Journal of Thermal Analysis and Calorimetry (2024) 149:8873–8884
https://doi.org/10.1007/s10973-024-13142-3

Thermoeconomic analysis of organic Rankine cycle with different working fluids for waste heat recovery from a coal-based thermal power plant

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Received: 30 August 2023 / Accepted: 1 April 2024 / Published online: 3 May 2024

Abstract

Energy waste from power plants, typically emitted into the atmosphere, contributes to climate change and resource depletion. Integrating heat recovery systems into power plants can improve overall efficiency. This study focused on utilizing waste heat from a 500-MW_e coal-based supercritical standalone plant through the organic Rankine cycle. The power plant uses Indian coal as a fuel input, and five distinct working fluids, R245fa, methanol, acetone, ethanol, and benzene, are considered working fluids for the ORC system. Thermodynamic analysis indicates that the standalone plant exhibits energy and exergy efficiencies of 27.33% and 25.01%, respectively. Following the integration of ORC, an overall efficiency improvement is observed. The increment in efficiency is because of the waste heat utilization, where the ORC generates additional electricity generation with outputs of 9.91 MW_e for R245fa, 13.71 MW_e for methanol, 13.97 MW_e for acetone, 14.04 MW_e for ethanol, and 14.11 MW_e for benzene. Additionally, the study reveals a substantial reduction in CO_2 emissions compared to the coal-based power plant with the same production of power, amounting to approximately 216.43 tons for R245fa, 299.43 tons for methanol, 305.10 tons for acetone, 306.63 tons for ethanol, and 308.16 tons for benzene. The thermodynamic investigation identifies the superior performance of the benzene-based ORC among the chosen fluids, and the economic study concludes that the ethanol-based ORC stands out as the most favorable option among the considered alternatives.

Keywords CO_2 reduction · Energy · Exergy · Economic · ORC

List of symbols

H	Specific enthalpy ($kJkg^{-1}$)
$\dot{I}$	Irreversibility rate (kW)
$\dot{m}$	Mass flow rate (kgs^{-1})
N	Molar flow rate ($kmols^{-1}$)
Q	Heat transfer rate (kW)
ΔT	Temperature difference (°C)
$\dot{W}$	Work rate (kW)
$\dot{E}$	Exergy rate (kW)
$\dot{W}_{waste}$	Exergy rate of the recovered waste heat (kW)
₹	Indian currency symbol (Rupees)
Z	Cost of each component (Rupees)

Greek symbols

η	Energy efficiency (%)
ε	Exergy efficiency (%)
Ψ	Specific exergy ($kJkg^{-1}$)

Abbreviations

LMTD	Logarithmic mean temperature difference
ORC	Organic Rankine cycle

Subscripts

min	Minimum
cv	Control volume
max	Maximum

Introduction

With the rapid increase in urbanization, industrialization, and modernization, the consumption of energy is increasing exponentially. Most of the demand is fulfilled by using fossil fuels, namely coal. Coal is more affordable and abundantly available, making it the primary source of energy. According

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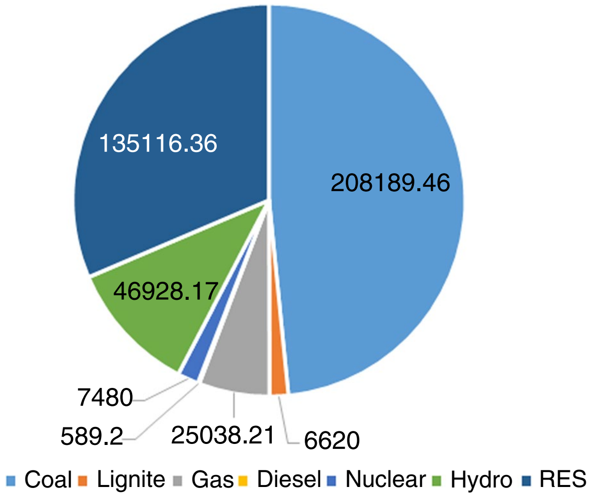


Fig. 1 Total installed capacity in India [1]

to the Central Electricity Authority [1], the total installed electricity generation from different resources in India as of January 2024 is 4,29,961.40 MW, as shown in Fig. 1. Coal constitutes India's dominant energy generation source, accounting for approximately 48.42% of the total capacity. A significant amount of waste heat is discharged within power plants at notably low temperatures [2]. Converting this heat into electrical power via conventional methods poses challenges. As a result, this excess heat is released into the atmosphere. The significant energy losses are prevalent primarily in the condenser, and subsequent losses occur during the flue gas exhaust phase. It is a widely acknowledged fact that technological advancements are continually progressing, resulting in an upward trajectory in energy consumption. Consequently, harnessing waste heat presents itself as a viable solution to curbing the rate of consumption of fossil fuels. Various low-grade power generation cycles, such as the Kalina cycle [3] and organic Rankine cycle (ORC) [4], stand out as widely employed methods for harnessing waste heat from diverse sections of the plant. The ORC, in particular, shows promise in generating electricity from lower-temperature heat sources. The ORC functions on a similar principle to the Rankine cycle, the sole distinction being its utilization of organic fluid in place of water [5]. By harnessing waste heat, the ORC system substantially mitigates the environmental consequences of coal-based power production. Utilization of waste heat presents an opportunity to bridge this energy deficit, concurrently lessening the reliance on fossil fuels and their detrimental environmental impacts [6]. With swift urbanization, industrialization, and modernization, energy consumption is experiencing rapid and exponential growth. Furthermore, the system's capacity to generate supplementary electricity enables it to fulfill incremental energy requirements.

Wang et al. [7] explored the influence of critical thermodynamic design parameters on the net power output and surface areas of a heat recovery vapor generator employing R123, R245fa, and isobutene. Zhao et al. introduced a thermodynamic model aimed at enhancing the efficiency of ORC systems through the utilization of zeotropic mixtures. Through theoretical data validation, their model highlights the substantial influence of heat source temperature on the composition of mixtures [8]. Mirzaei et al. explored ORC with various working fluids to utilize waste heat from metal smelting furnaces. Their finding reveals that m-xylene offers greater power output and efficiency with a lowest total cost [9]. Mitri et al. [10] used waste heat from compost to power the organic Rankine cycle. Mohammadi et al. introduced a hybrid power system designed for residential applications, which integrates a gas turbine, ORC, and absorption refrigeration cycle. This system generated 30 kW of power, provided 8 kW of cooling capacity, and delivered 7.2 tons of hot water [11]. Javanshir et al. thermodynamically investigated the subcritical and supercritical ORC, revealing that efficiency decreases with increased turbine inlet temperature. At the same time, isentropic working fluids offer higher efficiency and higher cycle net power output [12]. Mudasar et al. investigated the application of ORC in sewage plants for both power generation and district heating, utilizing biogas combustion as a heat source. Their findings indicate a peak work output of 156.4 kW [13]. Wang et al. investigated the ORC technology to harness low-grade waste heat from coal-fired power plants. Their findings suggest that ORC exhibits greater productivity when utilizing n-octane and toluene [14]. Acar et al. [15] investigated an ORC powered by solar geothermal energy, and their result indicates the energy generated from this study is 305,713.5 kWh. Xue et al. analyzed the thermodynamics of ORC powered by waste heat and solar energy. Their results showed an increment in energy efficiency of 1.7% and an exergy efficiency of 1.8% [16]. Wilberforce et al. [17] recovered waste heat using ORC from a 110-kW fuel cell system, resulting in a 0.9% increase in output power.

The literature strongly indicates widespread utilization of the ORC in various contexts, especially for harnessing waste heat or low-quality thermal energy. The working fluids for ORC are generally hydrofluorocarbons, which cause concern because of their high ozone depletion and global warming potential value. Due to environmental consequences, there may be a decrease in the use of these working fluids in the upcoming years. Thus, exploring substitute working fluids with similar thermophysical characteristics but causing less environmental harm is a promising avenue for long-term integration. However, the authors noticed a need for more literature concerning the thermoeconomic analysis of ORC, employing alternative working fluids like benzene, methanol, ethanol, and acetone. This study integrates an ORC into a standalone plant (500-MW$_e$ supercritical plant with CO_2 capture), i.e., the proposed plant, enhancing overall efficiency by utilizing waste heat from various portions of the plant. The integration optimizes energy resource utilization, enhancing the plant's overall performance. Goals include a thermodynamic comparison of standalone and proposed plants, a comprehensive economic and thermodynamic analysis of the ORC, and conducting a parametric study to explore variations in ORC and plant efficiencies. After the Introduction section, the remaining work is put together in the following way: Methodology, Plant configurations, Assumptions, Fluid properties, Model validation, and Economic analysis. The next section shows the results and discussion. It shows the efficiencies of the plant and uses graphs to show how the important parameters affect the power plant’s performance. In the last part, the main conclusions are summed up.

Methodology

A simulation software Cycle-Tempo is used to carry out the thermodynamic analysis [18]. The modeling of components initiates with the power plant flow diagram, where operational parameters like pressure, temperature, and inlet (i) and outlet (o) flow rates, as well as efficiencies of the compressor, pump, and motor, are specified for each component. The complete power cycle is depicted through thermodynamic equations, encompassing mass balance, energy balance, and exergy balance.

Plant configurations

In this study, a 500-MW$_e$ supercritical power plant with a CO_2 capture is considered standalone, as shown in Fig. 2 [19]. This plant uses Indian coal as fuel input. This plant comprises one high-pressure turbine, one intermediate-pressure turbine, two low-pressure turbines, and seven feed water heaters. The plant has 242.2 bar/537 °C supercritical steam characteristics with a reheating temperature of 565 °C and a final feed water temperature of 280 °C [19]. The CO_2 capture unit uses the monoethanolamine (MEA) solvent to capture and separate CO_2 from the flue gas, reducing the plant's carbon emissions.

ORC configuration

This study utilized the ORC to harness the waste heat in different plant sections, as depicted in Fig. 3. ORC is low-grade power conversion cycle that utilized waste heat to utilize additional power [20]. Five different organic fluids are used as working fluids in the ORC. The selected working fluids vaporize after taking heat from the energy source. After superheating from the superheater, the working fluid is sent to the turbine, where the power generation process is done. After that, it enters the condenser for cooling purposes.

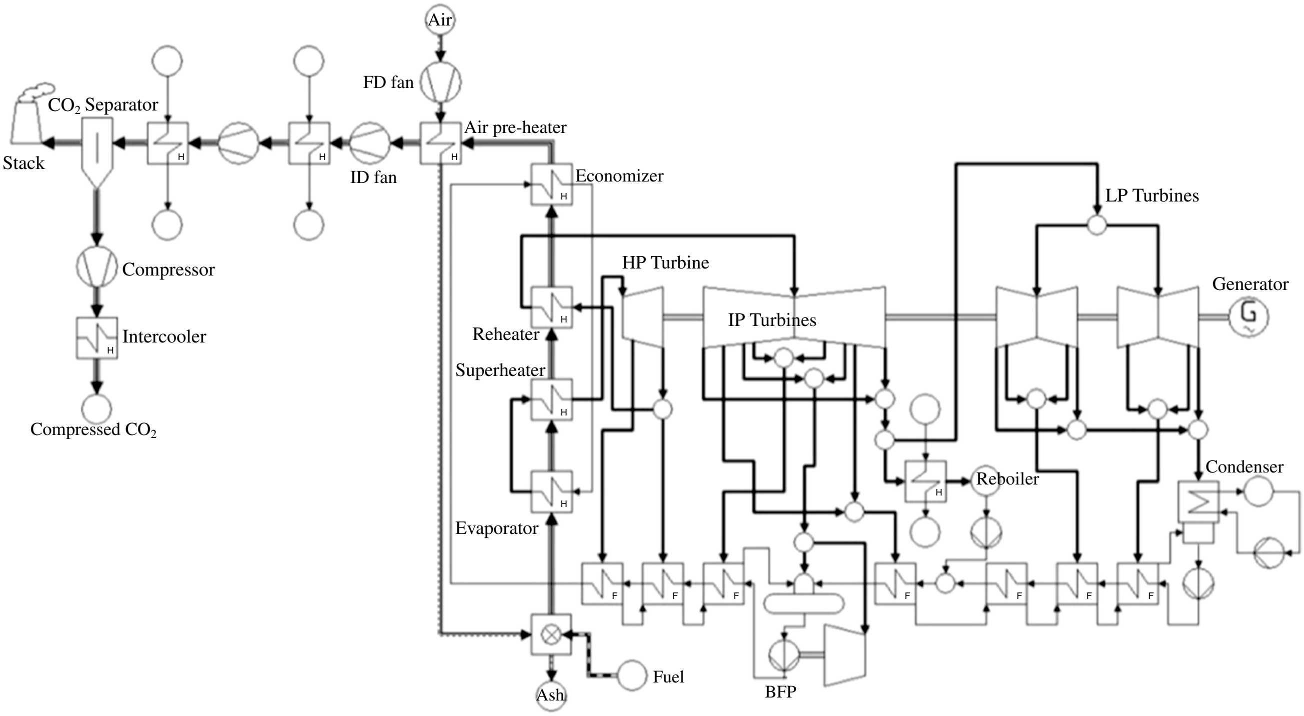


Fig. 2 Layout of the base plant with CO_2 capture system [19]

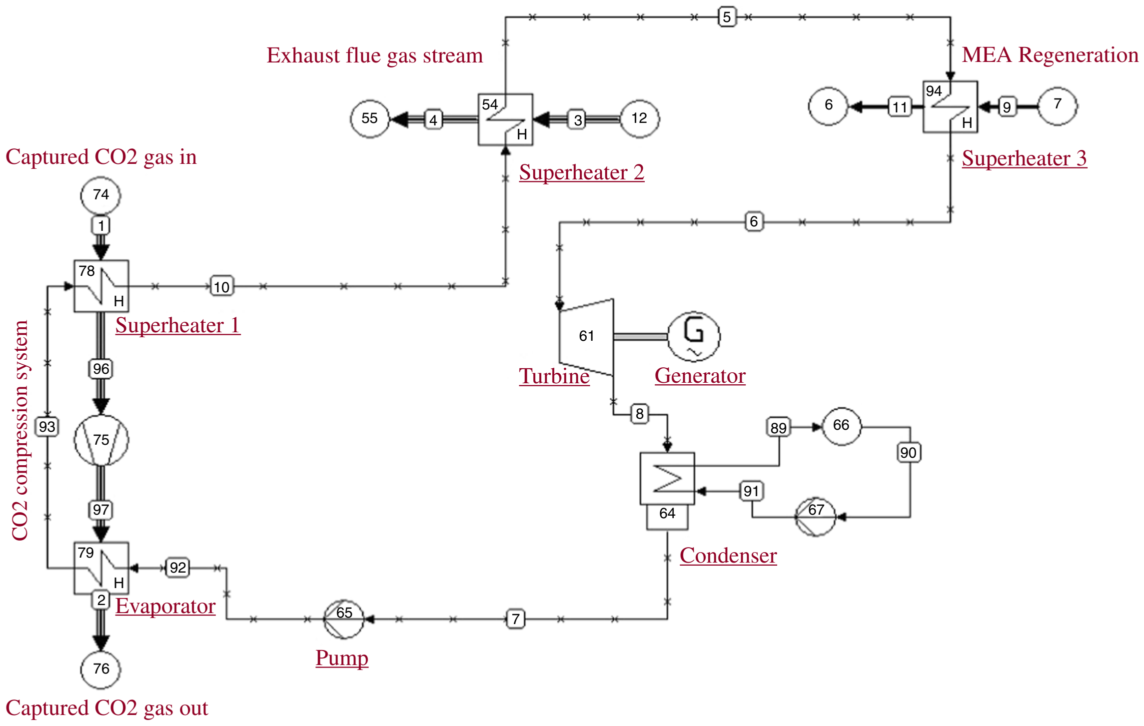


Fig. 3 Schematic diagram of ORC

Then, it is pumped back into the evaporator, and the cycle continues.

Characteristics of coal

The standalone plant utilizes Indian coal as its fuel source. Indian coal is characterized by its high ash content, which categorizes it as low-grade coal; however, its low sulfur level places it in the category of high-quality coal.

On a dry basis, the ultimate analysis of the coal reveals carbon at 39.16%, hydrogen at 2.76%, oxygen at 7.92%, nitrogen at 0.78%, sulfur at 0.51%, and ash at 48.87% [19].

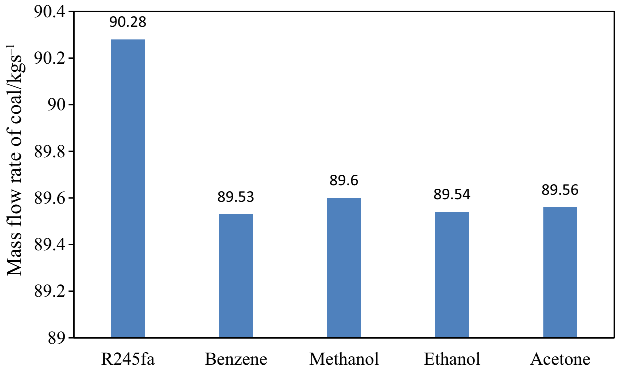


Fig. 4 Variation in coal mass flow rate after integration of ORC

Table 1 Characteristics of organic fluid used

Working fluid	Critical pressure/bar	Boiling point/°C	Critical temperature /°C
Methanol	82.15	64.54	239.35
Benzene	48.94	80.06	288.87
Acetone	47.00	56.07	234.95
Ethanol	62.88	78.42	241.56
R245fa	36.51	15.04	153.86

Characteristics of organic fluid

The performance of an ORC system is greatly influenced by the selection of the working fluid [21]. The working fluid's properties can impact its specific heat capacity, thermal efficiency, etc. The working fluid's thermophysical characteristics, including the critical pressure, boiling point, and critical temperature, are shown in Table 1.

Assumptions

The thermodynamic analysis has been conducted based on the following assumptions:

- A 500-MW$_e$ supercritical power plant with CO$_2$ capture unit is considered as standalone [19].
- The ORC employs five distinct working fluids in its operation.
- Ten-bar pressure is considered as evaporator pressure for ORC.
- At the condenser outlet, the working fluid is a saturated liquid, whereas at the turbine inlet, it is a saturated vapor.
- For turbines and pumps, the isentropic efficiencies are 90% and 85% [19].

Performance parameters

The system's thermodynamic performance can be evaluated through energy and exergy efficiency. Energy efficiency refers to the ability of a system to convert energy inputs into useful outputs with minimal waste. It measures the effectiveness of energy utilization and is expressed as a ratio of the output energy to the input energy. Exergy efficiency, also known as exergy utilization or availability efficiency, measures how effectively energy is used in a system or process. It is defined as the ratio of the exergy output of a system to the exergy input.

The energy efficiency (η) and exergy efficiency (ε) [17] of the ORC system can be determined using

$$\eta = \frac{\text{Electrical Output } (\dot{W}_{\text{orc}})}{\text{Heat recovered}} \tag{1}$$

$$\varepsilon = \frac{\dot{W}_{\text{orc}}}{\dot{W}_{\text{waste}}} \tag{2}$$

Below are the parameters employed in computing the outcomes for the proposed plant [19]:

$$\dot{W}_{\text{net}} = \dot{W}_{\text{st}} + \dot{W}_{\text{orc}} \tag{3}$$

$$\text{Energy Efficiency } (\eta) = \frac{\dot{W}_{\text{net}}}{\dot{m}_{\text{coal}} \, {*}\text{HHV}_{\text{coal}}} \tag{4}$$

Table 2 Cost equations [22–24]

Components	Equations
Pump (p)	$Z=3540(\dot{W}_p)^{0.7}$
Superheater (s)	$Z=130(A_s/0.093)^{0.78}$
Turbine (t)	$Z=6000(\dot{W}_t)^{0.7}$
Evaporator (e)	$Z=130(A_e/0.093)^{0.78}$
Condenser (c)	$Z=1773(\dot{m}_c)^{0.8}$

$$\text{Exergy Efficiency } (\varepsilon) = \frac{\dot{W}_{\text{net}}}{\dot{m}_{\text{coal}} \, {*}\Psi_{\text{coal}}} \tag{5}$$

Economic analysis of organic Rankine cycle

To obtain practical results, evaluating the system's performance from both thermodynamic and economic perspectives is necessary. The purchased equipment cost (PEC) formula for each ORC component is shown in Table 2. After calculating the cost of each part, the total PEC is calculated through the addition of cost of all components. The necessary heat transfer coefficient (U) for area calculations is given in Table 3. In addition, this economic investigation includes some monetary limitations, which are listed in Table 4.

$$A = \frac{\dot{Q}}{U \, * \, \text{LMTD}} \tag{6}$$

$$\text{LMTD} = \frac{\Delta T_{\max} - \Delta T_{\min}}{\ln \frac{\Delta T_{\max}}{\Delta T_{\min}}} \tag{7}$$

$$\text{PEC}_{\text{ORC}} = Z_e + Z_s + Z_c + Z_p + Z_t \tag{8}$$

Upon computation of the PEC, the capital recovery factor (CRF) is calculated through [23, 26, 27]:

$$\text{CRF} = \frac{i(1+i)^N}{i(1+i)^N - 1} \tag{9}$$

By evaluating various factors, the unit cost of electricity (C_{elec}) is calculated through [28]:

$$C_{\text{elec}} = \frac{\text{CRF} * \text{PEC} + \Phi}{\dot{W}_{\text{net}} * n} \tag{10}$$

Table 3 U value of heat exchanger [22, 25]

Parameters	U/kWm^{-2} K^{-1}
Evaporator	0.6
Superheater	0.6

Table 4 Economic limitations [22, 25]

Parameters	Unit	Value
Yearly operating span (n)	Hour	8000
Interest rate (i)	**	0.2
Service factor (Φ)	**	1.06
Lifespan (N)	Year	20

Table 5 Validation of ORC

Parameters	Referred paper [31]	Current study
Fluid type	R245fa	R245fa
Isentropic efficiency of pump/%	60	60
Evaporator pressure/bar	11.29	11.29
Isentropic efficiency of turbine/%	75	75
Condenser pressure/bar	2.43	2.43
Turbine output/MW	1.88	9.81
Heat input/MW	–	104.32
Energy efficiency/%	9.39	9.40

Table 6 Plant efficiencies with coal consumption

Plants	Energy efficiency/%	Exergy efficiency/%	$\dot{m}$ of the coal/Kgs^{-1}
Standalone plant [19]	27.33	25.01	92.07
Proposed plant			
R245fa	27.77	25.42	90.28
Methanol	28.01	25.62	89.60
Acetone	28.02	25.63	89.56
Ethanol	28.02	25.64	89.54
Benzene	28.03	25.65	89.53

Finally, the calculation of the payback period (PB) is computed through [29]:

$$\text{PB} = \frac{\log \frac{(\dot{W}_{\text{net}} * n * C_{\text{pric}}) - \Phi}{(\dot{W}_{\text{net}} * n * C_{\text{pric}}) - \Phi - (i * \text{PEC})}}{\log(1+i)} \tag{11}$$

In this context, C_{pric} denotes the regional electricity cost in West Bengal [30], valued at approximately 7.32 Rupees or \$0.08922, based on an exchange rate of 1\$ = 82.04 Rupees as of June 26, 2023.

Validation of ORC

The ORC system has been simulated, and its outcomes have been validated using the same parameters, such as evaporator pressure, condenser pressure, and isentropic efficiency of the turbine and pump, as outlined in the referenced paper [31]. Table 5 presents the energy efficiency of ORC and compares the simulated results with the findings reported in the literature. It is evident that there is a strong correlation between the outcomes of this study and the referred paper.

Table 7 Power production through ORC

Working fluids	Power/MW_e
R245fa	9.91
Methanol	13.71
Acetone	13.97
Ethanol	14.04
Benzene	14.11

Table 8 Reduction in CO_2 emission

Working fluids	Reduction in CO_2 emission/tonsday^{-1}
R245fa	216.43
Methanol	299.43
Acetone	305.10
Ethanol	306.63
Benzene	308.16

Results and discussion

The comparison of efficiencies between the plants is displayed in Table 6. The proposed plant exhibits high energy and energy efficiency compared to the standalone. This increment is due to the integration of the ORC. This table also indicates the decrement in coal consumption rate in the case of the proposed plant.

The additional power production through ORC, achieved by utilizing the plant waste heat, is depicted in Table 7, in which benzene stands out as the top of all the fluids available, with maximum power output. The dominance of benzene can be due to its thermophysical properties, which enable excellent performance even at high temperatures.

According to Mittal et al., a coal-based power plant emits 0.91 to 0.95 kg of CO_2 for one unit of electricity generation [32]. So, to generate this large amount of power, from the power plant, as shown in Table 7, a considerable amount of CO_2 would be produced, as shown in Table 8. The utilization of waste heat can avoid this amount of CO_2 emissions.

Table 6 indicates that the coal mass flow rate required before integrating the ORC was 92.07 kg/s. However, after incorporating the ORC, the coal flow rate decreases, as shown in Fig. 4, indicating that the ORC system is utilizes the waste heat generated in the power plant. This waste heat utilization leads to improved energy efficiency and reduced coal consumption. The decrease in the coal mass flow rate can also reduce greenhouse gas emissions and other pollutants associated with coal-based power generation.

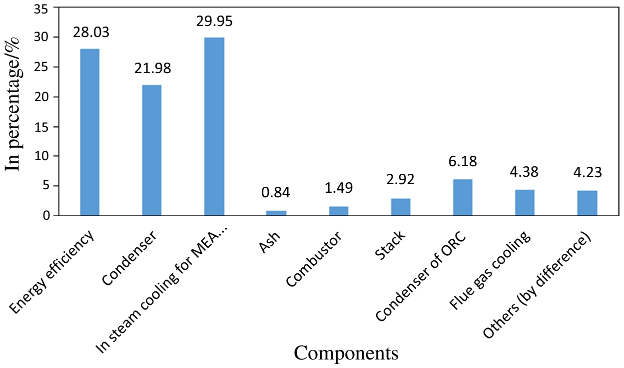


Fig. 5 Energy balance of proposed plant

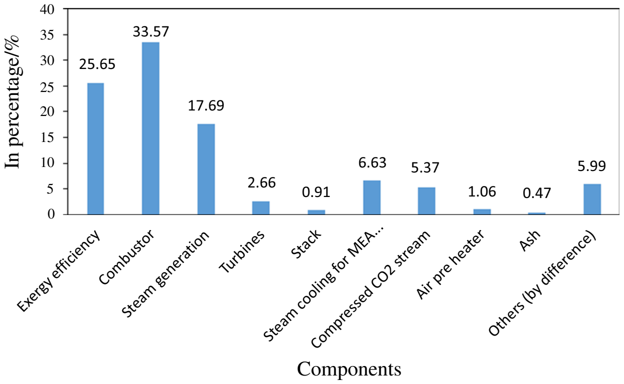


Fig. 6 Exergy balance of proposed plant

Energy balance of proposed plant

Figure 5 illustrates the energetic balance of the proposed plant (benzene), providing a thorough assessment of its energy efficiency. Analyzing energy balance allows for identifying areas where energy is lost, which in turn allows for identifying opportunities for energy conservation and optimizing plant operations to improve the efficiency. Based on the figure, the MEA regeneration suffers from more energetic losses (29.95%), followed by condenser (21.98%).

Exergy balance of proposed plant

Figure 6 illustrates the exergetic balance of the proposed plant (benzene), offering an intricate examination of the thermodynamic quality of the energy generated and consumed within the facility. Exergy represents the available work obtainable from a specific energy quantity. By analyzing the exergetic balance, areas of exergy losses attributed to irreversibilities in the plant can be identified. Based on the data shown in the figure, the combustor experiences a significant percentage of exergetic losses, precisely 33.57%.

Thermoeconomic evaluation of ORC

Table 9 presents the evaluation of the ORC based on thermodynamics and economics. According to the table, benzene demonstrates high energy and exergy efficiencies of 13.97% and 52.94%, respectively, based on thermodynamic analysis. Similarly, ethanol exhibits energy and exergy efficiencies very close to benzene, at 13.90% and 52.67%, respectively. However, from an economic standpoint, ethanol emerges as the superior option due to its shorter payback period and lower electricity generation cost.

Parametric analysis

The proposed plant's energy and exergetic efficiencies are expected to be influenced by various factors, such as combustor intake air temperature, steam pressure, and evaporator pressure of ORC. While varying certain parameters, all other values remained constant. The aim of the parametric study is to determine how various parameters affect the performance of a proposed plant with specific fluids.

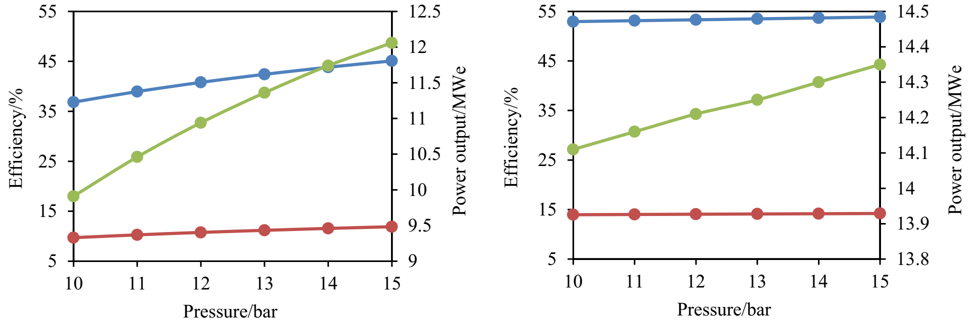
Effect of TIP on performance of ORC

Figure 7 illustrates the effect of the turbine inlet pressure (TIP) of ORC on the efficiency and power output of the ORC system with the selected working fluids. Increasing the turbine inlet pressure in an ORC system leads to an increase in power output and efficiency [33]. This is because higher

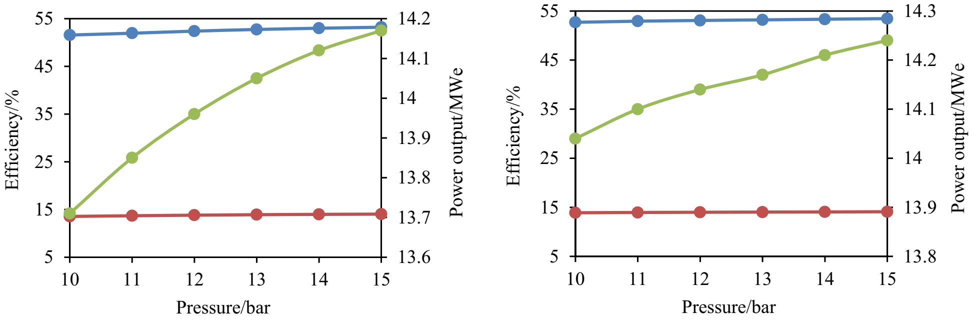
Table 9 Thermoeconomic results of ORC

Working fluid	Heat input MW	Electrical output MW	$\dot{W}_{\mathrm{waste}}$/MW	η/%	ε/%	PEC/₹	C_{elec}/₹kWh^{-1}	PB/year
R245fa	101	9.91	26.889	9.811	36.85	471,122,047.5	1.254	1.002
Methanol	101	13.71	26.581	13.574	51.57	583,359,241.6	1.116	0.882
Acetone	101	13.97	26.656	13.831	52.41	594,075,536.4	1.127	0.892
Ethanol	101	14.04	26.652	13.90	52.67	592,576,756.9	1.101	0.869
Benzene	101	14.11	26.655	13.970	52.94	599,093,046.9	1.124	0.889

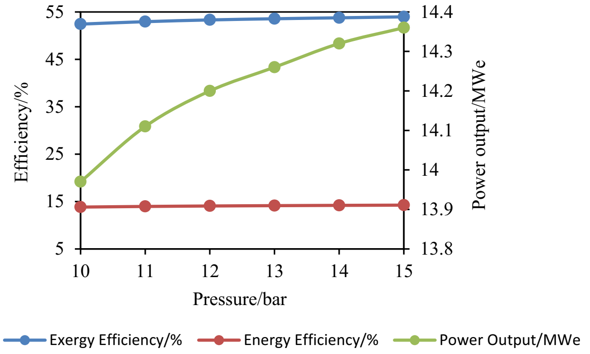
Fig. 7 **a**, **b**, **c**, **d**, **e** Effect of TIP on ORC Performance



(a) R245fa **(b)** Benzene



(c) Methanol **(d)** Ethanol



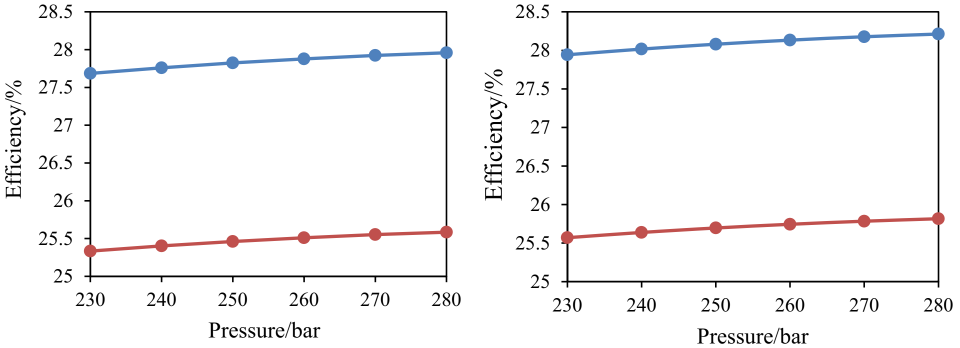
(e) Acetone

pressures result in higher enthalpy differences between the heat source and the condenser, which leads to higher energy conversion in the turbine. As a result, more work is extracted from the cycle, leading to higher power output as well as efficiency. As can be seen from the figures, for fluid R245fa, the energy efficiency, exergy efficiency, and power output continuously increase with increasing pressure from 10 to 15 bar, which implies that R245fa shows the best results at high pressure. For fluid benzene, there is a constant increment in energy, exergy, and power output of approximately 0.3%, with an increase in power output from 10 to 15 bar. For fluid methanol with increasing pressure from 10 to 15 bar, the increment percentage decreases for energy, exergy, and power output. The same trend is followed by ethanol and acetone because of the characteristics of the fluid.

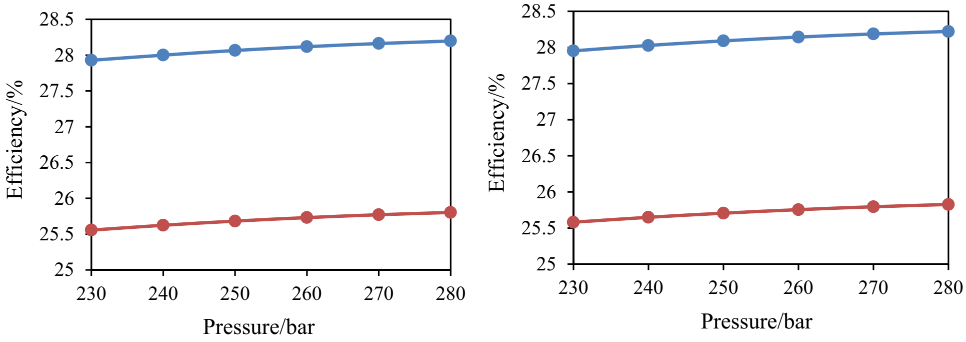
Effect of steam pressure on proposed plant efficiencies

Figure 8 shows the impact of steam pressure on the energy and exergy efficiencies of the proposed plant, employing various working fluids while maintaining a constant ORC turbine inlet pressure of 10 bar. All the figures demonstrate that increasing steam pressure from 230 to 280 bar improves both energy and exergy efficiency. This is because increasing the pressure raises the temperature at which heat is added to the cycle and reduces heat losses, thereby increasing the cycle's overall efficiency. As can be seen from the figures, the R245fa shows the minimum energy and exergy efficiency

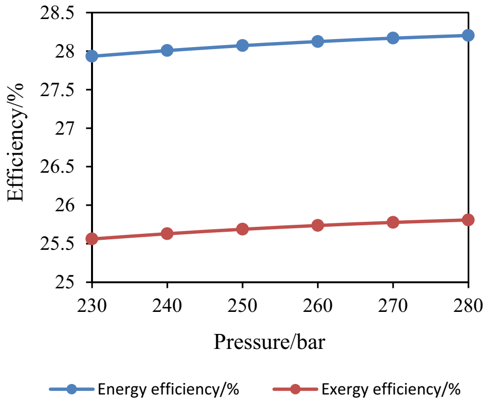
Fig. 8 **a**, **b**, **c**, **d**, **e** Effect of steam pressure on proposed plant efficiencies



(a) R245fa **(b)** Benzene



(c) Methanol **(d)** Ethanol



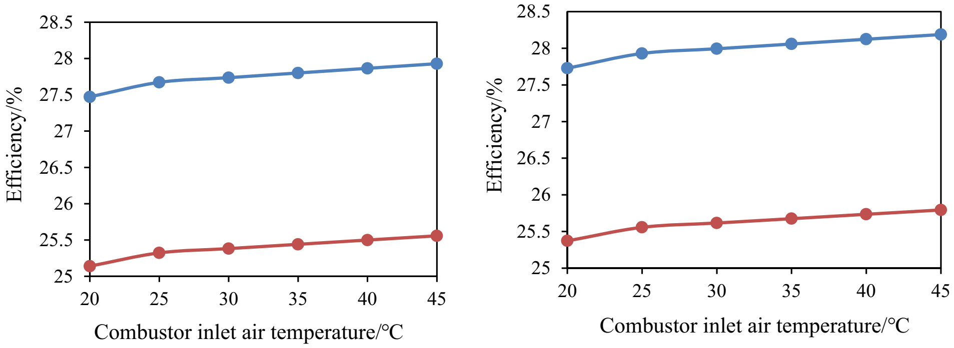
(e) Acetone

with respect to other fluids because of its lower ORC output, and benzene and ethanol show higher energy and exergy efficiency with respect to other fluids because of its ORC power output.

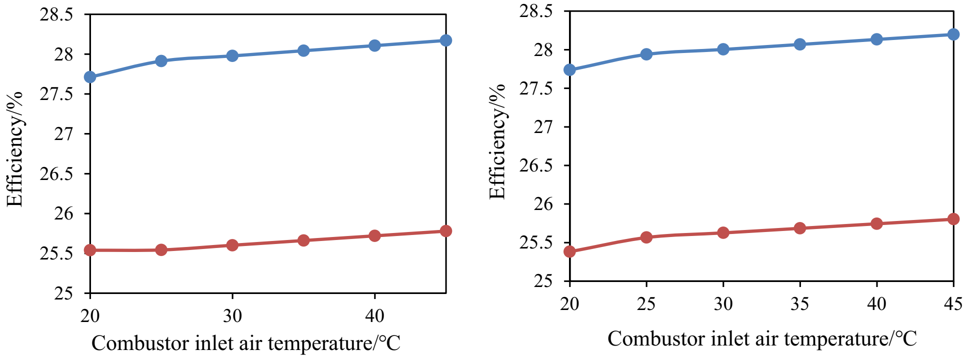
Effect of combustor inlet temperature on proposed plant efficiencies

Figure 9 shows how the combustor inlet air temperature, while maintaining a fixed ORC turbine inlet pressure of 10 bar, affects the efficiencies of the proposed plant using chosen working fluids. The figure indicates efficiency rises with higher incoming air temperatures to the combustor. This trend is primarily attributed to a reduction in exergy loss within the air preheater, which occurs as the temperature of the incoming air increases. As can be seen from the figures, the R245fa shows the minimum energy and exergy efficiency with respect to other fluids because of its lower ORC output, and benzene and ethanol show higher energy and exergy efficiency with respect to other fluids because of its ORC power output.

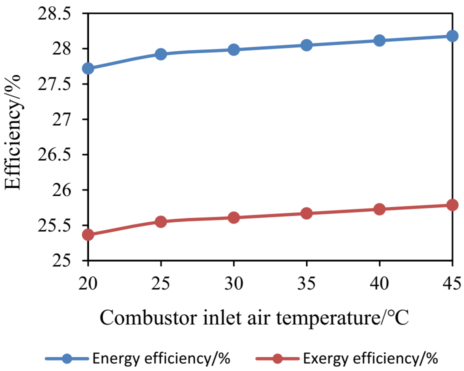
Fig. 9 **a**, **b**, **c**, **d**, **e** Effect of combustor inlet temperature on proposed plant efficiencies



(a) R245fa **(b)** Benzene



(c) Methanol **(d)** Ethanol



(e) Acetone

Carbon credit

The majority of thermal plants in India are coal-fired, and the release of greenhouse gases from these plants is a serious environmental issue. The most significant contributor to global warming is CO_2. Other greenhouse emissions, such as SO_x and NO_x, are also associated with the coal-based plant; however, due to the use of low-sulfur HA coal, CO_2 is our primary issue for investigation. By utilizing the waste heat, the ORC system can generate additional electricity, reducing the amount of primary fuel that needs to be burned. This, in turn, reduces CO_2 emission, resulting in the acquisition of carbon credits. The use of waste heat also increases the plant's overall efficiency, which is beneficial from both an economic and environmental perspective. Figure 10 illustrates the carbon credits that can be earned by integrating the ORC with the standalone plant [34].

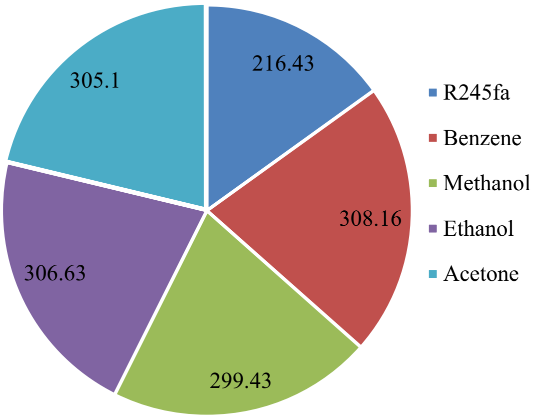


Fig. 10 Carbon credit of the proposed plant utilizing waste heat

Conclusions

This study comprehensively evaluated the proposed plant from a techno-economic standpoint. The results of the evaluation are as follows:

- The ORC demonstrates significant potential, generating additional electric power outputs of 9.91 MW_e for R245fa, 13.71 MW_e for methanol, 13.97 MW_e for acetone, 14.04 MW_e for ethanol, and 14.11 MW_e for benzene.
- The proposed plant reveals improvements in energy efficiency ranging from 1.61 to 2.52% and exergy efficiency enhancements from 1.64 to 2.56% when utilizing different working fluids, namely R245fa, methanol, acetone, ethanol, and benzene.
- The integration of ORC contributes to a decrease in CO_2 emissions, resulting in estimated reductions of 216.43 tons, 299.43 tons, 305.10 tons, 306.63 tons, and 308.16 tons per day for R245fa, methanol, acetone, ethanol, and benzene, respectively.
- Notably, the study explored unconventional working fluids such as methanol, acetone, ethanol, and benzene, which exhibited promising performance improvements over the conventional choice of R245fa.
- The thermodynamic analysis favors benzene-based ORC due to its superior performance. At the same time, the economic evaluation suggests that ethanol-based ORC is the best option due to its shorter payback period and lower electricity generation costs.

This investigation emphasizes the versatility and effectiveness of ORC systems and the complex relationship between thermodynamic performance and economic viability. It provides valuable insights for making informed decisions in sustainable power generation projects.

Author contributions NKC was involved in data curation, methodology, and writing—original draft preparation. SK helped with conceptualization, reviewing, and editing.

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