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Performance Evaluation of A Steam Turbine Test RIG and Oil Fired Boiler

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Abstract-The aim of this paper is further the performance improvement of a steam turbine and an oil fired boiler. This paper details the wholesome components of a steam turbine set up such as turbine, steam separator, steam condenser, separating and throttling calorimeter, boiler, and economizer. It also speaks about the performance of each component and efficiency of the system. The heat balance sheet provided fetches a systematic representation of a heat release and heat distribution per hour based on the readily attained value when calculated.

Keywords: Steam Turbine, Oil Fired Boiler, Performance and Efficiency, Heat Balance Sheet.

I. INTRODUCTION

Energy is the heart of universe, and it can't be created or be destroyed it can only change it's from.[1] The efficient transform is the standpoint of system efficiency. There are two types of energy resources available, renewable and non renewable. As far as world is concern we majorly use nonrenewable resources. India's most part of energy comes from coal, oil and LPG[2]. The non renewable energy resources can't be use again. An alarming demand has been dumped on engineers. One is to conserve energy and also produce an alternative energy source. To conserve energy we must know the basics of how energy is produced

A. Steam Turbine

It is a rotary device- where the heat energy of a steam is converted into kinetic energy. On simple explanation it simply breaks down to two parts a nozzle and a blade or a vane or a bucket. The good efficiency starts with a constructional design. A nozzle may be convergent or divergent or convergent divergent nozzle. It depends on the application used. Another important constructional feature is angle of placing, the blades, and the blades placement is important on meeting all the steam entering via nozzle. When steam is generated in the boiler it consists of high pressure and negligible velocity. To hit the blade high velocity is needed, this high velocity is created by nozzle. The nozzle reverses the condition, while entering the nozzle the steam has high pressure and negligible velocity at exit high velocity and low pressure. A pressure drop and a velocity increase are created in the nozzle by its design. The nozzle works under adiabatic expansion. Without any work done the process is changed from one form to another.[3]

B. Forces Acting On Blades

The steam turbine obtains its motive power from the change of momentum. When steam jet strikes the blade it exerts a pressure on the blade, when centrifugal force acts on the blade normal to the blade angle along the whole length of a blade. The effect of steam striking creates a velocity change and the centrifugal force which causes change in momentum which act as a motive force. The static pressure of a steam will not create an impact on blades. The principle is a high velocity steam is obtained by the nozzle and it strikes the blades and produces the kinetic energy so we obtain a mechanical work on rotor blades.[4]

C. Technical Features Of Our Steam Turbine

There are many types of steam turbines, here we use Single stage impulse turbine, condensing type. The blades have large clearance at the sides of the sides of the wheel. The blade is designed in such a way that there is negligible end thrust. The critical speed of the shaft is well above the operating speed. The steam enters the casing through the valve.[5]

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Table 1 Turbine specifications

Steam Turbine Type	Single Stage Impulse Turbine
Operating Medium	Steam
Nozzle Angle	32 ^o
Inlet Pressure	10 Kg\Cm ²
Inlet Temperature	120 To 160 ^o C
Power	500 Watts
No Of Nozzles	3
Steam Flow Rate	0.01 Kg\S\Nozzle
Speed Of Turbine	Not To Exceed 3000rpm

D. Steam Condenser

Steam condenser is a device which helps the exhaust steam from the turbine to condensate into water by exchanging heat into the continuously circulating storage tank. From storage tank it is fed into the boiler. The temperature of condensate water is more than that of storage tank so it is partially used to make steam by the recirculating process.

Table 2 Steam condenser specifications

Condenser Type	One Shell Two Tube Pass Condenser
Pumping Motor	230 V ,Single Phase, 0.75 Kw
Flow Rate	2 Lps
Head Of The Pump	18 Mwc
Vacuum Pump	Reciprocating Piston Type, 40mm Bore*45mStroke
Capacity	30 Lpm
Condensed Water Measuring Tank	100mm Dia * 0.5 M Height

E. Separating And Throttling Calorimeter

The quality of a steam is an important parameter. Steam quality can be determined by the separating and throttling calorimeter. There are three types of steams, dry steam, wet steam and superheated steam. Consider a system in which steam is flowing, the pressure and temperature can be directly measured by the thermometer and pressure gauges. The saturation temperature can be found out by using the steam tables. If the observed temperature is above the saturation temperature then the steam is said to be in superheated condition. If it is below the steam is said to be in wet or dry state, to find that out separating and throttling calorimeter is used. This type of calorimeter is very efficient and it can be used to find out the dryness fraction of the steam accurately even when the steam is too wet.[6]

F. Working Of Separating And Throttling Chamber

It consists of two parts a separating unit and a throttling unit. Both components consist of a stainless steel tube lagged with a glass wool and a water level indicator. It also consist of a pressure gauge to measure the pressure of the inside steam and a water level indicator to find the amount of water separated from the steam. The water particles are separated in the separating calorimeter and comparatively a dry steam enters the throttling chamber there it is made more dry. The separating and throttling chamber are linked by a narrow aperture.

G. Boiler

The boiler is a device which converts the water into steam. There are many types of boilers and in our set up we use an oil fired boiler. There is much kind of boilers and the aim of every set up is to obtain a good quality and quantity of a steam while utilizing minimum amount of resources. The methods such as recirculating using condensate help in reduced fuel consumption and are therefore used in this setup.

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Table 3 Boiler specifications

Type	Non IBR-Automatic, Three Pass, Oil Fired Boiler With Economizer.
Model	SBS 200
Operating Pressure	12 Kg\Cm ²
Capacity	200 Kg
Fuel	High Speed Diesel
Calorific Value	10833 Kj\Kg

H. Performance Evaluation Of Each Component

The Performance parameters of a steam condenser and separating and throttling calorimeter are listed below. The core view of this performance evaluation is looking through the test of an impulse steam turbine and test of an oil fired steam generator (boiler).

1) Condenser Efficiency:

Inlet temperature of a cooling water $T_1 = 35^{\circ}\text{C}$

Outlet temperature of a cooling water $T_0 = 46^{\circ}\text{C}$

Vacuum gauge reading = 87mm of Hg

$$= (760-87) * 0.00136\text{kg/ cm}^2$$

$$= 0.915\text{kg/ cm}^2$$

Saturation temperature $T_v = 96.22^{\circ}\text{C}$

Condenser efficiency = $T_0 - T_1 / T_v - T_1$

$$= 17.96\%$$

(1)

2) Calculating Dryness Fraction Using Separating And Throttling Calorimeter:

Pressure inside the separating calorimeter = 7.03kg/cm²

Corresponding specific enthalpy $h_1 = 165.6 \text{ kcal/kg}$

Corresponding latent heat $L_i = 493.8\text{kcal/Kg}$

Pressure of a stream after throttling = 0.5Kg / cm²

Corresponding specific enthalpy $h_2 = 642.75 \text{ kcal/Kg}$

Saturation temperature $T_s = 116^{\circ}\text{C}$

Volume of water collected in separating calorimeter $W = 5\text{ml}$

Volume of condensate water collected from the condenser $W_s = 190\text{ml}$

Dryness fraction for separating $X_1 = W_s / W + W_s$

$$= 0.9744$$

Dryness fraction for throttling $X_2 = h_2 + C_p (T - T_s) - h_1 / L$

$$= 0.9721$$

Dryness fraction for separating and throttling calorimeter $X = X_1 * X_2$

$$= .9472$$

(2)

(3)

H. Performance Of An Impulse Steam Turbine

Total steam consumption (T.S.C)

Volume of a condensate tank for 40mm rise = 0.353

T.S.C = $1271 / T_c \text{ Kg/hour}$

Specific steam consumption (S.S.C)

S.S.C = $T.S.C / P_d \text{ Kg/kW}$

(4)

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1) Rankine Efficiency:

$$\frac{(T_1 - T_2) * (1 + h_{fg1}/T_2) - T_2 * \ln(T_1/T_2)}{(T_1 - T_2) + h_{fg2}} \quad (5)$$

2) Rankine Engine Efficiency:

$$100 * (h_1 - h_2) / h_1 - h_{f2} \quad (6)$$

3) Brake Thermal Efficiency:

$$100 * 3600 * \text{turbine output power in kW/T.S.C} * (h_1 - h_2) \quad (7)$$

4) Relative Efficiency:

$$100 * \text{B.T.E} / \text{Rankine efficiency} \quad (8)$$

5) Blade Efficiency:

$$100 * 2 * \Delta C_u * U / C^2 \quad (9)$$

6) Gross Or Stage Efficiency:

$$\begin{aligned} &= \text{work done/enthalpy drop in a nozzle} \\ &= 100 * ((\Delta C_u * U) / g_c * J) / \Delta h \end{aligned} \quad (10)$$

I. Performance Test Of An Oil Fired Generator (Boiler)

Boilers are designed to evaporate steam at different pressures and temperatures, according to the requirements. High pressure super heated steam is used in power generating plants. Low pressure wet steam is used in mainly in chemical and processing industries for heating purpose. The following specifications are provided to give detailed information about boilers. Those are steam pressure, steam quality, type of fuel, type of draught and the firing method. When boilers are generating steam under different working condition, the capacity comparison is the best done by comparing the amount of heat added in the each boiler for steam generation this is known as "Equivalent Evaporation". [7]

1) *Boiler Thermal Efficiency*: The boiler efficiency is the rate of heat absorbed by the steam from the boiler per unit time to the heat liberated by the combustion of fuel in the furnace during the same time.

$$\text{Boiler efficiency} = m_s * (h - h_w) / mf * C.V8$$

2) *Heat Losses In A Boiler Plant*: There are various ways in which heat is lost in a boiler. Heat lost due to flue gases (Q_g). The flue gases contain many dry product of combustion and steam is generated due to combustion of hydrogen in the fuel.

$$Q_g = m_g * C_{pg} * (T_g - T_a) \text{ kj/hr} \quad (11)$$

Heat losses due to incomplete combustion (Q_{ic}), if the carbon burns as Co instead of Co_2 it is termed as incomplete combustion. In the presence of Co in the flue gas indicates that incomplete combustion is happening in the fuel

$$Q_{ic} = m_g * C_o * C / C_{o2} + C_o * 24800 \text{ kj/hour} \quad (12)$$

Radiation and convection losses (Q_{ua}), if the hot surface of the boiler are exposed to the atmosphere and therefore heat is lost to the atmosphere by convection and radiation. Those heat losses cannot be calculated so it is assumed to be 1% in total efficiency. Boiler efficiency is increased by reducing the amount of losses.

J. Data Collections

There are two types of parameter one is observed readings and another is calculated readings.

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Table 4 directly recorded readings for steam impulse turbine

Location	Parameter	Symbol	Unit	1	2	3	4
Ambient	Ambient Temperature	T_r	C	40	1.5	2	2.5
				4	4	4	
Inlet Steam	Pressure Of Steam At Inlet To Turbine	P_0	Kgf/ Cm2	10.	1	1	1
	4			0.4	0.4	0.4	
	Temperature Of Steam At Inlet To Turbine	T_0	C	20	2	2	2
	5			06.5	06	07	
Exit Steam	Pressure Of Steam At Exit To Turbine	P_1	Mm Hg	50	5	5	5
	0			00	00	00	
	Temperature Of Steam At Exit To Turbine	T_1	C	79	8	8	8
	0			1	1		
Condensate Tank	Time For 4cm Rise Of Condensate	T_c	S	8.3	8	8	8
	49.			5	5	5	
	Time Of Condensate	T_c	C	5	1	2	2
Condenser Cooling Water	Manometer Reading Of Flow meter	H_m	Cm Hg	30	3	3	3
	0			0	0		
	Water Temperature At Inlet			T_{w1}	C	34	5.5
	Water Temperature At Outlet	T_{w0}	C	39.	4	4	4
				5	1.5	1.5	2
Turbine	Dynamometer Torque Arm Radius	R	Mm	12	1	1	1
	6			26	26	26	
	Load On Spring Balance			W_D	Kg	1.8	.8
	Speed On Turbine In Tachometer	N	Rpm	28	3	3	3
				33	016	123	270

Table 5 Calculated readings of a steam impulse turbine

Location	Parameter	Formula	U nit	1	2	3	4
Turbine	Torque Developed	$Tq = 9.81 * R * WD / 1000$	N m	2	2.	2.	2.
	Power Developed	$Pd = N * Tq / 9554$	K w	.22	22	16	1
Inlet Steam	Absolute Pressure	$P_0 = 0.9807 * (P_0 + 1.0320)$	B ar	1	11	11	11
	Enthalpy Hg0	H_{g0}	K j/Kg	1.21	.21	.21	.21
Exit Steam	Absolute Pressure	$P_1 = 0.0013332 * (760 - P_1)$	B ar	2	27	27	27
	Enthalpy On P1	H_1	K j/Kg	781.5	81.6	81.6	81.8
	Actual Enthalpy	H_{g1}	K j/Kg	0	0.	0.	0.
Condensate	Enthalpy	$H_{fc} = 419 - 4.2 * (100 - T_c)$	K j/Kg	.3466	3466	3466	3466
				2	24	24	24
				400	00	00	00
				2	24	24	24
				457.2	57.2	57.2	57.3
				2	21	21	21
				06.9	3.2	7.4	7.4

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Cooling Water	Mass Flow Rate Of Cooling Water	$M_c = 0.285 * H_m^{0.5}$	K g/S	1 .561	1. 56101	1. 56101	1. 56101
	Enthalpy	$H_{fi} = 419 - 4.2 * (100 - T_{wi})$	K j/Kg	1 41.8	14 8.1	14 6	15 0.2
	Enthalpy	$H_{fo} = 419 - 4.2 * (100 - T_{w0})$	K j/Kg	1 64.9	17 3.3	17 3.3	17 5.4
Steam	Mass Flow Rate Of Steam	$M = 0.52 / T_c$	K g/S	0 .0425	0. 04413	0. 04413	0. 04413
	T.S.C	$T.S.C = 1271 / T_c$	K g/Hr	1 53.13	15 8.875	15 8.875	15 8.875
	S.S.C	$S.S.C = T.S.C / (Pd / 0.746)$	K g/HP	1 73.15	16 8.747	16 7.622	16 4.795

Table 6 Heat balance sheet on impulse steam turbine

Parameter	Formulae	Unit	1	2	3	4
Heat Input From Steam Generator	$H_{in} = T.S.C * H_0$	Mj/H	4 25.94	441 .927	44 1.943	44 1.958
Work Done By Turbine	$H_{wd} = 3600 * Pd$	Mj/H	2. 38	2.5 3	2. 55	2. 59
Heat Carried By Condensate	$H_{con} = T.S.C * H_{fc}$	Mj/H	3 1.683	38. 8722	34 .5394	34 .5394
Heat Carried Away By Condenser Cooling Water	$H_{cw} = 3600 * M_c * (H_{fo} - H_{fi})$	Mj/H	1 29.81	141 .61	15 3.42	14 1.61
Unaccounted Heat Loss	$H_{ua} = \text{By Balance}$	Mj/H	2 62.07	263 .911	25 1.442	26 3.215
Work Done By Turbine	$H_{wd}\% = 100 * H_{wd} / H_{in}$	%	0. 6	0.6	0. 6	0. 6
Heat Carried By Condensate	$H_{con}\% = 100 * H_{con} / H_{in}$	%	7 04	7.7	7. 8	7. 8
Heat Carried Away By Condenser Cooling Water	$H_{cw}\% = 100 * H_{cw} / H_{in}$	%	3 0.5	32	34 .7	32
Unaccounted Heat Loss	$H_{ua}\% = 100 * H_{ua} / H_{in}$	%	6 1.5	59. 7	56 .9	59 .6

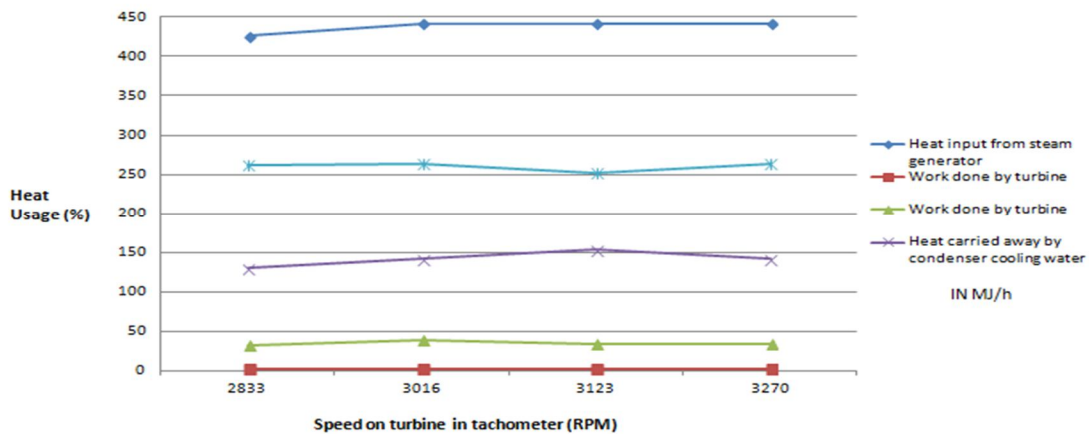


Fig. 1 Heat Balance Sheet on Impulse Turbine

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Table 7 Performance evaluated values of oil fired steam generator (boiler)

Parameter	Symbol/Formulæ	Unit	1	2	3	4
Clock Time	T_c	hour	.18	.35	.5	05
Initial Level Of Water	Wh	mm	90	05	15	90
Fall In Level Of Water	ΔWh	mm		5	0	5
Initial Level Of Oil	Dh	mm	10	90	60	35
Fall In Level Of Oil	ΔDh	mm		0	0	5
Air Orifice Meter Manometer Reading	Ah	mm	3	7	5	0
Steam Pressure	P	Kg/cm ²	2.5	2.5	3	2.75
Ambient Temperature	t_R	C	4	3	3	3
Flue Gas Temperature	T_g	C	55	56	58	58
Water Inlet Temperature	T_s	C	5	6	6	6
Steam Temperature	T_w	C	19	19	19	19

Table 8 Calculated values of oil fired boiler

Parameter	Symbol/Formulæ	Unit	Result
Duration of test	T_d	min	47
Average steam pressure	P	kg/cm ²	12.69
Absolute steam pressure	$p = 0.9807 \cdot (p_0 + 1.032)$	bar	13.45
Dryness fraction	X		0.85
Sp. Enthalpy of sat. liquid at pressure P	Hf	Kj/Kg	822
Sp. Enthalpy of sat. Steam at pressure P	Hfg	Kj/Kg	1966
Average feed water temperature	T_w	C	219
Average Room Temperature	T_r	C	43.25
Average Flue Gas Temperature	T_g	C	256.75
Average Manometer Reading	ΔAh	mm	28.75
Mass Of Steam Generated Per Hour	$m_s = (\sum \Delta Wh / 1000) \cdot 1.252 \cdot 0.602 \cdot 1000 \cdot 60 / t_d$	Kg/hr	192.4
Mass Of Fuel Oil Burnt Per Hour	$m_f = (\sum \Delta Dh / 10000 \cdot 0.4 \cdot 0.4 \cdot 950 \cdot 60 / t_d$	Kg/hr	14.6
Mass Of Air Supplied Per Hour	$m_a = 1.23 \cdot 0.62 \cdot 0.00785 \cdot (2 \cdot g \cdot 814 \cdot Ah) \cdot 5 \cdot 3600 \cdot 60 / t_d$	Kg/hr	589.53
Enthalpy Of Steam Per Kg At Pressure P	$h = h_f + X \cdot h_{fg}$	Kj/Kg	2493.1
Sp. Enthalpy Of Feed Water At T_w	Hfw	Kj/Kg	174

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Heat Gained By Steam Per Hour	$Q_s = m_s \cdot (h - h_{fw}) / 1000$	Kj/Kg	446.27 6
Equivalent Evaporation	$m_e = m_s \cdot (h - h_{fw}) / 2260$	Kg/hr	197.5
Heat Released By Burnt Fuel Oil Per Hour	$Q_f = m_f \cdot C \cdot V$	MJ/hr	647.61 7
Heat Lost To Fuel Gas	$Q_g = m_a \cdot c_{pg} \cdot (t_g - t_r)$	MJ/hr	138.5
Unaccounted Heat Loss	$Q_{uo} = Q_f - (Q_s + Q_g)$	MJ/hr	62.891
Evaporation Rate	$m = m_s / m_f$	Kg/Kg	13.2

Table 9 Heat balance in percent of heat input for boiler

Parameter	Formulae	Unit	Result
Heat Generated By Burnt Fuel Per Hour	$Q_f = 100$	%	100
Heat Gained By Steam Per Hour	$Q_s = 100 \cdot Q_s / Q_f$	%	68.9
Heat Lost To Flue Gas	$Q_g = 101 \cdot Q_g / Q_f$	%	21.4
Unaccounted Heat Loss	$Q_{ua} = 102 \cdot Q_{ua} / Q_f$	%	9.7

K. Efficiency Values Of Impulse Steam Turbine And Oil Fired Boiler

The efficiency calculation includes the wetness of steam, flue gas exhaust, losses due to convection and radiation. So direct method of efficiency calculation couldn't be applied. The losses are subtracted from the direct method so actual efficiency values are obtained

Table 10 Efficiency values of impulse steam turbine and oil fired boiler

Parameter	Formulae	Unit	1	2	3	4
Rankine engine efficiency	$\eta_e = 100 \cdot (h_g - h_f) / (h_g - h_{fc})$	%	1 4.8	1 4.9	1 4.9	1 4.9
Break thermal efficiency	$\eta_{Bte} = 100 \cdot 3600 \cdot p_d / (T.S.C \cdot (h_0 - h_1))$	%	4 .8	4. 9	4. 9	5
Blade efficiency	$\eta_{Be} = 100 \cdot U \cdot C_u / (C_f^2 / 2)$	%	1 2.9	1 3.7	1 4.2	1 4.8

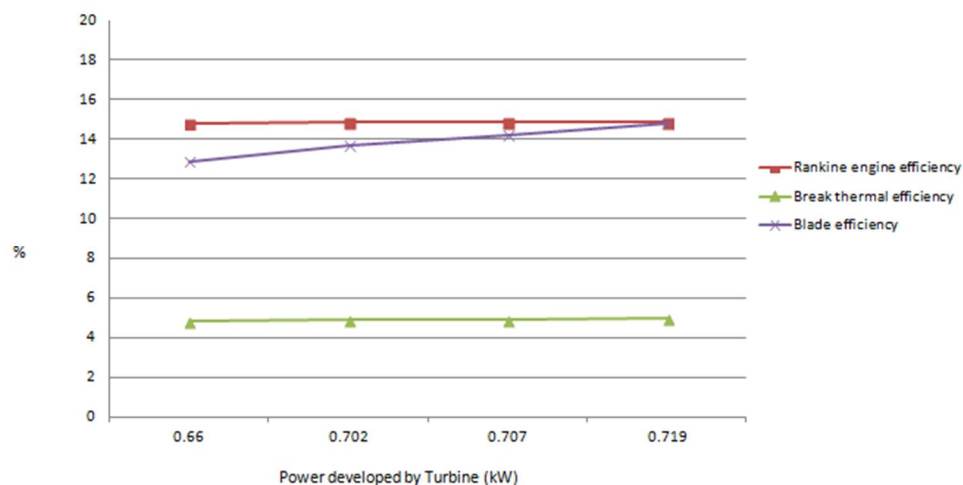


Fig. 2 Efficiency Values of Impulse Turbine and Oil Fired Boiler

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II. CONCLUSION

In this study it can be determined from the performance evaluation of a steam turbine test rig and oil fired boiler the test were done in the laboratory and the resultant data was then tabulated in the above tables. The graphs were drawn based on the the computed data. The performance and efficiency of a steam turbine is determined and the heat release and heat distribution per hour based on the readily attained value is calculated.

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