Objective

- To study the performance of a steam power plant unit.
- Perform 2nd law analysis for the cycle .

Experimental Setup

The experimental setup is shown in figure (1). The steam power plant unit consists of four main components . The first one is the steam generator, which is a steam boiler and a burner with a flowmeter to measure the mass flow rate of the steam and a graduated sight glass on the fuel tank to enable measuring the fuel consumption . The second component is the steam turbine, which is connected to an electrical generator through a couple.. The third component is the condenser, which uses water to condense the steam leaving the turbine. The last component is the vacuum pump, which increases the pressure of the working fluid from the pressure of the condenser to the pressure of the steam generator .

Figure (1) : Components of steam power plant unit

Start-up Procedure

1. Run the boiler and operate the burner. One hour is required to reach normal operating conditions of the boiler.
2. Operate the steam turbine. Enough time is needed for warming the turbine before it is connected to the electrical generator.

3. Run the vacuum pump and the circulating water pump which will circulate the water in the pipes.
4. The experiment now is ready to carry on.

Experimental Procedure

1. Perform the start-up procedure.
2. Wait until readings reach steady state, and then start recording the temperatures (T_1, T_2, T_3, $T_{3'}$,T_4), the boiler pressure, the condenser pressure, the mass flow rate of the steam , the mass flow rate of the cooling water and its inlet and outlet temperatures , the voltage and the current supplied by the electrical generator, the torque and the speed of the electrical generator, the amount of fuel consumed, and the time it took to consume that amount of fuel.

Given Data

- Atmospheric pressure P_{atm} = 100 kPa
- Atmospheric temperature T_{atm} = 15 ^oC
- Assume furnace temperature to be 1300 ^oC

Data observed

Table (1) :Data Observed

Device/Location	Item	Unit	Value
Diesel Fuel	Consumed	mL	800
	Time	s	150
	Density	Kg/m^3	750
	Calorific Value	kJ/kg	41000
Steam Generator	Feed Water Temperature	^oC	32
	Steam Temperature	^oC	285
	Boiler Pressure	Bar_Abs	10
	Mass flow Rate	kg/hr	150
Steam Turbine	Inlet	^oC	275
	Outlet	^oC	75
Steam Condenser	Inlet	^oC	70
	Condensate	^oC	30
	Pressure	bar_Abs	0.10
Cooling Tower	Flow rate	m^3/hr	15
	Inlet	^oC	17
	Outlet	^oC	23
Electrical Generator	Voltage	Volts	220
	Current	Ampere	11
	Torque	N.m	10
	Speed	Rpm	3000

Sample Calculations

The following figure represents the steam power plant cycle

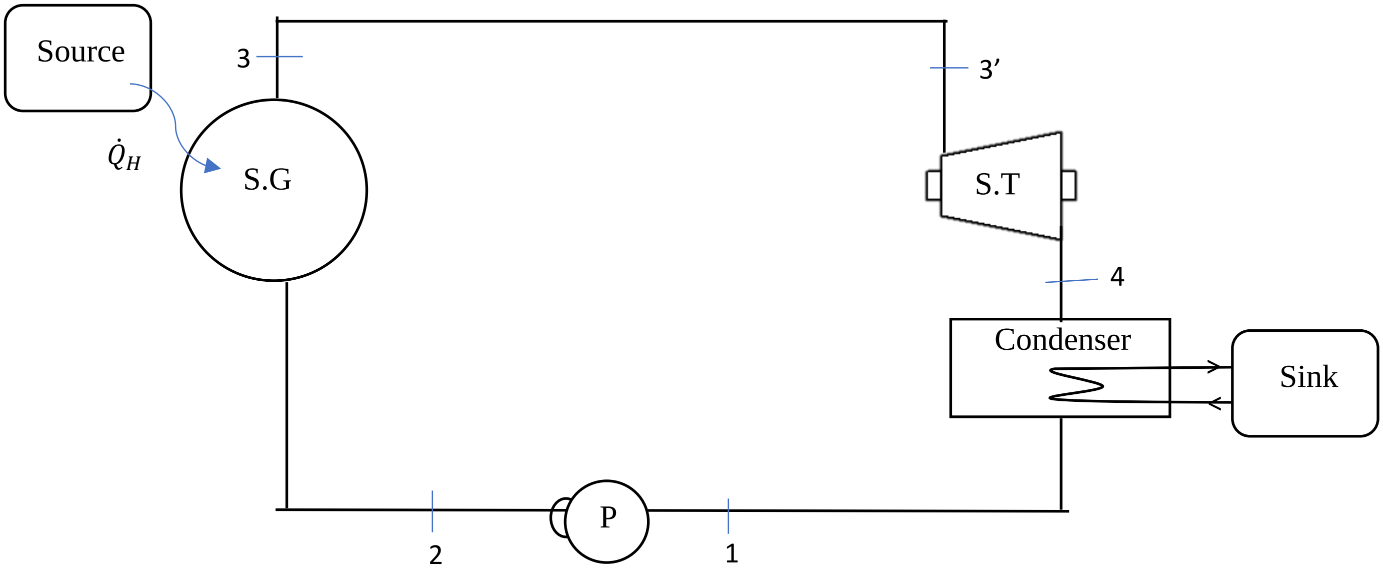

Figure (2) : Steam power plant cycle

Step(1): Find the specific enthalpy and the specific entropy at each state

State 1 :

T_1 = 30 °C
P_1 = 10 kPa

Subcooled
$h_1 = h_{f@30\,^oC}$ = 125.74 kJ/kg
$s_1 = s_{f@30\,^oC}$ = 0.4368 kJ/K.kg
$v_1 = v_f$ = 0.001004 m³/kg

State 2 :

T_2 = 32 °C
P_2 = 10.5 bar

Subcooled , from tables
h_{2a} = 134.99843 kJ/kg
$s_{2.a}$ = 0.463782 kJ/K.kg

State 3 :

T_3 = 285 °C
P_3 = 10 bar

Superheated
h_3 = 3019.4 kJ/kg
s_3 = 7.06750 kJ/K.kg

State 3' :

$T_{3'}$ = 275 °C
$P_{3'}$ = 10 bar

Superheated
$h_{3'}$ = 2997.57 kJ/kg
$s_{3'}$ = 7.02845 kJ/K.kg

State 4 :

T_4 = 275 °C
P_4 = 10 bar

Superheated
h_4 = 2630.3 kJ/kg
s_4 = 8.2891 kJ/K.kg

Step(2) : Take the steam generator as control volume and find $\dot{Q}_H, \dot{Q}_{in}$, $\eta_{S.G}$

$\dot{Q}_H = \frac{\rho_f \forall_f}{t} \times Q_{cv} \times \eta_c$ [1] $= \frac{750\times800\times10^{-6}}{150} \times 41000 \times 1 = 164$ kWatt

$\dot{Q}_{in} = \dot{m}_s \times (h_3 - h_2)$ [1] $= \frac{150}{3600} \times (3019.4 - 134.99843) = 120.183$ kWatt

$\eta_{S.G} = \frac{\dot{Q}_{in}}{\dot{Q}_H} = \frac{120.183}{164} \times 100\% = 73.28\%$

Step(2) : Take the steam turbine as control volume and find the following

The power delivered by the turbine $\dot{W}_T = \dot{m}_s \times (h_{3'} - h_4)$ [1]

$= \frac{150}{3600} \times (2997.75 - 2630.3) = 15.31$ kWatt

The power delivered to coupling = $\dot{W}_T$

The power delivered to electrical generator = $\dot{W}_{g\ in} = \tau \times \omega = \tau \times \frac{2\pi\frac{N}{60}}{1000}$ [1]

$= 10 \times \frac{2\pi\frac{3000}{60}}{1000} = 3.1416$ kWatt

The electrical power generated $\dot{W}_E = \frac{V \times I}{1000}$ [1] $= \frac{220\times11}{1000} = 2.42$ kWatt

$\eta_{coupling} = \frac{\dot{W}_{g\ in}}{\dot{W}_T} = \frac{3.1416}{15.31} \times 100\% = 20.52\%$

$\eta_{gen} = \frac{\dot{W}_E}{\dot{W}_{g\ in}} = \frac{2.42}{3.1416} \times 100\% = 77.03\%$

Step(3) : Take the cooling system as control volume and find $\dot{Q}_L, \dot{Q}_{cw}$, η_{Cond}

$\dot{Q}_L = \dot{m}_s \times (h_4 - h_1)$ [1] $= \frac{150}{3600} \times (2630.3 - 125.74) = 104.356$ kWatt

$\dot{Q}_{cw} = \dot{m}_{cw} \times C_{p,cw} \times \Delta T$ [1] $= \frac{15\times1000}{3600} \times 4.18 \times (23 - 17) = 104.5$ kWatt

$\eta_{Cond} = \frac{\dot{Q}_{cw}}{\dot{Q}_L} = \frac{104.5}{104.356} \times 100\% = 100.1\%$

Step(4) : Calculate the power consumed by the pump $\dot{W}_p$, the net power of the cycle $\dot{W}_{net}$ and the thermal efficiency of the cycle η_{th}

$\dot{W}_p = \dot{m}_s \times (h_2 - h_1)$ [1] $= \frac{150}{3600} \times (134.99843 - 125.74) = 0.3858$ kWatt

$\dot{W}_{net} = \dot{W}_T - \dot{W}_p$ [1] $= 15.31 - 0.3858 = 14.924$ kWatt

$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$ [1] $= \frac{14.924}{120.183} \times 100\% = 12.42$ %

Step(5) : Calculate the Carnot thermal efficiency η_{Carnot} and the 2nd law efficiency of the cycle η_{II}

$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$ [1] $= 1 - \frac{15+273}{1300+273} = 81.7\%$

$\eta_{II} = \frac{\eta th}{\eta Carnot} = \frac{12.42\%}{81.7\%} \times 100\% = 15.2\ \%$

Step(5) : Calculate the rate of exergy destroyed in the processes 3'- 4 and 2-3

$\dot{X}_{dest\ 3'-4} = \dot{m}_s T_o [s_4 - s_{3'}]\ [1] = \frac{150}{3600} \times (15 + 273) \times (8.2891 - 7.02845) = 15.1278$ kWatt

$$\dot{X}_{dest\ 2-3} = \dot{m}_s T_o \left[s_3 - s_2 - \frac{q_{in}}{T_H} \right] [1]$$

$$= \frac{150}{3600} \times (15 + 2730) \left(7.0675 - 0.463782 - \frac{2884.40157}{1300+273} \right) = 57.264 \text{ kWatt}$$

Results & Discussion

A steam power plant cycle is a cycle in which heat energy is converted into electrical energy. Since the objective of this experiment is to study the performance of a steam power plant cycle, several conclusions can be drawn from the results obtained from calculations.
Firstly, the efficiency of the steam generator is 72.28% .This value means that 0.7228 of the heat energy resulting from the combustion of the fuel is absorbed by the working fluid , while the rest is dissipated as heat losses. Secondly, the efficiency of the electrical generator is 77.03%. This value means that 0.7703 of the power delivered to the generator can be used as electrical power, while the rest of the power was dissipated due to frictional losses. Thirdly, it is obvious that the efficiency of the condenser is 100.1%,which means that the cooling water in the condenser is absorbing heat from the working fluid in the cycle and the ambient air.
Regarding the 2nd law efficiency of the cycle , it can be concluded that the performance of this cycle is not good, since the efficiency of this cycle is only 15.2% of the most efficient ideal Carnot cycle. Finally, it is noticeable that the exergy destroyed in the process 2-3 is greater than the corresponding value in the process 3'-4 because of the heat transferred in that process

Sources of Error

Errors in this experiment are caused by several factors such as: human error in recording the experimental data and computational. In addition , since the unit used in the experiment is old established, errors from the measuring devices are possible.

Summery & Conclusions

Overall, the experiment shows that steam power plant cycle are cycle that generates power using heat energy.. Frictional and heat losses dissipate most of the useful energy, which causes a reduction in the efficiency of the steam generator , the steam turbine and the efficiency of the whole cycle.

References

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