PROCEEDINGS, 45th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2020
SGP-TR-216

Selection of Working Fluids for Low Enthalpy Geothermal Organic Rankine Cycles

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Keywords: ORC, working fluids, Low Temprature, Thermodynamics

ABSTRACT.

India has great capacity to use the Organic Rankine Cycle to select the working fluid for Indian engine with the help of geothermal energy. It converts energy into Reaffirm energy. Regenerative Organic Rankine cycle is used to convert low temperature heat source to the powerful useful energy, It helps in the selection of proper organic fluid for engine. It can also convert energy into Mechanical energy and from it to Electrical energy. With the help of Organic Rankine cycle it improves the efficiency of existing energy else new generated energy.This concept uses first in Turbine engine. This paper reviews on the selection of working fluid of Organic Rankine Cycle for Indian Environment. The selection appropriate working fluid for Organic Rankine cycle is depends on the Environmental Temperature and Safety criteria of Environment. From the review on heat source it shows result that India has lots of waste heat and Reaffirm energy to generate electricity with the help of Organic Rankine Cycle. For Indian engines working fluids for ORC are such as Ammonia, R 134a, n-Pentane and R12 etc. Form so many studies and researches it results that India has opportunity and availability of resources to use this technology and it has so many challenges and difficulties but India has sufficient empowerment and technology to overcome from it.

1. INTRODUCTION

Energy conservation overall the globe is becoming very important in present time, especially the use of low grade temperature and small-scale heat sources.Removal of Energy 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 (ORC) is a technology that can convert thermal energy at relative low temperatures in the range of 80 to 350 °C to electricity. It can play an important role to improve the energy efficiency of new or existing energy-intensive applications. Organic Rankine Cycle has the ability to deal with low temperature heat to generate power. The traditional Rankine Cycle which uses H2O(water) as its 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 differ from 50°C to over 250°C. In recent years a lot of research has been conducted around the world and its been continuing with research to install ORC while many ORC systems have been already successfully installed in different countries, especially in USA, Canada, and couple of countries from Europe continent they are Germany and Italy

.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, to recover energy from exhaust gases from power trains, improving the fuel consumption and reducing their impact on climate changes can be done by Organic Rankine cycle. Organic Rankine Cycle and working fluids have been widely studied in different scientific articles and research. Some papers mostly studied the usage of Organic Rankine Cycle ORC in different applications, for exapmle, geothermal power plants, solar thermal power plants biomass power plants and waste heat recovery.

(bajaj et al, 2016)According to Roadmap 2050 from the European Climate Foundation 2010, the greenhouse emissions can be reduced by 80% in 2050. This target can be achieved through the modification of the current energy system and the following modifications should be accomplished by 2050:

- Increase effectiveness and reduce energy intensity of buildings by 950 TWHr/year and of Energy industry by 450 TWHr/year.
- Shift to renewable energies and clean power generation (Wind energy 25%, PV1 19%, CSP 25%, Biomass 12%, Geothermal 2% and Large hydro 12%).
- Electricity can be use instead of fossil fuels for transportation and space heating.
- Increase the grid capacity and reinforce the inter-regional transmission lines.
- Concentrating Solar Power (CSP) systems use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area
- Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect.

2. CLASSIFICATION OF ORC

Organic Rankine Cycle (ORC) is a technology that can convert thermal energy at relative low temperatures in the range of 80 to 350 °C to electricity and can therefore play an important role to improve the energy efficiency of new or existing applications. Beside industrial waste heat alternative heat sources such as solar and geothermal energy as well as biomass can be applied. The Organic Rankine Cycle has the same working principles and main components (evaporator, condenser, expander and pump) as the Steam Rankine Cycle. At the same time, there are some major differences between the two cycles. The differences are mainly related to the used working fluid in the cycle, the working fluid's thermo-physical properties, the heat source temperature and the cycle architecture. Organic Rankine Cycle can extract energy and generate power from much lower heat source temperature than traditional Rankine cycle

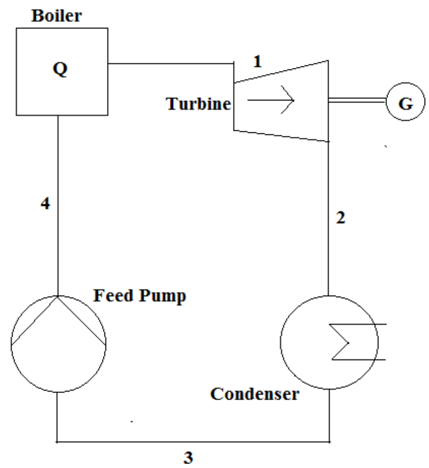

Figure 1: Line diagram of Rankine cycle

To better study the Organic Rankine Cycle the process of a very simple conventional steam power plant which is also known as Clausius Rankine Cycle is presented, check Figure 1. In a steam power plant the thermal energy is converted to electricity as water passes through a sequence of state changes. To implement these state changes the components like a turbine with generator, condenser, feed pump and boiler are needed.

Superheated steam passes into the turbine with high temperature and pressure (state 1). The turbine converts the thermal energy into mechanical energy, which is converted to electricity by the generator. While the turbine extracts energy from the steam the pressure and temperature decrease. If the expansion exceeds the saturated vapor curve wet steam occurs which may erode the turbine blades due to the impact of water droplets. The cool low pressure steam at turbine exit (state 2) is condensed to liquid water (state 3) and pressurized (state 4) by the feed pump. By adding heat to the water, steam is generated and superheated within the boiler. Now the condition before turbine (state 1) is reestablished and the thermodynamic cycle is closed. The water steam cycle is suitable for turbine inlet temperatures above 350 °C. At lower temperatures the efficiency significantly decreases and the danger of erosion due to droplets increases because the expansion goes deep into the wet steam region. By decreasing the turbine inlet pressure the steam quality at the end of the expansion can be improved. However, wet steam still exists and the efficiency additionally drops. ORC overcomes these problems by using an organic fluid, e.g. Pentane, instead of water (therefore it's called Organic Rankine Cycle). Organic fluids have lower boiling temperatures than water which make them suitable to explore heat potential with temperatures below 350 °C. By adoption of the working fluid to an existing waste heat temperature higher efficiencies can be achieved than with a conventional steam cycle.

There are three types of Organic cycles depending on where the four thermodynamic processes (compression, heat addition, expansion and heat rejection) occur.

- **Subcritical Organic Rankine Cycle :-** In this cycle the four processes occur at pressures lower than the critical pressures for the working fluid

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- **Trans-critical Organic Rankine Cycle :-** In this cycle the process of heat addition occurs at a pressure higher than the critical pressure for the working fluid. The heat rejection process occurs at a pressure lower than the critical pressure for the working fluid. The compression and expansion processes occur between the two pressure levels.

- **Supercritical Organic Rankine Cycle :-** In this cycle the four processes occur at pressures higher than the critical pressures for the working fluid.

3.SELECTION OF WORKING FLUIDS

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) 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 purpose. It is confirm that Most of the articles and papers and other researches are based on theoretical studies of working fluids using counterfeit of thermodynamic models. Many scientific articles mainly treat the thermo-physical properties of working fluids with a point on cycle efficiency, thermal efficiency, Net work out, second law efficiency etc. There are three types of working fluids, i.e. dry fluids, wet fluids and isentropic fluids. A dry fluid has a positive slope of the saturation curve on a T-S diagram; a wet fluid has a negative slope; and an isentropic fluid has an infinitely large slope. Generally, dry and isentropic fluids are better working fluids for power plants based on organic Rankine cycle because they do not condensate after the fluid goes through the turbine. '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.(T. C. Hung et al 1996)

Parameters	H_2O	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

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. The following criteria should be taken in consideration in order to figure out the best candidates.(Mago *et al*., 2007) (Sylvain 2011)

3.1 Environmental and Safety Criteria

Environmental and safety criteria are of most important in selection of working fluid, however many working are phased out or some are towards it.The phased out working fluids have high ozone depletion potential ODP and global warming potential GWP. Some working fluids have good thermodynamic properties but at the same time have undesirable environmental and safety effects. According to EC Regulation 2037/2000, many working fluids like CFC, CFCs and HCFCs refrigerant are already phased out. These refrigerants are banned due to their ozone depletion potential ODP and global warming potential GWP (Bajaj et, al, 2016)

3.2 Saturation vapor line in T-S diagram

An important characteristic to take into account during the working fluid selection is the slope of the saturation vapor line in the T-S diagram. When it comes to the saturation vapor line, the working fluids can be sorted in three different categories:

- Dry fluids which have positive ds/dt slopes. This category includes working fluids such as Decane, Nonane, Octane, Toluene, Heptane, Cyclohexane, Hexane, R113, R365mfc, etc.
- Wet fluids which have negative ds/dt slopes. Common working fluids in this category are Heavy water, Ethanol, Methanol, R21, Sulfur dioxide, DME, etc.
- Isentropic fluids with infinitely ds/dt slopes. Such common working fluids are R142b, Cis-butene, R11, R141b, Acetone, etc

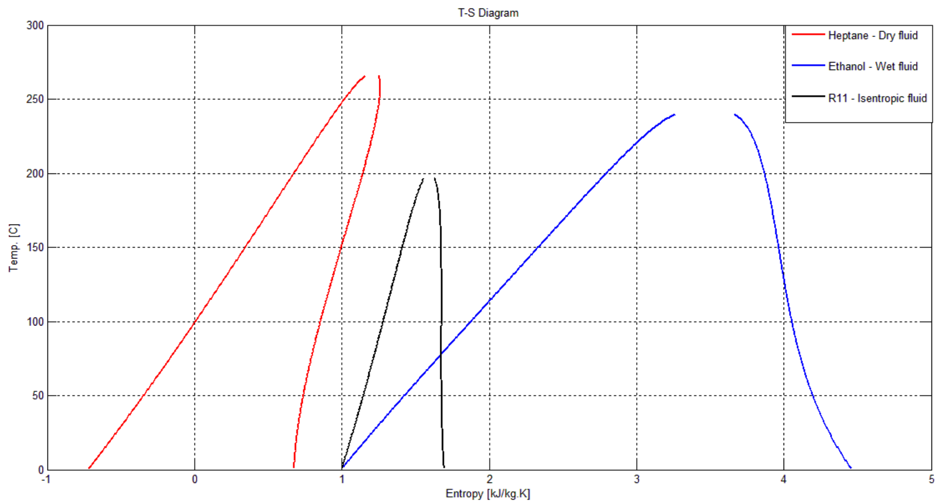

Figure.2 :-The T-S diagram for dry, isentropic and wet working

3.3 Thermodynamic properties

. Thermodynamic properties are of key importance in the design process of Organic Rankine Cycles, regarding optimal energy utilization and reducing exergy losses. The following are some important thermodynamic properties for working fluids:

- For a certain heat sink and heat source the Net Power Out, the thermal efficiency and the second law efficiency should be as high as possible.
- The condensing pressure should be higher than the atmospheric pressure to avoid leakage issues.
- In sub-critical cycles the critical pressure for the working fluid must be higher than the pressure in the evaporator.

The higher the density, the lower the specific volume and volumetric flow rate. Low volumetric flow is desirable to achieve smaller component and more compact machines. Low density fluids have high specific volume and need bigger components (heat exchangers and expander). A bigger component size leads to more expensive units and more costly systems. Furthermore, a high specific volume increases the pressure drop in the heat exchangers and needs higher pump work.

- Large enthalpy variation in the turbine leads to high Net Work Out.
- Higher convective heat coefficient and high-thermal conductivity increases the heat transfer process between the heat source, the heat sink and the working fluid.
- High heat capacity (CP) of the liquid leads to better energy recovery from the heat source and decrease the mass flow rate of the working fluid.
- The working fluid should be thermally and chemically stable.

4. FEASIBILITY OF ORC IN LOW TEMPREATURE MODEL

The feasibility study should also provide the best possible solution for the client. The feasibility stage should only be carried out once it is clear there is a chance of utilizing the geothermal fluid because a comprehensive feasibility study requires resources and time. The final outcome of a comprehensive feasibility study can be used as the front-end engineering design (FEED) and can also be used for an in-depth economic analysis. The goals of each step in Figure 5 of the guidelines are described in the following sections. The purpose of the feasibility stage is to further develop the initial approximate model from the prospect stage to determine if the project is economically and technically feasible. This stage of the design process involves a number of iterations and revisions to optimize the model

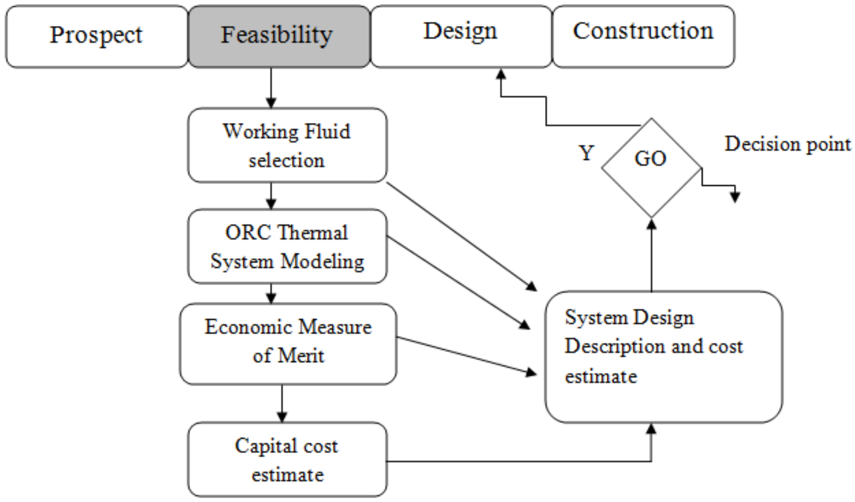

Figure 3:- Flowchart of Feasibility stage of ORC

5.APPLICATIONS OF ORC'S

Organic Rankine Cycle can efficiently be used in many applications in order to generate mechanical work or electrical power and following are some of the applications.(Rettig *et al*, 2011).

5.1 Solar Thermal Power

The solar thermal power is a well-proven technology. The parabolic dish, the solar tower and the parabolic though are three different technologies used to extract power from solar thermal. The parabolic tower can work at a temperature range of 300 °C – 400 °C. For a long time this technology was linked to the traditional Steam Rankine Cycle for power generation. The Organic Rankine Cycle seems to be a more promising technology. However, the Steam Rankine Cycle needs higher temperature and a higher installed power in order to be profitable. The Organic Rankine Cycle can work at lower temperatures, offers a smaller component size and needs much lower investment cost compared to steam cycles. The installed power can be reduced to kW scale. Technologies such as Fresnel linear concentrators (Ford, 2008) are particularly suitable for solar ORC's since they require lower investment cost, but work at a lower temperature.

5.2 Geothermal power plants

(Quoilin and Lemort, 2009)The range of temperatures of geothermal heat sources is large. Lowest possible temperature for ORC heat recovery is about 100 °C, while other ORC geothermal plants work at a temperature higher than 200°C. Higher temperature (>150°C) geothermal heat sources enable combined heat and power generation: the condensing temperature is set to a higher temperature (e.g. 60°C), allowing the cooling water to be used for space heating. The global energy recovery efficiency is therefore increased, at the expense of the electrical efficiency. Dry steam power plants, flash steam power plants and binary cycle power plants are three different technologies used to extract power in geothermal power plants(Bajaj et al, 2016).

5.3 Waste Heat Recovery

Waste heat recovery is a process in which the energy is extracted from waste heat which comes from many processes, especially in industrial applications. In some applications waste heat boilers, recuperators and regenerators are used in order to directly recover and redirect heat to the process itself. This heat can be converted into heat sources for other on-site applications, or used for space heating (e.g. district heating). For instance, (Engin et al. 2004) demonstrated through a case study that 40% of the heat used in cement industry was lost in flue gases, whose temperature varies between 215 and 315 °C. For economical reasons (Hung, 2001), traditional steam cycles wouldn't allow recovering heat in this range of temperatures. A huge potential market is therefore available for the ORC technology in this application field. In steam cycles the economics of waste heat recovery don´t justify when the temperature of the wasted heat is low. The Organic Rankine Cycle can be used to produce electricity from low grade heat sources.

6.CONCLUSION

The selection of optimal working fluid for Organic Rankine Cycle is very hard 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.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.From a thermodynamic perspective, the selection of the optimal working fluid depends basically on the heat source and the heat sink temperatures. For every heat source and heat sink temperature there are a number of working fluid candidates. The most selected working fluids should have good thermodynamic properties like high thermal efficiency, second law efficiency and Net Work Out. The thermal conductivity of working fluid is another important aspect that should be taken in consideration in working fluid selection process.

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