Working Fluid Selection in Organic Rankine Cycle (ORC) with Flue Gas Heat Utilization

Marlina Ayu Lestari [1,2], Ari Darmawan Pasek[1]

[1] Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung
[2] PT Perusahaan Listrik Negara (Persero)

Abstract. There are many potential sources of excess heat that have not been utilized, the ORC system offers a solution to utilize this energy, thereby increasing overall energy efficiency. Highlighting the advantages of the ORC system, including its ability to operate at lower temperatures, utilize a variety of working fluids, and utilize heat efficiently from various sources. describing the methodical process of choosing the best and most suitable working fluid, including the types of working fluids, how they affect system performance, and the standards for choosing the best working fluid based on physical and thermodynamic characteristics. Furthermore, emphasis is placed on environmental effects, safety considerations, and the kind of heat source that will be used. The use of exhaust gas heat will be the main topic of this essay from PLTMG engines according to the author's research.

Keywords: *organic rankine cycle; working fluids; engine waste heat recovery*

1 Introduction

In steam power plants, the steam Rankine cycle is a crucial procedure for turning substantial thermal energy into electrical power. The five main parts of the steam power cycle are the working fluid, boiler, condenser, pumps, and turbine. In this case, water is utilized as the working fluid due to its favorable thermodynamic characteristics. Water's stability, low viscosity, high heat capacity, and environmental friendliness make it the most popular choice. However, using water as a working fluid has a number of disadvantages, including the need for high temperatures that might damage the turbine blades. Therefore, high temperatures and big, centralized systems are better suited for water. Alternative fluids for use in the Organic Rankine Cycle (ORC) and other processes, have shown promise in reducing these issues for small and medium-sized power plants. [1].

The Organic Rankine Cycle may operate at lower pressures and with a variety of low, medium, and high-temperature heat sources. It is similar to the steam Rankine cycle in system construction but uses working fluids with lower boiling temperatures [1]. Hydrocarbons and hydrofluorocarbons are among the many different compounds that have been proposed as working fluids for ORC systems.

Received ________, Revised _________, Accepted for publication __________

The choice of working fluid has a significant influence on an ORC system's performance and expenses [2]. ORC excels in the use of low-temperature heat from sources such as biomass, geothermal energy, solar energy, and industrial waste heat like engine exhaust. ORC has gained a lot of popularity recently as a result of concerns about environmental problems and the depletion of fossil resources [2].

Based on BPS data shown in Figure 1, Fossil fuel power plants account for the majority of PLN's installed capacity by type of power plant in Indonesia in 2022. PLTU, for example, has an installed capacity of 37.2 GW, or 58% of the overall fossil power plant capacity of 63.5 GW [3]. However, the ability to respond to load changes faster than PLTU is one of the advantages of PLTG/GU/MG and PLTD so that it cannot be ignored, especially in isolated areas, power plants are needed to support the network with a fast response to load fluctuations and recovery.

Currently, based on data from PLTMG Tarakan, the exhaust gas temperature, which is between 450 and 500°C, is reported to be rather high. In this regard, a simulation research on the use of the exhaust gas of the Tarakan Gas Engine Power Plant with the addition of ORC will be carried out in order to identify the best working fluid to be utilized in the exhaust gas usage. The scope of the research is: (1) Selection of several ORC working fluids according to the literature, (2) Modeling and simulation of ORC using Aspen Hysys, (3) Calculation of efficiency and optimum power, (4) Determination of the best working fluid.

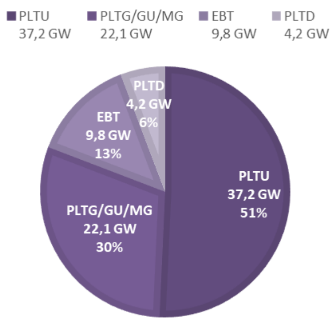

Figure 1 PLN installed capacity by type of Power Plant in Indonesia in 2022[3]

2 Organic Rankine Cycle

Thermodynamic cycles can be described in the form of diagrams based on state levels. The state levels of a cycle can be determined from two known properties.

Received ________, Revised _________, Accepted for publication __________

For example, if the pressure (P) and temperature (T) are known at a certain state, then other thermodynamic properties of that state can be known. The Carnot cycle in Figure 2 [4], is an example of an ideal process, where (p) is pressure and (v) is specific volume.

The configuration of the ORC system with a heat source is shown in Figure 3 [5] The evaporator, turbine, condenser, and pump are the four primary parts of an ORC [5], [6]. The working fluid is pumped into the evaporator to obtain heat to produce steam. The steam is then used to drive the ORC turbine. The turbine rotation will be used to rotate the generator and will produce an electricity source [5]. To finish the cycle, the steam from the turbine is condensed and then pushed back to the evaporator [5].

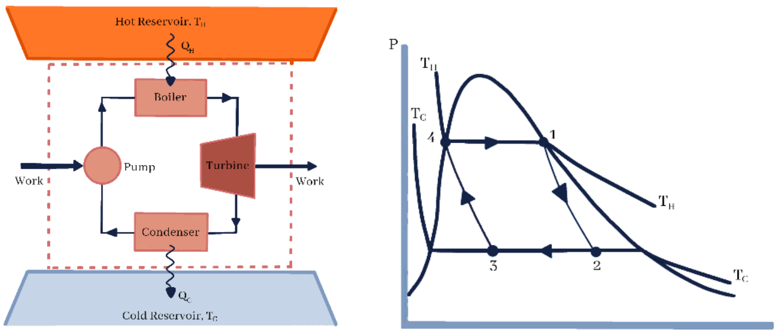

Figure 2 Carnot Cycle [4].

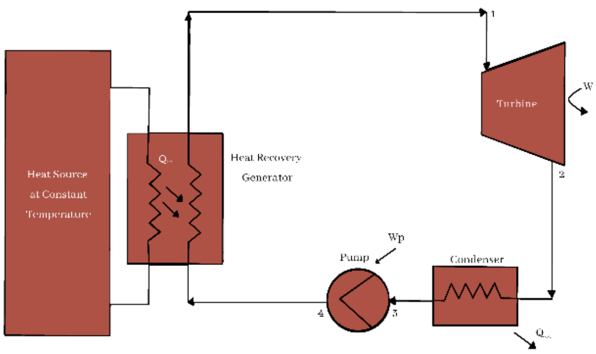

Figure 3 Schematic of the ORC System [5]

ORC is an energy system that has attracted attention due to its potential to reduce the environmental impact of conventional energy sources. A comprehensive bibliographic review of ORC has been conducted, updating previous reviews and including analysis of new cycles and working fluids. The analysis established that

Received ________, Revised _________, Accepted for publication __________

recovery and regenerative cycles exhibit greater efficiencies compared to reheat cycles and simple one-stage cycles. When compared to single-stage cycles, two-stage cycles can produce more net power and have higher thermal efficiency, with improvements of up to 20% and 44%, respectively [7]. Theoretical studies have shown that hybrid systems, integrating the Brayton cycle and ORC, have the highest efficiencies, despite requiring very high operating temperatures. In conclusion, the review of the organic Rankine cycle demonstrates its potential as a sustainable energy solution. The efficiency and performance of ORCs can be improved through the use of advanced cycle configurations, working fluids, and integration with other energy systems. Further research and development in this area is needed to optimize ORCs for various applications and contribute to the transition to a more sustainable energy future [7].

3 Methodology

In this study, simulations were conducted on different working fluids that have been selected and will be analyzed to be compared from thermodynamic, safety and environmental aspects to obtain the best working fluid results. In this simulation, To get the best results, the exhaust gas temperature will be adjusted in relation to the turbine's efficiency and work output, and the evaporator's incoming fluid pressure will likewise be adjusted in relation to the turbine's efficiency and work output. assuming that the isentropic efficiencies of the pump and turbine are 80% and 80%, respectively. Because friction losses of the fluid moving in the pipe were ignored during the analysis, operating conditions such as isobaric heat supply (at the evaporator), expansion (at the turbine), isobaric heat rejection (at the condenser), and compression (at the pump) were assumed [6]. A constant temperature of 35°C was maintained for the condenser. Furthermore, in order to prevent air leakage into the system, the condenser pressure was always thought to be higher than the atmospheric pressure (1 atm) [8]. Recommended cycle pressure to avoid mechanical problems due to pressure such as leakage. Low condenser pressure may result in issues with the system's ability to seal off ambient air intrusion. The heat exchanger unit's pressure needs to be kept between 100 and 2500 kPa for safety reasons [8]. In this study, the performance was evaluated quantitatively.

Table 1 characteristics of the chosen working fluid.

Working Fluid	M (kg/kmol)	T_c (°C)	P_c (kPa)	T_b (°C)	C_p (kJ/kg·K)	ODP	GWP
Benzene[7]	78,1	288,8	4906	80,1	1,72	0	~2
Toluene[9]	92,1	318,6	4126	110,6	1,68	0	~3
R-1233zd(E) [10]	130,5	165,5	3624	29,3	1,05	0	1
R-1336mzz(Z)[10]	164,0	171,3	3300	33,4	1,12	0	2

Received ________, Revised _________, Accepted for publication __________

C_p = Specific Heat Capacity
M = Molar Mass
P_c = Critical Pressure
T_b = Boiling Temperature
T_c = Critical Temperature

The temperature and pressure of the evaporator are changed in order to evaluate the variations in thermal efficiency and mass flow rate per unit of ORC output power under different operating conditions. Various organic working fluids are considered, and each one's performance is evaluated separately (Table 1) [7], [9], [10].

4 Working Fluid Selection

ORC performance is largely dependent on the working fluid. Various studies have identified that an ideal working fluid should have suitable thermodynamic properties, be non-flammable, non-toxic, non-corrosive and special properties such as suitable boiling point, high critical temperature, small specific volume, high thermal conductivity, thermal stability and machine compatibility [11].

This study examines and discusses the selection of working fluid and expansion machine for ORC systems. When selecting a fluid, factors including the kind of heat source, temperature, and efficiency indicators are crucial; mixed fluids provide greater temperature compatibility but require further research. The choice of working fluid is also influenced by operational conditions, equipment design, and environmental safety. The selection of expansion machines should also take into account factors like power capacity, efficiency, cost, and system requirements in order to guarantee peak performance for a variety of applications [1].

The heat source and pinch temperature (ΔT) determine the predefined maximum temperature (TU), which determines the optimal working fluid for an ORC. A new method classifies fluids by their temperature-entropy points to find those allowing an ideal adiabatic expansion within the desired temperature range. This ensures that both initial and final states remain in the superheated dry vapor region, avoiding issues like droplets or superheated steam, and allowing a simpler ORC setup without extra components like a superheater or droplet separator. [12].

Received ________, Revised _________, Accepted for publication __________

5 Working Fluid ORC Applications in Engine Waste Heat Recovery

Working fluid selection for waste heat recovery depends on the kind of heat source; fluids with low liquid-specific heat and high latent heat are needed for closed systems, whereas fluids with high liquid-specific heat and low latent heat are needed for open systems. For closed-type systems, the selection method is based on maximizing thermal efficiency and net power for open-type systems [13].

Wang Et al. [11] The effectiveness of the nine pure organic working fluids that were selected depends on proper design in the ORC system. Important metrics like net power production and thermal efficiency are essential, and condensing temperature and evaporating pressure particularly the condensing temperature have a significant impact on thermal efficiency. Keeping the condensing temperature near ambient is vital for optimizing waste heat utilization [11].

Many organic working fluids' thermodynamic models were analyzed and compared using a Matlab application that employed REFPROP to determine the evaporating pressure and condensing temperature. When safety and environmental effect were taken into account, R245fa and R245ca were determined to be the optimum working fluids for engine waste heat recovery. The model determined thermodynamic parameters, and the highest errors in liquid density, vapor density, and vapor pressure were 0.2%, 0.4%, and 0.4%, respectively, according to REFPROP [11].

From research conducted by Wang Et al. [11] the optimal operating region's edge is where maximum thermal efficiency is attained, with the most effective operational sites for each fluid detailed in Table 1. R11 exhibits the maximum efficiency and minimal exergy loss for type A, whereas butane is superior for type B. Using an IHE with R245fa boosts ORC efficiency by 13.2%. The favorable evaporating pressure of R245fa at 1.4923 MPa aids in evaporator design. For transient engine processes, adjusting the ORC's evaporating pressure and condensing temperature to optimal values maximizes efficiency [11].

Received ________, Revised _________, Accepted for publication __________

Table 2 Comparison of several working fluids' ideal operating conditions for a 10 kW net power output.

Substance	η_{th}[%]	P_e[MPa]	T_e[K]	$\dot{Q}_e$[kW]	T_c[K]	P_c[MPa]	π	$\dot{m}[kg/s]$	$\dot{V}_3$[L/s]	$\dot{W}_p$[kW]	$\dot{W}_s$[kW]	$\dot{I}_{tot}$[kW]	$\dot{I}_p$[kW]	$\dot{I}_e$[kW]	$\dot{I}_s$[kW]	$\dot{I}_c$[kW]
(a) Selected working condition for A type of ORC																
R245fa	8,40	1,4923	380,9	119,08	304,44	0,1874	7,964	0,4988	5,738	0,615	10,615	45,080	0,1101	35,582	7,214	2,174
R245ca	8,63	1,4923	395,05	119,64	315,56	0,1882	7,929	0,4815	5,666	0,584	10,584	45,336	0,1009	32,607	6,897	5,731
R236ea	8,22	1,7231	377,51	121,6	300	0,2196	7,848	0,5979	4,882	0,791	10,791	46,229	0,1436	37,766	7,375	0,945
R141b	9,28	1,7231	420,42	107,8	328,89	0,2173	7,929	0,4054	5,137	0,65	10,650	39,947	0,1077	24,746	6,773	8,321
R123	8,88	1,5385	406	112,59	320	0,1926	7,986	0,5458	5,614	0,652	10,652	42,128	0,111	28,649	6,913	6,455
R114	8,75	1,8154	385,81	114,28	300	0,2275	7,981	0,6722	4,550	0,919	10,919	42,899	0,1668	34,318	7,416	0,998
R113	8,68	1,1231	418,61	115,23	331,33	0,1411	7,959	0,6026	7,673	0,499	10,499	43,331	0,0821	26,791	6,371	10,087
R11	9,57	1,400	399,72	104,46	313,33	0,1754	7,981	0,4919	6,557	0,523	10,523	38,427	0,0909	27,178	7,207	3,951
Butane	9,17	2,000	387,51	109,1	300	0,258	7,752	0,233	4,294	0,887	10,887	40,541	0,161	32,127	7,475	0,778

Substance	η_{th}[%]	P_e[%]	T_e[K]	$\dot{Q}_e$[kW]	T_c[K]	P_c[MPa]	T_4[K]	T_2[K]	T_{4a}[K]	T_{2a}[K]	π	$\dot{m}[kg/s]$	$\dot{V}_3$[L/s]	$\dot{W}_p$[kW]	$\dot{W}_s$[kW]	$\dot{I}_{tot}$[kW]	$\dot{I}_p$[kW]	$\dot{I}_e$[kW]	$\dot{I}_s$[kW]	$\dot{I}_c$[kW]	$\dot{I}_{IHE}$[kW]
(b) Selected working condition for B type of ORC																					
R245fa	9,51	1,4923	380,90	105,16	304,44	0,1874	337,84	305,09	308,36	325,42	7,964	0,4988	5,738	0,615	10,615	38,746	0,11010	29,859	7,214	1,273	0,290
R245ca	9,61	1,4923	395,05	104,10	315,56	0,1882	351,62	316,18	319,72	339,27	7,929	0,4815	5,666	0,584	10,584	38,264	0,10090	26,729	6,897	4,234	0,303
R236ea	9,55	1,7231	377,51	104,71	300,00	0,2196	334,82	300,78	304,19	322,87	7,848	0,5979	4,882	0,791	10,791	38,545	0,14360	30,662	7,375	0,014	0,350
R141b	10,30	1,7231	420,42	97,08	328,89	0,2173	363,76	329,78	333,18	351,52	7,929	0,4054	5,137	0,65	10,650	35,071	0,10770	21,032	6,773	6,969	0,190
R123	10,00	1,5385	406,00	100,04	320,00	0,1926	354,84	320,79	324,2	342,49	7,986	0,5458	5,614	0,652	10,652	36,420	0,11100	24,028	6,913	5,131	0,234
R114	10,22	1,8154	385,81	97,86	300,00	0,2275	337,91	300,98	304,67	325,17	7,981	0,6722	4,550	0,919	10,919	35,425	0,16680	27,465	7,416	0,016	0,362
R113	10,35	1,1231	418,61	96,60	331,33	0,1411	395,46	347,65	352,43	380,02	7,959	0,6026	7,673	0,499	10,499	34,851	0,08210	17,431	6,371	10,625	0,395
R11	10,29	1,400	399,72	97,18	313,33	0,1754	340,23	314,08	316,69	330,44	7,981	0,4919	6,557	0,523	10,523	35,116	0,09090	24,324	7,207	3,380	0,115
Butane	10,46	2,000	387,51	95,57	300,00	0,2580	335,45	301,08	304,52	324,26	7,752	0,233	4,294	0,887	10,887	34,385	0,16100	26,469	7,475	0,013	0,267

Although the thermal efficiencies of working fluids vary from 8.22% to 9.57% for A type and from 9.51% to 10.46% for B type, safety and environmental impacts also need to be considered. Butane is flammable, and working fluids like R11, R113, and R114 have a high global warming potential (GWP) and ozone depletion potential (ODP). The phase-out of R141b and the ban on R123 highlight the need for ecologically friendly alternatives. R245fa and R245ca are the ideal working fluids for engine waste heat recovery, considering environmental issues [11].

6 ORC Simulation in Aspen HYSYS

Simulation modeling in Aspen HYSYS is based on the ORC system schematic by A.H. Pamungkas et al. [5], and using the Peng-Robinson fluid package. In this simulation the author uses data according to the data and assumptions listed in the Table 3. The analysis is carried out by varying the exhaust gas heat temperature, evaporator pressure in relation to cycle efficiency and net power generation, respectively. The ORC system design utilized in this simulation is seen in Figure 4.

Table 3 Data assumptions used in ORC.

Properties	Value
Turbine Isentropic Efficiency	80%
Pump Efficiency	80%
Condenser Temp	35 °C
Gas Engine Exh. Temp	350 – 450 °C
Cond. & Evaporator Press	300 – 2500 kPa

Received ________, Revised _________, Accepted for publication __________

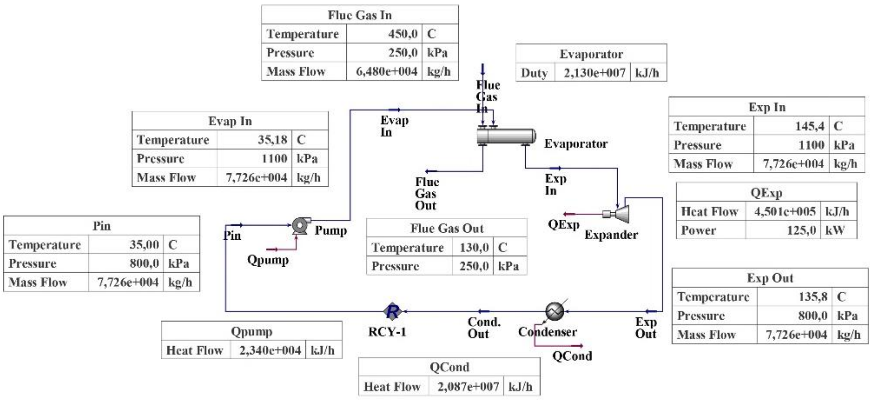

Figure 4 ORC system simulation

7 Result and Discussion

7.1 Variation of Efficiency and Net Power Output with Exhaust Flue Gas Temperature

An examination of the effects of changes in flue gas temperature on net power and efficiency for four working fluids—benzene, toluene, R-1233zd(E), and R-1336mzz(Z)—is shown below: The efficiency as a function of flue gas temperature in Figure 5 shows the following trends: Among all temperature ranges, benzene has the best efficiency, with an efficiency of over 16% at 450 °C. This is because to its favorable thermodynamic properties, especially its high critical temperature and latent heat, which allow it to effectively extract more energy from the heat source.

Toluene shows a moderate increase in efficiency, peaking at the greatest temperature at almost 11%. Because of its comparatively poorer thermodynamic characteristics, including its critical pressure, it performs worse than benzoene. At higher temperatures, the efficiencies of R-1233zd(E) and R-1336mzz(Z) are significantly reduced, ranging from 4 to 7%. This is because it is less efficient at converting heat to work at higher temperatures due to its lower critical temperature and latent heat. The significance of higher heat source temperatures to optimize thermodynamic performance is highlighted by the efficiency's linear rise with flue gas temperature, particularly for organic Rankine cycle (ORC) systems.

Received ________, Revised _________, Accepted for publication __________

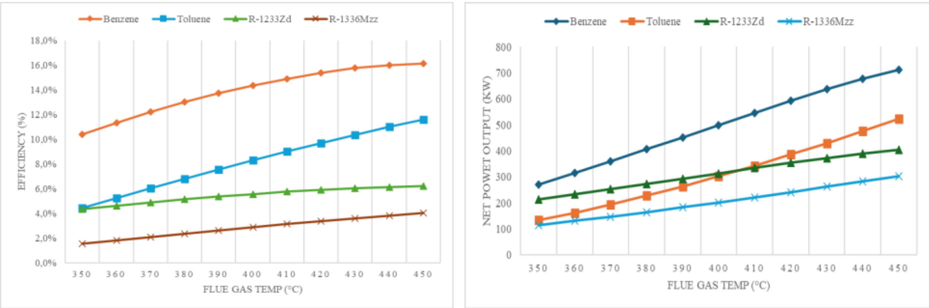

Figure 5 Variation of Efficiency and Net Power Output with Exhaust Flue Gas Temperature

At 450 °C, benzoene produced the most net power (712 kW). Its increased efficiency is in line with this. At the highest temperature, toluene came next with a net power output of 523 kW. The net power levels of R-1233zd(E) and R-1336mzz(Z) were significantly lower, peaking at 405 kW and 300–302 kW, respectively. Although they are hydrocarbon-based fluids with excellent thermodynamic efficiency, benzoene and toluene present safety and flammability issues. Because of this, they can be used in regulated settings where safety precautions are crucial. Notwithstanding their worse performance, R-1233zd(E) and R-1336mzz(Z) are greener substitutes as they have no potential to deplete the ozone layer and a lower global warming potential (GWP). Their use is advantageous in systems where environmental regulations are currently of utmost importance.

Higher exhaust gas temperatures greatly increase power output and efficiency for all working fluids, as the trends in both figures make abundantly evident. However, the extent of improvement is highly dependent on the thermodynamic properties of each fluid.

7.2 Variation of Efficiency and Net Power Output with Exhaust Flue Gas Temperature

From the Figure 6 shows the simulation results of net output power (in kW) as a function of evaporator pressure (in bar) with the same exhaust gas temperature of 450 C for four working fluids: Benzene, Toluene, R-1233zd, and R-1336mzz. The pressure is varied from 3 to 25 bar, with each working fluid showing a different output power trend as the pressure increases.

Benzene produces the highest net output power of about 700 kW at 25 bar. The curve trend for Benzene is consistently upward, showing an almost linear increase with evaporator pressure. Toluene follows the same pattern as Benzene but with a slightly lower output power, reaching a peak of about 500 kW at 25 bar. R-

Received ________, Revised _________, Accepted for publication __________

1233zd shows a moderate output power, reaching about 400 kW at the highest pressure. The curve trend is non-linear, with the output power increasing more gradually at higher pressures. The R-1336mzz has the lowest output power, reaching around 300 kW at 25 bar. The Curve Trend is similar to the R-1233zd but slightly lower in magnitude at all pressure levels.

The Optimal Pressure Range can be seen from the most significant increase in output power occurring between 3 and 15 bar for all fluids, with diminishing returns observed above 20 bar.

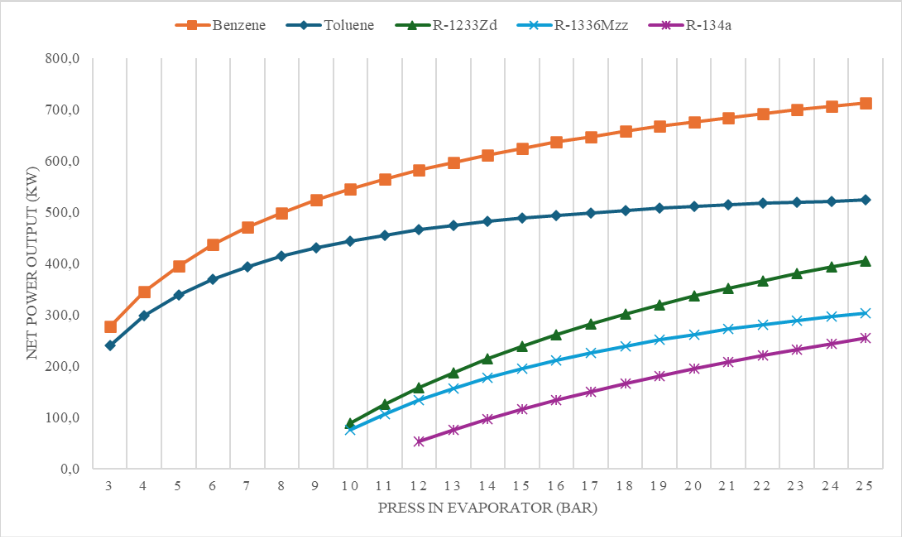

Figure 6 Net Power Output Variation with Pressure in Evaporator

8 Conclusion

The efficiency of an ORC system for engine exhaust heat recovery depends on the choice of working fluid. Several working fluids, including R11, R141b, R113, R123, R245fa, and R245ca, were assessed by Wang et al. Among the fluids examined, R245fa and R245ca were shown to be the best options, but underlined the importance of prioritizing safety and considering environmental impacts[11].

This study highlights the trade-offs between performance, safety, and environmental effects on choosing an ORC system's operating fluid. Benzene and Toluene offer superior performance with high efficiencies of 11-16% but require safety measures although ODP and GWP are still within safe limits, both have safety and environmental risks. R-1233zd and R-1336mzz offer more sustainable alternatives with moderate power outputs and relatively low

Received ________, Revised _________, Accepted for publication __________

efficiencies of around 4-7%. Working fluid selection must balance performance, safety, and environmental impact needs.

To ensure the sustainability and effectiveness of ORC systems, future efforts should focus on developing safer and more environmentally friendly working fluids with low toxicity, flammability, ODP and GWP while maintaining high performance, such as Benzene and Toluene. Optimizing system design for higher temperature adaptability and advanced heat recovery can improve efficiency. In addition, integrating ORC systems with renewable energy sources, complying with environmental regulations, and conducting life cycle assessments (LCAs) of working fluids are essential for long-term sustainability. Collaboration between industry and academia can further drive innovation and accelerate the adoption of sustainable ORC technologies.

9 References

[1] J. Bao and L. Zhao, "A review of working fluid and expander selections for organic Rankine cycle," *Renew. Sustain. Energy Rev.*, vol. 24, pp. 325–342, 2013, doi: 10.1016/j.rser.2013.03.040.

[2] B. F. Tchanche, G. Lambrinos, A. Frangoudakis, and G. Papadakis, "Low-grade heat conversion into power using organic Rankine cycles - A review of various applications," *Renew. Sustain. Energy Rev.*, vol. 15, no. 8, pp. 3963–3979, 2011, doi: 10.1016/j.rser.2011.07.024.

[3] BPS, "Kapasitas Terpasang PLN menurut Jenis Pembangkit Listrik (MW), 2020-2022," p. 6, 2015, [Online]. Available: https://www.bps.go.id/id/statistics-table/2/MzIxIzI=/kapasitas-terpasang-pln-menurut-jenis-pembangkit-listrik.html

[4] S. Lecompte *et al.*, "Review of experimental research on supercritical and transcritical thermodynamic cycles designed for heat recovery application," *Appl. Sci.*, vol. 9, no. 12, 2019, doi: 10.3390/app9122571.

[5] A. H. Pamungkas and A. B. K. Putra, "Studi Variasi Flowrate Refrigerant pada Sistem Organic Rankine Cycle dengan Fluida Kerja R-123," *J. Tek. Pomits*, vol. 2, no. 2, pp. B273-b277, 2013.

[6] H. M. D. P. Herath, M. A. Wijewardane, R. A. C. P. Ranasinghe, and J. G. A. S. Jayasekera, "Working fluid selection of Organic Rankine Cycles," *Energy Reports*, vol. 6, pp. 680–686, 2020, doi: 10.1016/j.egyr.2020.11.150.

[7] J. C. Jiménez-García, A. Ruiz, A. Pacheco-Reyes, and W. Rivera, "A Comprehensive Review of Organic Rankine Cycles," *Processes*, vol. 11, no. 7, 2023, doi: 10.3390/pr11071982.

[8] V. Maizza and A. Maizza, "Working fluids in non-steady flows for waste energy recovery systems," *Appl. Therm. Eng.*, vol. 16, no. 7, pp. 579–590, 1996, doi: 10.1016/1359-4311(95)00044-5.

Received ________, Revised ________, Accepted for publication __________

[9] V. Apostol, A. Dobrovicescu, T. Prisecaru, and M. Prisecaru, "Thermodynamic Analysis of ORC Configurations Used For WHR from a Turbocharged diesel engine," vol. 100, pp. 549–558, 2015, doi: 10.1016/j.proeng.2015.01.402.

[10] D. Zhou *et al.*, "Theoretical study of low-GWP refrigerants in high-temperature heat pump systems," no. August, pp. 881–886, 2023.

[11] E. H. Wang, H. G. Zhang, B. Y. Fan, M. G. Ouyang, Y. Zhao, and Q. H. Mu, "Study of working fluid selection of organic Rankine cycle (ORC) for engine waste heat recovery," *Energy*, vol. 36, no. 5, pp. 3406–3418, 2011, doi: 10.1016/j.energy.2011.03.041.

[12] A. R. Imre, R. Kustán, and A. Groniewsky, "Thermodynamic selection of the optimal working fluid for organic Rankine cycles," *Energies*, vol. 12, no. 10, 2019, doi: 10.3390/en12102028.

[13] X. Zhang, C. Zhang, M. He, and J. Wang, "Selection and Evaluation of Dry and Isentropic Organic Working Fluids Used in Organic Rankine Cycle Based on the Turning Point on Their Saturated Vapor Curves," *J. Therm. Sci.*, vol. 28, no. 4, pp. 643–658, 2019, doi: 10.1007/s11630-019-1149-x.

Received _______, Revised ________, Accepted for publication _________