trigeneration, Multigeneration, etc…

In Vapour compression Refrigeration cycles, there is a lot of heat rejected by the refrigerant as it passes through the condenser. This heat is released as waste to the atmosphere. Using this heat for constructive application is the point where our Project begins.

5.1 THERMODYNAMIC CYCLES

A thermodynamic cycle consists of a linked sequence of thermodynamic processes that involve transfer of heat and work into and out of the system, while varying pressure, temperature, and other state variables within the system, and that eventually returns the system to its initial state. In the process of passing through a cycle, the working fluid may convert heat from a warm source into useful work, and dispose of the remaining heat to a cold sink, thereby acting as a heat engine. Conversely, the cycle may be reversed and use work to move heat from a cold source and transfer it to a warm sink thereby acting as a heat pump.

The two thermodynamic cycles that we will be using in our mini project are

(i)Vapour Compression Refrigeration Cycle (VCR) and

(ii) Organic Rankine Cycle (ORC)

5.2 VAPOUR COMPRESSION REFRIGERATION CYCLE (VCR)

This refrigeration cycle is approximately a Rankine cycle run in reverse. A working fluid (often called the refrigerant) is pushed through the system and undergoes state changes (from liquid to gas and back). The latent heat of vaporization of the refrigerant is used to transfer large amounts of heat energy, and changes in pressure are used to control when the refrigerant expels or absorbs heat energy.

Step 1: Compression

The refrigerant enters the compressor at low temperature and low pressure. It is in a gaseous state. Here, compression takes place to raise the temperature and refrigerant pressure. The refrigerant leaves the compressor and enters to the condenser.

Step 2: Condensation

The condenser is essentially a heat exchanger. Heat is transferred from the refrigerant to a flow of water. This water goes to a cooling tower for cooling in the case of water-cooled condensation.

Step 3: Throttling and Expansion

When the refrigerant enters the throttling valve, it expands and releases pressure. Consequently, the temperature drops at this stage. Throttling valves play two crucial roles in the vapor compression cycle. First, they maintain a pressure differential between low- and high-pressure sides. Second, they control the amount of liquid refrigerant entering the evaporator.

Step 4: Evaporation

At this stage of the Vapor Compression Refrigeration Cycle, the refrigerant is at a lower temperature than its surroundings. Therefore, it evaporates and absorbs latent heat of vaporization. Heat extraction from the refrigerant happens at low pressure and temperature. Compressor suction effect helps maintain the low pressure.

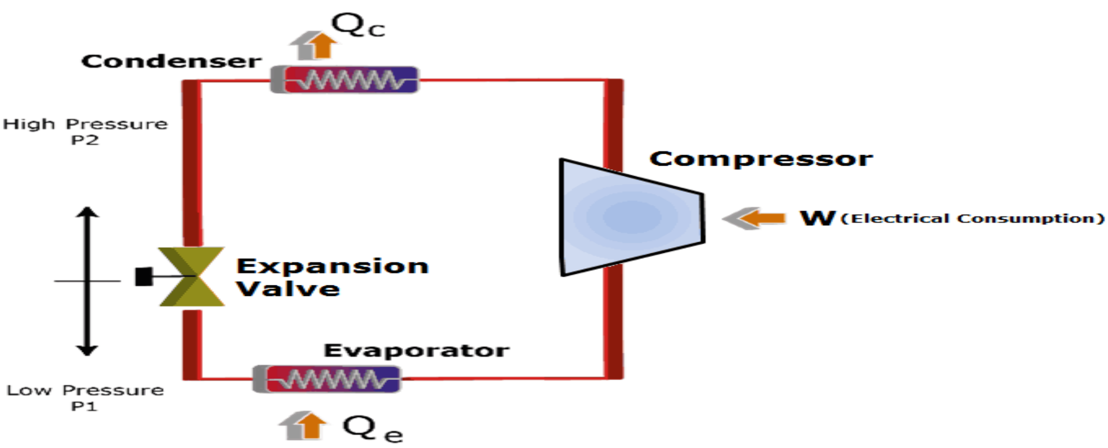


Fig 1: Schematic Representation of the Steps in VCR

5.3 ORGANIC RANKINE CYCLE

Organic Rankine Cycle (ORC) systems are used for power production from low to medium temperature heat sources in the range of 80 to 350 °C and for small-medium applications at any temperature level. This technology allows for exploitation of low-grade heat that otherwise would be wasted. The main components of an Organic Rankine Cycle power plant design are:

1. THE TURBINE

it's the key component of the entire ORC power plant, which determines the ORC system performance. It expands the working fluid producing mechanical energy that is converted into electricity by a generator coupled with the turbine shaft.

2. THE HEAT EXCHANGERS

The working fluid flows through the heat exchangers, extracting the heat from the heat source.

3. THE CONDENSER

With the direct air to fluid heat exchanger, the organic fluid is cooled and liquefied before entering the pump. The use of air eliminates the requirement for water to treatment and make up. It is possible to use also a water-cooled condenser.

4. THE FEED PUMP

Brings the organic fluid from the condensation pressure to the maximum pressure of the Organic Rankine Cycle. The pump is usually driven by an electric motor at variable rotating speed.

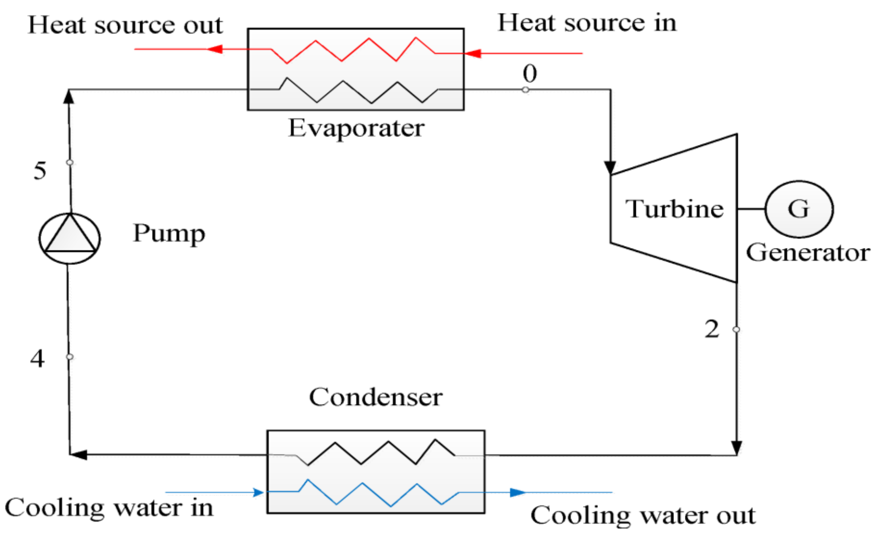


Fig 2: Schematic Representation of the Steps in ORC

6. COGENERATION SYSTEM

Cogeneration systems refer to energy systems that have the ability to produce two useful commodities simultaneously. A good example of cogeneration systems are combined heat and power plants, where electricity and useful heat are both produced from one plant. Cogeneration is a highly efficient energy orientation that can achieve primary energy savings compared to conventional power and heat supply. Furthermore, aside from electricity and heat combination, commodities include heat for fruit drying, desalination, and chemical applications. Therefore, cogeneration applications include residential, commercial, and industrial applications.

The Cogeneration system that we use here in our project consist of both the Vapour Compression Refrigeration cycle and Organic Rankine cycle being used so that the waste heat liberated by the condenser of the VCR is absorbed by the ORC and used to run the turbine by employing a heat exchanger between the two cycles.

6.1 PROPOSED COGENERATION SYSTEM

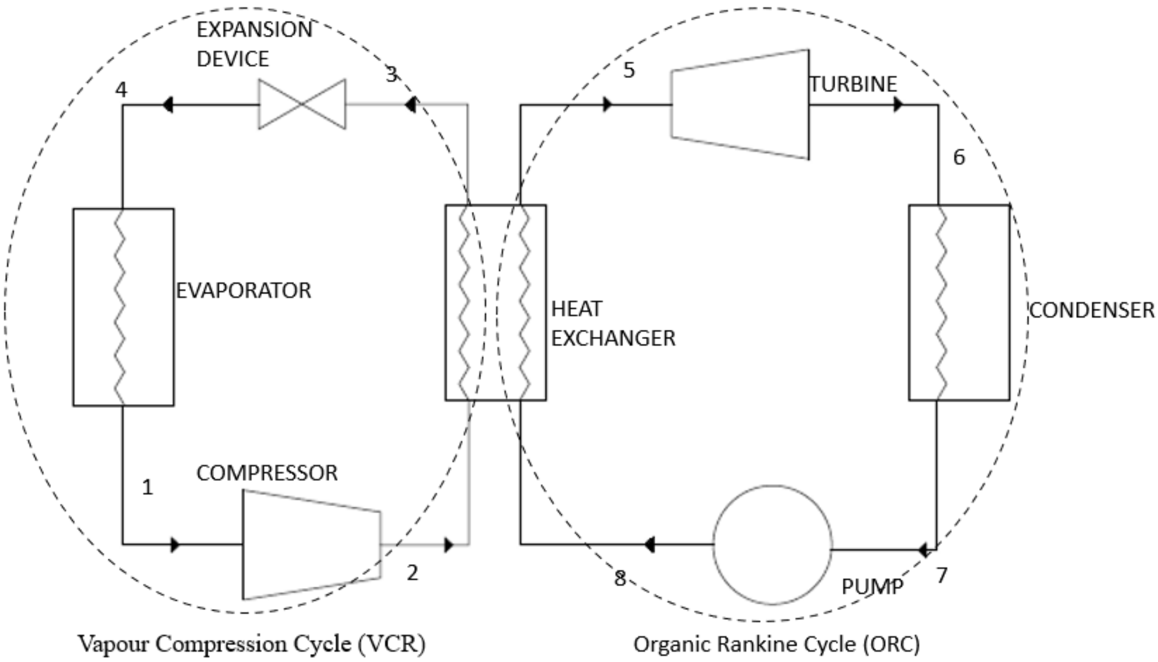


Fig 3: Schematic Representation of the proposed cogeneration of system

In this proposed cogeneration system, it consists of two cycles namely:

(i) Vapour Compression Refrigeration Cycle (VCR)
(ii) Organic Rankine Cycle (ORC)

The Proposed Cogeneration system consists of a heat exchanger which acts as a medium for heat transfer between the two thermodynamic cycles. Here, in the VCR the condenser rejects waste heat which when captured by the heat exchanger transfers this heat to the boiler in the ORC. The heat is used to evaporate the working fluid in the ORC and used to run the turbine.

7. DIFFERENT OPERATING CONDITIONS OF VCR

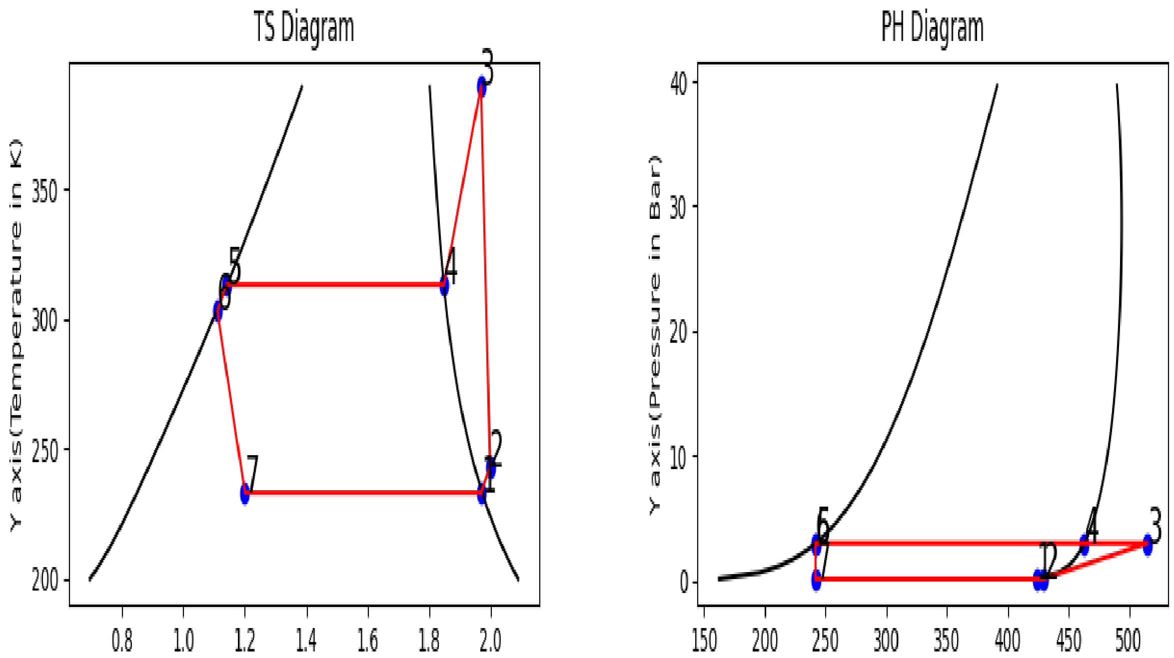


Fig 4: T-S AND P-H diagram of different operating conditions of VCR

1-2: Superheating before inlet to compressor

2-3: Isentropic Compression

3-4-5: Constant pressure heat rejection

3-4: De-superheating in condenser

4-5: Phase change at constant temperature in condenser

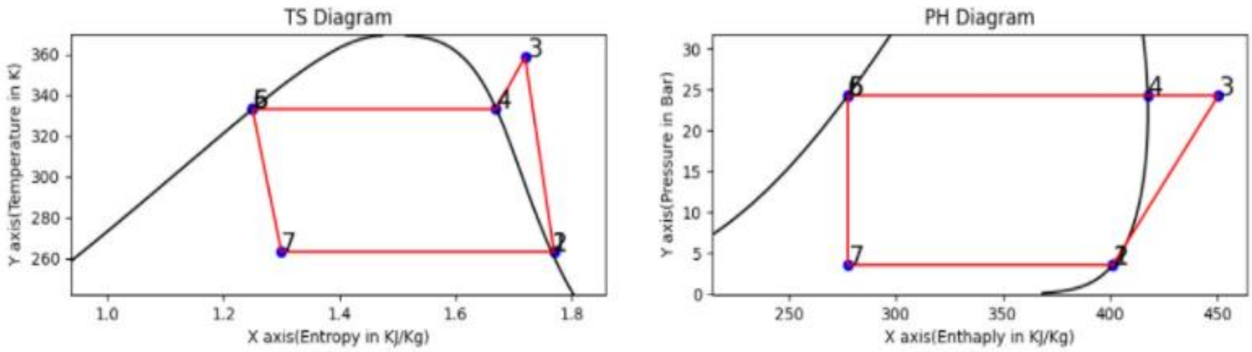
5-6: Subcooling in Condenser

6-7: Expansion

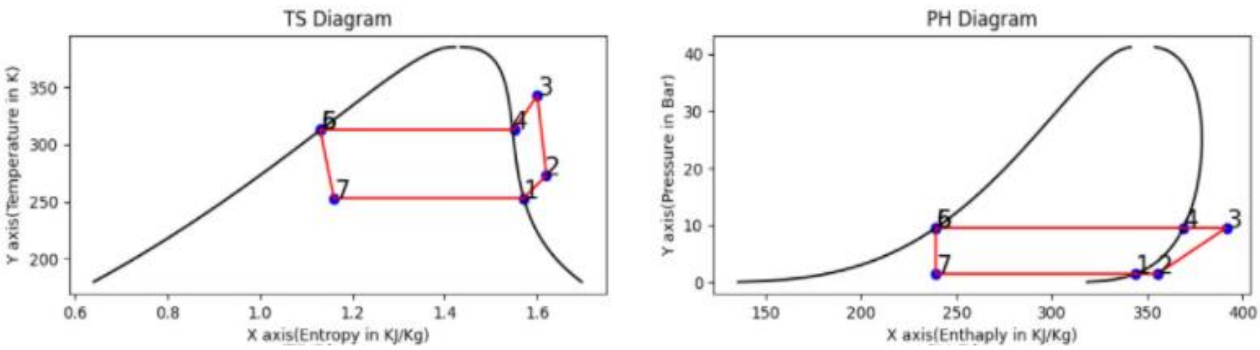
7-1: Constant pressure heat addition

The different operating conditions of VCR that we have considered in this project are:

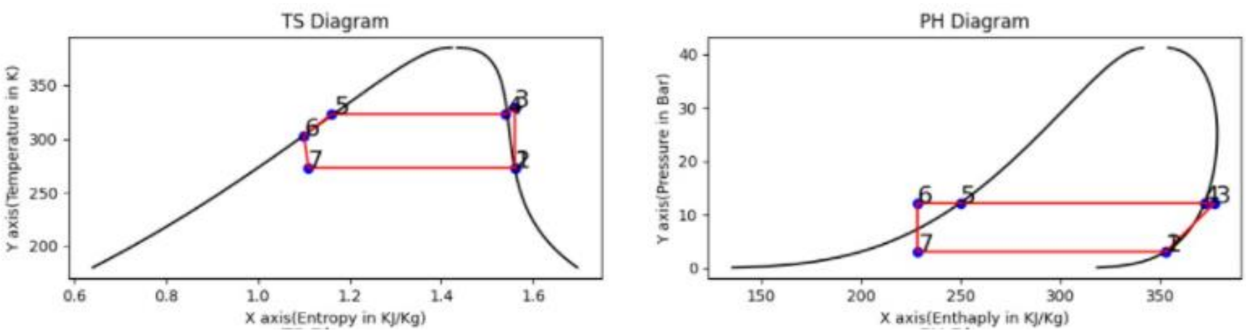
- No Superheating and No Subcooling



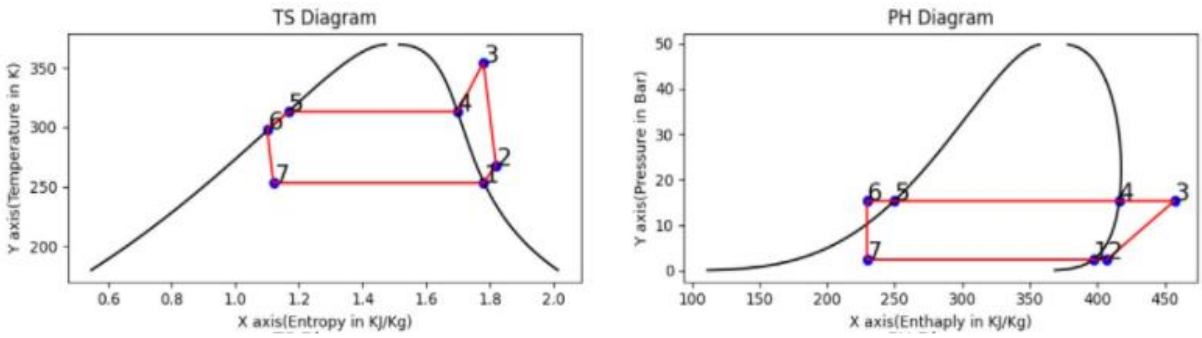
- Only Superheating No Subcooling



- Only Subcooling No Superheating



- Both Superheating and Subcooling



8. DIFFERENT OPERATING CONDITIONS OF ORC

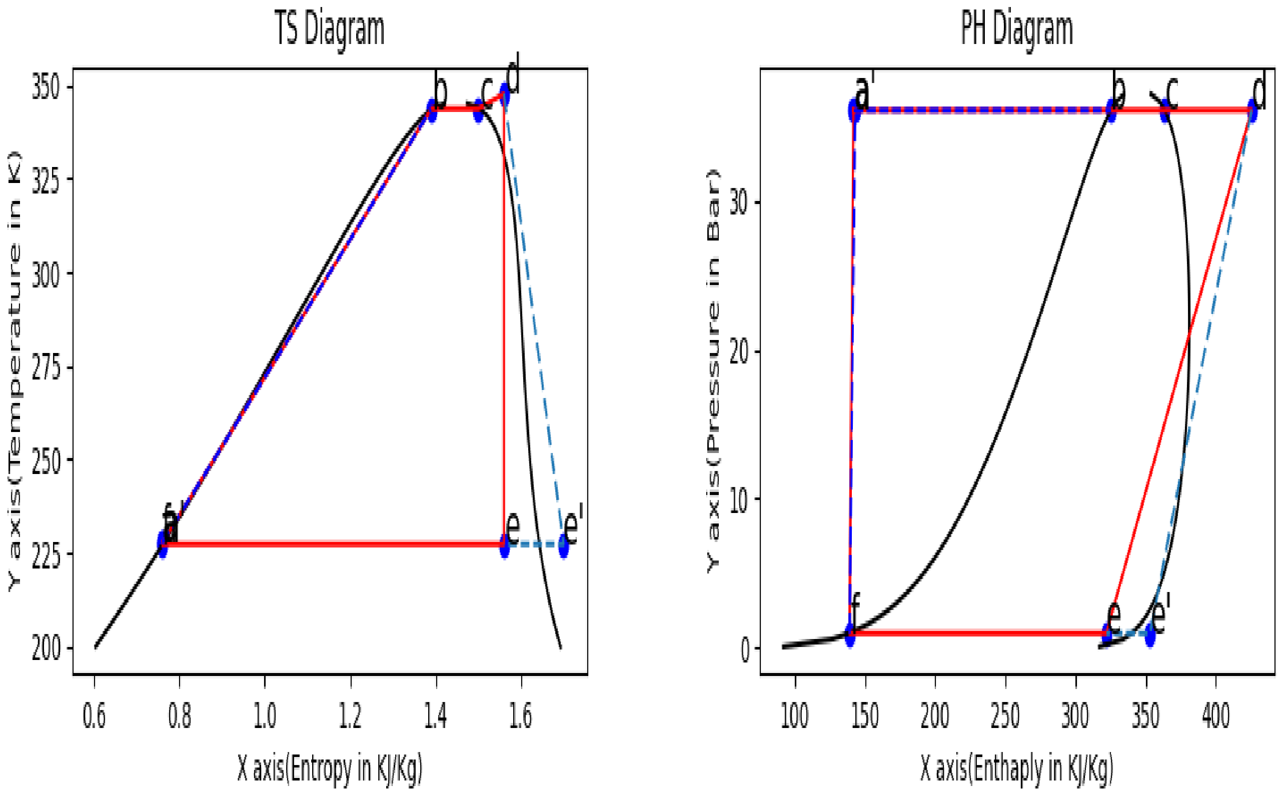


Fig 5: T-S AND P-H diagram of different operating conditions of ORC

a-b-c-d: Constant pressure heat addition in boiler

c-d: Superheating in boiler

d-e: Adiabatic expansion in turbine

d-e’: Actual expansion in turbine

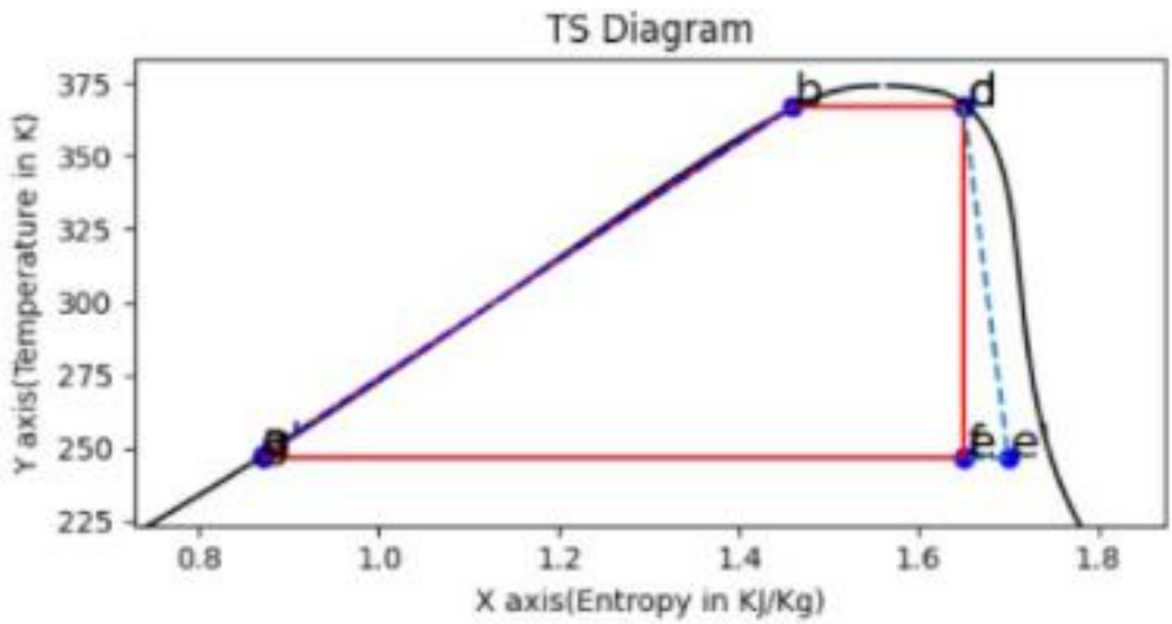
e-f: Constant pressure heat rejection

f-a: Adiabatic compression

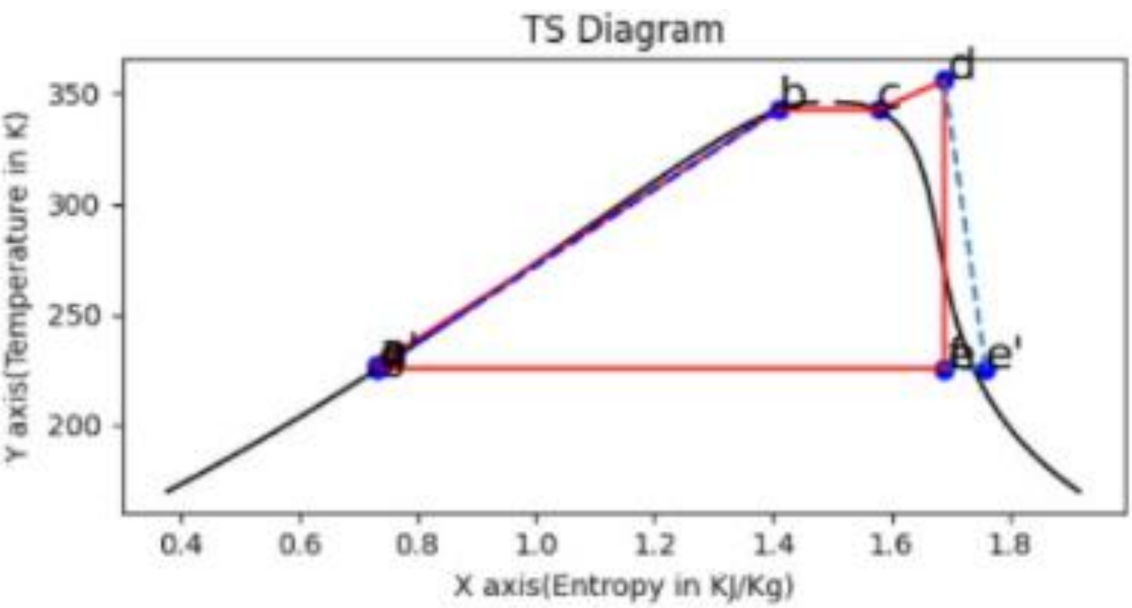
f-a’: Actual compression

The different operating conditions of ORC that we have considered in this project are:

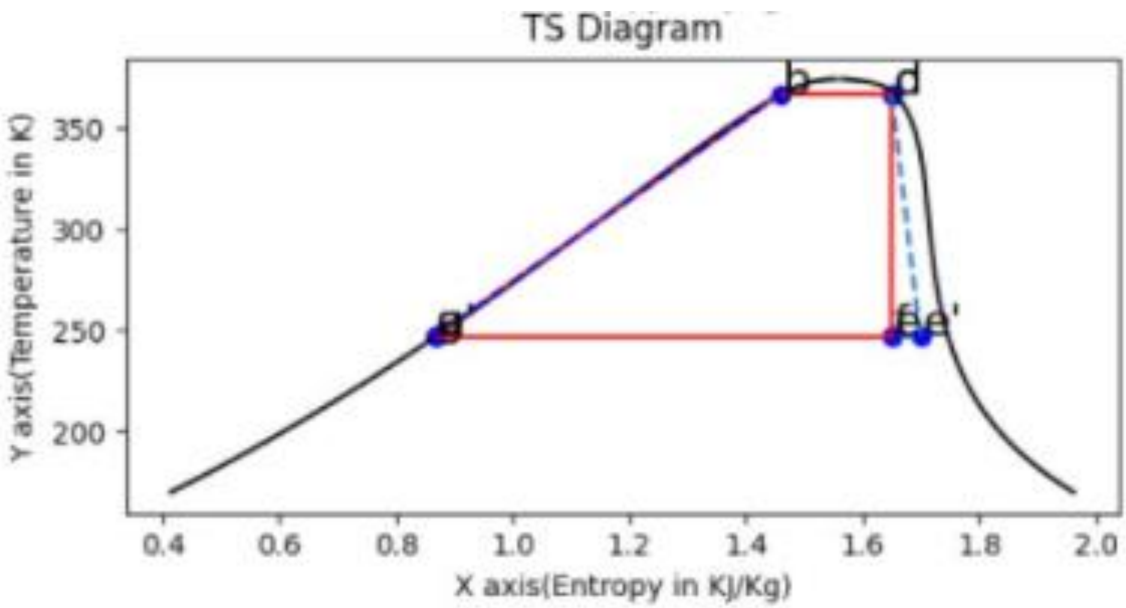
- Quality of Steam is Saturated State at Inlet to Turbine:



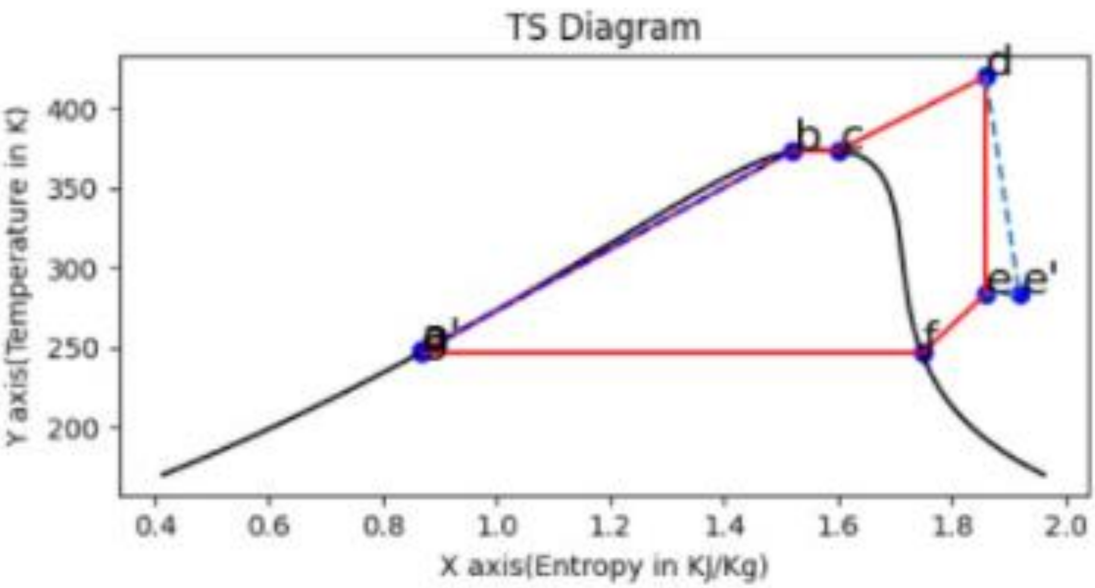
- Quality of Steam is Superheated State at Inlet to Turbine:



- Quality of steam is Saturated State at exit of Turbine:



- Quality of steam is superheated state at exit of Turbine:



9. WORKING FLUIDS

A working fluid is a gas or liquid that primarily transfers force, motion, or mechanical energy. In this project we use two working fluids in the co-generation system, one in each cycle. Few of the working fluids used in VCR and ORC cycles are:

R124, R125, R134a, R141b, R142b, R143a, R152a, R161, R21, R218, R22, R227ea, R12, R404a, R123, R11, CO2, NH3, R113, R114, R115, R116, R40, R407c, R41, R410a, and a few others.

Classification of Refrigerants: - The refrigerants are broadly classified into primary groups:

- Chlorofluorocarbons (CFCs), including R12. This is known to contribute to the greenhouse gas effect. Production of new stocks ceased in 1994.
- Hydrochlorofluorocarbons (HCFCs), including R22. Slightly less damaging to the ozone than R12, but the EPA has still mandated a phase out as a result of the Clean Air Act of 2010. R22 will phase out completely by 2020.
- Hydrofluorocarbons (HFCs), including R410A and R134. With no chlorine in the mix, this is safer for the environment and is now being used in place of R22. Air conditioners that run on R410A are more efficient, offer better air quality, increase comfort and improve reliability.
- Hydrocarbons (HC'S), Hydrocarbon refrigerants are increasingly being used in small refrigeration equipment. Over the next decade it is possible that most domestic refrigerators, refrigerated display cabinets and refrigerated vending machines will shift to hydrocarbon refrigerant.

However, keeping in mind, the effects of chlorine-containing compounds which contribute to depletion of ozone layer and hence contributing to global warming, conventional refrigerants are to be replaced by environment-friendly working fluids. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are being substituted by hydrofluorocarbons (HFCs), hydrofluorooelifins (HFOs), and a variety of mixtures. In view of the global warming potential of these newly synthesized refrigerants, the recent trend is to go back to the originally used natural fluids such as ammonia, carbon dioxide, hydrocarbons, water vapour, etc.

For the working fluid in ORC, as the working temperature of the cycle is relatively lower compared to normal rankine cycles we use organic fluids which have lower boiling temperatures than water.

Common refrigerants and their Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) are indicated below.

- Ozone Depletion Potential (ODP) of a chemical compound is the relative amount of degradation it can cause to the ozone layer
- Global Warming Potential (GWP) is a measure of how much a given mass of a gas contributes to global warming. GWP is a relative scale which compares the amount of heat trapped by greenhouse gas to the amount of heat trapped in the same mass of Carbon Dioxide.

The list of fluids we are using are:

Category	Working Fluid	$P_{critical}$(bar)	$T_{critical}$(C)	GWP	ODP
HCFC	R22	49.9	96.145	1760	0.055
HFC	R134a	40.5928	101.06	1,300	0
HFC	R404a	37.348	72.12	3,922	0
HFC	R143a	37.61	72.707	4,800	0
HFC	R245fa	36.51	153.86	858	0
HCFC	R21	51.812	178.33	148	0.04
HC	Propane	42.512	96.74	3.3-9.5	0
HC	Butane	37.96	151.975	4-6.5	0

Table 1: list of fluids used

9.1 SELECTION CRITERIA

- For Organic Rankine Cycle, working Fluid Selection is based on Critical Pressure of Fluids.
- For Vapour Compression Cycle, working Fluid Selection is based on Critical Temperature of Fluids.
- Maximum Operating Pressure of Refrigerants is less than/equal to Critical Pressure of Refrigerant used.
- It is planned to use the working fluid to be free from Chlorine and Florine i.e. HFC and HC.
- Working fluid used must not be highly flammable.
- Working fluid used in VCR should have high latent heat of Vaporization to get high Refrigeration Effect.
- Working fluid used in ORC should have less latent heat of Vaporization, since heat is recovered from low temperature.
- Working fluid used in VCR should have low Pressure to minimize Power Consumed for the Compressor.
- Working fluid used in ORC should have high Pressure because it needs to run the Turbine
- Working fluid should be non-corrosive and non-toxic in nature.

Hence, due to the above-mentioned criteria, we use only the following working fluids:

R22, R134a, R404a, R143a, R245FA, R21, Propane, Butane.

10. PYTHON LIBRARIES USED

A Python library is a reusable chunk of code that we include in our program.

Compared to languages like C++ or C, a Python library does not pertain to any specific context in Python. Here, a 'library' loosely describes a collection of core modules. Essentially, then, a library is a collection of modules. A package is a library that can be installed using a package manager. The following are the libraries we use:

- Cool Prop is used to fetch values Unknown Values like Enthalpy, Entropy, Pressure, Temperature of Fluid Used.
- We use Matplotlib to Plot Graph in Python.
- We use pandas to write data to Excel.

10.1 COOLPROP

Cool Prop is an open-source database of fluids and humid air properties, formulated based on the most accurate formulations in open literature. It has been validated against the most accurate data available from the relevant references.

- It supports various Programming Languages like MATLAB, Python, C++, C#, Java.
- **SYNTAX Used in Our Work to Extract Properties:**

PropsSI(UNKOWNVALUE,'P',Corresponding Value of Pressure ,'Q',Quality of fluid ,Fluid Name)

- Example to Find Enthalpy of Ammonia at X=0 and Pressure of P=20bar the following command used.

PropsSI(H, 'P',20*E5,'Q',0,NH3)

It shows the Enthalpy of Ammonia at X=0 and Pressure of 20bar.

Similarly, we can find the Unknown Value when any Two Thermodynamic parameters are given.

10.2 MATPLOTLIB

Matplotlib is a plotting library for Python. It is used along with NumPy to provide an environment that is an effective open-source alternative for MatLab. It can also be used with graphics toolkits like PyQt and wxPython.

Conventionally, the package is imported into the Python script by adding the following statement –

from matplotlib import as plt

Here matplotlib() is the most important function in matplotlib library, which is used to plot 2D data.

10.3 PANDAS

Pandas is an open-source Python package that is most widely used for data science/data analysis and machine learning tasks. It is built on top of another package named Numpy, which provides support for multi-dimensional arrays.

Pandas makes it simple to do many of the time consuming, repetitive tasks associated with working with data.

11. FORMULAE USED

11.1 GENERAL FORMULAE USED FOR VAPOR COMPRESSION CYCLE:

- S1+Cp1*ln(T2/T1)=S4+Cp4*ln(T3/T4)
- $H=H_f+(x*H_{fg})$
- $H=H_g+Cp(T2-T1)$
- $COP_{ideal}=T1/(T4-T1)$
- $COP_{actual}=(H2-H7)/(H3-H2)$
- Refrigerating Effect (RE)= $((H2-H7)*(m_{vcr}))/(3500)$
- Heat lost from Condenser $=m_{vcr}*(H3-H6)$
- Power input to Compressor$=m_{vcr}*(H3-H2)$

11.2 GENERAL FORMULAE USED FOR ORGANIC RANKINE CYCLE:

- Work Input to Pump (Wp)$=V_f(P_a-P_f)$
- Work Input to Pump (Wp)$=H_a-H_f$
- Heat Supplied in Boiler (Qin)$=H_d-H_a$
- $Tsup=((H_d-H_c)/C_c)+T_c$
- $S_e=S_f+(x*S_{fg})$
- $H_e=H_f+(x*H_{fg})$
- $W_p=H_d-H_e$
- $ORC_{Ideal\ Efficiency}=W_t-W_p/Q_{in}$

- $Wp_{Actual}=W_p$/Pump Efficiency
- $Wt_{Actual}=W_t$*Turbine Eficiency
- $ORC_{ActualEfficiency} = (Wt_{Actual}-Wp_{Actual})/Q_{in}$
- Specific Fluid Consumption(SFC)=3600/Q_{in}

12. NOMENCLATURE

SYMBOLS	ABBREVIATIONS
M_f	Mass flow rate
V_f	Volume flow rate
P	Pressure
RE	Refrigeration Effect
COP_{ideal}	Ideal Coefficient of Performance
COP_{actual}	Actual coefficient of performance
H_{fg1}	Latent heat of vaporization at evaporator pressure
H_{fg2}	Latent heat of vaporization at condenser pressure
H2	Enthalpy at the inlet of compressor
H3	Enthalpy at the outlet of compressor
H4	Enthalpy after De-superheating in condenser
H5	Enthalpy at the outlet of condenser
H6	Enthalpy at the inlet of expansion device
H7	Enthalpy at the inlet of evaporator
S2	Entropy at the inlet of compressor
S3	Entropy at the outlet of compressor
S4	Entropy after De-superheating in condenser
S5	Entropy at the outlet of condenser
S6	Entropy at the inlet of expansion device
S7	Entropy at the inlet of evaporator
T_{sub}	Temperature of subcooling
T_{sup}	Temperature of superheating
X	Dryness fraction
W_p	Work input to pump
W_t	Work done by
W_c	Work input to compressor
$ORC_{Ideal\ Eff}$	Ideal efficiency of ORC
$ORC_{actual\ eff}$	Actual efficiency of ORC
SFC	Specific fluid consumption
Q_{in}	Heat supplied to boiler
$W_{p\ actual}$	Actual work done by pump
$W_{t\ Actual}$	Actual work done by turbine
H_a	Enthalpy at the inlet of boiler
H_c	Enthalpy at the inlet of superheater
H_d	Enthalpy at the outlet of boiler

H_e	Enthalpy at the outlet of turbine
H_f	Enthalpy at the outlet of condenser
H_g	Enthalpy at the outlet of compressor
RC	Refrigeration capacity

Table no 2: Nomenclature

13. PROGRAM USED

13.1 PROCESS FLOW CHART

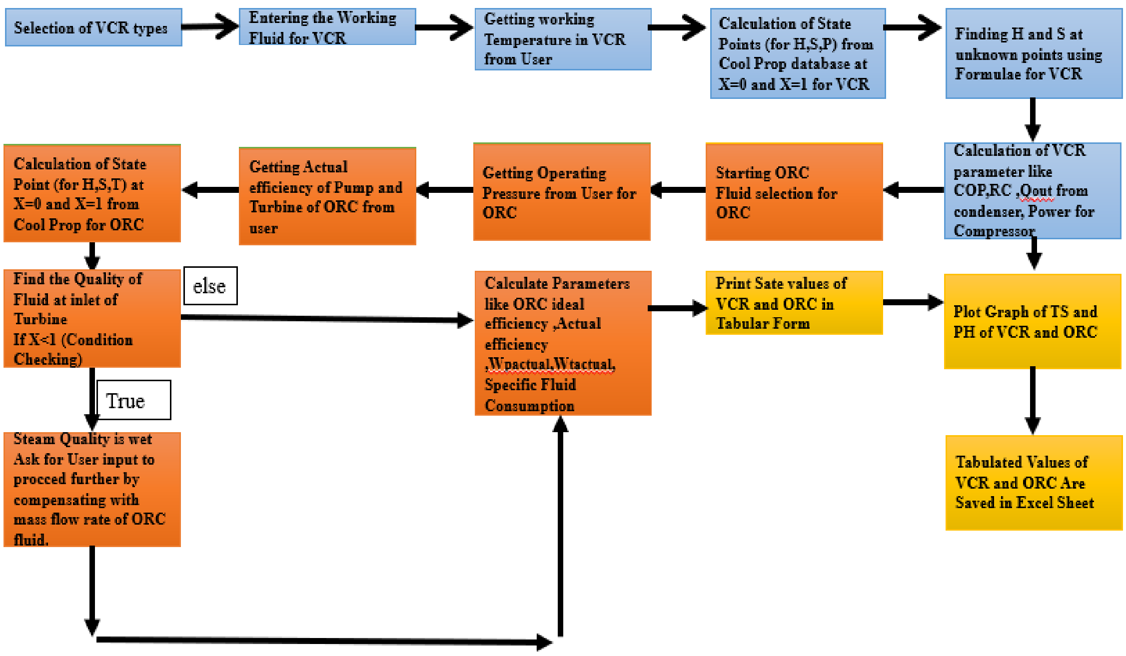
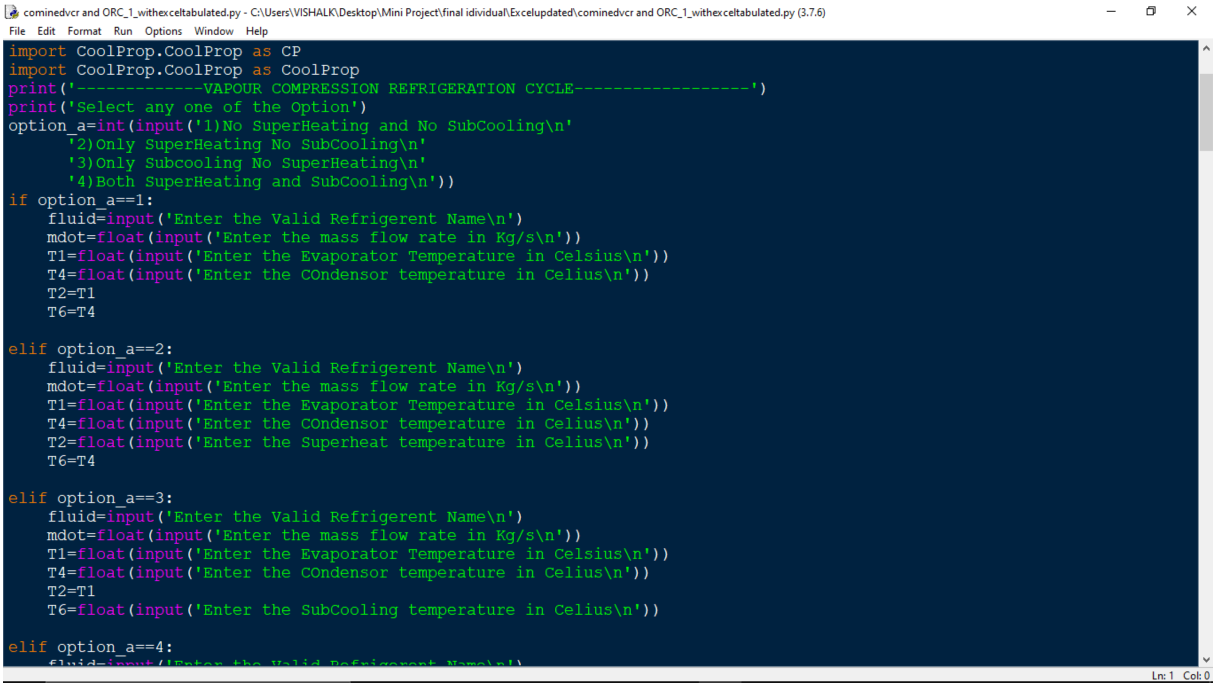


Fig 6: Process Flowchart

13.2 A SCREENSHOT OF THE PROGRAM:



```
import CoolProp.CoolProp as CP
import CoolProp.CoolProp as CoolProp
print('-------------VAPOUR COMPRESSION REFRIGERATION CYCLE-----------------')
print('Select any one of the Option')
option_a=int(input('1)No SuperHeating and No SubCooling\n'
      '2)Only SuperHeating No SubCooling\n'
      '3)Only Subcooling No SuperHeating\n'
      '4)Both SuperHeating and SubCooling\n'))
if option_a==1:
    fluid=input('Enter the Valid Refrigerent Name\n')
    mdot=float(input('Enter the mass flow rate in Kg/s\n'))
    T1=float(input('Enter the Evaporator Temperature in Celsius\n'))
    T4=float(input('Enter the COndensor temperature in Celius\n'))
    T2=T1
    T6=T4

elif option_a==2:
    fluid=input('Enter the Valid Refrigerent Name\n')
    mdot=float(input('Enter the mass flow rate in Kg/s\n'))
    T1=float(input('Enter the Evaporator Temperature in Celsius\n'))
    T4=float(input('Enter the COndensor temperature in Celius\n'))
    T2=float(input('Enter the Superheat temperature in Celius\n'))
    T6=T4

elif option_a==3:
    fluid=input('Enter the Valid Refrigerent Name\n')
    mdot=float(input('Enter the mass flow rate in Kg/s\n'))
    T1=float(input('Enter the Evaporator Temperature in Celsius\n'))
    T4=float(input('Enter the COndensor temperature in Celius\n'))
    T2=T1
    T6=float(input('Enter the SubCooling temperature in Celius\n'))

elif option_a==4:
```

Fig 7: A screenshot of the program.

13.3 USER INPUTS

These are the data that the user will need to feed the program with to get the desired output.

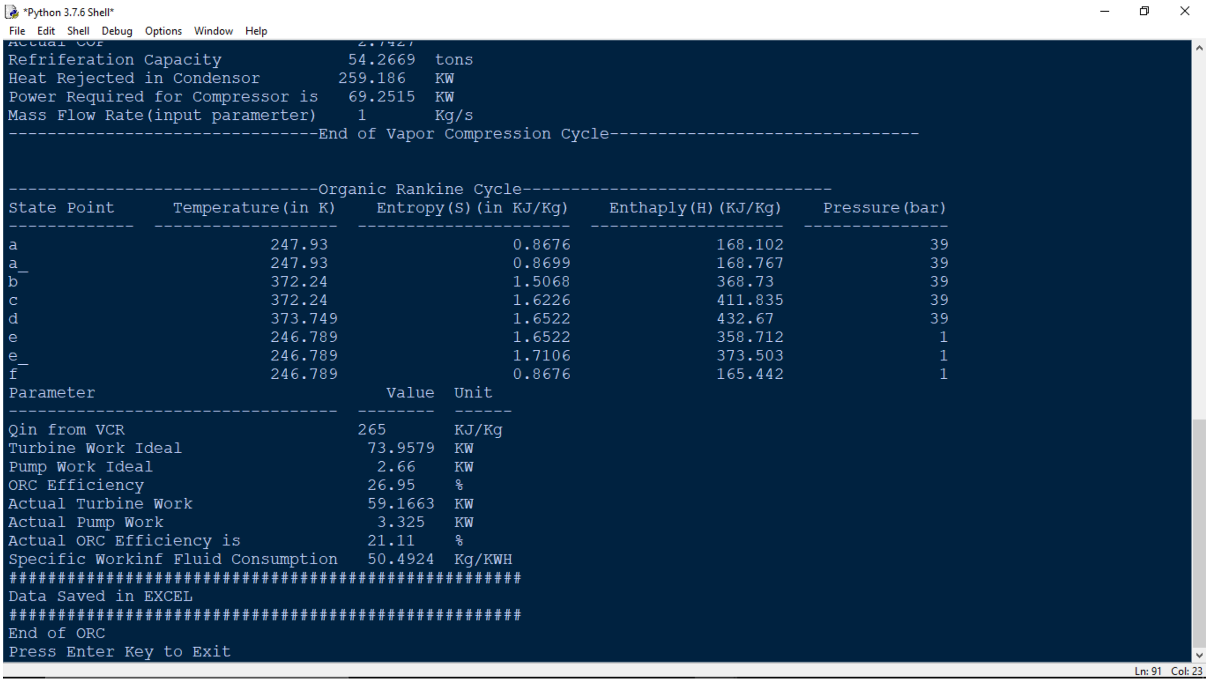
For VCR the user inputs are:

- Working fluid in VCR
- Evaporator temperature in Celsius
- Superheat temperature in Celsius
- Condenser temperature in Celsius
- Sub-cooling temperature in Celsius

For ORC the user inputs are:

- Working fluid in ORC
- Boiler temperature in Celsius
- Condenser temperature in Celsius

13.4 OUTPUTS



```
Refrigeration Capacity         54.2669  tons
Heat Rejected in Condensor     259.186   KW
Power Required for Compressor is  69.2515  KW
Mass Flow Rate(input paramerter)    1       Kg/s
-------------------------------End of Vapor Compression Cycle-------------------------------


-------------------------------Organic Rankine Cycle-------------------------------
State Point      Temperature(in K)    Entropy(S)(in KJ/Kg)    Enthaply(H)(KJ/Kg)     Pressure(bar)
-------------  -------------------  ---------------------  --------------------  --------------
a                           247.93                 0.8676               168.102              39
a_                          247.93                 0.8699               168.767              39
b                           372.24                 1.5068               368.73               39
c                           372.24                 1.6226               411.835              39
d                           373.749                1.6522               432.67               39
e                           246.789                1.6522               358.712               1
e_                          246.789                1.7106               373.503               1
f                           246.789                0.8676               165.442               1
Parameter                             Value  Unit
----------------------------------  --------  ------
Qin from VCR                        265       KJ/Kg
Turbine Work Ideal                   73.9579  KW
Pump Work Ideal                       2.66    KW
ORC Efficiency                       26.95    %
Actual Turbine Work                  59.1663  KW
Actual Pump Work                      3.325   KW
Actual ORC Efficiency is             21.11    %
Specific Workinf Fluid Consumption   50.4924  Kg/KWH
#####################################################
Data Saved in EXCEL
#####################################################
End of ORC
Press Enter Key to Exit
```

Fig 8: A screenshot of the output of the programme

14. GRAPHS OBTAINED FROM PROGRAM

There are a few conditions that we have considered while obtaining the graphs from the program:

For VCR:

- Evaporator temp=0*C
- condenser temperatures are 30,35 and 40*C
- Mass flow rate of working fluid =1kg/s
- No superheating and no subcooling.

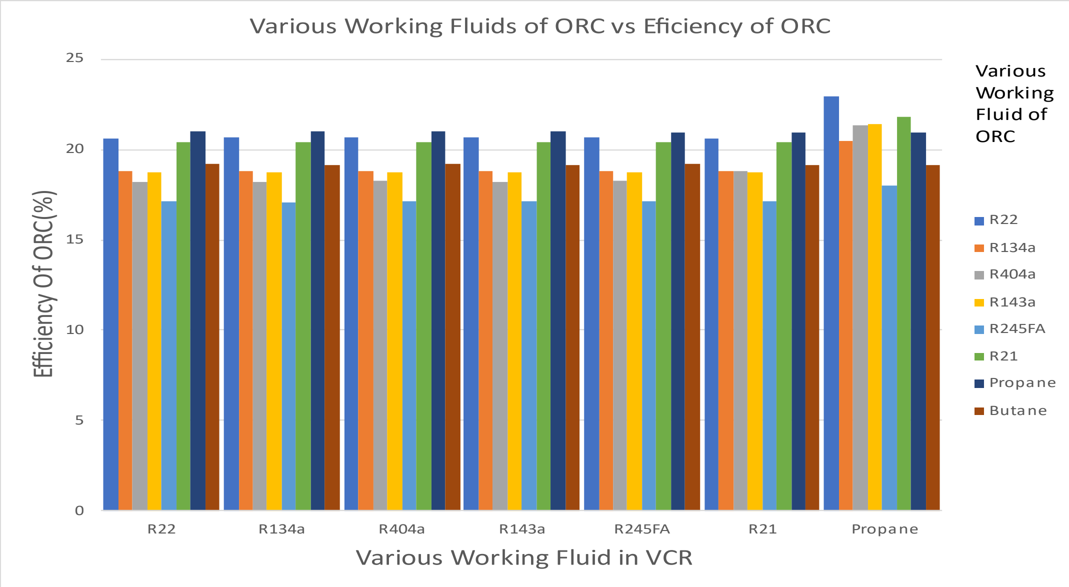
FOR ORC:

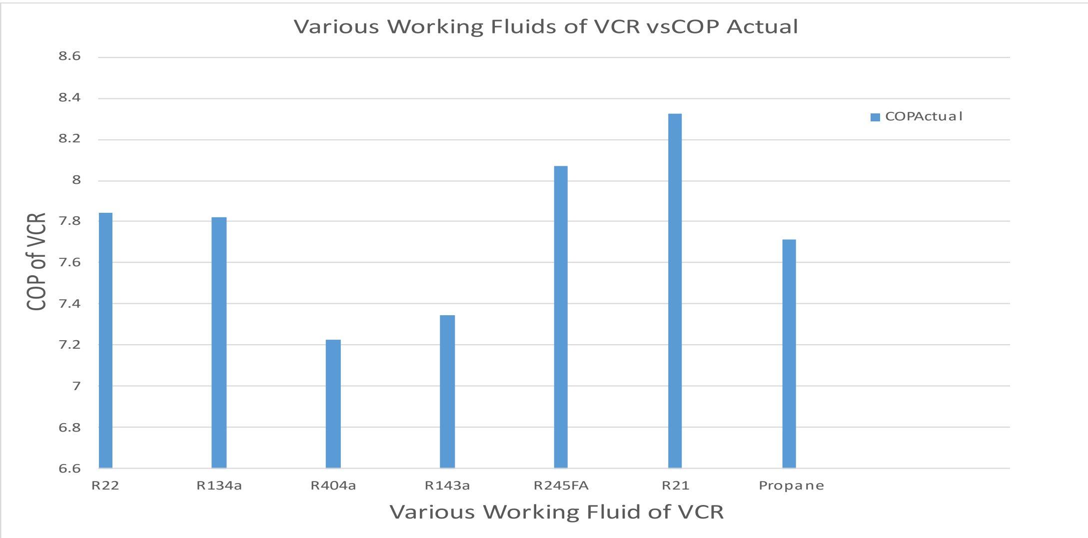
- Max operating pressure(boiler)=35 bar
- Condenser pressure= 1 bar.

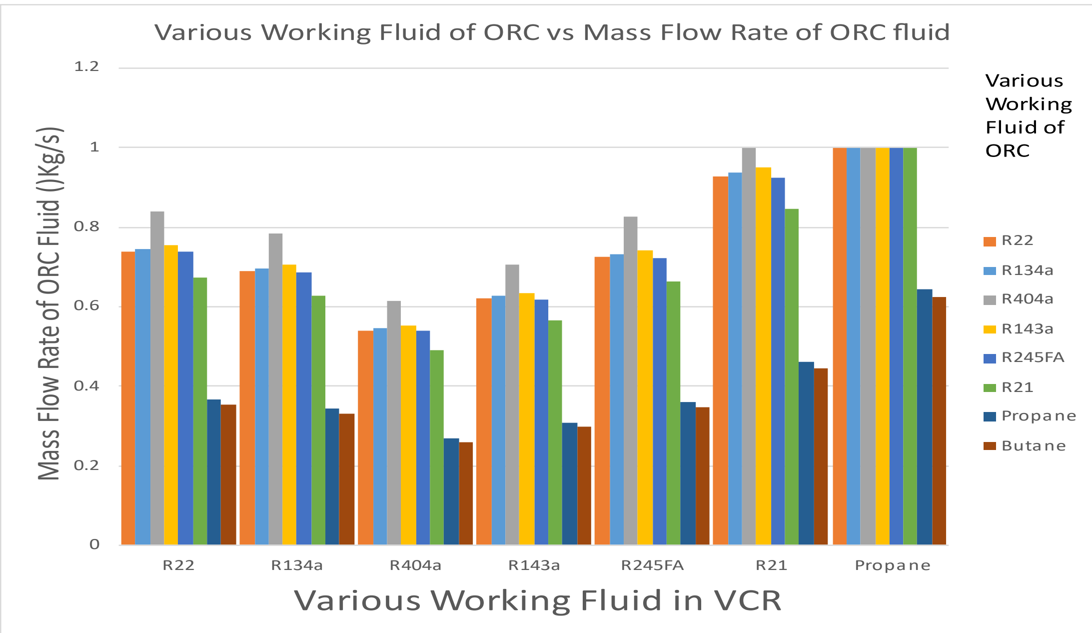
The graphs obtained pertaining to these conditions are:

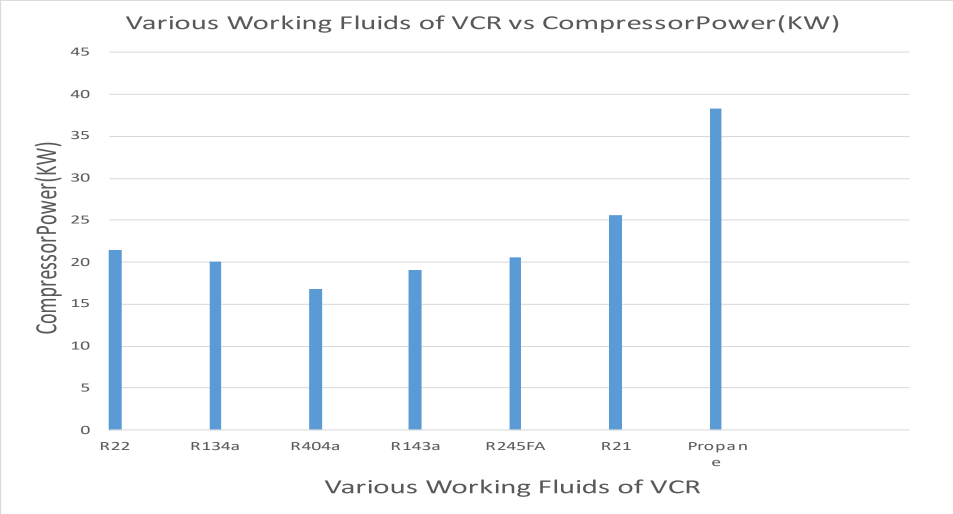
- For condenser temperature of 30°C:

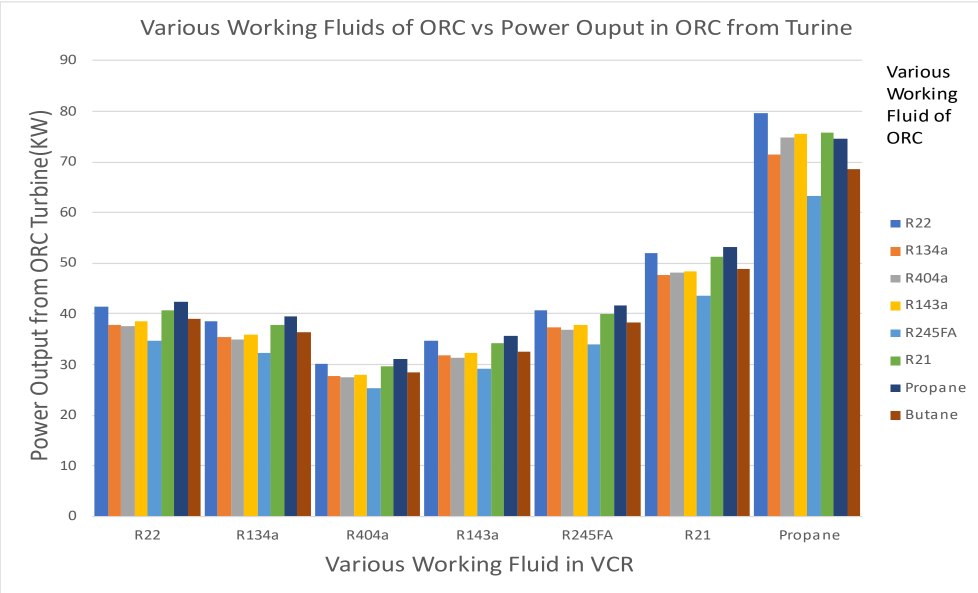
Condensor Temp	Working Fluid in VCR	COPActual	Refrigeration Capacity (tons)	QoutcondensorVCR(KW)	CompressorPower(KW)	Working Fluid in ORC	Actual Turbine Work(KW)	Actual ORC Efficiency is(%)	Mass Flow Rate of Working Fluid in ORC
30	R22	7.8457	48.1212	189.8912	21.4671	R22	41.3976	20.64	0.738
						R134a	37.9074	18.79	0.746
						R404a	37.4841	18.24	0.84
						R143a	38.4617	18.73	0.756
						R245FA	34.7019	17.12	0.737
						R21	40.7267	20.39	0.674
						Propane	42.5106	20.99	0.367
						Butane	39.0437	19.21	0.355
	R134a	7.8223	44.8232	176.9366	20.0555	R22	38.5929	20.65	0.688
						R134a	35.3159	18.79	0.695
						R404a	34.9405	18.24	0.783
						R143a	35.867	18.75	0.705
						R245FA	32.3005	17.1	0.686
						R21	37.9471	20.39	0.628
						Propane	39.6148	20.99	0.342
						Butane	36.2941	19.16	0.33
	R404a	7.2257	34.8003	138.6576	16.8566	R22	30.2348	20.65	0.539
						R134a	27.6938	18.8	0.545
						R404a	27.3991	18.25	0.614
						R143a	28.0831	18.73	0.552
						R245FA	25.3319	17.12	0.538
						R21	29.7293	20.39	0.492
						Propane	31.0432	20.99	0.268
						Butane	28.4854	19.19	0.259
	R143a	7.3437	40.0716	159.3485	19.098	R22	34.7785	20.67	0.62
						R134a	31.8097	18.79	0.626
						R404a	31.4598	18.24	0.705
						R143a	32.3058	18.75	0.635
						R245FA	29.0987	17.11	0.618
						R21	34.2007	20.41	0.566
						Propane	35.6765	20.99	0.308
						Butane	32.6647	19.15	0.297
	R245FA	8.0726	47.3873	186.4012	20.5456	R22	40.6684	20.66	0.725
						R134a	37.2468	18.81	0.733
						R404a	36.8147	18.25	0.825
						R143a	37.7494	18.73	0.742
						R245FA	34.0427	17.11	0.723
						R21	40.0016	20.4	0.662
						Propane	41.6998	20.98	0.36
						Butane	38.2738	19.18	0.348
	R21	8.3226	60.8393	238.5232	25.5855	R22	51.9994	20.64	0.927
						R134a	47.6638	18.81	0.938
						R404a	48.2166	18.79	1
						R143a	48.3315	18.74	0.95
						R245FA	43.5539	17.11	0.925
						R21	51.1803	20.4	0.847
						Propane	53.2831	20.95	0.46
						Butane	48.9421	19.17	0.445
	Propane	7.7158	84.5808	334.3998	38.367	R22	79.7443	22.96	1
						R134a	71.5331	20.5	1
						R404a	74.8107	21.35	1
						R143a	75.4719	21.43	1
						R245FA	63.308	18.04	1
						R21	75.8487	21.79	1
						Propane	74.7122	20.95	0.645
						Butane	68.6289	19.17	0.624

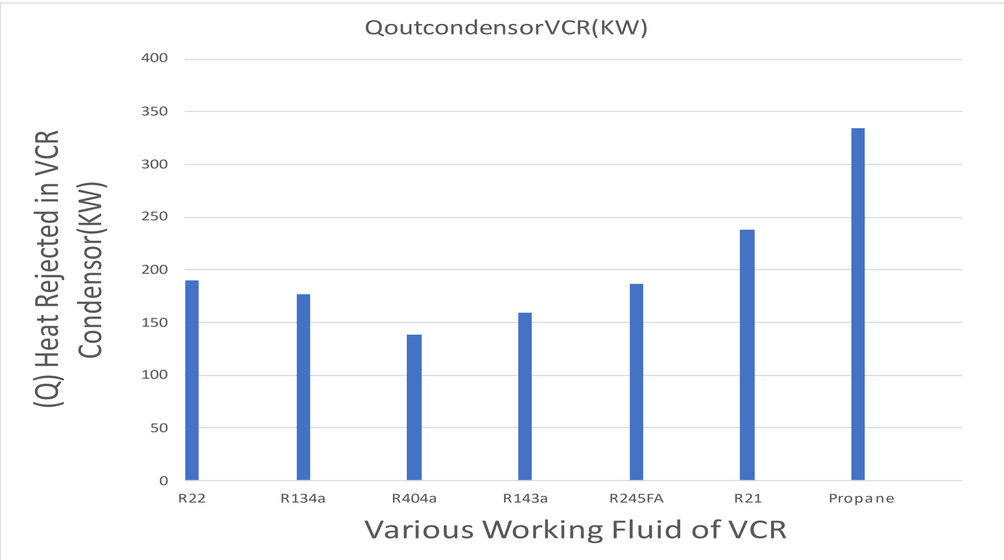

Various Working Fluids of ORC vs Eficiency of ORC
Efficiency Of ORC(%)
25
20
15
10
5
0
R22
R134a
R404a
R143a
R245FA
R21
Propane
Various Working Fluid in VCR
Various Working Fluid of ORC
R22
R134a
R404a
R143a
R245FA
R21
Propane
Butane


Various Working Fluids of VCR vsCOP Actual
COP of VCR
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
COPActual
R22
R134a
R404a
R143a
R245FA
R21
Propane
Various Working Fluid of VCR


Various Working Fluid of ORC vs Mass Flow Rate of ORC fluid
Mass Flow Rate of ORC Fluid ()Kg/s)
1.2
1
0.8
0.6
0.4
0.2
0
R22
R134a
R404a
R143a
R245FA
R21
Propane
Various Working Fluid in VCR
Various Working Fluid of ORC
R22
R134a
R404a
R143a
R245FA
R21
Propane
Butane


Various Working Fluids of VCR vs CompressorPower(KW)
CompressorPower(KW)
45
40
35
30
25
20
15
10
5
0
R22
R134a
R404a
R143a
R245FA
R21
Propan
e
Various Working Fluids of VCR


Various Working Fluids of ORC vs Power Ouput in ORC from Turine
Power Output from ORC Turbine(KW)
90
80
70
60
50
40
30
20
10
0
R22
R134a
R404a
R143a
R245FA
R21
Propane
Various Working Fluid in VCR
Various Working Fluid of ORC
R22
R134a
R404a
R143a
R245FA
R21
Propane
Butane


QoutcondensorVCR(KW)
(Q) Heat Rejected in VCR Condensor(KW)
400
350
300
250
200
150
100
50
0
R22
R134a
R404a
R143a
R245FA
R21
Propane
Various Working Fluid of VCR

15. APPLICATIONS OF THIS PROJECT

- Milk chilling plants
- Production of hydrogen and oxygen plants
- Petrochemical industries
- Pharma industries
- Food processing industries

16. CONCLUSIONS

A combined power and refrigeration system consisting of ORC and VCC has been analyzed using Python as Programming Language and running the same for different inputs. It is done by keeping mass flow rate of working fluid as 1Kg/s, Evaporator Temperature as 0C and Condenser Temperature of 30C and in ORC working Pressures are 35bar and 1bar.It is done for different combinations of working fluids.

Best VCR Working Fluid

It is evident that from the graph of Various Working Fluids of VCR vs COP Actual that COP is very high for R21 as working fluid in VCR but since its GWP is very high it is best preferred to use R245fa since it is HFC and has low GWP and High COP for given working conditions.

In the graph of Various Working Fluids of VCR vs Compressor Power (KW) we can conclude that R404a is best working fluid in VCR since power consumed by compressor is low but it also has very low COP hence R245fa is preferred.

Hence overall in VCR it is best to use R245fa as working fluid.

Best ORC Working Fluid

By considering the ORC working Fluid based on Efficiency of ORC it is observed that not much difference in efficiency is observed. There exits the difference of maximum 2% with Propane being highest and R245fa being lowest.

By considering the mass flow rate of Working Fluid, it is evident that mass flow rate has to minimum as it reduces the complexity and overall cost of plant. Therefore, Propane or Butane is the best suited regarding the mass flow rate.

And Power Out of the Turbine is high for Propane and Butane with very minued difference.

Hence overall in ORC it is best to use Propane/Butane as working fluid.

Finally, we can say that for the given operating conditions the Working Fluid for VCR is R245fa and for ORC is Propane.

17. REFERENCES

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