Comprehensive Review Of ORC's Application: Waste Heat Recovery System In IC Engine

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ABSTRACT

Organic Rankine cycle (ORC) is a technology that can convert thermal energy at a relatively low temperature in the range of 80 to 350 °Cto electricity. ORC plays an important role to improve the energy efficiency in order to generate mechanical or electrical work of new or existing applications like solar thermal power, geothermal power or waste heat recovery system. A key and current solution for increasingly stringent fuel economy and CO2 emission standard is effective recovery of IC engine waste heat. This paper presents the challenges and possible solutions of IC engine ORC waste heat recovery development. It also presents major topics including ORC architecture selection impact on engine,ORC efficiency, and system complexity, Review of control approaches and power optimization methods for IC Engine ORC-Waste heat recovery system, Summary of simulation, limiting factors and results for IC Engine ORC-Waste heat recovery systems. The system architecture selection, the tradeoff between fuel savings and system complexity.The simulation studies predict higher power recovery levels than that in experimental work.

1. INTRODUCTION

Energy conservation over the globe is becoming very salient in recent years, especially the use of low grade temperature and small-scale heat sources. Energy extraction from industrial waste heat, biomass energy, solar energy, and turbine exhaust heat is becoming more popular. Organic Rankine Cycle is an effective way to convert these heat sources into electrical power. Organic Rankine Cycle offers the ability to deal with low temperature heat to generate power. The traditional Rankine Cycle which uses water as the working fluid needs much higher temperature heat source while Organic Rankine Cycle ORC can generate power at a much lower temperature. The heat source temperature can vary from 50 to over 250°C. In recent years a lot of research has been conducted around the world and many ORC systems have been successfully installed in different countries, especially in USA, Canada, Germany and Italy**.**

[Ravikumar *et.al*.2007][Polyzakis *et.al*.2009] Considering the climate change and the shortage of non-renewable energy resources,the interests in waste heat recovery has been growing remarkably, especially during the past decade. Waste heat recovery from internal combustion engines (ICE) is one of the opportunities for economizing of energy consumption. In an ICE, a great amount of fuel energy is wasted in form of heat due to thermal limitations. Roughly one-third of fuel energy is converted to mechanical power and the rest is released to the ambient in form of heat. For example,[Chammas *et al*.2005] for a spark ignition 1.4 liter ICE with thermal efficiency of 15 to 32%, 1.7 to 45 kW of energy is wasted through coolant in radiator and 4.6 to 120 kW of energy is wasted by the exhaust gas. Different methods have been recommended for waste heat recovery from ICE; such as thermoelectric, absorption refrigeration system, and organic Rankine cycle (ORC). For example in 2011 Ramesh Kumar *et al*. have studied thermoelectric method in exhaust gas waste heat recovery of a three cylinder spark ignition engine through an experimental test. [Kadota *et al*.2008] [Ringler *et al*.2009] [Zhang *et al*.2011] [Tahani *et al*.2013] Waste heat recovery using ORC is an efficient method compared with the other techniques; so automobile manufacturers use this method to enhance the efficiency of their products .

Organic Rankine Cycles offer power production from renewable, waste heat and law-grade heat sources like, geothermal energy, biomass, solar energy and waste heat from industry and thermal power plants. Furthermore, Organic Rankine Cycle can be used to recover energy from exhaust gases from power trains, improving the fuel consumption and reducing their impact on climate changes. Organic Rankine Cycle and working fluids have been widely studied in different scientific articles. Some papers widely studied the usage of Organic Rankine Cycle ORC in different applications like waste heat recovery, geothermal power plants, biomass power plants and solar thermal power plants.

[Ringler *et al*.2009] [Wang T *et al*.2011.] [Sprouse and Depcik, 2013] As one of the most promising heat recovery technologies to convert wasted energy from Internal Combustion Engine (ICE) into useful energy, Organic Rankine Cycle (ORC) attracts ever increasing attention from both academic and industry. [Velez et al.2012] pointed out the market available for ORC systems with the power ranges of 0.2 to 2 MWe under the cost of around 1 and 4×103 € /kWe.[Sprouse and Depcik, 2013] Most of the current research interest for engine waste heat recovery is mainly focusing on the recovery of engine exhaust energy because of the relatively high temperature from this energy source, which can potentially form a high thermal efficiency ORC system.[Boretti A et 2012] [Lu Y *et al*.2015] [Roskilly AP *et al*.2017] [yiji LU *et al*.2017] However, the engine coolant energy containing about 30% of the overall fuel energy, is difficult to recover and attracts ever increasing attention due to high demand for high energy efficiency and low emissions engines.

In 2007, Hountalas *et al* investigated efficiency of a heavy diesel engine using the methods of heat recovery from exhaust gas. These methods include mechanical turbo compounding, electrical turbo compounding and steam Rankine cycle. In 2010 Farzaneh-Gord *et al*.

investigated heat recovery from a 1.7 liter natural gas powered internal combustion by CO2 transcritical power cycle. [Maizza *et al.*2001] [Wipplinger *et al.*2006] [Endoet al.2007] [Saleh *et al.*2007] [Drescher *et al.*2007] [Mago *et al.*2008] [Wei *et al.*2008] Many researchers have been performed about using different working fluids, different configurations of Rankine cycle, and improving the system components during the recent years. In 2009, Dai *et al.* studied the effect of using different fluids on the heat recovery Rankine cycle and optimized the thermodynamic parameters like exergy efficiency for the studied working fluids. [Vaja and Gambarotta, 2010] studied the effect of various working fluids on the efficiency of Rankine cycle used for waste heat recovery. [Tahir *et al.*2010] investigated the effect of using Rotary- Vane Type expander on the efficiency of Rankine cycle used for waste heat recovery. [Srinivasan *et al.*2010] examined the exhaust waste heat recovery potential of a high-efficiency, low-emissions dual fuel low temperature combustion engine using an ORC

2. ORGANIC RANKINE CYCLE

Considered configurations of Organic Rankine cycle in the review

Using an adaptable configuration corresponding to the heat sources is one of the methods to improve the performance of co-generation system. Various configurations have been presented for heat recovery using ORC. Some of them are simple, preheat, and regenerated Rankine cycle. The amount of recovered heat and consequently cycle output power for these configurations depend on their characteristics. In this study two different configurations are proposed for simultaneous coolant and exhaust gas heat recovery: Preheat and two-stage configurations

2.1 Preheat Configuration

The first configuration presented in this paper is conventional preheat Rankine cycle. As shown in fig.1, the working fluid pressure has increased through process 1-2, after that a preheater was used for waste heat recovery from the coolant. The working fluid was preheated in this heat exchanger (process 2-3) then, entered the evaporator and was converted to saturated vapour by absorbing heat from the exhaust gas (process 3-4). After that it entered the expander and generated mechanical power by expanding (process 4-5), this configuration is unable to absorb the total heat released by the coolant. Thus, an air-cooled heat exchanger should be used to reduce the temperature of coolant before returning the engine.
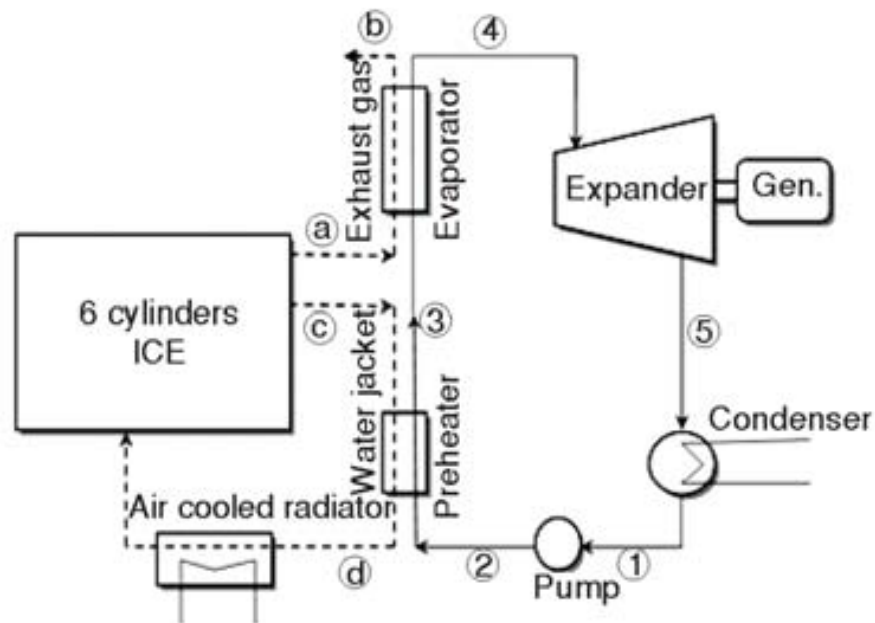

Figure 1: Preheat configuration combined with the ICE

2.2 Two-Stage Configuration

The second configuration is shown in fig. it is the system rarely used for heat recovery from ICEs until now. Two pumps and one expander with two inlets and one outlet, usually called dual expander, were used in this system. As shown in this figure 2, in this configuration, the working fluid flows in two different stages with different pressures after leaving the condenser (process 1-2 and 1-3). Low pressure stage relates to heat recovery from the coolant (process 2-4) and another one relates to heat recovery from exhaust gas (process 3-5). Finally, both low and high pressure flows expanded through a dual expander (process 4 and 5-6). Using this configuration, total wasted heat of coolant can be recovered and there is no need to air-cooled heat exchanger for coolant. Using two-stage configuration for Rankin cycle named as "dual pressure steam cycle" was recommended by Wang et al in 2009 for heat recovery from a cement production factory. They used a dual steam turbine for compression and power generation stage.
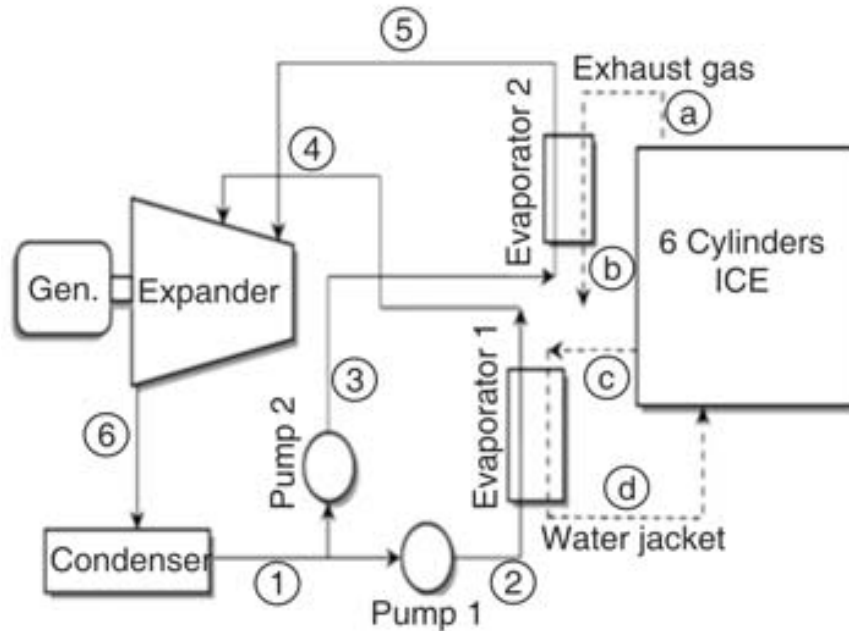
Figure 2: Two-stage configuration combined with the ICE

2.3 Selection Of Working Fluid

The selection of an organic working fluid depends on many criteria such as the nature of the heat source, turbines and costs of pumps as well as fluid properties (saturation vapor curve, low freezing point, high stability temperature, high heat of vaporization and density, viscosity, heat transfer characteristics, low-environmental impact, high stability temperature, safety, good availability and low cost, acceptable pressures, compatibility of materials etc.). (bajaj et, al, 2016) (Ajwalia et, al.2020) The choice of the right working fluid is of key importance for the cycle efficiency, Net Work Out and etc. The selection of working fluid has been used in many papers and scientific articles and other research purposeThe fluids were categorized based on the slope of their saturation vapor line in *T-s* diagram into three groups: Wet fluids with positive slope of saturation vapor line, dry fluids with negative slope of saturation vapor line, and isentropic fluids with an approximately vertical saturation vapor line. The wet fluid leads to droplets at the later stages of expander and requires superheating at the turbine inlet whereas the dry fluids are superheated even after the expansion from the expander.(Roy et al 2010) For an isentropic fluid, having a near-vertical saturated vapor line, the saturated vapor remains in the saturated condition and liquid droplets are not formed during expansion in expander. In an ORC utilizing this type of fluid under operation, most of the heat addition and rejection is carried out during change of phase only without the need of regenerative systems and it makes the ORC system a simpler one . (T. C. Hung et al 1996) (Ajwalia et al 2020) The thermophysical properties is can be consideration for selection of working fluids, which are compared and presented in Table 1. It is apparent that dry and isentropic organic fluids generally have much lower relative enthalpy drops during expansion than the water-steam mixture.

The choice of the ideal working fluid depends basically on the heat sink temperature and the heat source. The choice the right working fluid is not an easy process. The fluid selection process is a trade-off between thermodynamic specifications, safety, environmental and economy aspects

Parameters	H$_2$O	NH$_3$	Benzene	R134a	R12	R11	R13
Molecular weight	18	17	78.14	102	121	137	187
Vapor line	Negative	Negative	Positive	Isentropic	Isentropic	Isentropic	Positive
Enthalpy drop acroos tubine	1570~900 (kJ/kg)	725~70 (kJ/kg)	120~230 (kJ/kg)	55~22 (kJ/kg)	43~20 (kJ/kg)	80~40 (kJ/kg)	85~60 (kJ/kg)
Max. Stability temp(k)	None	750	600	450	450	420~450	450~500
Tubine stage	3(or more)	3(or more)	Single	Single	Single	Single	Single
Critical point (k)	647	405.2	562.3	374.14	385	471	487.3
Boling point at 1 atm	373 (k)	239.7 (k)	353 (k)	248 (k)	243.2 (k)	296.2 (k)	320.38 (k)
Latent heat at 1 atm (kJ/kg)	2256.6	1347	438.648	215.52	166.1	178.8	143.9

Table 1: Thermophysical Properties Of Working Fluids

3. HEAT RECOVERY FROM INTERNAL COMBUSTION ENGINES

An Internal Combustion Engine only converts about one third of the fuel energy into mechanical power. For instance, for a typical 1.4 liter Spark Ignition ICE, with a thermal efficiency ranging from 15 to 32%, 1.7 to 45 kW are released through the radiator (at a temperature close to 80 - 100°C) and 4.6 to 120 kW through the exhaust gas (400 - 900°C). The heat recovery Rankine cycle system is an efficient means for recovering heat (in comparison with other technologies such as thermo-electricity and absorption cycle air-conditioning). The idea of associating a Rankine cycle to an ICE is not new and the first technical developments followed the 70's energy crisis. For instance, Mack Trucks designed and built a prototype of such a system operating on the exhaust gas of a 288 HP truck engine. A 450 km on-road test demonstrated the technical feasibility of the system and its economical interest: an improvement of 12.5% of the fuel consumption was reported. Systems developed today differ from those of the 70's because of the advances in the development of expansion devices and the broader choice of working fluids. However, at the present time, Rankine cycle systems are under development, but no commercial solution seems to be available yet. Most of the systems under development recover heat from the exhaust gases and from the cooling circuit. By contrast, the system developed by researcher says that it only recovers heat from the cooling circuit. Different architectures can be proposed to recover engine waste heat: The heat recovery system can be a direct evaporation system or a heat transfer loop system. In the first case, the evaporator of the ORC is directly connected to the exhaust gases. The advantage of such a configuration is the high temperature of the heat recovery, allowing higher cycle efficiency. In the second case, thermal oil is used to recover heat on the exhaust gases and is then directed to the evaporator. This second system acts as buffer and reduces the transient character of the ORC heat source, which simplifies its control. It also shows the advantage of avoiding hot spots in the evaporator, which could damage the organic working fluid. The expander output can be mechanical or electrical. With a mechanical system, the expander shaft is directly connected to the engine drive belt, with a clutch to avoid power losses when the ORC cycle power output is too low. The main drawback of this configuration is the imposed expander speed: this speed is a fixed ratio of the engine speed and is not necessarily the optimal speed for maximizing cycle efficiency. In the case of electricity generation, the expander is coupled to an alternator, used to refill the batteries or supply auxiliary equipments such as the air conditioning. It should be noted that current vehicle alternators show a quite low efficiency (about 50 to 60%), which reduces the ORC output power. As for the expander, the pump can be directly connected to the drive belt, to the expander shaft, or to an electrical motor. In the latter case, the working fluid flow rate can be independently controlled, which makes the regulation of such a system much easier. The control of the system is particularly complex due to the (often) transient regime of the heat source. However, optimizing the control is crucial to improve the performance of the system. It is generally necessary to control both the pump speed and the expander speed to maintain the required conditions (temperature, pressure) at the expander inlet. Performance of the recently developed prototypes of Rankine cycles is promising. For instance, the system designed by Honda showed a maximum cycle thermal efficiency of 13%. At 100 km/h, this yields a cycle output of 2.5 kW (for an engine output of 19.2 kW) and represents an increase of the engine thermal efficiency from 28.9% to 32.7%.

4.ORC SYSTEM IMPROVEMENT

Unlike Steam Rankine Cycle, the optimization of the Organic Rankine Cycle is quite limited, The limitations are mainly affected by the low heat source temperature. Using isentropic and dry fluids in ORC, the working fluid leaves the expander as superheated vapour and no attention is paid to the vapour quality at the end of the expander

The superheated vapour has a great advantage for turbo machine expanders which always get damages due to low vapour quality. The turbo machines expanders in ORC systems can have a much longer life spam than in steam cycles. To overcome the low vapour quality at the expander outlet, screw and scroll expanders can be used instead of turbo machinery expanders. Screw and scroll expanders have much better resistance for vapour quality than turbo machinery expanders. (TAHANI et, al.2013)It follows that superheat is not recommended in cycles using dry and isentropic fluids. To overcome the low vapour quality in last expansion stages in Rankine Cycle the superheat is recommended.

The layout of the Organic Rankine Cycle is much simpler than that of the Rankine Cycle. In the Organic Rankine Cycles, the water-steam drum is eliminated and a single heat exchanger can be used instead of the three-part heat exchanger (economizer, preheater and superheater). (TAHANI et al 2013)Reheating and turbine bleeding are not recommended for some working fluids while a recuperator can work as a preheater and be installed between the expander outlet and the pump outlet. Figure 3 shows the cycle layout for an ORC using a recuperator and figure 5 shows the T-S diagram for ORC.

Following are the six main thermodynamic processes for an Organic Rankine Cycle uses a recuperator (internal heat exchanger IHE).

Process (1-2) Pump: the condensate working fluid is pumped from condenser pressure to evaporator pressure.

Process (2-3) Recuperator: heat transfer process between undercooled working fluid at pump outlet and superheated vapour at expander outlet.

Process (3-4) Evaporator: after the working fluid leaves the recuperator enters the evaporator to absorb more thermal energy from heat source. Here the working fluid changes the phase from under cooled liquid to saturated or superheated vapour.

Process (4-5): Expander: the saturated or superheated vapour enters the expander and the absorbed thermal energy in recuperator and evaporator converts to useful work. The working fluid leaves the expander as superheated vapour.

Process (5-6) Recuperator: heat transfer occurs between the high temperature vapour at expander outlet and low temperature fluid at pump outlet.

Process (6-1): the cooled working fluid at recuperator outlet enters the condenser. The working fluid stars condensation and more heat is rejected with help of a heat sink**.**
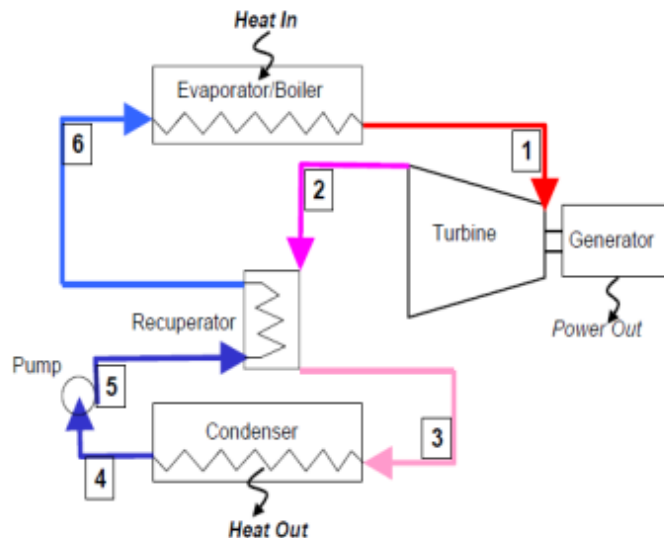

Figure 3 Organic Rankine Cycle using Recuperator

5. COMPARISONS WITH THE STEAM RANKINE CYCLE

Figure 4 shows in the T-s diagram the saturation curves of water and of a few typical organic fluids in ORC applications. Main difference can be stated as:
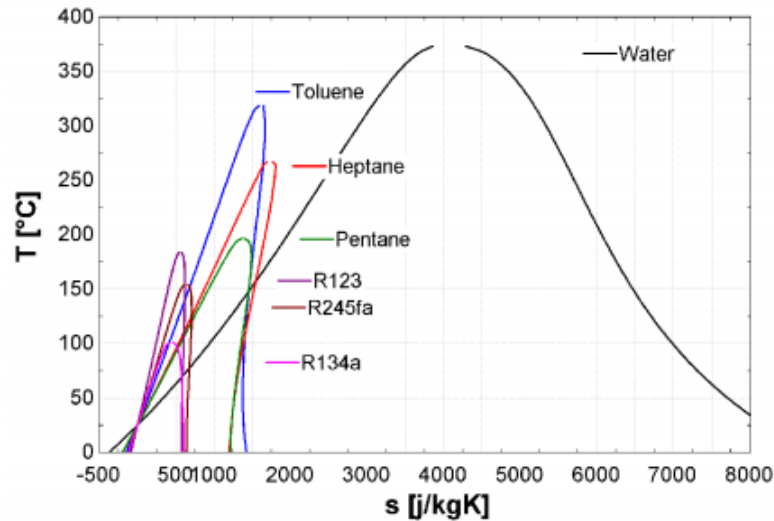

Figure.4: T-S diagram showing saturation curves of water

- The slope of the saturated vapour curve (right curve of the dome) is negative for water, while the curve is much more vertical for organic fluids. As a consequence, the limitation of the vapour quality at the end of the expansion process disappears in an ORC cycle, and there is no need to superheat the vapour before the turbine inlet

- Superheating. As previously stated, organic fluids usually remain superheated at the end of the expansion. Therefore, there is no need for superheating in ORC cycles, contrary to steam cycles. The absence of condensation also reduces the risk of corrosion on the turbine blade, and increases its lifetime up to 30 years instead of 15-20 for steam turbines .

- •Low temperature heat recovery. Due to the lower boiling point of the organic working fluids, heat can be recovered at a much lower temperature. This allows for, among others, power generation from geothermal heat sources.

- Components size. The size of the components is very dependent on the volume flow rate of the working fluid because pressure drops increase with the square of the fluid velocity. This leads to the necessity of increasing the heat exchangers hydraulic diameter and the pipe diameter to reduce this velocity. The turbine size is roughly proportional to the volume flow rate

- Turbine inlet temperature. In steam Rankine cycles, due to the superheating constraint, a temperature higher than 450°C is required at the turbine inlet to avoid droplets formation during the expansion. This leads to higher thermal stresses in the boiler and on the turbine blades and to higher cost

- Pump consumption. Pump consumption is proportional to the liquid volume flow rate and to the pressure difference between outlet and inlet. It can be evaluated by the Back Work Ratio (BWR), which is defined as the pump consumption divided by the turbine output power. In a steam Rankine cycle, the water flow rate is relatively low and the BWR is typically 0.4%. For a high temperature ORC using toluene, typical value is 2 to 3%. For a low temperature ORC using HFC-134a, values higher than 10% can be stated. Generally speaking, the lower the critical temperature, the higher the BWR.

- High pressure. In a steam cycle, pressures of about 60 to 70 bar and thermal stresses increase the complexity and the cost of the steam boiler. In an ORC, pressure generally does not exceed 30 bar. Moreover, the working fluid is not evaporated directly at the heat source (e.g. a biomass burner) but by the intermediary of a heat transfer loop. This makes the heat recovery easier since thermal oil is at ambient pressure, and avoids the necessity of an on-site steam boiler operator.

- Condensing pressure. In order to avoid air infiltrations in the cycle, high condensing pressures are advisable. It is not the case for water, whose condensing pressure is generally lower than 100 mbar absolute. Low temperature organic fluids such as HFC-245fa, HCFC-123 or HFC-134a meet this requirement since they condense at a pressure higher than the atmospheric pressure. However, fluids with a higher critical temperature such as hexane or toluene are subatmospheric at ambient temperature.

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- Fluid characteristics. Water as working fluid is very convenient compared to organic fluids. Its main assets are:

  -Cost-effectiveness and availability

  -Non-toxicity

  -Non-flammability

  -Environment friendly: low Global Warming Potential (GWP), null Ozone Depleting Potential (ODP).

  -Chemical stability: no working fluid deterioration in case of hot spot in the evaporator

- Low viscosity: lower friction losses, higher heat exchange coefficients However, steam cycles are generally not fully tight: water is lost as a result of leaks, drainage or boiler blow down. Therefore, a water-treatment system must be integrated to the power plant to feed the cycle with high-purity deionised water

- Efficiency. The efficiency of current high temperature Organic Rankine Cycles does not exceed 24%. Typical steam Rankine cycles show a thermal efficiency higher than 30%, but with a more complex cycle design (in terms of number of components or size). The same trend is stated for low temperature heat sources: steam Rankine cycles remain more efficient than ORC cycles.

- Therefore the ORC cycle is more profitable in the low to medium power range (typically less than a few MW), since small-scale power plants cannot afford an on-site operator, and require simple and easy to manufacture components and design.

6. THERMAL CONDUCTIVITY AND VISCOSITY

The thermal conductivity and viscosity of working fluids are two very important parameters in the design of heat exchanger and other Organic Rankine Cycle equipment. The knowledge of thermal conductivity is necessary to estimate the size of heat exchanger while the knowledge of viscosity is required to determine the required work for pumping the working fluid. High thermal conductivity and low viscosity is desirable in order to keep down heat exchangers size and to reduce the needed work for pumping the working fluid. Figure 5 & 6 show the thermal conductivity and viscosity for the working fluids which give the highest thermal efficiency. The thermal conductivity is estimated at 373K and saturation liquid while the viscosity is estimated at 298K and saturation liquid. The thermal conductivity and viscosity data are not available for sulfur dioxide SO2. Water is not considered a working fluid for Organic Rankine Cycle and it is added to these figures just to compare its properties to the properties for other working fluids

The selection of optimal working fluid for Organic Rankine Cycle is not an easy process. There are many different working fluids to choose among and many criteria should be taken in consideration. Some working fluids have good thermodynamic properties but at the same time have undesirable environmental and safety data. Other fluids have a good environmental and safety data but they are not efficient thermodynamically. There is no ideal working fluid can achieve all the desired criteria and the fluid selection process is a trade-off between thermodynamic, environmental and safety properties.

According to results and regarding thermal efficiency, the best working fluids for subcritical cycles are: ammonia, cyclopropane, R152a, sulfur dioxide SO2, R21, heavy water, toluene, methanol, acetone, cis-butene, trans-butene, butane and R11. Furthermore the best working fluids for trans-critical cycles are: R11, R21, ammonia, cyclopropane and SO2.
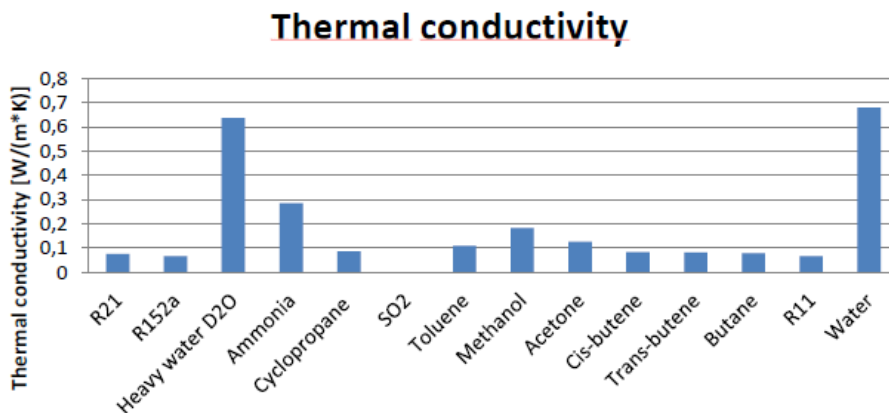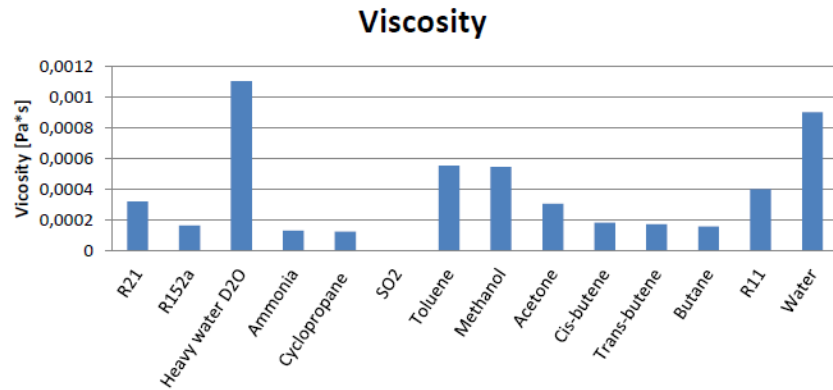

Figure.5: Refrigerant vs Thermal conductivity

Figure. 6. Viscosity vs Thermal conductivity

Regarding the environmental and safety criteria, the selected working fluid should have zero ozone depilation potential ODP, non-flammable, non-toxic and global warming potential should be very low. Taking all these criteria in consideration, following working fluids are not optimal: ammonia (flammable and toxic), SO2 (toxic), R21 (flammable, toxic and ODP=0,04), methanol (flammable), acetone (flammable), trans-butene (highly toxic), butane (highly toxic), R152a (toxic), and R11 (ODP=1 and GWP=4750). The environmental and safety data are not available for toluene and heavy water and the safety group for cyclo propane is also not available. Here the conclusion is that there is no ideal working fluid which can have all desirable criteria and properties at the same time. The trade-off is between high thermodynamic performance and environmental and safety criteria. There are some safe and environmental friendly working fluids like R124, but their thermodynamic performance is quite low.

7. CONCLUSION

A Comprehensive review respect to Waste heat recovery finds that IC engine exhaust contains heat with sufficient energy to justify implementation of a secondary cycle. Among the different cycles, ORC's are the most commonly implemented WHR systems in order to generate power from low-grade to medium-grade waste heat. This is because Rankine systems use standard components and operate efficiently using these grades of energy. Turbomachines are preferred for large output systems while displacement-type expanders dominate small-scale efforts. Finally, no single working fluid is best for all ORC's as the selection of the proper working fluid requires consideration of operating conditions, environmental concerns and economic factors. The amount of wasted heat from different parts of a 12 liter compression ignition engine and their potential for waste heat recovery were reviewed. Then, two configurations were introduced for simultaneous heat recovery from exhaust gases and coolant. An optimization process was applied for the configurations in which the goal was to maximize the work generation and thermal efficiency

REFERENCES

Ravikumar, N., *et al.*, Thermodynamic Analysis of Heat Recovery Steam Generator in Combined Cycle Power Plant, *Thermal Science, 11* (2007), 4, pp. 143-156

Polyzakis, A. L., *et al.*, Long-Term Optimization Case Studies for Combined Heat and Power System, *Thermal Science, 13* (2009), 4, pp. 46-60

Chammas, El., Clodic, R., Clodic, D., Combined Cycle for Hybrid Vehicles, SAE paper No. (2005)- 01-1171, 2005

Ramesh Kumar, C., *et al.*, Experimental Study on Waste Heat Recovery from an IC Engine Using Thermoelectric Technology, *Thermal Science*, *16* (2011), 4, pp. 1011-1022

Zhang, H., *et al.*, Study of Parameters Optimization of ORC for Engine Waste Heat Recovery, *Adv Mat Res*, *201-203* (2011), pp. 585-589

Kadota, M., Yamamoto, K., Advanced Transient Simulation on Hybrid Vehicle Using Rankine Cycle System, SAE paper 2008-01-0310, 2008

Ringler, J., *et al.*, Rankine Cycle for Waste Heat Recovery of IC Engines, SAE paper 2009-01-0174, 2009

Mojtaba TAHANI a, b, Saeed JAVAN c*, and Mojtaba BIGLARI A COMPREHENSIVE STUDY ON WASTE HEAT RECOVERY FROM INTERNAL COMBUSTION ENGINES USING ORGANIC RANKINE CYCLE. THERMAL SCIENCE: Year 2013, Vol. 17, No. 2, pp. 611-624

Wang T, Zhang Y, Peng Z, Shu, G. A review of researches on thermal exhaust heat recovery with Rankine cycle, Renewable and Sustainable Energy Reviews, 15 (2011) 2862-2871.

Sprouse C, Depcik IC. Review of organic Rankine cycles for internal combustion engine exhaust waste heat recovery, Applied Thermal Engineering, 51 (2013) 711-722.

Ringler J, Seifert M, Guyotot V, Hübner W. Rankine Cycle for Waste Heat Recovery of IC Engines, SAE Int. J. Engines, 2(1) (2009) 67- 76.

Vélez, F, Segovia JJ, Martín MC, Antolín G, Chejne F, Quijano A. 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 (2012) 4175-4189.

Lu Y, Wang C, Dong L,Wang L, Roskilly AP, Design and assessment on a novel integrated system for power and refrigeration using waste heat from diesel engine, Applied Thermal Engineering, 91 (2015) 591-599.

Lu Y, Roskilly AP, Smallbone A, Yu X, Wang Y. Design and parametric study of an Organic Rankine cycle using a scroll expander for engine waste heat recovery, Energy Procedia, 105C (2017) pp. 1421-1426.

Boretti A. Recovery of exhaust and coolant heat with R245fa organic Rankine cycles in a hybrid passenger car with a naturally aspirated gasoline engine, Applied Thermal Engineering, 36 (2012) 73-77.

Yiji lu , Anthony paul roskilly, Long Jiyang, Xiaoli Yu Working fluid selection for small scale organic rankine cycle recovering engine waste heat

Hountalas, D. T., *et al*., Study of Available Exhaust Gas Heat Recovery Technologies for HD Diesel Engine Applications, *Int. J. Altern Propul, 1* (2007), 2/3, pp. 228-249

Farzaneh-Gord, M., *et al*., Heat Recovery from a Natural Gas Powered Internal Combustion Engine by CO2 Transcritical Power Cycle, *Thermal Science, 14* (2011), 4, pp. 897-911

Endo, T., *et al*., Study on Maximizing Exergy in Automotive Engines, SAE paper 2007-01-0257, 2007 Tahani, M., *et al*.: A Comprehensive Study on Waste Heat Recovery from ...

Saleh, B., *et al*., Working Fluids for Low-Temperature Organic Rankine Cycles, *Energy, 32* (2007), 7, pp. 1210-1221

Wei, D., *et al*., Dynamic Modeling and Simulation of an Organic Rankine Cycle System for Waste Heat Recovery, *Appl. Therm. Eng., 28* (2008), 10, pp. 1216-1224

Wipplinger, K. P. M., *et al*., Stainless Steel Finned Tube Heat Exchanger Design for Waste Heat Recovery, *J. of Energy in Southern Africa, 17* (2006), 2, pp. 47-56

Drescher, U., Bruggermann, D., Fluid Selection for the Organic Rankine Cycle in Biomass Power and Heat Plants, *Appl. Therm. Eng., 27* (2007), 1, pp. 223-228

Maizza, V., Maizza, A., Unconventional Working Fluids in Organic Rankine Cycles for Waste Heat Recovery Systems, *Appl. Therm. Eng., 21* (2001), 3, pp. 381-390

Mago, P. J., *et al*., An Examination of Regenerative Organic Rankine Cycles Using Dry Fluids, *Appl. Therm. Eng., 28* (2008), 8-9, pp. 998-1007

Dai, Y., *et al*., Parametric Optimization and Comparative Study of Organic Rankine Cycle for Low Grade Waste Heat Recovery, *Energy Convers. Manage., 50* (2009), 3, pp. 576-582

Vaja, I., Gambarotta, A., Internal Combustion Engine (ICE) Bottoming with Organic Rankine Cycles, *Energy, 35* (2010), 2, pp. 1084-1093

Tahir, M. B. M., *et al*., Efficiency of Organic Rankine Cycle System with Rotary-Vane- Type Expander for Low-Temperature Waste Heat Recovery, *Inter. Jour. of Civil and Environmental Engineering, 2* (2010), 1, pp. 11-16

Srinivasan, K. K., *et al*., Analysis of Exhaust Waste Heat Recovery from a Dual Fuel Low Temperature Combustion Engine Using an Organic Rankine Cycle, *Energy, 35* (2010), 6, pp. 2387-2399

Roy, J. P., *et al*., Parametric Optimization and Performance Analysis of a Waste Heat Recovery System Using Organic Rankine Cycle, *Energy*, *35* (2010), 12, pp. 5049-5062

T. C. HUNG, T. Y. SHAI**,** and S. K. WANG: A Reviw of Organic rnakine Cycles (ORC's)for the Recovery of Low grade waste heat https://www.sciencedirect.com/science/article/abs/pii/S036054429600165X

Md. Abdul Raheem Junaidi, and. Irfan Sadaq)Review of organic Rankine cycles for internal combustion engine exhaust waste heat recovery