Indian Institute Of Technology - Gandhinagar

Project-2 (Fall 2019)

Thermodynamics

ES 211

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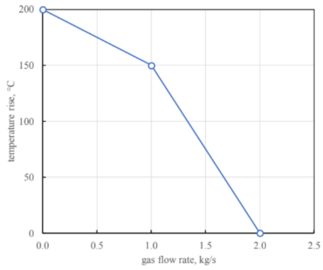
1 Problem 1

1.1 Problem re-statement

In order to design a power facility for ChandraLab, we have to choose a simple Brayton cycle with Argon as the working fluid & pressure ratio of 6. The heat exchanger functions to maintain the state at the entrance to the compressor at 50 kPa and -20 °C. For the necessary heat transfer, solar collectors have been adopted. Tests of these collectors give the temperature increase results shown in the figure. Our task is to develop a plot of the power that will be produced by this system and its thermal efficiency as a function of the argon mass flow rate. Also, we have to determine whether there is a "best" flow rate at which this power plant can operate. Following curve shows the temperature & mass flow rate relation:-



1.2 Brayton Cycle

Brayton cycle describes the working of constant Pressure heat engine.

1-2: Isentropic Compression

2-3: Constant Pressure heat addition

3-4:Isentropic Expansion

4-1: Constant Pressure heat rejection

$$Q_{input} = C_p(T_3 - T_2)$$
$$Q_{output} = C_p(T_4 - T_1)$$
$$Work = Q_{input} - Q_{output}$$
$$\text{Efficiency}(\eta\ ) = \frac{Q_{input} - Q_{output}}{Q_{input}}$$

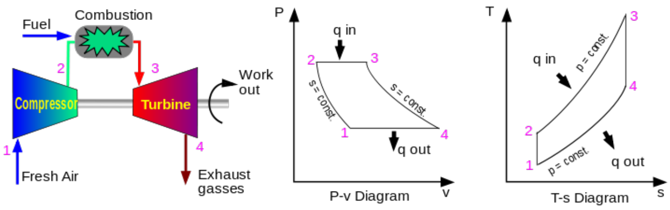


Figure 2: Brayton Cycle

1.3 Engineering Analysis and Solution

Following properties of state-1 are known:-

$$T_1 = -20^oC$$
$$P_1 = 50kPa$$

Hence, following properties of state-1 have been computed:-

$$\text{Entropy}(S_1) = 3.9 \times 10^3 J/K$$

$$\text{Enthalpy}(H_1) = -2.3415 \times 10^4 J/kg$$

At State 2

$$S_2 = S_1$$
$$P_2 = P1 \times 6$$

Enthalpy (H_2) = 1.144 $\times 10^5$ J/kg

We have the relation between δ T and m

$$T = 250 \text{ -50m} \implies 0 < m < 1$$
$$T = 300\text{-150m} \implies 1 < m < 2$$

Started the For Loop to find variables in the state 3.

$$Q_{input} = C_p \times m \times (250 - 50m) \implies 0 < m < 1$$
$$Q_{input} = C_p \times m \times (300 - 150m) \implies 1 < m < 2$$

$$H_3 = H2 + Q_{input}$$

We defined the state 3 with Pressure and Enthalpy. Hence we got the value of the Entropy at State 3 .

At State 4
$S_4 = S_3$
For state 4, we know S_4 and P_4 so we can find the value of H_4 through Cantera.

$$Q_{output} = H_4 - H_1$$

$$Work = Q_{input} - Q_{Output}$$

$$Efficiency(\eta\ ) = \frac{Q_{input} - Q_{Output}}{Q_{input}}$$

1.4 MATLAB Graph

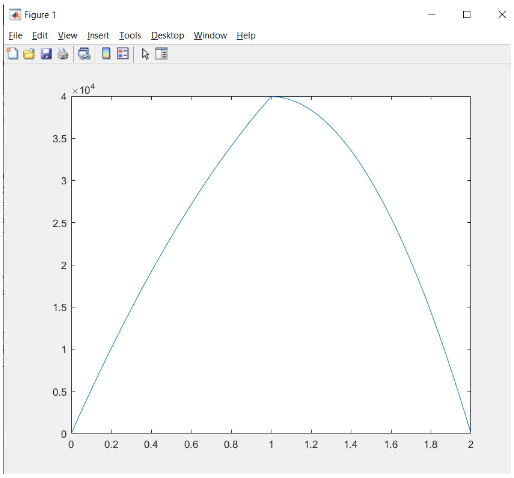


Figure 3: Power vs Mass Flow Rate

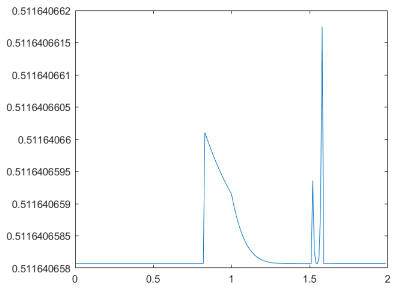


Figure 4: Efficiency vs Mass Flow Rate

The maximum peak of the graph is obtained at the mass flow-rate of **1.58 kg/s**. Yes there is best mass flow rate at **m = 1.58 kg/s**

The maximum Power is obtained to 39.665 kW, at the mass flow rate of m = 1 kg/s. The Power delivers by the cycle at the peak of the efficiency versus mass-flow rate curve is **26.5 kW**.

2 Problem 2

2.1 Problem re-statement

Considering a 10 MW geothermal power plant at a site where geothermal water is available at 230 °C, our task is to determine the optimum pressure of flash chamber & the thermal efficiency, both using various test cases for pressures. The details are as follows:-

Geothermal water is to be flashed into a chamber to a lower pressure where part of the water evaporates. The liquid is returned to the ground while the vapor is used to drive the steam turbine. The pressures at the turbine inlet and the turbine exit are to remain above 200 kPa and 8 kPa, respectively. High-pressure flash chambers yield a small amount of steam at high temperature whereas lower-pressure flash chambers yield considerably more steam but at a lower temperature. Assume that 10 percent of the power produced is used to drive the pumps and other auxiliary equipment.

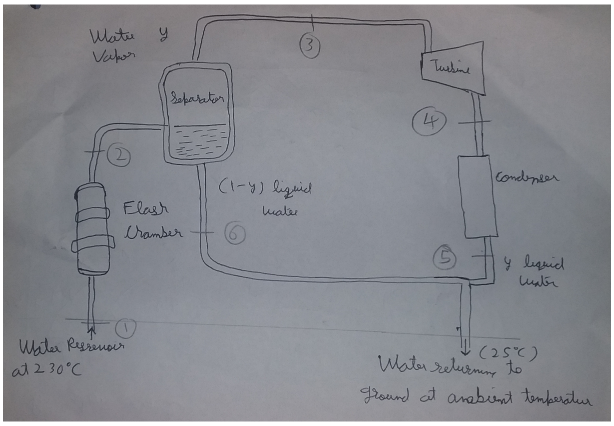


Figure 5: Schematic representation of Geo-thermal power plant

2.2 Assumptions:

1. The flash chamber raises the pressure of the incoming water, by an isenthalpic flashing process. Water is in liquid-vapor mixture state at the exit of flash chamber.
2. There is no heat exchange or work interaction at the separator. The separator separates the vapor and the liquid water.
3. The only heat input to the power-plant is due the hot water entering the plant.

4. Turbine is the only device that is producing the work-output. The turbine operates insentropically. The pressure at the outlet of turbine is maintained at 8 kPa and the vapor leaves the turbine with 100% quality.
5. The pressure losses in the pipes are negligible.

2.3 Stream Path

Water at 230° C is being pumped into the flash chamber. The flash chamber increases the pressure of the water. The water, without having any pressure drop, enters a separation tank. The pressure of the vapor leaving the flash separation tank is same as the pressure at the exit of flash chamber.

2.4 Problem Solution

Water enters the flash chamber as super-cooled liquid at $230°C$. The pressure at the turbine inlet is same as the pressure at the exit of flash chamber. Let P_2 be the pressure of the vapor-liquid mixture leaving the flash chamber.

Enthalpy at State-1 $= h_1 = h_{f@230°C} = -1.4981 \times 10^7$ kJ/kg

The pressure at state-2 is P_2 and the enthalpy at state-2 is same as h1.

$$h2 = h1$$

Also, P_2 is known. So, by finding $h_{f@P_2}$ and $h_{g@P_2}$, The quality (y) of the mixture can be determined as follows:-

$$y = \frac{h_2 - h_f}{h_g - h_f}$$

The amount of the steam entering the turbine is y kg, whereas $(1-y)$ kg of water leaves the separator and flows to the ground.At the inlet of turbine :

$$P_3 = P_2 \implies h_3 = h_{g@P_3}, s_3 = s_{g@P_3}$$

At the turbine outlet, expansion in turbine is isentropic :

$$P_4 = 8kPa, s_4 = S_3 \implies h4 \text{can be known}$$

.

$$w_{turb} = h_3 - h_4$$

Work per unit mass

$$W_{turb} = y(h_3 - h_4)$$

First Law Analysis of the Power-plant :

Let m_{cond}, be the mass of the water that flows through the condenser that is used for the cooling of the turbine outlet stream. m_w is the mass of water flowing from the reservoir at 230° C

$$Q_{in} - W_{out} = \Delta E_{sys}$$

$$0 - W_{turb} = m_w(h_6 - h_1) + m_{cond} C_v \Delta T_{cond}$$

(where ΔT_{cond} is the temperature increase of the water flowing through the condenser)

$$-W_{turb} = -Q_{in} + Q_{out}$$

where $Q_{in} = m_w(h_1 - h_6)$ and $Q_{out} = m_{cond} C_v \Delta T_{cond}$
The stream leaving the turbine, then enters the condenser. In the condenser, the steam is cooled down to water at the ambient temperature of $25°C$. For a unit mass of water entering the flash-chamber per unit time, i.e., $m_w = 1$ kg/s,

$$h_6 = h_{f@25°C} = -1.5866 \times 10^7 \text{J/kg} \text{..................From CANTERA}$$

$$q_{in} = 1(h_1 - h_6) = 8.8524 \times 10^5 \text{J/kg}$$

Out of the total power produced by the turbine, 10% is used to drive the pumps and other auxiliary equipment.

$$\text{Efficiency}(\eta) = \frac{0.9 \times w_{turb}}{q_{in}} \times 100$$

2.5 MATLAB Solution

We have written a code in MATLAB to calculate efficiencies at various values of pressure. Since the pressure at the inlet has to be greater than 200 kPa, we started with the initial value of pressure as 200 kPa and successively increased it. The detailed MATLAB file has been attached in the folder alongwith.

2.6 Data Collected

Quality	Pressure (kPa)	Efficiency	Power (kW/kg)
0.2204	200	0.1067	94.486
0.2178	210	0.1071	94.831
0.2154	220	0.1074	95.115
0.213	230	0.1077	95.345
0.2106	240	0.1079	95.525
0.2084	250	0.1081	95.662
0.2062	260	0.1082	95.759
0.2041	270	0.1082	95.819
0.202	280	0.1083	95.847
0.2	290	0.1083	95.844
0.198	300	0.1082	95.814
0.1961	310	0.1082	95.759
0.1942	320	0.1081	95.681
0.1924	330	0.108	95.582
0.1906	340	0.1078	95.463
0.1888	350	0.1077	95.325
0.1871	360	0.1075	95.171
0.1854	370	0.1073	95.001
0.1838	380	0.1071	94.817
0.1821	390	0.1069	94.619
0.1805	400	0.1066	94.408
0.179	410	0.1064	94.185
0.1774	420	0.1061	93.952
0.1759	430	0.1059	93.708
0.1744	440	0.1056	93.455
0.1729	450	0.1053	93.192
0.1715	460	0.105	92.921
0.17	470	0.1047	92.642
0.1686	480	0.1043	92.356
0.1672	490	0.104	92.062
0.1659	500	0.1037	91.762

The value of quality, camber pressure (kPa), efficiency, and electric power produced by the turbine is tabulated in the table. We have used more than 400 values of pressure to find the optimum efficiency. The table containing more values has been attached in the folder.

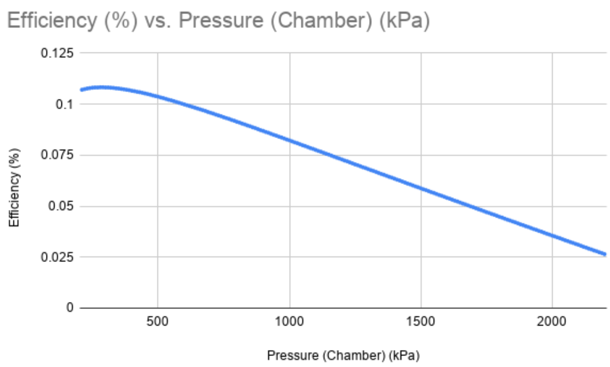


Figure 6: Efficiency versus Chamber Pressure

2.7 Conclusion

The optimum efficiency for the power plant is **10.93 %**. The pressure needed to achieve this efficiency is **285 kPa** and the electric power produced after considering the losses is **95.85 kW/kg-s**.