Experiment 9
THERMAL POWER PLANT

1. OBJECTIVE

- To study and observe the performance of a small model thermal power plant in operation consisting of a pump, boiler, turbine, and condenser.
- To evaluate the first law efficiency of each component and the whole cycle.

2. INTRODUCTION &THEORETICAL BACKGROUND

A steam power plant mainly comprises of a **boiler**, **condenser**, **pump** and a **turbine** that is connected to a generator to produce electricity. It uses water as a working fluid. For electricity to be produced the turbine is rotated by high pressure and high temperature steam producing mechanical power that rotates the motor in the generator, thus converting the mechanical power into electricity. To ensure continuous production of steam and thus electricity, steam goes through a number of processes described below; this cycle is known as the Rankine cycle. (See figure 1)

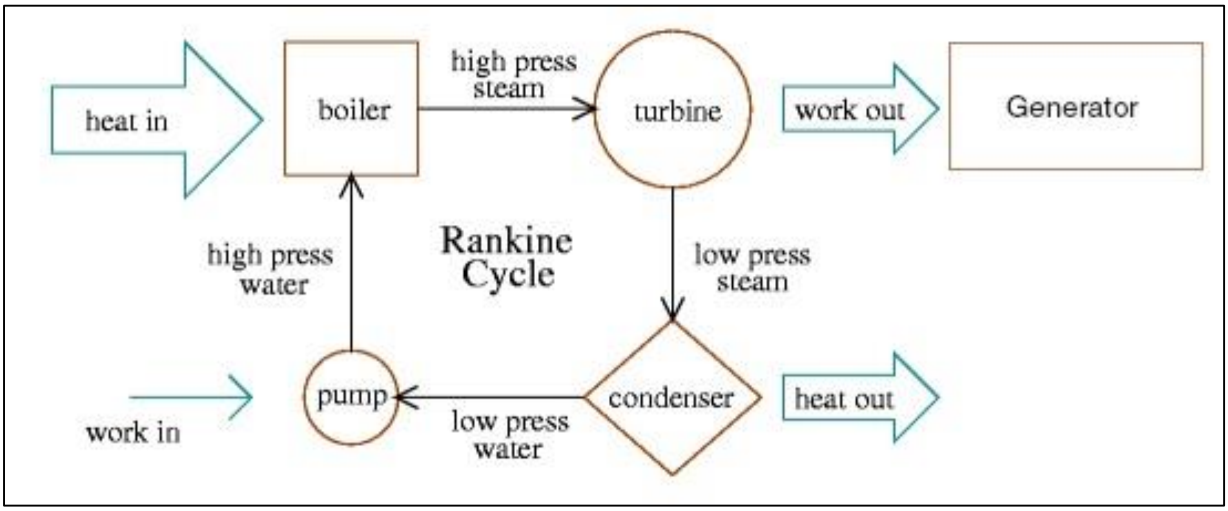

Fig. 1: Basic Ideal Rankine cycle

1- The ideal Rankine cycle

The ideal Rankine cycle does not involve any internal irreversibility's and consists of the four processes.

<u>**Process (1-2):** Isentropic compression in the pump.</u>

Water enters the pump at state 1 as saturated liquid and is compressed isentropically to operating pressure of the boiler. The water temperature increases somewhat during this isentropic compression process due to slight decrease in the specific volume of water.

Process (2-3): Constant pressure heat addition in the boiler.

Water enters the boiler as a compressed liquid at state 2 and leaves as a superheated vapor at state 3. Heat is transferred to the water essentially at constant pressure.

Process (3-4): Isentropic expansion in the turbine.

The superheated vapor at state 3 enters the turbine, where it expands isentropically and produces work by rotating the shaft connected to an electric generator. The pressure and the temperature of the steam are drop during this process to the values at state 4, where steam enters the condenser.

Process (4-1): Constant pressure heat rejection in the condenser.

At this state, the steam is usually a saturated liquid-vapor mixture with a high quality. Steam is condensed at constant pressure in the condenser by rejecting heat to the cooling tower. Steam leaves the condenser as saturated liquid and enters the pump, completing the cycle. (See figure 2)

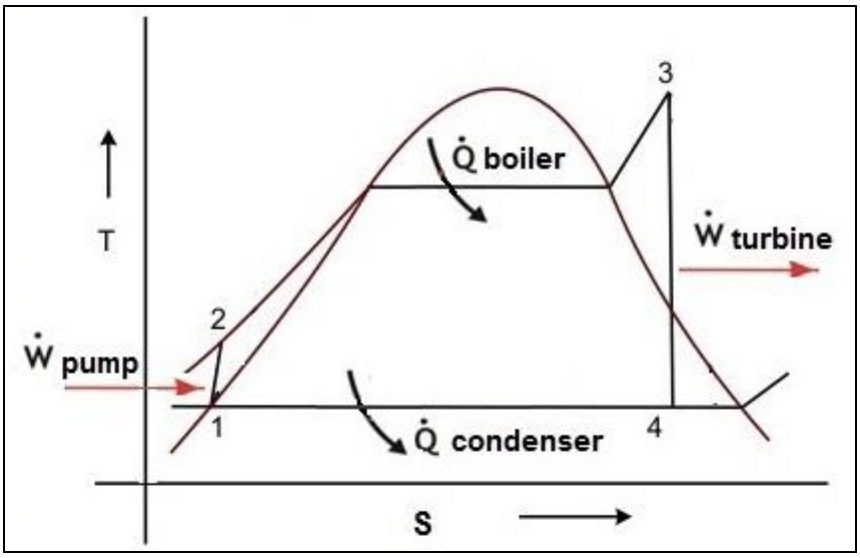

Fig. 2: The T-S Diagram of Ideal Rankine cycle

2- The Actual Rankine cycle

The actual vapor power cycle differs from the ideal Rankine cycle, as a result of irreversibilites in various components. *Fluid friction* and *heat loss* to the surroundings are the two common sources of irreversibilites.

Fluid friction causes pressure drop in the boiler, the condenser, turbine, and the piping between various components.

Heat loss from the steam to the surrounding as the steam flows through various components.

In actual practice, the pump and the turbine cannot be operated under isentropic condition because of irreversibilities. Therefore process (1-2) and (3-4) are non-isentropic. (See Figure 3)

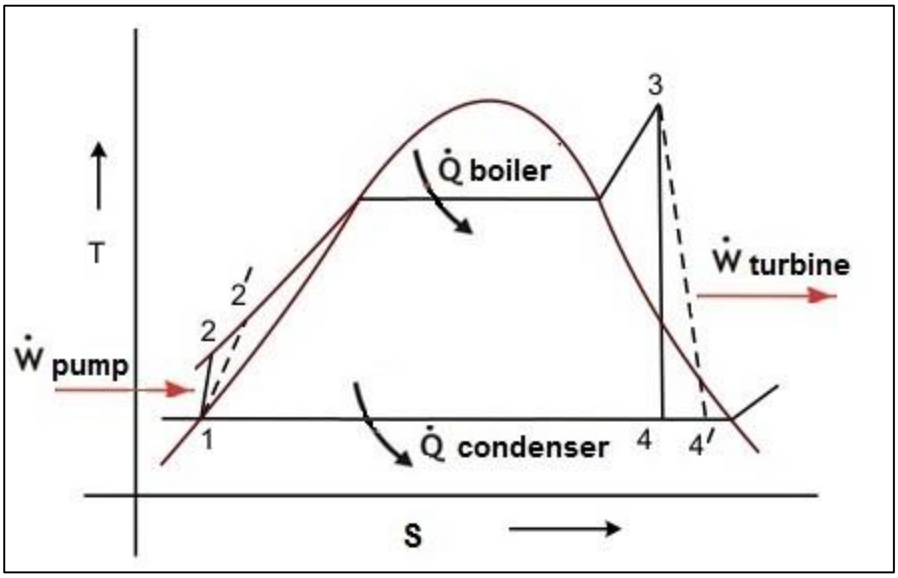

Fig. 3: T-S Diagram of Actual Rankine Cycle

3. APPARATUS

The steam power plant apparatus is consisting of:

Feed Pump: To force water into the boiler, by mechanical energy.

Boiler: To convert water to steam, there are two types:

- **A fire tube boiler**: In Fire-tube boilers hot flue gases pass through tubes and water surrounds them, like the one in our experiment.

- A **water tube boiler**: In Water-tube boilers water passes through tubes and hot flue gasses surround them. There are many advantages of water tube boiler: Larger heating surface can be achieved, due to convectional flow, movement of water is much faster, and hence rate of heat transfer is high which results into higher efficiency, very high pressure can be obtained smoothly.

Steam Turbine: A Steam Turbine is a mechanical device that extracts thermal energy from pressurized steam and transforms it into mechanical work.

Condenser: The condenser brings the exit steam into contact with a usually cold in order to remove heat and condense it back to water known as condensate.

Cooling Tower: To decrease the temperature of the cooling water after condensing the steam in the condenser. The type used is cross flow tower, where the tower provides a horizontal air flow as the water falls down the tower in the form of small droplets. The fan centered at one side of unit draws air through the cells.

AC Electric Generator: a generator is a device that converts mechanical energy to electrical energy for use in an external circuit, where the source of mechanical energy is the steam turbine coupled to the generator. (See figure 4)

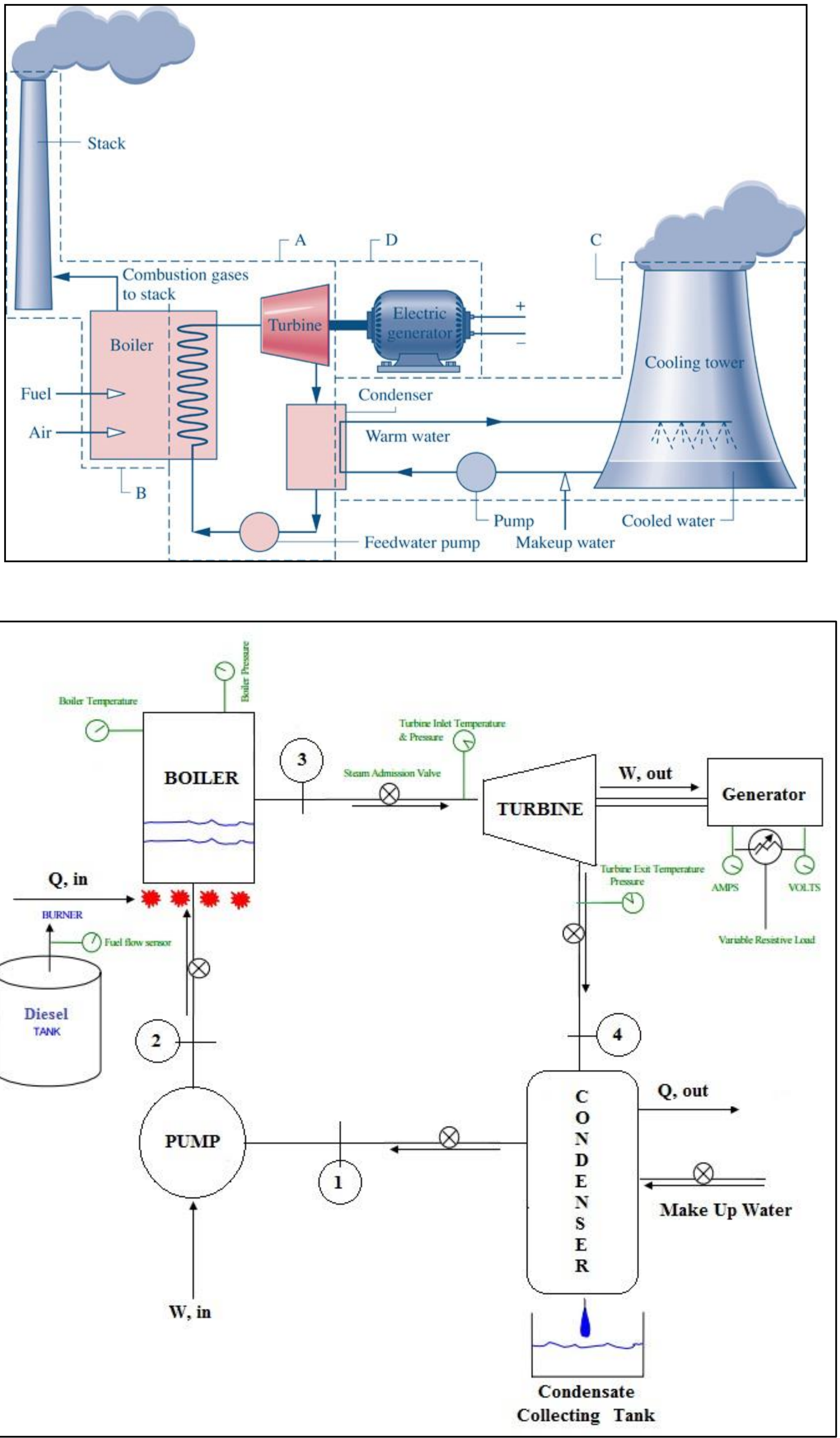

Fig. 4: Thermal Power Plant

4. PROCEDURE

1. Start the boiler and operate the burner.
2. One hour is necessary to obtain the normal operation conditions of the boiler.
3. Start the steam turbine.
4. A reasonable time should be allowed for warming the turbine before applying the load.
5. Start the circulation water pump.
6. Start the vacuum pump.
7. At the end of the experiment, close the Main Steam valve then turn off the light switches on the main switchboard. Leave the cooling water pump running for about an hour.

5. OBSERVATIONS

Table 1: DATA OBSERVED

Atmospheric Pressure: __________bar			
SERIES	**Item**	**Value**	**Unit**
Fuel (Diesel)	Consumed volume		ml
	Time taken		sec
	density	880	kg/m^3
	Calorific value	41400	kj/kg
Boiler Section	Feed water temperature		T1 / °C
	Exit steam temperature		T3 / °C
	Exit steam pressure (abs.)		P_2/kpa
	Mass flow rate of steam		kg/hr
Turbine Section	Steam inlet temperature		T3 / °C
	Steam exit temperature		T4' / °C
	Steam inlet pressure		P_2/kpa
Condenser Section	Condensate flow rate		m^3 / hr
	Condensate temperature		T5 / °C
	Condensate pressure(gauge)		P_2/kpa
	Cooling water inlet temperature		T_{wi} / °C
	Cooling water exit temperature		T_{wo} / °C
Generator Section	Generated Voltage		$Volt$
	Generated Current		$Ampere$
	Torque		$N.m$
	Speed		rpm

6. DATA ANALYSIS

1- Energy Analysis of the Actual Rankine Cycle

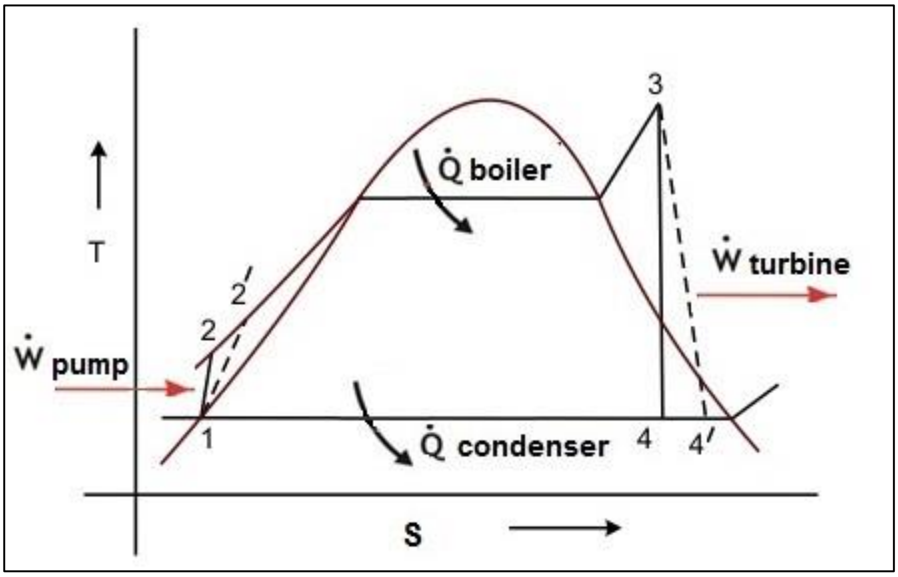

Fig. 6: T-S Diagram of Practical Rankine Cycle

The boiler efficiency is:

$\eta_b = \frac{\textit{Heat absorbed by water}}{\textit{Heat given by the consumed fuel}} = \frac{\dot{m}_s \times (h3 - h2)}{\dot{m}_f \times I.c.v}$	(1)

Where: $\dot{m}_s$: mass flow rate of steam measured by the flow meter

$\dot{m}_f$: mass flow rate of fuel to the burner $= \rho_f \times \dot{V}_f$

$\dot{V}_f = \frac{\textit{fuel volume collected}(m^3)}{\textit{elapsed time }(sec)}$	(2)

ρ_f: the density of fuel used – Diesel $(880\ \mathrm{kg/m^3})$

$h2$ = enthalpy of water at inlet to boiler at the inlet temperature

$h3$ = enthalpy of steam at exit of the boiler at exit temperature and pressure

I. c. v: lower calorific value of fuel used – Diesel (41400 kj/kg)

The turbine efficiency is defined here as:

$\eta_t = \frac{(h3 - h4')}{(h3 - h4)}$	(3)

$h4'$ = Actual enthalpy of steam leaving the turbine

$h4$ = Enthalpy of steam at condenser pressure if the expansion was isentropic $S3 = S4$

To obtain h4 you should equate the heat rejected by steam in the condenser to the heat taken by the cooling water in the condenser, i.e.

$\dot{m}_s \times (h4' - h1) = \dot{m}_w \times Cp_w \times (Tw_o - Tw_i)$	(4)

$\dot{m}_w$ = The mass flow rate of cooling water through the condenser.

Cp_w = the specific heat of cooling water 4.186 kj/kg. K

Tw_o and Tw_i = exit and inlet temperatures of cooling water respectively.

The Cycle or Thermal efficiency is defined as:

$$\eta_{th} = \frac{Turbine\ work}{heat\ added\ in\ the\ boiler} = \frac{(h3 - h4')}{(h3 - h2)}$$	(5)

The mechanical efficiency of the turbine / generator is:

$$\eta_m = \frac{\frac{\tau \times \omega}{1000}}{Turbine\ output} = \frac{\frac{\tau \times \omega}{1000}}{\dot{m}_s\left((h3 - h4')\right)}$$	(6)

Where: τ is the torque N. m, and ω is the rotational speed, rad/sec

The generator efficiency is:

$$\eta_G = \frac{Power\ output}{Power\ input} = \frac{(V \times I)}{(\tau \times \omega)}$$	(7)

Where: V and I are the generator voltage and current respectively.

7. RESULTS & DISCUSSION

Table 2: SUMMARY OF RESULTS

No.	Item	Value %
1	Boiler efficiency	
2	Turbine efficiency	
3	Thermal efficiency	
4	Mechanical efficiency	
5	Generator efficiency	

1. Draw the associated Rankine- cycle for the thermal power plant on the T-S diagram showing all processes
2. Calculate the following efficiencies:
    a) Boiler efficiency
    b) Turbine efficiency
    c) Cycle efficiency
    d) Mechanical efficiency
    e) Generator efficiency
3. All the results were recorded and tabulated under the results table.
4. State three methods to improve the thermal efficiency of the cycle with briefly with neat sketch for each.

Note: to perform the required calculations each student must have his own steam tables.

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