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FIRST LAW AND SECOND LAW ANALYSIS OF EXTRACTION CONDENSING STEAM TURBINE IN SUGAR INDUSTRY

SANJAY S. BHAGWAT[1], DR. SANJAY D. POHEKAR[2]

1. Associate Professor, Mechanical Engineering Department, Babasaheb Naik College of Engineering, Pusad,(MS) INDIA.
2. Professor, Mechanical Engineering Department, Presidency University, Bangalore, INDIA

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Abstract: In this paper, first and second law analysis of a extraction condensing steam turbine in a heat-matched bagasse based cogeneration plant of a typical 2500 tcd. Sugar factory is presented. In the analysis, exergy methods in addition to the more conventional energy analyses are employed to evaluate turbine efficiencies and to identify and assess the thermodynamic losses. Condensing steam turbine plant performs with energy and exergy efficiency of 0.95 and 0.51, respectively. Energy analysis deals with quantity aspect whereas exergy analysis deals with quality aspect in addition to quantity. Exergy analysis focuses on magnitude and true location of energy loss. In this analysis, energy efficiency, exergy destruction, exergy efficiency and turbine heat rate are evaluated at 100 % maximum continuous rating (MCR) of steam turbine.

Keywords: Energy Efficiency, Exergy Efficiency, Exergy destruction.

Corresponding Author: MR. SANJAY S. BHAGWAT

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INTRODUCTION

The sugar industry is now moving towards substantially improved power stations, by adopting HP/HT steam conditions and high efficiency steam turbines, so that it can export surplus power to grid when the prices are attractive, or otherwise can save surplus bagasse, which can be utilized for many other productive purposes. Wide range of steam inlet parameters is used in the sugar industries and varies between 21–110 bar in pressure and 300–540^{0}C in temperature. Number of combinations is possible within these limits of pressure and temperature [2].

The general energy supply and environmental situation requires an improved utilization of energy sources. Therefore, the complexity of power-generating units has increased considerably. Plant owners are increasingly demanding a strictly guaranteed performance. This requires thermodynamic calculations of high accuracy. As a result, the expenditure for thermodynamic calculation during design and optimization has grown tremendously. The most commonly-used method for evaluating the efficiency of an energy-conversion process is the first-law analysis[1]. However, there is increasing interest in the combined utilization of the first and second laws of thermodynamics, using such concepts as exergy, entropy generation and irreversibility in order to evaluate the efficiency with which the available energy is consumed.

Exegetic analysis allows thermodynamic evaluation of energy conservation, because it provides the tool for a clear distinction between energy losses to the environment and internal irreversibilities in the process. Exergy is defined as the maximum theoretical useful work (or maximum reversible work) obtained as a system interacts with an equilibrium state [2,3]. Exergy is generally not conserved as energy but destructed in the system. Exergy destruction is the measure of irreversibility that is the source of performance loss. Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system.

Energy and exergy analysis is used for the identification of these loses. Energy analysis evaluates the energy generally on its quantity only, whereas exergy analysis assesses the energy on quantity as well as the quality. The aim of the exergy analysis is to identify the magnitudes and the locations of real energy losses, in order to improve the existing systems, processes or components.

Cogeneration turbine systems, which produce heat at useful temperatures at the expense of reduced electrical power, have higher efficiencies than conventional steam turbine systems. The correct merit of cogeneration systems should be determined with the help of exergy analysis because energy analysis tends to overstate performance [5,6].

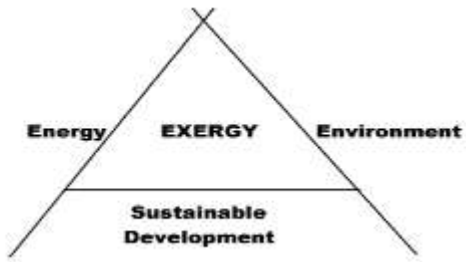

Figure.1 Interdisciplinary triangle covered by exergy analysis [4]

1.1Aim

The main aim of the study is to identify areas where energy and exergy losses are occurring and develop them for efficient and effective improvement in a cogeneration system.

1.2 Energy Concept

The concept of energy was first introduced in mechanics by Newton when he hypothesized about kinetic and potential energies. However, the emergence of energy as a unifying concept in physics was not adopted until the middle of the 19th century and was considered one of the major scientific achievements in that century. The concept of energy is so familiar to us today that it is intuitively obvious, yet we have difficulty in defining it exactly. Energy is a scalar quantity that cannot be observed directly but can be recorded and evaluated by indirect measurements. The absolute value of energy of system is difficult to measure, whereas its energy change is rather easy to calculate. In our life the examples for energy are endless. The sun is the major source of the earth's energy. It emits a spectrum of energy that travels across space as electromagnetic radiation. Energy is also associated with the structure of matter and can be released by chemical and atomic reactions. Throughout history, the emergence of civilizations has been characterized by the discovery and effective application of energy to societies needs [3].

1.3 Exergy Concept

Exergy is a generic term for a group of concepts that define the maximum possible work potential of a system, a stream of matter and/or heat interaction, the state of the (conceptual) environment being used as the datum state. In an open flow system there are three types of energy transfer across the control surface namely work transfer, heat transfer, and energy associated with mass transfer and/or flow. The work transfer is equivalent to the maximum work which can be obtained from that form of energy. The exergy of heat transfer Q from the control surface at temperature T is determined from maximum rate of conversion of thermal energy to work Wmax is given by kinetic, potential and physical exergy. The kinetic and potential energy are almost equivalent to exergy.

The physical specific exergy and depends on initial state of matter and environmental state. Energy analysis is based on the first law of thermodynamics, which is related to the conservation of mass and degradation of the quality of energy along with the entropy generation in the analysis design and improvement of energy systems. Exergy analysis is useful method, to complement but not to replace energy analysis [3].

2. STEAM TURBINE SPECIFICATION

Manufacturer: Siemens Ltd. Gujarat

Model & Type: EHNG 50/40/50

Nominal Rating: 17700 kW

Nominal Speed: 6800 rpm

Normal first bled steam pressure: 25 bar

Normal first bled steam temperature: 535C

Normal exhaust steam pressure: 2.5 bar

Normal exhaust steam temperature: 144^0C

2.1. DATA OF STEAM TURBINE

Data for study is taken at 100 % MCR of Extraction condensing steam turbine Fig 2 working at Purna Ltd. Basamatnagar, Hingoli.

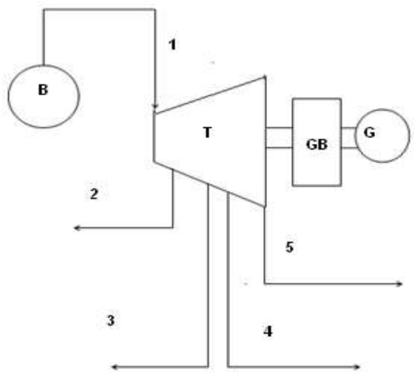

Fig 2 Process Flow Diagram of Extraction Condensing Steam Turbine

B-BOILER ; T- Turbine,

GB-Gear Box; G- Generator

1. INLET STEAM FLOW: 24.47kg/s, STEAM PRESSURE:105kg/ cm^2, STEAM TEMP:535^{0}C

2. FIRST EXTRACTION STEAM FLOW: 3kg/sec , STEAM PRESSURE: 25kg/ cm^2, STEAM TEMP.: 359^{0}C

3. M.P. STEAM FOR SUGAR FACTORY STEAM FLOW:4.53 kg/Sec,STEAM PRESSURE:8kg/cm^2,

STEAM TEMP.:249^{0}C

4. LP. STEAM TO SUGAR FACTORY STEAM FLOW: 17.28 Kg/Sec,STEAM PRESSURE: 2.5kg/ cm^2,

STEAM TEMP. :144^{0}C

5. TO CONDENSER STEAM FLOW:1.67 Kg/Sec STEAM PRESSURE: 0.18kg/ cm^2, STEAM TEMP:57^{0}C

Table.3.1 DATA OF STEAM TURBINE

SR. No.	Particulars	Unit	Value at 100% MCR
1	Main steam flow rate m_1	kg/s	26.47
2	Main steam Pressure P_1	kg/cm^2	105
3	Main steam Temp.T_1	^{0}C	535

4	Enthalpy of inlet steam h_1	kJ/kg	3458.89
5	Entropy of inlet steam S_1	kJ/kg k	6.7
6	First Extraction flow m_2	kg/s	3
7	First Extraction Temp.T_2	^0C	359
8	First Extraction Pressure P_2	kg/cm^2	25
9	Enthalpy of first Extraction steam h_2	kJ/kg	3131.13
10	Entropy of First Ext. steam S_2	kg/kg k	7.185
11	MP Extraction flow m_3	kg/s	4.53
12	MP Extraction Temp.T_3	^0C	249
13	MP Extraction Pressure P3	kg/cm^2	8
14	Enthalpy of MP Ext. steam h_3	kJ/Kg	2949.04
15	Entropy of Inlet HP Ext. steam S_3	kg/kg k	7.4
16	LP Extraction flow m_4	kg/s	17.28
17	LP Extraction Temperature T_4	^0C	144
18	LP Extraction Pressure P_4	kg/cm^2	2.5
19	Enthalpy of LP Exh. Steam h_4	kJ/kg	2679.04
20	Entropy of inlet LP Exh. Steam S_4	kg/kg k	7.31
21	To condenser steam flow m_5	kg/s	1.67
22	Second Extraction Temp T_5	^0C	57
23	To condenser steam Pressure P_5	kg/cm^2	0.18

24	To condenser steam Enthalpy of steam h_5	kJ/kg	2427.88
25	To condenser steam entropy S_5	kg/kg k	8.02
26	Generator Power P	kW	17700

3. FIRST LAW ANALYSIS FOR 100 % MCR

1. Energy input is equal to product of mass of steam into turbine and its enthalpy at entry.[3]

$\dot{E}i = m_1 \times h_1$

$= 91556.82$ kJ/s.

2. Energy output is sum of heat extracted and heat exhausted.

$\dot{E}o = (m_2 \times h_2)+(m_3 \times h_3)+$

$(m_4 \times h_4)+(m_5 \times h_5)$

$= 73100.91$ kJ/s.

3. Work input is equal to the energy in steam at entry to turbine minus that at exit.

$W.D = \dot{E}i - \dot{E}o$

$= 18455.91$ kW.

4. Actual Power Develop by Turbine Shaft:

P = 17700 kW

5. First law Efficiency (Energy efficiency) of Turbine:

η_I = <u>Actual Power Develop by Turbine Shaft</u> $(\dot{E}in - \dot{E}out)$

= 95.95 %.

6. Heat Rate of Turbine :

HR = <u>Net Heat Input</u>

Turbine Power

= (Ėi - Ėo) x 3600 s

17700 kWh

= 3753.64 kJ/kWh.

4. SECOND LAW ANALYSIS FOR 100 % MCR

1. Exergy Input:

$\Psi in = m_1 (h_1 - T_0S_1)$

= 37820.07 kJ/s.

where T_0 – reference Temperature =30^0C

2. Exergy Out:

$\Psi out = m_2 (h_2 - T_0S_2) + m_3 (h_3 - T_0S_3)$

$+ m_4(h_4 - T_0S_4) + m_5 (h_5 - T_0S_5)$

= 14080.39kJ/s.

3. Exergy Destruction in Turbine :

Ψdes = Ψin - Ψout – Ψpower

= 6039.68kJ/s.

4. Second law Efficiency (Exergy efficiency) of Cogeneration Turbine :

η_{II}= Ψpower / (Ψin- Ψout)

= 74.56 %

5. Exergy loss = Exergy destroyed

Exergy in

= 15.96%

6. Exergy of M.P. = Exergy out

and L.P.Steam Exergy in

= 37.22%

5. RESULTS AND DISCUSSION

The energy and exegy analysis results of extraction steam turbine are as in Table2 and Fig 3.

Table 2: EXPERIMENTAL RESULTS

Sr. No	17.7 MW Extraction Condensing Steam Turbine	
	Particulars	**Value at 100 % MCR**
1	Energy Efficiency (%)	95.91
2	Exergy Destruction (kJ/S)	6039.68kJ/s.
3	Heat Input (kJ/S)	91556.82
4	Useful Heat Output (kJ/S)	73101.422
5	Turbine Work Output (kW)	17700
6	Exergy Efficiency (%)	74.56
7	Heat Rate (KJ/kWh)	3753.64

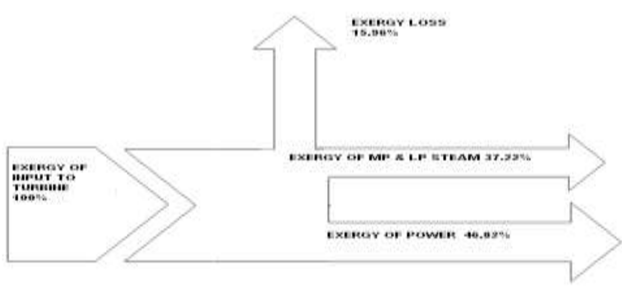

Figure 3: Sankey diagram for exergy flow through steam turbine at 100% MCR

The results presented in this paper are the exergy and energy flow rates for a heat-matched bagasse-based cogeneration plant of a typical 2500 tcd sugar factory. The results show the distribution of loss of exergy in the steam turbine.

CONCLUSION

Turbine exergy efficiency is lower than its energy efficiency as utilization of heat is at lower temperature than inlet. Turbine exergy loss is 15.96 % at 100 % MCR. When. Thus, it is more advantageous to run turbine at higher MCR. Extraction condensing steam turbine cogeneration plant is the highly efficient steam power cycle from the surplus power generation point of view. Thus, the choice of plant configuration depends upon the project background and designer's intelligence. In spite of all these considerations, bagasse-based cogeneration plants in the Indian sugar industries are normally considered as environmentally and economically attractive, as they burn waste fuel i.e. bagasse.

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