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Performance evaluation of cogeneration plant at various turbine inlet temperatures

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Abstract

This experimental study examines the efficiencies of a cogeneration plant under various constant turbine inlet temperatures. The study considers the effects of changes in mass flow rate, inlet pressure and inlet temperature on the electrical and overall efficiencies of the system. The findings indicate that the electrical and overall efficiencies are relatively consistent across different mass flow rates but vary slightly across different inlet pressures. The highest overall efficiency and electrical efficiency are obtained at a mass flow rate of 21.56 kg/s, an inlet pressure of 83 kG/cm^2 and an inlet temperature of 507°C. Under these operating conditions, the overall efficiency reached 58.06% and the electrical efficiency was 26.26%. These findings suggest that the optimum conditions for this system depend on the specific requirements and priorities.

Keywords: Mass flow rate of steam; Electrical efficiency; Overall efficiency; Heat-to-power ratio

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1. Introduction

Thermal power plants are significant sources of electricity generation around the world and their efficient operation is crucial for meeting the growing energy demand. Cogeneration, also known as combined heat and power (CHP), is a technology that allows for the simultaneous generation of electricity and heat from the same energy source. By utilising the waste heat generated during electricity generation, cogeneration systems can significantly improve the energy efficiency of thermal power plants.

One of the key factors that affects the performance of cogeneration systems is the steam flow parameters, such as pressure, temperature and mass flow rate. These parameters have been shown to have a significant impact on the thermal efficiency, electricity generation, and overall energy utilisation of cogeneration systems.

The purpose of this research is to look into the performance of a thermal power plant cogeneration system by varying steam flow parameters through hourly-based experimentation. This study will provide valuable insights into optimising cogeneration systems and contribute to developing more energy-efficient thermal power plants. Ozdil et al. [1] conducted an in-depth analysis of a 14.25 MW cogeneration plant in Adana, Turkey, utilising the first and second laws of thermodynamics. Their study examined the system's key components and assessed its thermodynamic performance. Findings revealed that exergy destruction in the boiler accounted for a significant 42% of the system's total irreversibility. Gambini and Vellini [2] focused on the development of highly efficient heat and power cogeneration systems and explored strategies for enhancing overall energy efficiency. High-efficiency cogeneration, as defined by compliance with specific criteria for accessing support systems, is rewarded with energy

Nomenclature

CV – calorific value, kJ/kg
F_i – fuel energy input, kW
h – specific enthalpy, kJ/kg
m_s – mass flow rate of steam, kg/s
P – pressure, kG/cm^2
Q_s – steam input energy, kW
Q_u – process heat, kW
T – temperature, ºC, K
W_t – power generated, kW
$1,\ldots,10$ – point states in thermodynamic cycle

Greek symbols
δ – heat-to-power ratio
η_e – electrical efficiency, %
η_o – overall efficiency, %

Subscripts and Superscripts
i – inlet
o – output

Abbreviations and Acronyms
CHP – combined heat and power
FW – feed water
HU – heat utilisation
4E – energy-exergy-environment-economics

efficiency certificates (white certificates) based on the energy savings achieved annually.

Chicco et al. [3] explored the potential of distributed cogeneration technologies to improve efficiency and cater to niche markets. They evaluated cogeneration plants using three primary metrics: energy savings, environmental impact and financial viability. Their study introduced a method for analysing electrical and thermal production using incremental indicators, with a focus on microturbines and internal combustion engines — the two most common small-scale cogenerative prime movers. Dinakaran et al. [4] advanced the concept of bagasse cogeneration, emphasising the efficient generation of heat and electricity from sugarcane waste (bagasse) in sugar mills. Their research addressed the economic aspects of modern cogeneration systems within the sugarcane industry. By replacing inefficient mill turbines with hydraulic drives and DC (direct current) motors, sugar mills can achieve high operational efficiency (65–75%) and supply surplus power to the grid, thereby boosting revenue streams for sugar plants. Gulhane et al. [5] published a study focused on optimising energy use while minimising its adverse impacts. The paper highlights several key findings based on extensive research and first-hand observations of local power plants. The primary objective was to determine the magnitude and sources of irreversibilities in a 35 TPH (tons per hour) boiler within a 6 MW captive power plant. These insights aim to help system designers identify the processes contributing most to energy losses. Gambini and Vellini [2] worked on advancing high-efficiency cogeneration systems for heat and power production while striving to enhance overall energy efficiency. ‘High-efficiency cogeneration’ refers to systems that meet the necessary conditions and protocols for integration into the cogeneration support framework. Such systems are annually awarded energy efficiency certificates (white certificates) proportional to the energy savings achieved. Gladysz et al. [6] developed a sophisticated algorithm to evaluate the share of cogeneration in district heating systems. The study concluded with a set of empirical equations that demonstrated how various factors influence the optimal cogeneration ratio, both for systems with and without thermal storage. Vazini Modabber et al. [7] conducted a ‘4E (energy-exergy-environment-economics) analysis’ of a power and water cogeneration plant using MATLAB to evaluate its energy efficiency, total costs and environmental impact. Bhalodia et al. [8] developed a thermal analysis to enhance the efficiency of a 25 MW plant by identifying and quantifying thermodynamic losses within the cogeneration facility. Silveira et al. [9] introduced a thermo-economic functional analysis based on the Second Law of thermodynamics, which was applied to four cogeneration systems under investigation. Assuming constant electricity generation and steam processing rates in the exergy framework, the proposed method aimed to minimise the energy production cost (EPC) of the cogeneration plant. Among the configurations analysed, the most economical system, requiring no additional firing, comprised a gas turbine coupled with a heat recovery steam generator. Kamate et al. [10] analysed a bagasse-based cogeneration system with an extraction condensing steam turbine and backpressure for a typical 2500 TCD (tonnes crushed per day) sugar refinery, focusing on energy efficiency. The study combined traditional energy analysis with advanced energy methods to evaluate overall and component efficiencies and quantify thermodynamic losses. Korobitsyn et al. [11] investigated cogeneration and found that efficiency could be enhanced by modifying the basic cycle to recover heat from turbine exhaust for steam production in a steam turbine bottoming cycle. Barigozzi et al. [12] demonstrated how the performance of a waste-to-energy cogeneration plant could be improved by optimising the condensation system, highlighting the benefits of combining wet and dry cooling systems. Kanoglu et al. [13] evaluated the efficiency of various building cogeneration systems, measuring and analysing energy and exergy efficiencies. The study considered systems utilising steam turbines, gas turbines, diesel engines and geothermal energy for simultaneous production of electricity and heat (e.g. for space heating and hot water). Actual operating data were used for analysis and performance assessment.

Manesh et al. [14] advanced the development of the R-curve concept through sophisticated exergetic, exergoeconomic, and exergoenvironmental analyses. They proposed a systematic approach for optimally designing and assessing cogeneration systems using a detailed cogeneration targeting model. Bisulandu et al. [15] reported that turbine inlet temperature (TIT) is one of the strongest direct drivers of gas turbine performance: increasing TIT typically raises engine specific work and cycle thermal efficiency, and in combined/CHP plants increases the available heat for the bottoming cycle or process steam, improving overall energy utilisation. Liu et al. [16] examined the effect of ambient temperature and humidity on TIT and overall plant output: higher inlet air temperatures reduce mass flow and compressor performance, lowering net output and often lowering overall CHP electrical efficiency unless inlet-air cooling or other strategies are used. Kazemiani-Najafabadi and Rad [17] emphasised that the several recent 4E studies have quantified that an 'optimum' TIT exists when environmental penalties and capital/operating costs (e.g. advanced cooling or blade materials) are accounted for. For CHP, optimal TIT must be balanced against the temperature/quality required by the process steam or district heating load. Mehregan et al. [18] in their study proposed a new combined heat and power (CHP) system configuration featuring a dual prime mover: a proton exchange membrane (PEM) fuel cell and a Stirling engine. The hybrid integration of the fuel cell and Stirling engine enables assessment of potential performance improvements and identification of optimal operating conditions compared to conventional single–prime mover CHP systems. Sanjay et al. [19] evaluated the thermodynamic performance of an MS9001 gas turbine-based cogeneration cycle equipped with a two-pressure heat recovery steam generator (HRSG), considering various blade-cooling methods. In this configuration, one steam drum in the HRSG produces steam to satisfy the turbine blade cooling demand, while a second steam drum supplies steam for process heating. Feidt et al. [20] examined the optimisation of these systems, focusing on maximising exergy while considering practical constraints, such as mechanical energy limitations, heat demand requirements, and physical constraints like heat source availability and temperature limitations of the system.

The purpose of this research is to determine efficiency of a cogeneration plant by varying the steam flow parameters at different constant temperatures at the inlet of the steam turbine.

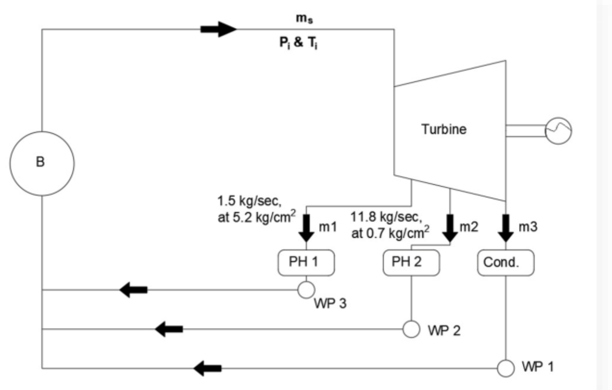

Fig. 1. Extraction condensing steam turbine cogeneration plant: B − boiler; Cond. − condenser; PH1, PH2 – process heat at extraction stages 1 and 2; WP1–WP3 – water pumps, m_1–m_3 – steam mass flow rates at extraction stages.

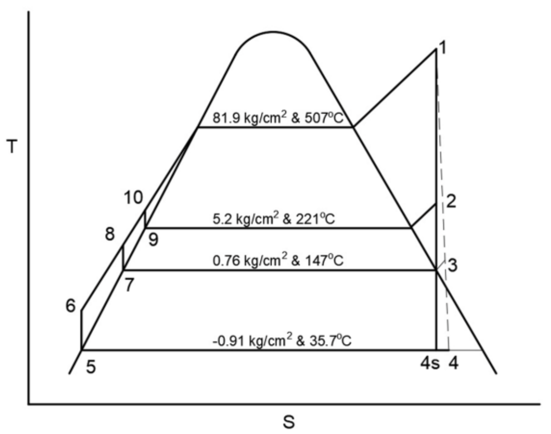

Fig. 2. Temperature-entropy (T–S) diagram.

2. Description of the extraction condensing steam turbine cogeneration plant

The system under study is the most common layout of a modern cogeneration plant in the sugar industry. The plant in this design burns all of the bagasse it produces to generate steam. After meeting the plant's minimum requirement for process steam, any excess steam is routed to the condenser, where it can potentially generate more electricity.

To estimate the performance characteristics of the steam turbine, it is required to measure the steam parameters at the inlet and stage levels. Steam temperature, pressure and mass flow rate at the inlet of the turbine and at the stages of the turbine are considered as the influencing parameters. To measure these parameters, pressure gauges, thermocouples and Venturi meters are located at the inlet and stage levels.

3. Experimental analysis

3.1. Methodology

The experimental parameters for the cogeneration plant included pressure, steam temperature and mass flow rate, which were tested in various combinations. The tests were performed at several constant inlet temperatures. System performance was evaluated in terms of power output and overall efficiency. Figure 1 presents the sequence of steps used to estimate the performance of a steam turbine-based cogeneration system, which is the most widely used configuration in industry (Fig. 2). While the general methodology is applicable to all cogeneration systems, the subsequent formulations specifically focus on steam turbine cogeneration. The key output parameters analysed include electrical efficiency, heat-to-power ratio and overall plant efficiency. Cogeneration involves the simultaneous generation of electricity and useful heat, meaning the system produces two forms of energy. Therefore, a common benchmark is required to assess its efficiency. According to the first law of thermodynamics, the primary performance indicators are electrical efficiency for conventional power plants and overall energy efficiency for cogeneration systems. These metrics assess only the quantitative characteristics of energy conversion.

The electrical efficiency is given by the equation:

$$\eta_e = \frac{W_t}{Q_s} \times 100, \tag{1}$$

where W_t is the electrical power received directly at the generator output, and Q_s is the steam energy input to the turbine:

$$Q_s = m_s(h_1 - h_{10}), \tag{2}$$

where m_s is the steam mass flow rate, h_1 is the specific enthalpy of the steam entering the turbine, and h_{10} is the specific enthalpy of the feed water to the boiler.

The electrical efficiency is calculated in relation to the steam energy input to the turbine at various constant temperatures: 507°C, 500°C and 495°C.

The overall efficiency of the plant is given by the following equation:

$$\eta_o = \frac{W_t + Q_u}{F_i} \times 100, \tag{3}$$

where W_t is the power or electrical energy generated as determined by a digital indicator, and Q_u is the process heat extracted from the turbine at usable temperatures during the in-stage extraction process.

The energy input from the fuel source is given as:

$$F_i = m_f \mathrm{CV}, \tag{4}$$

where m_f is the mass flow rate of bagasse and CV is its calorific value of 9500 kJ/kg.

The heat-to-power ratio is expressed by the formula:

$$\delta = \frac{Q_u}{W_t}. \tag{5}$$

The heat energy usage in stages 1 and 2 of the turbine is as follows:

$$\text{heat utilisation at stage } 1 = m_1 h_1, \tag{6}$$

$$\text{heat utilisation at stage } 2 = m_2 h_2, \tag{7}$$

where m_1 and m_2 represent the steam mass flow rates at the first and second extraction stages, respectively, and h_1 and h_2 denote the specific enthalpy at the respective pressure and temperature conditions.

Finally, the heat output (Q_u) and the total energy output (Q_o) are represented by the following relations, respectively:

$$Q_u = m_1 h_1 + m_2 h_2, \tag{8}$$

$$Q_o = W_t + Q_u. \tag{9}$$

3.2. Results and discussion

The inlet pressure fluctuates between 81.3 and 84.9 kG/cm^2, as seen in Fig. 3 and Table 2. While the overall efficiency falls between 56.04% and 58.06%, the electrical efficiency falls between 23.84% and 26.26%. The findings show that across the investigated input pressures, both electrical and total efficiency remain largely constant. Nevertheless, the maximum electrical efficiency of 26.26% and the highest overall efficiency of 57.05% are produced by the highest inlet pressure of 84.1 kG/cm². These findings indicate that 84.1 kG/cm^2 is the ideal input pressure for this system's maximum efficiency (Table 2).

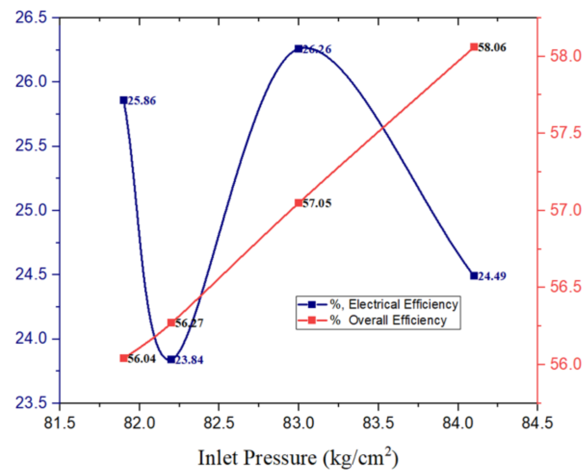

Fig. 3. Electrical efficiency and overall efficiency vs. inlet pressure at 507ºC.

Table 1. Conditions for steam flow input parameters and net power output at 507°C.

Inlet				Ext. 1			Ext. 2			FW		W_t, kW
m_f, kg/s	m_s, kg/s	T_i, °C	P_i, kG/cm²	m_1, kg/s	T_1, °C	P_1, kG/cm²	m_2, kg/s	T_2, °C	P_2, kG/cm²	T_{10}, °C	P_{10}, kG/cm²	
9.86	21.92	507	81.9	1.47	240	5.11	14.27	156	0.88	174	120	15227
10.14	22.58	507	84.1	1.50	238	5.10	13.05	154	0.87	174	120	14892
9.83	21.89	507	82.2	1.44	241	5.00	13.52	156	0.89	176	120	14061
9.69	21.56	507	83.0	1.61	228	5.20	13.75	146	0.87	170	120	15374

Table 2. Electrical efficiency and overall efficiency at various inlet mass flow rates and pressures at 507°C.

m_f, kg/s	m_s, kg/s	T_i, °C	P_i, kG/cm²	Q_s, kW	F_i, kW	Q_o, kW	W_t, kW	δ	η_e, %	η_o, %
9.86	21.92	507	81.9	58883.95	94323.37	52860.78	15227	2.47	25.86	56.04
10.14	22.58	507	84.1	60814.43	97192.52	59354.76	14892	2.98	24.49	58.06
9.83	21.89	507	82.2	58991.87	94203.82	53010.65	14061	2.77	23.84	56.27
9.69	21.56	507	83.0	58538.42	92769.25	53859.97	15374	2.50	26.26	57.05

Figure 4 and Table 1 and 2 illustrate the electrical efficiency and total efficiency, as a function of the inlet mass flow rate at 507ºC. The range of the mass flow rate is 21.56–22.58 kg/s. The overall efficiency ranges from 56.04% to 58.06%, while the electrical efficiency ranges from 23.84% to 26.26%. According to the data, the electrical and total efficiencies remain comparatively constant throughout the various mass flow rates. The best overall efficiency of 58.06% is achieved at the highest mass flow rate of 22.58 kg/s, while the highest electrical efficiency of 26.26% is achieved at a mass flow rate of 21.56 kg/s (Table 2). As a result, the system's ideal settings would be based on the specific requirements and objectives.

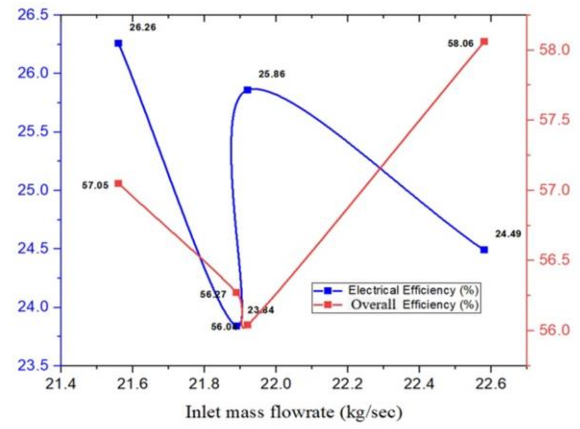

Fig. 4. Electrical efficiency and overall efficiency vs. inlet mass flow rate at 507°C.

The intake pressure varies from 81.7 kG/cm^2 to 85.3 kG/cm^2, as shown in Fig. 5 and Table 4. The overall efficiency is between 56.23% and 57.27%, while the electrical efficiency is between 24.31% and 25.53%. The data shows that there are minor differences in electrical and total efficiency between various inlet pressures. According to the findings, an input pressure of 82.8 kG/cm^2 produced the maximum total efficiency of 57.27%, with an electrical efficiency of 25.2% (Table 4). Accordingly, an input pressure of 82.8 kG/cm^2 would be the ideal condition for this system, while a mass flow rate of 21.56 kg/s would yield the best electrical

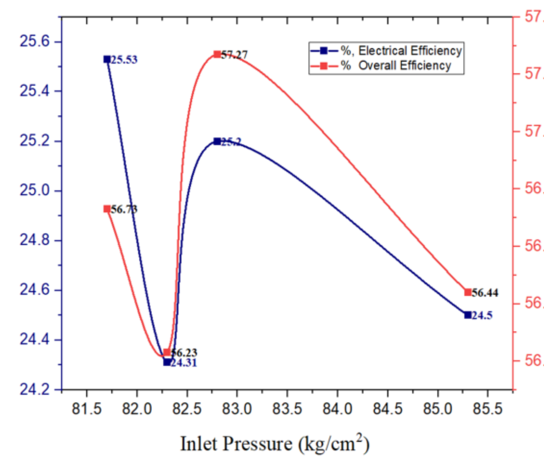

Fig. 5. Electrical efficiency and overall efficiency vs. inlet pressure at 500ºC.

efficiency of 26.26%. As a result, the particular needs and priorities would determine the best conditions for this system.

The mass flow rate ranges from 21.67 kg/s to 22.67 kg/s, as shown in Fig. 6 and Tables 3 and 4. The overall efficiency is

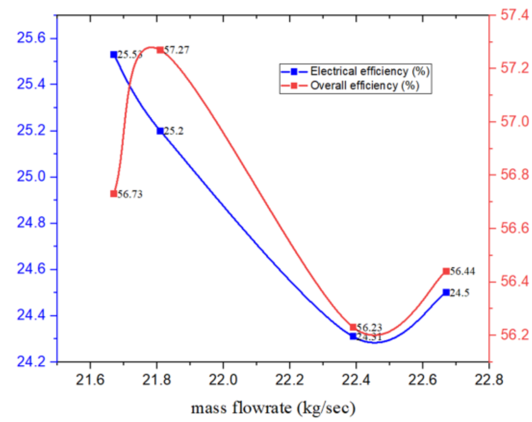

Fig. 6. Electrical efficiency and overall efficiency vs. inlet mass flow rate at 500°C.

Table 3. Conditions for steam flow input parameters and net power output at 500°C.

Inlet				Ext. 1			Ext. 2			FW		W_t, kW
m_f, kg/s	m_s, kg/s	T_i, °C	P_i, kG/cm^2	m_1, kg/s	T_1, °C	P_1, kG/cm^2	m_2, kg/s	T_2, °C	P_2, kG/cm^2	T_{10}, °C	P_{10}, kG/cm^2	
9.83	21.81	500	82.8	1.50	221	5.2	11.86	147	0.77	171	120	15480
10.00	22.67	500	85.3	1.56	217	5.2	14.25	149	0.85	169	119	15436
9.75	22.39	500	82.3	1.53	213	4.9	12.31	148	0.70	168	119	14801
9.89	21.67	500	81.7	1.50	190	5.3	12.22	145	0.73	164	120	15483

Table 4. Electrical efficiency and overall efficiency at various inlet mass flow rates and pressures at 500°C.

m_f, kg/s	m_s, kg/s	T_i, °C	P_i, kG/cm^2	Q_s, kW	F_i, kW	Q_o, kW	W_t, kW	δ	η_e, %	η_o, %
9.83	21.81	500	82.8	61432.31	94084.2	52860.78	15480	2.48	25.20	57.27
10.00	22.67	500	85.3	63015.85	95638.4	59354.76	15436	2.49	24.50	56.44
9.75	22.39	500	82.3	60880.51	93486.5	53010.65	14801	2.55	24.31	56.23
9.89	21.67	500	81.7	60645.68	94801.5	53859.97	15483	2.47	25.53	56.73

Table 5. Conditions for steam flow input parameters and net power output at 495°C.

Inlet				Ext. 1			Ext. 2			FW		W_t, kW
m_f, kg/s	m_s, kg/s	T_i, °C	P_i, kG/cm²	m_1, kg/s	T_1, °C	P_1, kG/cm²	m_2, kg/s	T_2, °C	P_2, kG/cm²	T_{10}, °C	P_{10}, kG/cm²	
9.61	28.4	495	82.1	1.50	221	5.2	11.86	147	0.77	171	120	15359
8.97	28.6	495	84.3	1.56	217	5.2	14.25	149	0.85	169	119	15341
9.92	30.2	495	83.4	1.53	213	4.9	12.31	148	0.70	168	119	15462
9.19	29.3	495	85.3	1.50	190	5.3	12.22	145	0.73	164	120	15316

Table 6. Electrical efficiency and overall efficiency at various inlet mass flow rates and pressures at 495°C.

m_f, kg/s	m_s, kg/s	T_i, °C	P_i, kG/cm²	Q_s, kW	F_i, kW	Q_o, kW	W_t, kW	δ	η_e, %	η_o, %
9.61	28.4	495	82.1	60952.64	92171.5	15359	48440.1	2.47	25.20	52.55
8.97	28.6	495	84.3	62619.68	85835.4	15341	48412.6	2.98	23.71	56.40
9.92	30.2	495	83.4	62087.00	94921.1	15462	49370.5	2.77	24.90	52.01
9.19	29.3	495	85.3	62920.36	87987.3	15316	49863.4	2.50	24.34	56.60

between 56.23% and 57.27%, while the electrical efficiency is between 24.31% and 25.53%. At a mass flow rate of 21.81 kg/s, the highest overall efficiency of 57.27% was achieved. At a mass flow rate of 21.67 kg/s, the greatest electrical efficiency of 25.53% was achieved (Table 4).

Figure 7 and Table 6 show the change in the efficiency for inlet pressure varied between 82.1 kG/cm² and 85.3 kG/cm². The total and electrical efficiencies range from 23.71% to 25.20% and from 23.71% to 25.2%, respectively. It should be noted that an increased inlet pressure typically results in an increased overall efficiency. However, this relationship is inconsistent, as it can be observed that at the greatest inlet pressure of 85.3 kG/cm², overall efficiency actually slightly declines. It is evident that an input pressure of 84.3 kG/cm² gave the greatest overall efficiency of 56.60% (Table 6).

Figure 8 and Tables 5 and 6 depict the change in the efficiency for a mass flow rate range of 28.4 kg/s to 30.2 kg/s. The electrical efficiency ranges from 23.71% to 25.2%, and the overall efficiency ranges from 52.01% to 56.6%. The highest overall efficiency of 56.6% was obtained at a mass flow rate of

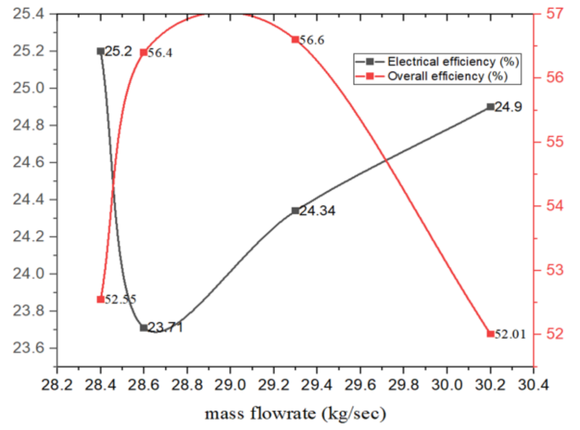

Fig. 8. Electrical efficiency and overall efficiency vs. inlet mass flow rate at 495°C.

22.6 kg/s. The highest electrical efficiency of 25.20% was obtained at a mass flow rate of 28.4 kg/s (Table 6). The maximum electrical and overall efficiencies obtained at constant temperatures of 495°C, 500°C and 507°C are tabulated in Tables 7 and 8, respectively, and depicted in Fig. 9.

The data in Fig. 9 indicate that as the inlet temperature increases, both electrical and overall efficiency increase. The increase in electrical efficiency is 0.63% with an increase in inlet temperature from 495°C to 500°C and 0.79% between 500°C and 507°C. The increase in overall efficiency is 0.67% between increased inlet temperatures of 495°C and 500°C and 0.79% between 500ºC and 507ºC. Inlet temperature has a significant impact on the efficiency of the system being measured. The higher the temperature of the steam entering the system, the

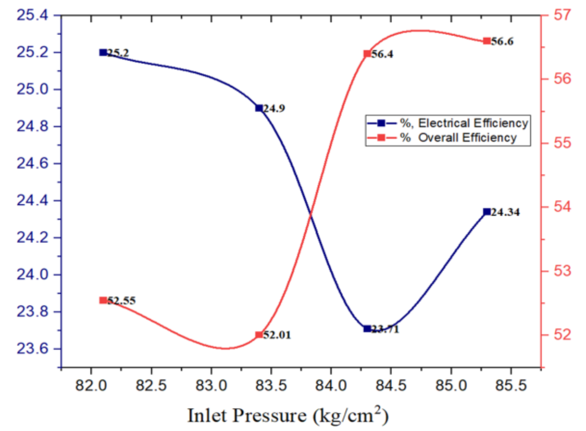

Fig. 7. Electrical efficiency and overall efficiency vs. inlet pressure at 500ºC.

Table 7. Maximum electrical efficiency at various inlet mass flow rates and pressures, at different inlet temperatures.

T_i, °C	m_s, kg/s	P_i, kG/cm²	η_e, %
507	21.56	83.0	26.26
500	21.67	81.7	25.53
495	28.40	82.1	25.20

Table 8. Maximum overall efficiency at various inlet mass flow rates and pressures, at different inlet temperatures.

T_i, °C	m_s, kg/s	P_i, kG/cm^2	η_o, %
507	22.58	84.1	58.06
500	21.81	82.8	57.27
495	29.30	85.3	56.60

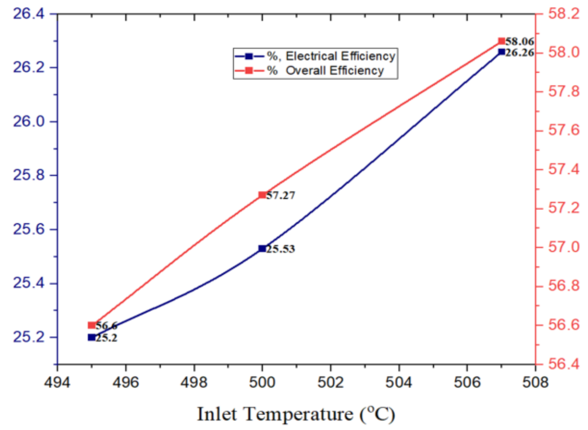

Fig. 9. Effect of inlet temperature on the electrical efficiency and overall efficiency.

higher the efficiency of the system. This could be due to factors such as reduced losses, improved thermal efficiency or increased power output.

4. Conclusions

Based on the given results and discussion, it can be concluded that the steam turbine's electrical efficiency is not only affected by the pressure and mass flow rate of the steam. According to the findings, the greatest efficiency value of 26.26% was achieved at a steam pressure of 83 kG/cm^2 with a mass flow rate of 21.3 kg/s and a corresponding temperature of 507°C. Conversely, the lowest efficiency value of 23.71% was observed at a pressure of 84.3 kG/cm^2, a mass flow rate of 22.1 kg/s and a corresponding temperature of 495°C. The maximum overall efficiency of 58.06% was recorded with an inlet steam pressure of 83.1 kG/cm^2 at a constant temperature of 507°C, while the minimum of 52.01% was observed at an inlet steam pressure of 84.3 kG/cm^2 at a constant temperature of 495°C. As a result, the efficiency of the plant is influenced by every fractional value, based on practical values, and their continuous changes by altering the parameters of the extraction stage affect the plant's efficiency at different constant temperatures of 507°C, 500°C and 495°C, causing variations in electrical and overall efficiency irrespective of the inlet pressure and steam mass flow rate. Consequently, the parameters of the steam extraction stages play a crucial role in determining the electrical and overall efficiency of the cogeneration power plant.

The highest electrical efficiencies were achieved at constant input temperatures of 507°C, 500°C, and 495°C, which are 26.26% at 83 kG/cm^2, 25.53% at 81.7 kG/cm^2, and 25.2 % at 83.4 kG/cm^2, respectively.

For constant input temperatures of 507°C, 500°C and 495°C, the maximum overall efficiency values reached 58.06% at the pressure of 84.1 kG/cm^2, 57.27% at the pressure of 82.8 kG/cm^2, and 55.72% at the pressure of 83 kG/cm^2, respectively.

Controlling the inlet temperature is one way to improve the efficiency of the system, but it is also important to consider other factors that may be contributing to losses or inefficiencies in the system. It is evident that as working inlet temperatures rose from 495°C to 500°C, the electrical efficiency and total efficiency increased by 0.33% and 0.73% percent, respectively. The values of electrical efficiency and overall efficiency increased by 0.67% and 0.79%, respectively, as operational intake temperatures rose from 500°C to 507°C, indicating that the efficiencies were boosted by raising temperatures and the amount of fuel consumption.

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