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Performance analysis through Experimental Investigation on thermal power plant cogeneration system

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Abstract:
The demand for electricity in developing countries such as India is constantly growing, driven by the needs of the industrial sector. Steam power plants play a critical role in meeting this demand, but their efficiency can be improved through the use of cogeneration. Cogeneration, also known as combined heat and power (CHP), involves the simultaneous production of electricity and useful heat, which can be used for various purposes such as heating and cooling. This study focused on a sugar mill with a 16 MW cogeneration unit to investigate the performance of the steam turbine through steam turbine extraction cogeneration method. The researchers conducted experiments at different stages of the process, taking into account various parameters such as steam flow, pressure, temperature, and flow rate. The results of the study show that the cogeneration system significantly increased the efficiency of both the turbine and the plant as a whole. The experimental data revealed that even minor changes in pressure and mass flow rate can have a significant impact on the turbine's efficiency. This highlights the importance of carefully controlling these parameters to optimize the performance of the cogeneration system. The study demonstrates that the use of cogeneration in steam power plants can lead to a reduction in fuel consumption and lower costs for power generation. The findings of this research are particularly relevant to developing countries, where efficient use of resources is crucial. By improving the efficiency of steam power plants, cogeneration can contribute to sustainable development and help meet the growing energy needs of these countries. The study provides valuable insights into the potential benefits of cogeneration and highlights the importance of further research in this area.

Key Words*:Cogeneration; CHP; mass flowrate; Specific enthalpy; Heat to Power ratio.*

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I. Introduction

Energy now plays a major role in every sector around the world to meet these needs. In daily life, the majority of energy conversion for power generation is critical. Industries generate power in a variety of ways. Steam generation is by far the most common method of generating electricity. The majority of power plants use fossil fuels to generate steam. The energy in the steam supplied to the turbine is not fully utilised, and the majority of the steam energy is wasted. In contrast, steam power plants are inefficient, emit more pollutants, and contribute to global warming. As a result, auxiliary methods must be employed in order to improve the efficiency of existing steam turbines. A few scientists recently proposed increasing steam turbine efficiency by utilising available energy in steam at the intermediate and exhaust stages. Cogeneration is one of the most common methods for increasing plant efficiency while using the same fuel energy input.

Kabeyi et al. [1] demonstrated an operational diesel-engine power plant's cogeneration capability. The cogeneration potential of a 119.7 MW operating power plant in Kenya has been established. Subject to the limitations imposed by the presence of sulphur in the fuel and thus the presence of Sulphur dioxide in the exhaust, the study discovered that each engine with a capacity of 17.1 MWe has a recoverable thermal energy of about 1.33 MW, while the entire plant with seven engines has a recoverable thermal energy of about 9.3 MW at plant optimum loading conditions, which can generate 8.5 MWe extra electricity under optimal conditions.S.C. Kamate et al. [2] used back pressure and extraction condensing steam turbines to calculate the overall and component efficiencies of a bagasse-based cogeneration plant. The study by Nebra et al. [3] analyzed different cogeneration system options in sugarcane factories to assess the potential for boosting power generation. Meanwhile, G.V. Varma et al. [4] used heat recovery plant analysis to gauge the power generation capacity of a 12.5 MW power plant, and Sinan Kara et al. [5] conducted experiments on a plant at part load to study the isentropic efficiencies of a steam turbine and the thermal efficiency of a power plant under varying load conditions. R. Chacartegui et al. [6] utilized the Spencer-Cotton-Cannon method to predict the performance of fossil fuel steam power plants during different operating or maintenance conditions, particularly for large steam turbine generator units. In another study, Luis Olmos-Villalba et al. [7] investigated the thermal performance of a cogeneration system that generated electricity and dried aromatic herbs, while H. VaziniModabber et al. [8] developed a computer code using MATLAB to estimate the Exergetic efficiency, total cost rate, and total environmental impact rate of a 4E Analysis of Power and Water Cogeneration Plant. Darshan H Bhalodia et al. [9] performed thermal analysis on a cogeneration plant to identify thermodynamic losses and increase the efficiency of a 25 MW plant, and Lee et al. [10] studied combined cycle cogeneration to determine changes in performance due to potential plant losses caused by return temperature. All these experimental methods aimed to reduce losses and increase plant efficiency. This study aimed to vary the steam flow parameters at the inlet steam turbine mass flow rate and temperature to investigate energy savings and thermal power plant efficiency by steam bleeding at different stages in the steam turbine and utilizing process steam in cogeneration power plants.

II. Methodology

Description of the Plant

Fig 1. Shows the configuration of using backpressure and extraction condensing steam turbine plant in the sugar industry. In this configuration, the cogeneration plant generates, power and useful process steam required for heat utilization.

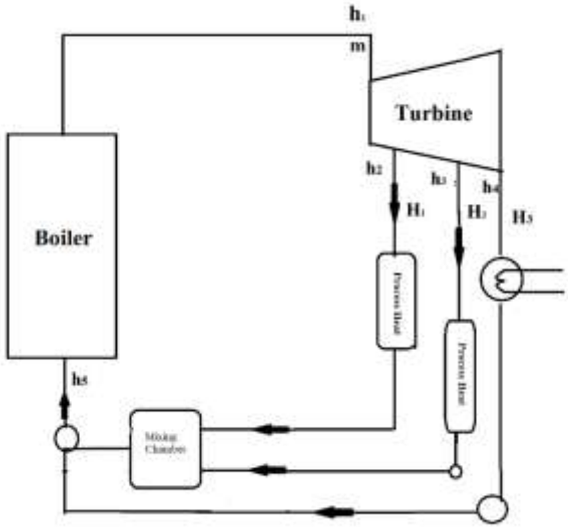

Fig.1. Lay out of the cogeneration plant

Methodology

The methodology adapted to calculate the output parameters of the plant discuss in this section. The equations presented below are tailored to steam turbine cogeneration systems and are utilized to determine various output parameters, including thermal efficiency, stage efficiencies, heat-to-power ratio, and overall plant efficiency. Continual observations were conducted at constant temperatures ranging from 5 to 12^0 degrees Celsius, with power output in MW and efficiency in percentage selected as the variables of interest. The heat input to the steam turbine can be computed using equation 1.

Heat input to the turbine (q) = $m_1 (h_1 . h_{11})$ (1)

Where h1 is the steam enthalpy at inlet of the steam turbine

h_{11} is the enthalpy of feed water

The heat extraction in the turbine at each stage can be determined using the equations below.

The enthalpies of steam at different pressures and temperatures are obtained from the steam tables.

The enthalpy values include:

Enthalpy of steam at turbine inlet	: h1, measured in kJ/kg
Enthalpy of steam at first extraction	: h2, measured in kJ/kg
Enthalpy of steam at second extraction	: h3, measured in kJ/kg
Enthalpy of steam at the condenser	: h4, measured in kJ/kg

Heat extraction from inlet to stage 1 extraction (ΔH_1)

$\Delta H_1 = (h_1 - h_2)$,kJ/kg (2)

Heat extraction from stage 1 to stage 2 extraction (ΔH_2):

$\Delta H_2 = (h_2 - h_3)$,kJ/kg (3)

Heat extraction from stage 2 extraction to condenser (ΔH_3)

$\Delta H_3 = (h_3 - h_4)$,kJ/kg (4)

The theoretical estimation of steam heat extraction is determined using the Mollier diagram (also known as the H-f diagram). The theoretical heat drop for different expansion stages is computed and presented below, based on the diagram.

Isentropic enthalpy after the 1st extraction : H1, measured in kJ/kg
Isentropic enthalpy after the 2nd extraction : H2, measured in kJ/kg
Isentropic enthalpy at the condenser condition : H3, measured in kJ/kg
Isentropic Heat Extraction from Inlet to Stage 1 Extraction (h_8): $= h_1 - H_1$ (5)
Isentropic l Heat Extraction from Stage 1 to Stage 2 Extraction (h_9): $= H_1 - H_2$ (6)
Isentropic Heat Extraction from Stage 2 Extraction Condensation (h_{10}): $= H_2 - H_3$ (7)

$$\text{Stage 1 efficiency}(\eta_{s1}) = \frac{\text{Heat Extraction actual}}{\text{Isentropic Heat extraction}} = \frac{h_1 - h_2}{h_1 - H_1} \times 100 \quad (8)$$

$$\text{Stage 2 efficiency}(\eta_{s2}) = \frac{\text{Heat Extraction actual}}{\text{Isentropic Heat extraction}} = \frac{h_2 - h_3}{h_2 - H_2} \times 100 \quad (9)$$

Thermal Efficiency of the Plant(η)=P/q×100 (10)

where,
m_1 = Mass flow rate of steam, kg/sec
h_1 = Enthalpy of inlet steam, kJ/kg
h_{11}= Enthalpy of feed water, kJ/kg
P = Average power generated, kW
Calculate the plant heat output

$$\text{Heat output (Q), kW} = m_2 h_2 + m_3 h_3 \quad (11)$$

$$\text{Total output, kW} = P + m_2 h_2 + m_3 h_3 \quad (12)$$

P = Average power generated kW

Fuel input to the plant (Fi) = m_f x CV of the fuel (13)

where mf is Mass flow rate of bagasse kg/s, and CV is Calorific value of bagasse

Overall Efficiency(η_o) = Total output / Heat input to the plant

$(\eta_O) = (P+Q)/F_i$ x100 (14)

Experimental Investigation Procedure

To estimate the performance of the cogeneration power plant, the following experimental procedure was conducted:

2.1 The power plant was set to a 16 MW capacity and the input parameters such as inlet pressure, steam mass flow rate, and steam inlet temperature were varied.
2.2 A performance test was conducted on the power plant while taking note of the variation in steam turbine efficiency with the different inlet parameters.
2.3 The steam turbine efficiency was measured and recorded for each set of input parameters.
2.4 The data collected was analyzed to determine the relationship between the input parameters and the turbine efficiency.
2.5 The results of the analysis were used to optimize the input parameters for maximum efficiency and minimum fuel consumption.
2.6 The experimental procedure was repeated several times to ensure the accuracy and reliability of the results.

III. Results

The variation in steam turbine efficiency with inlet parameters are furnished in tables 1 to 4.

Table 1: Electrical Efficiency and heat input of turbine calculated from experimental data of input.

S.No.	Mass flow rate of steam (TPH)	Temperature, (^{O}C)	Pressure, (kg/cm^2)	Heat input to turbine (kW)	Power Output (kW)	Electrical Efficiency of plant (%)
1	78.9	507	81.9	58883.95	15227	25.86
2	81.3	507	84.1	60814.43	14892	24.49
3	78.8	507	82.2	59092.56	14061	23.79
4	77.6	507	83	58538.42	15374	26.26
5	78.5	507	83.6	58920.36	15429	26.19
6	81.6	507	83.1	60374.93	15122	25.05
7	80.6	507	84.2	59995.06	15436	25.73
8	78	507	82.7	58096.78	15312	26.36
9	78.8	507	84	58470.69	15173	25.95
10	79.5	507	81.4	59536.23	15489	26.02
11	83.9	507	83.9	62871.86	15452	24.58
12	81.4	507	82.8	60529.04	15057	24.88
13	76.8	507	81.5	57417.39	15357	26.75
14	82.1	507	81.3	61286.28	14544	23.73

Table 2: Stage1 efficiency calculated with Stage pressure , mass flow rate & temperature of steam at stage 1

S.No.	m_2 (TPH)	T_2 (OC)	P_2 (kg/cm^2)	$\Delta\mathbf{H}_{\mathbf{actual}}$ (kJ/kg)	$\Delta\mathbf{H}_{\mathbf{th}}$ (kJ/kg)	Ƞs1(%)
1	5.4	221	5.2	651.79	667.33	97.7
2	5.6	217	5.2	646.08	664.81	97.2
3	5.5	213	4.9	649.16	669.63	96.9
4	5.4	190	5.3	654.63	665.22	98.4
5	5.5	215	5.2	652.29	665.39	98.0
6	5.8	240	5.3	639.39	665.11	96.1
7	5.5	229	5.2	649.85	664.7	97.8
8	5.4	228	5.1	649.36	667.27	97.3
9	5.5	227	5.2	652.22	664.93	98.1
10	5.5	215	4.9	650.62	670.55	97.0
11	5.3	213	4.9	648.06	667.69	97.1
12	5.4	220	5	645.22	668.04	96.6
13	5.3	222	5	658.31	669.52	98.3
14	5.4	227	5.4	656.80	666.33	98.6

Table 3: Stage2 efficiency calculated with Stage pressure , mass flow rate & temperature of steam at stage 2

S.No.	Mass flow rate (TPH)	Temperature (^{O}C)	Pressure (kg /cm^2)	Actual enthalpy drop (kJ/kg)	Isentropic enthalpy drop (kJ/kg)	Stage2 Efficiency (%)
1	42.7	147	0.77	464.48	566.32	82.02
2	51.3	149	0.85	461.29	562.04	82.07
3	44.3	148	0.7	442.20	550.42	80.34
4	44	145	0.73	404.58	504.62	80.18
5	43.7	146	0.78	453.92	552.76	82.12
6	52.3	153	0.9	494.45	600.54	82.33
7	49.4	147	0.82	482.17	580.6	83.05
8	42.1	148	0.8	475.97	577.67	82.39
9	44.6	146	0.83	479.31	575.07	83.35
10	45.1	148	0.77	446.74	550.32	81.18
11	49.1	148	0.81	443.04	544.13	81.42
12	49.3	150	0.81	453.94	559.13	81.19
13	44.1	144	0.72	470.55	569.21	82.67
14	53.1	145	0.76	483.81	581.89	83.14

Table 4: Overall efficiency, heat output and Heat to Power ratio calculated from experimental data

S.No.	Mass flow rate of fuel (TPH)	Pressure (kg /cm^2)	Heat output (kW)	Total output (kW)	Heat to Power ratio	Overall Efficiency, (%)
1	35	81.9	36683.24	51910.24	2.409092	55.8284
2	36	84.1	43421.6	58313.6	2.915767	64.55965
3	37	82.2	37856.84	51917.84	2.692329	59.2206
4	38	83	37599.6	52973.6	2.445662	52.47424
5	39	83.6	37523.62	52952.62	2.432019	51.10849
6	37.5	83.1	44249.72	59371.72	2.926181	59.59619
7	36	84.2	41890.58	57326.58	2.713824	56.78618
8	36	82.7	36134.23	51446.23	2.359864	53.79244
9	38	84	38216.73	53389.73	2.518732	57.74956
10	36.5	81.4	38473.4	53962.4	2.483917	51.42382
11	37.3	83.9	41380.17	56832.17	2.677982	57.35293
12	35.5	82.8	41619.23	56676.23	2.764112	60.09562
13	36	81.5	37569.49	52926.49	2.446408	55.34021
14	37	81.3	44565.4	59109.4	3.064178	65.44068

The variation in the Electrical efficiency of the steam turbine with inlet pressure is shown in Fig.3.

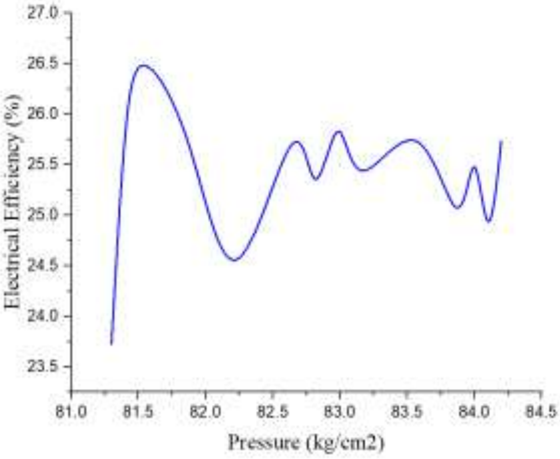

Fig. 3. Electrical Efficiency Vs Inlet Steam Pressure

The maximum electrical efficiency of 26.75% is achieved at an inlet steam pressure of 81.5 kg/cm^{2}and a constant inlet steam temperature of 507^{0}C. The electrical efficiency decreases to 23.79% at an inlet steam pressure of 82.5 kg/cm^2, but then increases to 26.36% at 82.7 kg/cm^2, and remains almost constant with slight decreases even after increasing the inlet steam pressure. The reason for this efficiency pattern is due to the mass flow rate of the steam conditions and the stage extraction of the steam at intermediate stages. However, the efficiency of the turbine is not solely dependent on the steam inlet pressure but also on the inlet steam flow-rate conditions.

The variation in efficiency with the inlet steam flow rate at a constant temperature of 507^{0}C is shown in Figure 4.

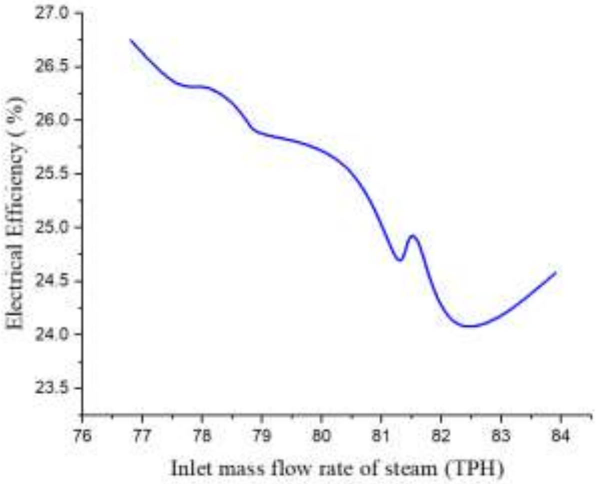

Fig.4. Electrical Efficiency Vs inlet Mass flow rate of steam

The maximum electrical efficiency of 26.74% occurs at a steam flow rate of 76.2 TPH and a constant temperature of 507^0C. However, the efficiency decreases to 25.72% at a steam flow rate of 80.6 TPH and further decreases to 23.73% as the flow rate changes to 82.1 TPH, with a slight increase in efficiency to 24.57% at a flow rate of 83.9 TPH. The decrease in efficiency is due to the turbine stage conditions. To increase the efficiency of the turbine, steam extraction may be introduced at intermediate stages.

The performance of the turbine is significantly affected by the stage-wise extraction of steam at intermediate locations. In the present work, two-stage steam extraction was introduced in medium- and low-turbine-pressure zones. The maximum power generation of a turbine occurs in the high-pressure zone; hence, the intermediate is introduced in medium- and low-pressure zones to utilize the energy of steam wasted in medium- and low-pressure zones in a cogeneration system was introduced. In a cogeneration system, the unutilized energy in the steam is extracted and utilized for floor heating, process steam, generation of power, and production of ancillary products such as floor heating and refrigeration, producing byproducts such as making sugar juice and sugar production in sugarcane cogeneration plants. The variation in efficiency with cogeneration stages as shown in Fig. 5 and 6.

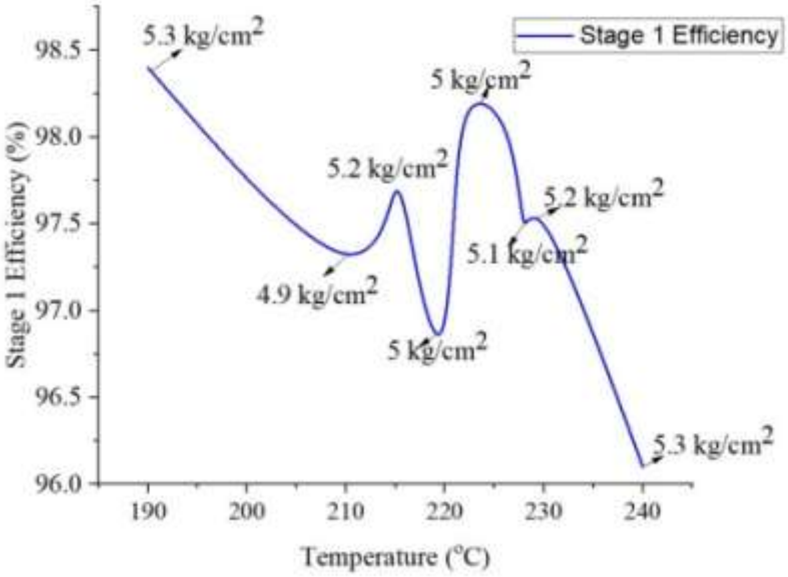

Fig. 5. Stage1 Efficiency versus temperature of steam at stage 1 Extraction

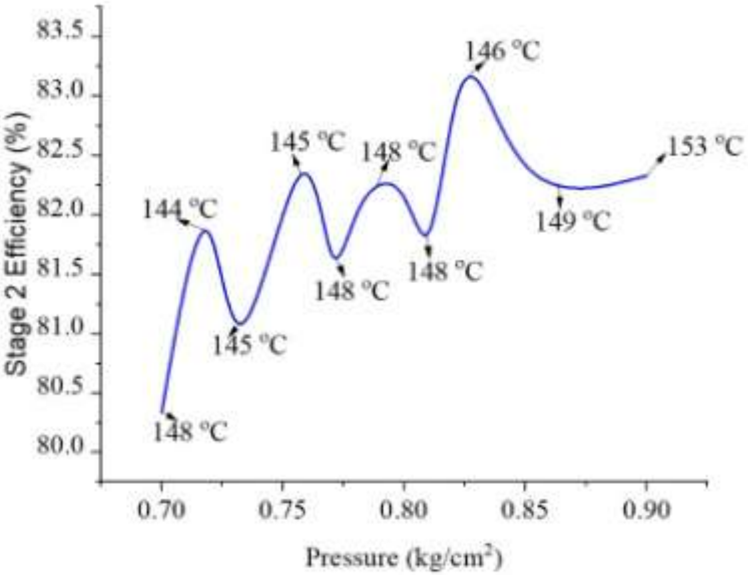

Fig.6. Stage 2 Efficiency versus pressure of steam at stage 2 Extraction

The maximum stage 1 efficiency of 98.4 at extraction of steam at stage1 pressure 5.3 kg/cm^2 at 190^{0}C and mass flow rate of steam of 5.4 TPH further decreases to 96.1% at pressure and temperature are 4.9 kg/cm^2 and 213^{0}C at mass flow rate of 5.3 TPH there is slight fluctuations in stage efficiencies at stage 1 steam parameters. owing to the maximum extraction steam exergy. Further, the remaining energy in the steam was extracted in stage 2. Pressure and temperatures dropped nearly 0.8 kg/cm^2 so at stage 2 having heat energy is utilized for the processing of the steam of efficiencies at stage 2 are maximum of 83.5% at o.83 kg/cm^2 at temperature of 146^{0}C and minimum of 80.18% at 0.73 kg/cm2 is due to variation in mass flow rate of steam, temperature and exhaust conditions.

In cogeneration system further observed parameters heat to power ratio is maximum 3.06 at pressure of 81.3 kg/cm^2 and at mass flow rate of 82.1 TPH and further decreased to 2.35 at pressure of 82.7kg/cm^2. As pressure varies from 81.5 kg/cm^2 to 84.5 kg/cm^2 the heat to power fluctuates between 3.06 to 2.35 at constant temperature the variation the fluctuation of heat to power ratio is due to variation in mass flow rate of the steam shown Fig. 7.

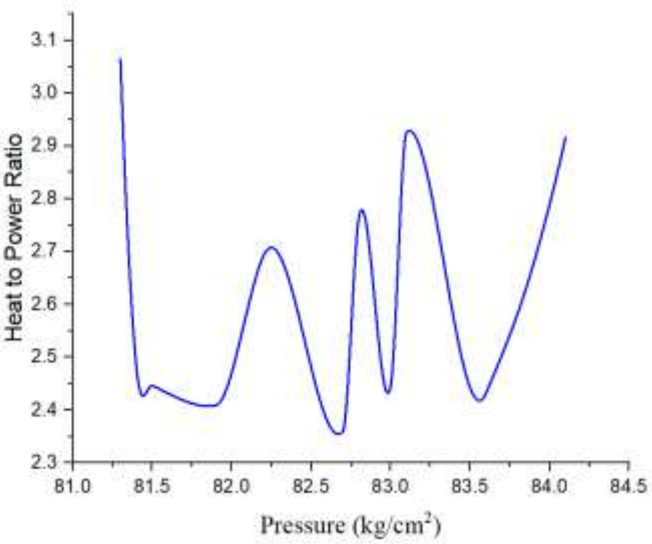

Fig. 7. Heat to Power ratio versus Pressure

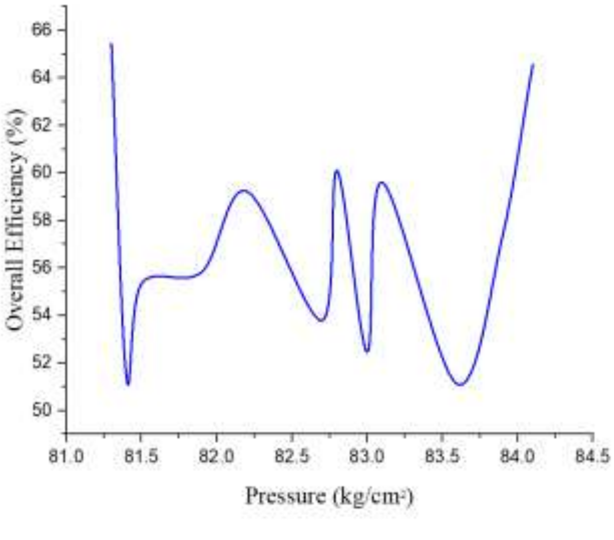

Fig.8. Overall efficiency versus inlet Pressure

From Fig.8 the overall efficiency of a system at different inlet steam pressures. The overall efficiency ranges from 51.10% to 65.44%, with the highest efficiency being achieved at an inlet pressure of 81.3 kg/cm^2. The second highest efficiency of 64.56% is obtained at an inlet pressure of 84.1 kg/cm^2. On the other hand, the lowest efficiency of 51.10% is observed at an inlet pressure of 83.6 kg/cm^2. However, there is no clear trend between the inlet pressure and the overall efficiency, indicating that other factors are also influencing the system's performance. Hence that optimizing the inlet pressure of the steam may help improve the system's overall efficiency, and should be considered in future design and operational decisions.

IV. Conclusion

In this study, the performance of a steam power plant with a cogeneration system was investigated experimentally. The influence of performance characteristics, such as the steam pressure mass flow rate, inlet temperature, efficiency of the turbine and overall efficiency of the plant, were investigated. The turbine's efficiency and the plant's overall efficiency improved as a result of the stages. The maximum thermal efficiency 26.75%occurs at 81.5 kg/cm^2 steam pressure, at a constant temperature of 507^{0}C.Maximum stage 1 efficiency of 98.4 at steam extraction at stage 1 pressure of 5.3 kg/cm^2 at 190^{0}C and steam mass flow rate of 5.4 TPH. At the second stage, Pressures and temperatures dropped nearly 0.8 kg/cm^2 so heat energy is used for steam processing at stage 2. Efficiency at stage 2 is 83.5 at 0.83 kg/cm^2 at 146^{0}C and 80.18 at 0.73 kg/cm^2. The maximum overall efficiency of 62.408% at an inlet steam pressure of 83.1 kg/cm^2 at 507^{0}C.The Power plant Cogeneration experimentation is carried out based on the above changing parameters on an hourly basis. As a result, every point fraction value has an effect on the plant's efficiency based on practical values, and their continuous changes observed by changing extraction stage parameters on the plant's efficiency.

References

[1] M. J. B. Kabeyi and O. A. Olanrewaju, “Cogeneration potential of an operating diesel engine power plant,” Energy Rep., vol. 8, pp. 744–754, Dec. 2022, doi: 10.1016/j.egyr.2022.10.447.

[2] S. C. Kamate and P. B. Gangavati, “Exergy analysis of cogeneration power plants in sugar industries,” Appl. Therm. Eng., vol. 29, no. 5, pp. 1187–1194, Apr. 2009, doi: 10.1016/j.applthermaleng.2008.06.016.

[3] A. Ensinas, S. A. Nebra, M. Lozano, and L. Serra, “Analysis of cogeneration systems in sugar cane factories – Alternatives of steam and combined cycle power plants,” Jul. 2006.

[4] G. V. Pradeep Varma and T. Srinivas, “Design and analysis of a cogeneration plant using heat recovery of a cement factory,” Case Stud. Therm. Eng., vol. 5, pp. 24–31, Mar. 2015, doi: 10.1016/j.csite.2014.12.002.

[5] A. S. Karakurt, “Performance Analysis of a Steam Turbine Power Plant at Part Load Conditions,” J. Therm. Eng., vol. 3, no. 2, pp. 1121–1121, Apr. 2017, doi: 10.18186/thermal.298611.

[6] R. Chacartegui, D. Sa´nchez, J. A. Becerra, A. Mun˜oz, and T. Sa´nchez, “Performance Analysis of a 565 MW Steam Power Plant,” presented at the ASME 2011 Turbo Expo: Turbine Technical Conference and Exposition, May 2012, pp. 2427–2436. doi: 10.1115/GT2011-46272.

[7] L. Olmos-Villalba, B. Herrera, A. Gallego, and K. Cacua, “Experimental Evaluation of a Diesel Cogeneration System for Producing Power and Drying Aromatic Herbs,” Sustainability, vol. 11, no. 18, Art. no. 18, Jan. 2019, doi: 10.3390/su11185121.

[8] H. VaziNi Modabber and M. H. KhoshgoftarManesh, “4E Analysis of Power and Water Cogeneration Plant based on Integrated MED-TVC and RO Desalination Units,” Int. J. Thermodyn., vol. 23, no. 2, pp. 107–126, May 2020, doi: 10.5541/ijot.616899.

[9] I. Journal, “Thermodynamic Analysis of Cogeneration Power Plant,” Int. J. Eng. Sci. Amp Res. Technol., Apr. 2014, Accessed: Dec. 26, 2022. [Online]. Available: https://www.academia.edu/6994478/Thermodynamic Analysis of Cogeneration Power Plant

[10] J. Lee, K. M. Kim, S. Im, S. H. Shin, W. S. Chang, and M. S. Oh, “A study on the variation of the performance and the cost of power generation in a combined heat and power plant with the change of the user facility’s return temperature,” J. Mech. Sci. Technol., vol. 34, no. 2, pp. 905–915, Feb. 2020, doi: 10.1007/s12206-020-0140-5.

[11] M. Atmaca, M. Gumus, A. T. Inan, T. Yilmaz: Optimization of Irreversible Cogeneration Systems under Alternative Performance Criteria, Springer, Page no 1724-1732, - 2009

[12] Hisham S. Bamufleh Jose Marı´a Ponce-Ortega, Mahmoud M. El-Halwagi: Multi-objective optimization of process cogeneration systems with economic, environmental, and social tradeoffs, Springer-Verlag Vol 15 Page no 185–197 2012

[13] G. Barigozzi, A. Perdichizzi, S. Ravelli : Wet and dry cooling systems optimization applied to a modern waste-to-energy cogeneration heat and power plant. Elsevier, Applied Energy 88 (2011) 1366–1376, Year 2010.

[14] Mehmet Kanoglu , Ibrahim Dincer : Performance assessment of cogeneration plants

[15] Elsevier, Energy Conversion and Management, Vol 50, Page no 76-81, Year 2009

[16] M.H. KhoshgoftarManesh, P. Navida, A.M. Blanco Marigorta b, M. Amidpour a,

[17] M.H. Hamedia : New procedure for optimal design and evaluation of cogeneration system based on advanced exergo economic and exergo environmental analyses. Elsevier, Energy Vol. 59, (2013) 314-333 Year 2013