IC ENGINE WASTE HEAT RECOVERY (WHR) BY USING ORGANIC RANKINE CYCLE (ORC) AND ANALYSIS OF WORKING FLUID SELECTION BY USING MAT LAB

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Abstract: The objective of this project is to analyze waste heat recovery based on Organic Rankine cycle and to understand how the working fluid properties affect the thermal performance of the Rankine cycle-based waste heat recovery systems for internal combustion engines. The thermal efficiency formula is validating under several different operating conditions. A simulation code was developed using MAT LAB, where the working fluid thermal properties were calculated. Working fluid selection is one of the most important procedures in the design of Rankine cycle-based waste heat recovery systems for internal combustion engines. The system's performance, cost, and environmental impacts can be greatly influenced by the properties of its working fluid. In this project we observe and validate using multiple working fluids under different operation conditions.

Key Words: -Organic Rankine cycle, Waste heat recovery, Thermal efficiency, IC engine, Working fluid, MATLAB.

1.INTRODUCTION

1.1 WASTE HEAT

Many processes, especially in industrial applications, produce large amounts of waste or excess heat, i.e., heat beyond what can be efficiently used. Waste heat is heat generated in a process by way of fuel combustion or chemical reaction, which is usually discarded into the environment and not utilized. Waste heat recovery (WHR) methods attempt to extract some of the energy that otherwise would be wasted. The mechanism to cover the unused heat depends on the temperature of the waste heat gases and the economics involved. Typical methods of recovering heat in industrial applications include direct heat recovery to the process itself, recuperators, regenerators, and waste heat boilers. If some of the waste heat could be recovered, then a considerable amount of primary fuel could be saved. An important issue to consider is that in many applications, especially those with low-temperature waste heat streams.

1.2 CLASSIFICATION OF WASTE HEAT

Waste heat can be classified as high, medium, and low-temperature

- Waste heat at temperatures between 923 and 1,873 K is considered high-temperature waste heat and results from devices, such as solid waste incinerators and zinc, aluminum, and copper refining furnaces, among others
- Waste heat, which ranges from 503 and 923 K is considered medium-temperature waste heat. Some examples of medium-temperature waste heat sources are steam boiler exhaust (503–753 K), gas turbine exhaust (642–813K), and reciprocating engine exhaust (588–873 K), among others
- Waste heat at temperatures between 328 and 503 K is considered low-temperature waste heat. Examples of low temperature waste heat include process steam condensate, cooling water from furnaces, etc.

1.3 WASTE HEAT RECOVERY BY ORC

Waste heat is energy that is rejected to the environment. It arises from equipment and operating inefficiencies, as well as from thermodynamic limitations on equipment and processes. Often, part of waste heat could potentially be used for some useful purpose. At present, about 20 to 50% of energy used in industry is rejected as waste heat. A significant part of this wasted energy is low-temperature heat that is sent to the atmosphere mainly from cooling water, fin-fan coolers and flue gases. Usually, distillation column overhead streams at temperatures of 100–200C reject heat by fin-fan coolers, and streams at a temperature less than 100C reject heat to the cooling water system. About 50 % of the fuel we use to produce power in conventional power plants is wasted due to the limitations of the power conversion processes.

Waste heat recovery is an economic method to increase the overall efficiency of the plant and, thus, to lower fuel demand. Exhaust gas of various processes is carrying a huge amount of energy also referred to as waste heat. Often industrial processes produce enough waste heat to generate electricity. Waste Heat Recovery Units (WHRUs) or heat to power units could recover the waste heat and transform it into electricity by using, for example, an Organic Rankine Cycle (ORC). Often, waste heat is of low temperature quality. It can be difficult to efficiently utilize the heat contained. In these cases, the ORC-Technology can bring an additional benefit to raise the overall plant efficiency. The ORC-Unit utilizes this otherwise wasted energy and converts it into power.

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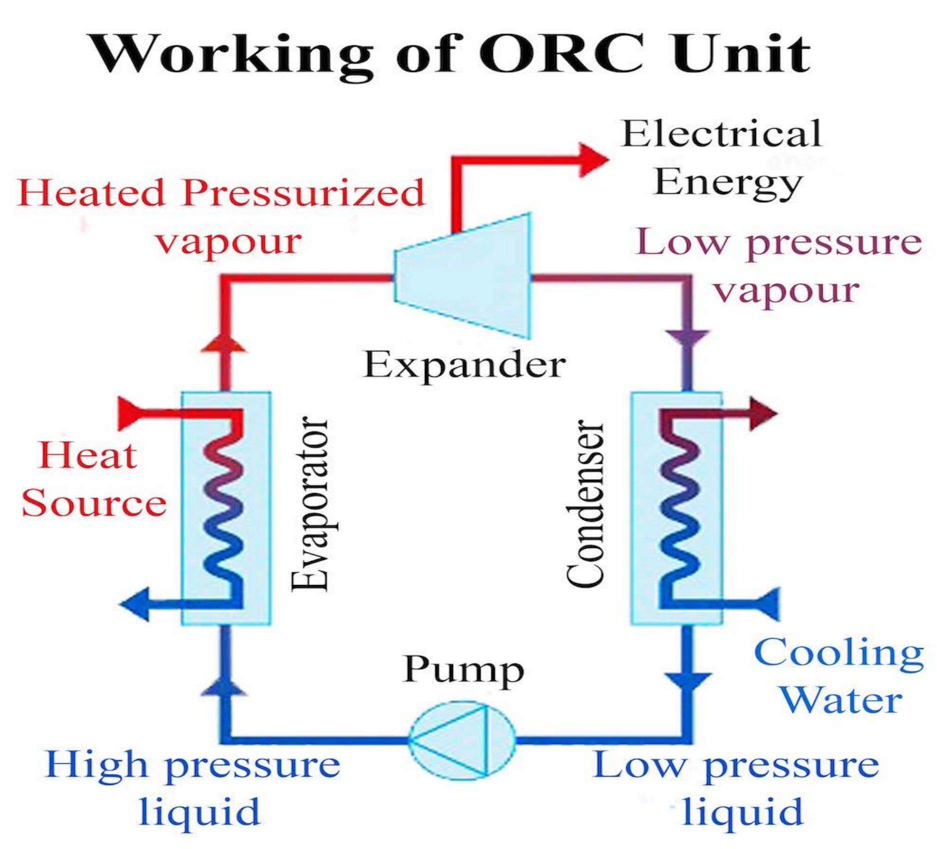
1.4 PERFORMANCE OF ORC



An ORC system using low-grade energy sources in the system is composed of an evaporator (waste heat boiler), a turbine expander, a condenser, and a pump. A working fluid flows into the evaporator in which the high-temperature heat source (which is in the form of steam) is utilized. The vapour of the boiling fluid enters the turbine expander and generates power.

The exit fluid from the turbine expander then enters the condenser in which the low-temperature cooling water (i.e., the cold water) is utilized to condense the fluid. Finally, a fluid pump raises fluid pressure and feeds the fluid into the evaporator to complete the cycle. So long as a temperature difference between the high and low-temperature ends is large enough, the cycle will continue to operate and generate power. The objective of this study is focused on thermodynamic analyses of the working fluid and the overall system efficiency rather than hard ware arrangements such as the system integration of thermal energy. Therefore, issues regarding material selections, component configurations, and frictional losses, heat transfer performances of the evaporator and condenser, and cost analysis are not considered in this study.

2 LITERATURE SURVEY

Yiji Lu et al. [1] studied a designed small-scale engine coolant and exhaust heat recovery system using different ORC working fluids. The evaluations of the designed ORC system using a targeted scroll expander to recover the waste heat from a 6.5 kW small ICE have been conducted. He concluded that R134a and R152a have the advantages of relatively high net power output, low requirement of condenser thermal load, low rotational speed of the scroll expander and high overall ORC thermal efficiency compared with R245a, R600, R124.

Ramin Marodi et al [2] worked on thermodynamic simulation of a small-scale organic cycle testing facility using R245fa as the working fluid. He showed that even when the steam generator produces steam at maximum flow rate (corresponding to maximum energy in the hot source), main components of the ORC system do not reach to their maximum performance limit; therefore, the system can work with more available energy in the hot source with higher overall performance.

Usman Muhammad, et al.,[3] this paper presents an experimental investigation of a small scale (1 kW range) organic Rankine cycle system for net electrical power output ability, using low-grade waste heat from steam. The system was designed for waste steam in the range of 1–3 bar. After the organic Rankine cycle system was designed and thermodynamic simulation was performed, equipment selection and construction of test rig was carried out. R245fa was used as working fluid; a scroll type expansion directly coupled with electrical generator produced a maximum electrical power output of 1.016 kW with 0.838 kW of net electrical power output. The thermal efficiency of the system was 5.64%, Maximum thermal efficiency was 6.9% and maximum expander isentropic efficiency obtained was 77.74% during the experiment. Both expander and screw pump were losing power in electric and mechanical losses (generator/motor) presenting a need of further development of these components for better efficiency. Heat loss in piping is also a factor for improving efficiency along with the ability of heat exchangers and control system to maintain the least possible degree of superheat of working fluid at expander inlet.

T.C. Hung, et al.,[4] discussed regard Rankine cycles using organic fluids (as categorized into three groups: wet, dry, and isentropic fluids) as working fluids in converting low-grade energy are investigated in this study. The main purpose is to identify suitable working fluids which may yield high system efficiencies in an organic Rankine cycle (ORC) system. Efficiencies of ORC systems are calculated based on an assumption that the inlet condition of the working fluid entering turbine is in saturated vapour phase. Parameters under investigation are turbine inlet temperature, turbine inlet pressure, condenser exit temperature, turbine exit quality, overall irreversibility, and system efficiency. The low-grade energy source can be obtained from a solar pond or/ and an ocean thermal energy conversion (OTEC) system. Results indicate that wet fluids with very steep saturated vapour curves in T-s diagram have a better overall performance in energy conversion efficiencies than that of dry fluids. It can also be shown that all the working fluids have a similar behavior of the efficiency-condenser exit temperature relationship. Furthermore, an appropriate combination of solar energy and an ORC system with a higher turbine inlet temperature and a lower condenser temperature (as operated deeply under sea level) would provide an economically feasible and environment-friendly renewable energy conversion system.

3 WORKING FLUID SELECTION

The main difference between a Rankine cycle and Organic Rankine cycle is the working fluid. In a normal Rankine cycle the working fluid used is water but in organic Rankine cycle instead of using water as the working fluid organic fluids were used as the working fluids.

Except for the structural point of view and type of atoms in the fluid molecule, the working fluids could be categorized according to the saturation vapour curve, which is one of the most crucial characteristics of the working fluids in an ORC. This characteristic affects the fluid applicability, cycle efficiency, and arrangement of associated equipment in a power generation system there are generally three types of vapour saturation curves in the temperature-entropy (T–s) diagram.

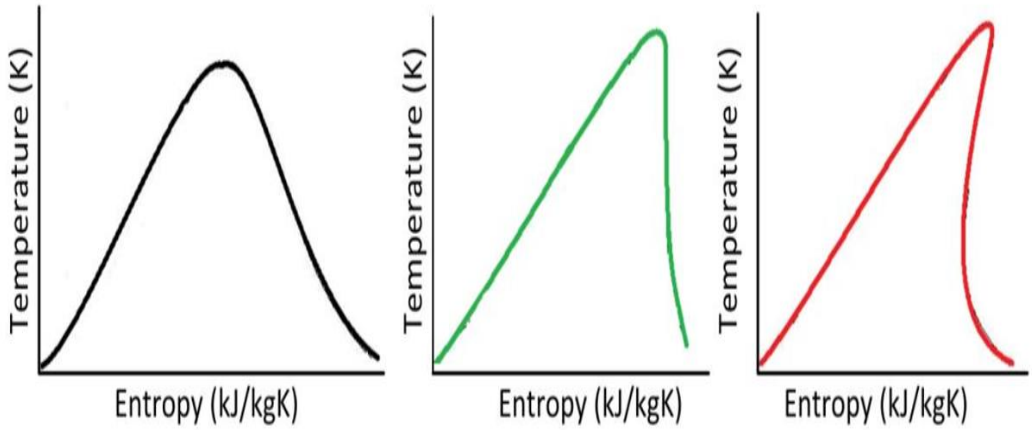


Fig 2.1 wet, isentropic and dry fluids

- A wet fluid with negative slopes (e.g. water, ammonia)
- A dry fluid with positive slopes (e.g. R245fa)
- An isentropic fluid with nearly infinitely large slopes (e.g.R11)

While isentropic and dry fluids do not need superheating, thereby eliminating the concerns of impingement of liquid droplets on the expander blades. Moreover, the superheated apparatus is not needed. Therefore, the working fluids of dry or isentropic type are more adequate for ORC systems. If the fluid is too dry, the expanded vapour will leave the turbine with substantial super- heat, which is a waste and adds to the cooling load in the condenser. Usually a regenerator is used to reclaim these exhaust vapour to increase the cycle efficiency; however, it would increase the system's initial investment and complexity, which exists trade-off. Therefore, isentropic fluids are most suitable for recovering low-temperature waste heat. In this project R245fa and R123 are selected as the working fluids for the simulation.

4.SIMUTATION IN MATLAB

The name MATLAB stands for matrix laboratory. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

MATLAB WORKING ENVIRONMENT

MATLAB DESKTOP

MATLAB Desktop is the main MATLAB application window. The desktop contains five sub windows, the command window, the workspace browser, the current directory window, the command history window, and one or more figure windows, which are shown only when the user displays a graphic.

The command window is where the user types MATLAB commands and expressions at the prompt (>>) and where the output of those commands is displayed. MATLAB defines the workspace as the set of variables that the user creates in a work session. The workspace browser shows these variables and some information about them. Double clicking on a variable in the workspace browser launches the Array Editor, which can be used to obtain information and income instances edit certain properties of the variable.

The current Directory tab above the workspace tab shows the contents of the current directory, whose path is shown in the current directory window. For example, in the windows operating system the path might be as follows: C:\MATLAB\Work, indicating that directory "work" is a subdirectory of the main directory "MATLAB"; WHICH IS INSTALLED IN DRIVE C. clicking on the arrow in the current directory window shows a list of recently used paths. Clicking on the button to the right of the window allows the user to change the current directory.

MATLAB uses a search path to find M-files and other MATLAB related files, which are organize in directories in the computer file system. Any file run in MATLAB must reside in the current directory or in a directory that is on search path. By default, the files supplied with MATLAB and math works toolboxes are included in the search path. The easiest way to see which directories are on the search path.

The easiest way to see which directories the search path are soon, or to add or modify a search path, is to select set path from the File menu the desktop, and then use the set path dialog box. It is good practice to add any commonly used directories to the search path to avoid repeatedly having the change the current directory.

The Command History Window contains a record of the commands a user has entered in the command window, including both current and previous MATLAB sessions. Previously entered MATLAB commands can be selected and re-executed from the command history window by right clicking on a command or sequence of commands.

This action launches a menu from which to select various options in addition to executing the commands. This is useful to select various options in addition to executing the commands. This is a useful feature when experimenting with various commands in a work session.

Using the MATLAB Editor to create M-Files

The MATLAB editor is both a text editor specialized for creating M-files and a graphical MATLAB debugger. The editor can appear in a window by itself, or it can be a sub window in the desktop. M-files are denoted by the extension .m, as in pixelup.m. The MATLAB editor window has numerous pull-down menus for tasks such as saving, viewing, and debugging files. Because it performs some simple checks and also uses color to differentiate between various elements of code, this text editor is recommended as the tool of choice for writing and editing M-functions. To open the editor, type edit at the prompt opens the M-file filename.m in an editor window, ready for editing. As noted earlier, the file must be in the current directory, or in a directory in the search path.

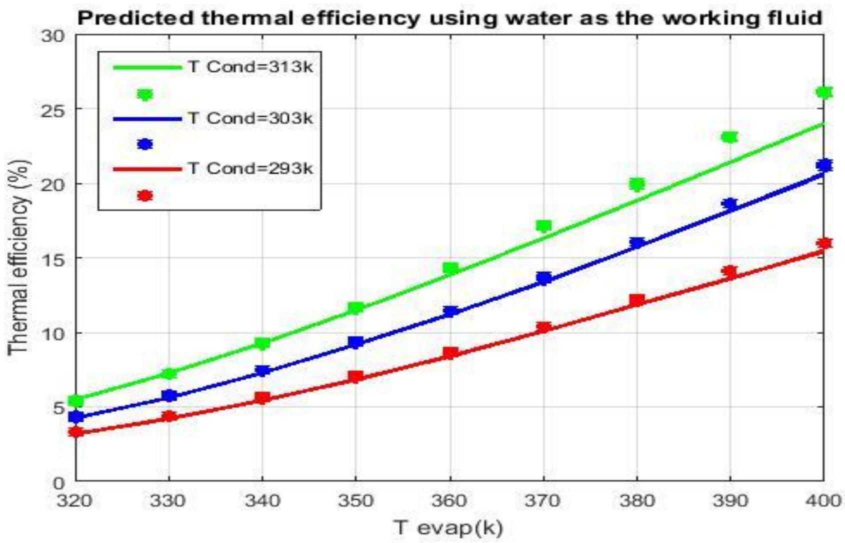
Getting Help

The principal way to get help online is to use the MATLAB help browser, opened as a separate window either by clicking on the question mark symbol (?) on the desktop toolbar, or by typing help browser at the prompt in the command window. The help Browser is a web browser integrated into the MATLAB desktop that displays a Hypertext Markup Language (HTML) documents. The Help Browser consists of two panes, the help navigator pane, used to find information, and the display pane, used to view the information. Self-explanatory tabs other than navigator pane are used to perform a search.

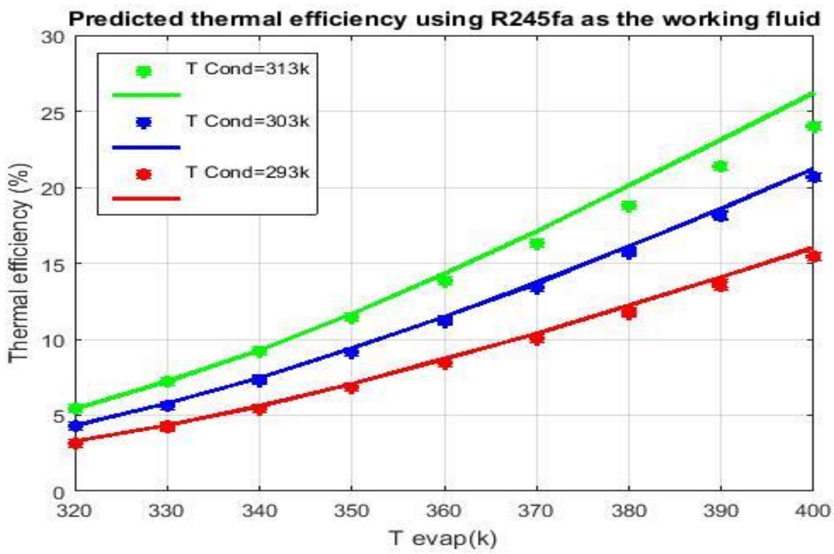
5. RESULTS AND DISCUSSIONS

In this study three different fluids were selected for the study namely water, R245fa, R123 as the working fluids. The temperatures of the evaporator are varied from 320k to 400k at the condenser temperatures 203k, 303k, 313k. The outputs obtained are the graphs between thermal efficiency and the evaporator temperatures with respect to the condensation temperatures. The dotted line represents theoretical approximation and the solid line represents actual solution. Different colors in the graph represents the different condenser temperatures. Red color line implies that the temperature of the condenser is 293K and the Blue color line represents that the temperature of the condenser is 303K and similarly the green color represents that the condenser is operating at temperature 313K.

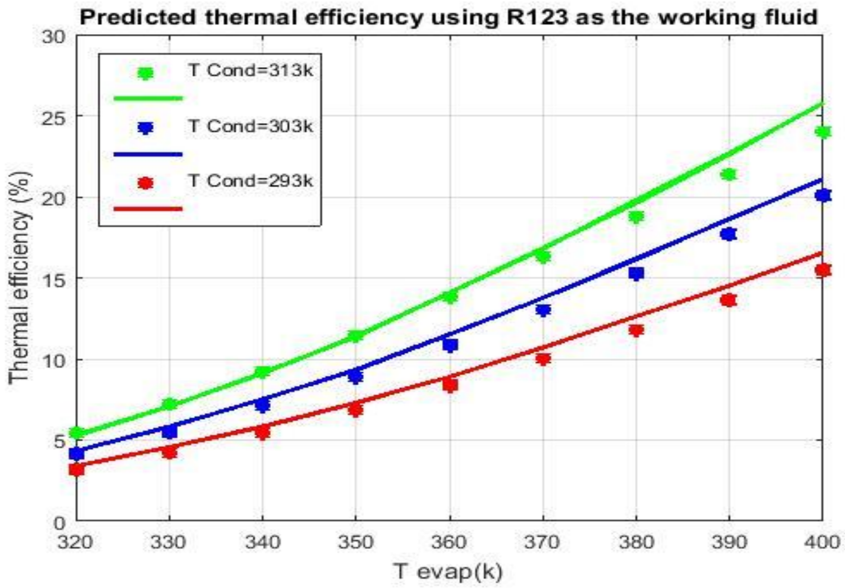
Since water is the working fluid in the general Rankine cycle it cannot be used as a working fluid in the Organic Rankine cycle because the boiling point temperature of water is more. The amount of temperature present in exhaust gases is not enough for water to boil so that the conversion into steam will not takes place. So, in this analysis water is used as the reference fluid and the best working fluid is selected on the basis of thermal efficiency by comparing the efficiency of the working fluid R245fa and R123 with water. The fluid which gives more efficiency is considered as the best working fluid.



- In the above graph water is used as the working fluid and the thermal efficiencies are considered at different evaporative temperatures with respect to the different condenser temperatures.
- Since the boiling point of water is more the exhaust gas temperature is not sufficient to convert into steam, so the final actual output thermal efficiency is less than the theoretical approximation efficiency.



- In the above graph R245fa is used as the working fluid and the thermal efficiencies are considered at different evaporative temperatures with respect to the different condenser temperatures.
- As the boiling point of the fluid is 288K less compared to the water the fluid is converted to steam by the temperature of the exhaust gases.
- The actual thermal efficiency is more compared to the theoretical approximation efficiency.



- In the above graph R123 is used as the working fluid and the thermal efficiencies are considered at different evaporative temperatures with respect to the different condenser temperatures.
- As the boiling point of the fluid is 300K less compared to the water the fluid is converted to steam by the temperature of the exhaust gases.
- The actual thermal efficiency is more compared to the theoretical approximation efficiency.

5.CONCLUSION

Many industrial processes produce waste heat that is typically rejected to lower temperature heat sinks. There are number of ways in which such waste heat can be recovered to produce useful energy. Recovery of waste heat offers the benefit of increasing overall efficiency in case of power generation or provides auxiliary power in other waste heat application.

As the heat released by the exhaust gases of ic engines is not much more so a normal Rankine cycle cannot be used in this process. So, an Organic Rankine cycle is used to perform the analysis. Organic Rankine cycle uses organic fluids as the working fluids as they can vaporize at lower temperatures compared to the remaining fluids so that usage of organic fluids will increase the efficiency of the overall cycle.

In the present work analysis is carried out in an Organic Rankine cycle. The organic fluids used for the analysis are R245fa and R123. The boiling points of R245fa is 300K and the boiling point of R123 is 288K. An analysis is carried out for the thermal efficiency of the two fluids with respect to the different evaporator temperatures and condenser temperatures. By the results obtained it is observed that the thermal efficiency of the organic fluid R245fa is more than the thermal efficiency of the organic fluid R123. In the results obtained in the above case as the water is the working fluid the thermal efficiency obtained is less than the efficiency of theoretical approximation. So, it is not used as a working fluid in the Organic Rankine cycle.

It is also observed that as the temperature in condenser is increasing the thermal efficiency of the cycle is also increasing. So, by the above result obtained it is observed that it is beneficial to use R245fa as the working fluid for an Organic Rankine cycle rather than using R123 as a working fluid.

6 FUTURE SCOPE

- The temperature of the exhaust forms the most industrial process and power plants are less than 3700. If this kind of waste heat is let in to environment directly, it would not only waste heat but also make heat pollution to environment. Using conventional methods to recover energy from this kind of exhaust is economically infeasible. The Organic Rankine Cycle (ORC) system exhibits great flexibility, high safety and low maintenance requirements in recovering this grade of waste heat.
- There are different organic fluids are available. In this study the analysis is carried out with only two organic fluids. Performing the same analysis on different organic fluid gives different results as they vary in the boiling point

temperatures. So, by doing analysis on remaining organic fluids and we compare all the results a best suitable fluid can be obtained which gives maximum thermal efficiency.

- ORC can be used in gas power plants as the exhaust gases coming out from turbine is at higher temperatures
- ORC can be used in cement industries, chemical industries as they liberate large amount of heat through exhaust.

7 REFERENCES

[1] Yiju Lu, Anthony Paul Roskilly. Long Jiang, Xiaoli Yu "*Working fluid selection for a small-scale Organic Rankine cycle recovering engine waste heat*" Energy Procedia 123 (2017) 346-352 Elsevier Ltd

[2] Ramin Moradi, Roberto Tascioni, Emanuele Habib, Luca Cioccolanti, Mauro Villarini, Enrico Bocci, "*Thermodynamic simulation of a small-scale Organic Rankine cycle testing facility using R245fa*" Energy procedia 105 (2017) 1889-1894 Elsevier Ltd

[3] Usman Muhammad, Muhammad Imran, Dong Hyun Lee, Byung Sik Park *"Design and experimental investigation of a 1 kW organic Rankine cycle system using R245fa as working fluid for low-grade waste heat recovery from steam*" Energy Conversion and Management 103 (2015) 1089–1100 Elsevier Ltd

[4] T.C. Hung, S.K. Wang, C.H. Kuo, B.S. Pei, K.F. Tsai *"A study of organic working fluids on system efficiency of an ORC using low-grade energy sources Energy*" 35 (2010) 1403–1411

[5] Jiaxin Ni, Zhi Wang, Li Zhao*, Ying Zhang, Zhengato Zhang, Minglu Ma, Shan lin "*Dynamic simulation and analysis of Organic Rankine cycle system for waste recovery from diesel engine*" Energy Procedia 142 (2017) 1274-1281 Elsevier Ltd

[6] Hanzhi Wang, Huashan Li, Lingbao Wang, Xianbiao Bu "*Thermodynamic Analysis of Organic Rankine Cycle with Hydrofluoroethers as Working Fluids*" Energy Procedia 105 (2017) 1889-1894 Elsevier Ltd

[7] E. Galloni, G. Fontana, S. Staccone, "*Design and experimental analysis of a mini ORC (organic Rankine cycle) power plant based on R245fa working fluid*", Energy, 90 (2015) 768-775.

[8] Z. Mat Nawi, S.K. Kamarudin, S.R. Sheikh Abdullah, S.S. Lam "The potential of exhaust waste heat recovery from marine diesel engines via Organic Rankine cycle" Energy Procedia 166 (2019) 17-31 Elsevier Ltd

[9] P.J. Mago, L.M. Chamra, C. Somayaji, "*Performance analysis of different working fluids for use in organic Rankine cycles*", Proc. Inst. Mech. Eng., Part A: J. Power Energy 221 (3) (2007) 255–263.

[10] Donghong Wei *, Xuesheng Lu, Zhen Lu, Jianming Gu "*Performance analysis and optimization of organic Rankine cycle (ORC) for waste heat recovery*" Energy Conversion and Management 48 (2007) 1113–1119

[11] Takahisa Yamamoto, Tomohiko Furuhata, Norio Arai, Koichi Mori "*Design and testing of the Organic Rankine Cycle*"Energy 26 (2001) 239– 251.

[12] F.J. Fernández*, M.M. Prieto, I. Suárez "*Thermodynamic analysis of high-temperature regenerative organic Rankine cycles using siloxanes as working fluids*" energy 36(2011) 5239e5249

[13] Teemu Turunen-Saaresti et al "*Design and testing of high temperature micro-ORC test stand using Siloxane as working fluid*" J. Phys.: Conf. Ser. 821 012024