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Exhaust Heat Recovery System using Organic Rankine Cycle (ORC) Technology: A Comprehensive Investigation

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ABSTRACT

The Organic Rankine Cycle (ORC) systems are well known as the advanced available method to develop mechanical or electrical energy.Continuous developments are undergone to develop new methods to improve the efficiency.In these systems, the organic fluids with medium temperatures are usually used to generate power.Large amount of exhaust gases and waste heat are generated in industries which are usually discharged into the environment.This heat is recovered and taken as input by the ORC system and used effectively in various processes.Earlier, only the low and medium temperature fluids were only used but now even high temperature working fluids are used for this purpose.This paper represents the technological and economic advances in the ORC technology to reuse the unwanted energy produced from various places and convert it into useful electrical or mechanical energy which can be used further.

Keywords:*Thermal energy, Organic fluid,ORC cycle, Waste heat recovery, Energy storage, Economical advancement*

1. INTRODUCTION

Organic Rankine system (ORC) was discovered on 1950s which was used to convert the low temperature energy into power.The working of the system depends on the fluid used as well as process undergone.The heat is recovered from the organic systems like biomass combustion, solar ponds and so on [**1**]. One of the significantimplementationsof ORC is the recovery of heat from exhaust of automobile engines which is one of the major causes for air pollution [**2**]. ORC have high range of promising heat recovery with huge potential market.They are preferable for low or medium heat sources which is reliable, and it can be easily accessible than steam Rankine cycles (SRCs) [**3**].Thisdevelopment emerged from SRC technology with both having same principle[**4, 5**].In case of SRCs the fluids used are mainly coal, oil combustion etc but in case of ORC it is usually organic fluids.Apart from this the former SRCs are used mainly in large power plants because the power generated will be high.While in case of later one the high temperature leads to the decomposition of organic fluids used[**6-8**].

Now-a-days the implementation of public power generation system based on sustainable methods becomes a necessary project to safeguard our environment.In this sense,the ORC plays an important role in generating electricity from renewable energy sources [**9, 10**]. In recent years, the use of this technology has spread worldwide with an average power generation of about 0.2 to 2.0 MW.The main aim is to generate economical,safer,non-toxic,inflammable,eco-friendly process.

2. ORGANIC RANKINE CYCLE (ORC): Working Principle

This is closed loop in which the working-fluid continuously flows inside loop to convert the waste heat generated to useful power[**11, 12**]. The selection of evaporation process is the initial stage;the waste heat generated is captured by the system which is used to increase the temperature of fluid passing through the device.Then the process of evaporation occurs, and this vapour is allowed to pass via the expander in which the mechanical or electrical power is produced.After that it is condensed into liquid form with the help of condenser.Finally, a pump compresses the fluid back into the system and energy is used as power.Thisis the operating principle of ORCs[**13,14**]. The working principle is same as SRC, but the fluid is organic in nature with low boiling point instead of liquid water [**15**].

3. WORKING FLUID REQUIREMENTS

This is mainly based on the temperature that needs to be used in the system.Apart the fluid selected should not cause much harm to the environment that is it should never contribute to ozone layer depletion and other natural calamities.Along with this the

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safety is an important parameter [**16**].In which the working fluid should be inflammable,eco-friendly,non-corrosive and should be non-toxic so that it should not affect the system's construction material.

The working fluid chemical properties can affect the process. The pressure required by the fluid to complete the process should be taken into consideration. The fluid should be selected accordingly. Along with this the fluid should be available and affordable. A high cost of fluid can limit the application of the process. The properties like freezing point and thermodynamic property should be less comparatively [**17**].Obviously, temperature is one of the important properties used to select the fluid along with other thermo physical properties.

4. ADVANTAGES OF ORC OVER SRC

- **High thermal efficiency:** Working fluids used in ORC mainly are dry or isentropic which do not need to be super-heatedagain while the wet fluids like water which is used in SRC has negative saturation curve. This super-heated fluid does not corrode the system as well as they don't hit the turbine at high speed which can cause damage to the parts. Along with this the temperature inside the system is well maintained in ORC systems [**18**]. Hence the reversible process doesn't happen, and more efficiency is obtained.
- **Easy construction:** The capacity to hold power will be high in ORC as low or medium temperature fluids are used.Fluids used are of low latent heat capacity so large mass flow rate is required which make it easier to construct ORC.Another thing is that critical pressure of water is much higher so higher expansion ratio is required for SRCs.But in case of other one only less expansion ratio is required.Hence, we can conclude that ORC is more effective and efficient than SRCs [**19**].

5. WASTE HEAT RECOVERY SYSTEMS

Usually, the industries discharge large amount of waste heat to the surroundings. From the literature survey, many studies are undergone to recover this waste heat by more efficiency. ORC is better method, but a more suitable working fluid must be found out in which the presentresearch worksare going on to recover maximum energy in more sustainable way. Figure 1 shows a typical plant which generates power from waste heat.

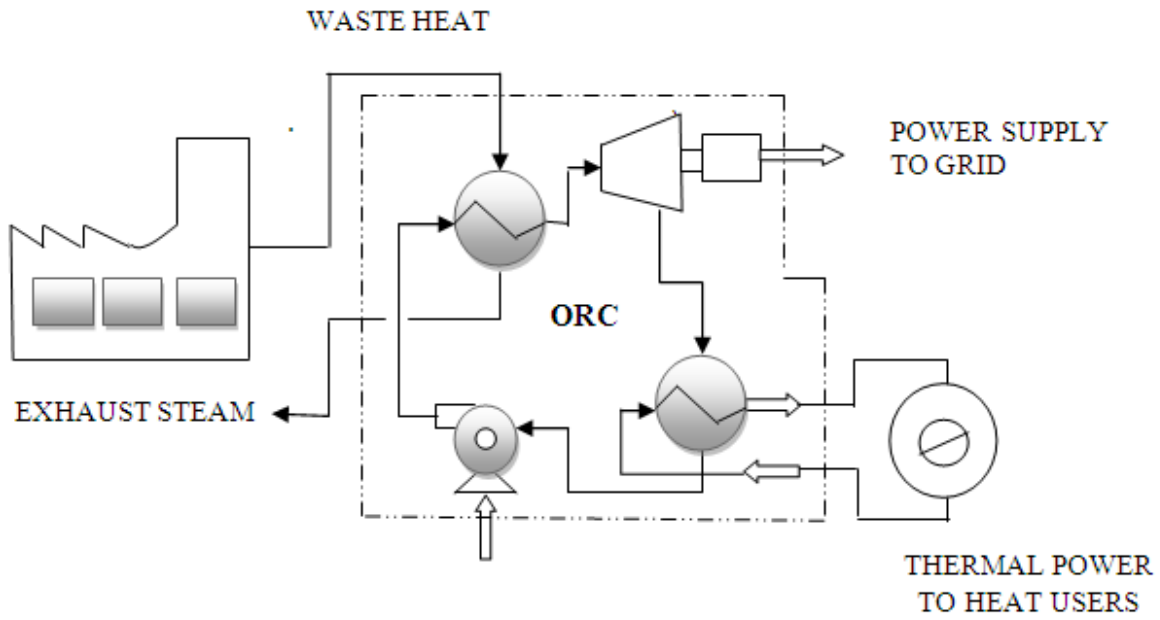

Figure 1: Power generation utilizing waste heat energy

When this ORC technology was compared with all other methods, it is found that the ORC is the most suitable method to generate power by recoveringheat at a temperature of about 200^0C to 400^0 C [**20**].

5.1 COMPRESSION IGNITION ENGINES

The essential components in engine- ORC system arepump, evaporator, CI engine, condenser, and expander.In this system, the gas generates high pressure which is sent to the evaporator where the vapour is formed.Then it is expanded and produces electrical energy with the help of alternator. The schematic representation of an unutilized heat recovery engine-ORC system is provided in

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Figure 2. Compressor ignition engines mainly uses diesel and hydrogen as fuel and when it is supplied together the generated power varies along with the amount of exhaust gas produced [**21**]. Theexhaust gas energy and heat transfer lossesare shown in Figure 1.

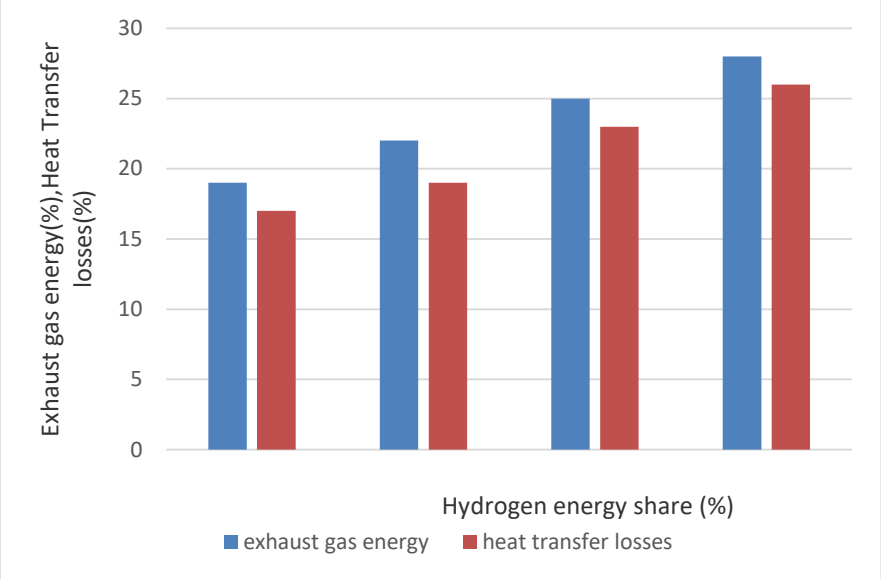

Figure 1: Thermal energy transfer losses and exhaust energy with the diesel-hydrogen dual fuel

A typical dual loop ORC system [**22**] attached with diesel engine is used for heat recovery is shown in Figure 2.

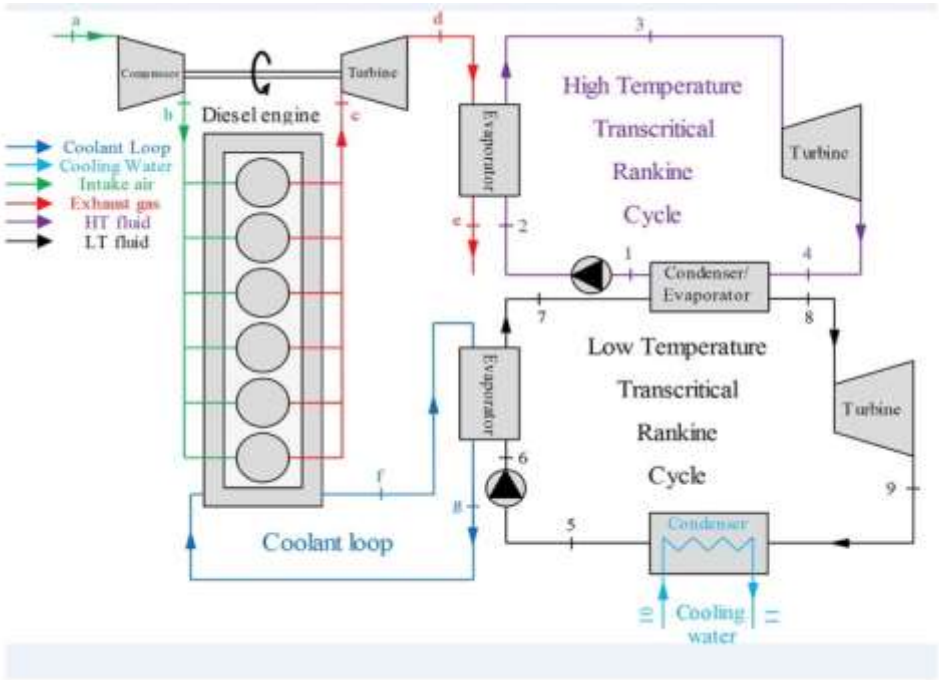

Figure 2: Dual loop ORC system in CI engines [Source: Mohammadkhani, F., &Yari, M. (2019). *doi:10.1016/j.applthermaleng.2018.12.158*]

6. CONCLUSION

Based on technical reviews conducted on this paper, ORC technology has an enormous potential to generate large amount of electrical energy with the help of organic fluids. The low or medium temperature fluids are used which make it easier to handle and make it more economic. Butresearchers show that even high temperature fluids also work well with ORC technology. The mechanical or electrical energy is developed from the renewable sources. Now-a-days, industries are growing in a wide range, and this generates large amount of waste exhaust, and this can be used as input to the system for converting into valuable substance. This resulted in the increase of researchrelated to the ORC system. When the system is developed the performance of ex pander and the working fluid for RC system is a major criterion for achieving highest efficiency. In this paper the waste heat recovery system mainly the IC engines are discussed.Apart from this advanced low pilot ignited natural gas,FCE-ORC and so on are also

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discovered. Moreresearch works are undergoingon to develop better working fluid and to optimize the parameters accordingly to improve the efficiency.

REFERENCES

1. Radonja, R., &Reljac, B. (2019, January). Utilization of cryogenic energy from the natural gas regasification terminal. In 34. Međunarodniznanstveno-stručnisusretstručnjaka za plin.
2. Schilling, J., Eichler, K., Pischinger, S., &Bardow, A. (2018). Integrated design of ORC process and working fluid for transient waste-heat recovery from heavy-duty vehicles. In Computer Aided Chemical Engineering (Vol. 44, pp. 2443-2448). Elsevier.
3. Zhao, R., Zhang, H., Song, S., Tian, Y., Yang, Y., & Liu, Y. (2018). Integrated simulation and control strategy of the diesel engine–organic Rankine cycle (ORC) combined system. *Energy conversion and management*, *156*, 639-654.
4. Tian, H., & Shu, G. Q. (2017). Organic Rankine Cycle systems for large-scale waste heat recovery to produce electricity. In *Organic Rankine Cycle (ORC) Power Systems* (pp. 613-636). Woodhead Publishing.
5. Roy, U., & Majumder, M. (2019). Evaluating heat transfer analysis in heat exchanger using NN with IGWO algorithm. Vacuum, 161, 186-193.
6. Zhang, X., Wu, L., Wang, X., & Ju, G. (2016). Comparative study of waste heat steam SRC, ORC and S-ORC power generation systems in medium-low temperature. Applied Thermal Engineering, 106, 1427-1439.
7. Roy, U., & Majumder, M. (2019). Economic optimization and energy analysis in shell and tube heat exchanger by meta-heuristic approach. Vacuum, 166, 413-418.
8. Roy, U., & Majumder, M. (2019). Productivity yielding in shell and tube heat exchanger by MCDM-NBO approach. Measurement and Control, 52(3-4), 262-275.
9. Vélez, F., Segovia, J. J., Martín, M. C., Antolín, G., Chejne, F., & Quijano, A. (2012). A technical, economical, and market review of organic Rankine cycles for the conversion of low-grade heat for power generation. Renewable and Sustainable Energy Reviews, 16(6), 4175-4189.
10. Roy, U., Pant, H. K., & Majumder, M. (2018). Detection of significant parameters for shell and tube heat exchanger using polynomial neural network approach. Vacuum. doi:10.1016/j.vacuum.2018.11.047
11. Lang, W., Colonna, P., &Almbauer, R. (2013). Assessment of waste heat recovery from a heavy-duty truck engine by means of an ORC turbogenerator. Journal of Engineering for Gas Turbines and Power, 135(4), 042313.
12. Roy, U., Majumder, M., & Barman, R. N. (2017). Designing configuration of shell-and-tube heat exchangers using grey wolf optimisation technique. International Journal of Automation and Control, 11(3), 274-289.
13. Tocci, L., Pal, T., Pesmazoglou, I., & Franchetti, B. (2017). Small scale organic rankine cycle (ORC): A techno-economic review. Energies, 10(4), 413.
14. Roy, U., & Majumder, M. (2018). International Journal of Heat and Technology. Journal homepage: http://iieta. org/Journals/IJHT, 36(2), 663-671.
15. Tian, H., & Shu, G. Q. (2017). Organic Rankine Cycle systems for large-scale waste heat recovery to produce electricity. In Organic Rankine Cycle (ORC) Power Systems (pp. 613-636). Woodhead Publishing.
16. Roy, U., & Majumder, M. (2016). Impact of climate change on small scale hydro-turbine selections. Springer.
17. Yagli, H., Koc, A., Karakus, C., &Koc, Y. (2016). Comparison of toluene and cyclohexane as a working fluid of an organic Rankine cycle used for reheat furnace waste heat recovery. International Journal of Exergy, 19(3), 420-438.
18. Tchanche, B. F., Lambrinos, G., Frangoudakis, A., & Papadakis, G. (2011). Low-grade heat conversion into power using organic Rankine cycles–A review of various applications. Renewable and Sustainable Energy Reviews, 15(8), 3963-3979.
19. Park, B. S., Usman, M., Imran, M., &Pesyridis, A. (2018). Review of Organic Rankine Cycle experimental data trends. Energy conversion and management, 173, 679-691.
20. Wang, L., LI, Q. H., MENG, A. H., & ZHANG, Y. G. (2010). Review of Waste Heat Recovery for Power Generation With Organic Rankine Cycle [J]. Energy Technology, 1.
21. Chintala, V., & Subramanian, K. A. (2014). Assessment of maximum available work of a hydrogen fueled compression ignition engine using exergy analysis. Energy, 67, 162-175.
22. Mohammadkhani, F., &Yari, M. (2019). A 0D model for diesel engine simulation and employing a transcritical dual loop Organic Rankine Cycle (ORC) for waste heat recovery from its exhaust and coolant: Thermodynamic and economic analysis. Applied Thermal Engineering, 150, 329-347.