A REVIEW ON ORGANIC RANKINE CYCLE WITH RESPECT TO POWER PLANT ENGINEERING

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Abstract

New energy conversion technologies required in order to insure the production of electricity without generating the environmental pollution. An important number of new solutions have been proposed to generate electricity from alternative heat source. Waste heat recovery is one of the most important development fields for the organic Rankine cycle (ORC). It can be applied to heat and power plants (for example a small scale cogeneration plant on a domestic water heater) , or to industrial and farming processes such as organic products fermentation, hot exhausts from ovens or furnaces (e.g. lime and cement kilns), flue-gas condensation, exhaust gases from vehicles, inter cooling of a compressor, condenser of a power cycle, etc. Biomass is available all over the world and can be used for the production of electricity on small to medium size scaled power plants. The problem of high specific investment costs for machinery such as steam boilers are overcome due to the low working pressures in ORC power plants. Another advantage is the long operational life of the machine due to the characteristics of the working fluid, that unlike steam is non eroding and non corroding for valve seats tubing and turbine blades. The ORC process also helps to overcome the relatively small amount of input fuel available in many regions because an efficient ORC power plant is possible *for smaller sized plants.*

Key words; ORC, Applications of ORC, ORC to power plant.

Introduction

Energy is a critical input in any industrial process, and thus directly determines to a large extent, the environmental impact of the manufacturing process and the products of a any company. Most of the production processes involve heat energy that is generally produced by burning fossil fuels, as prime source of energy. Such production processes are inherently energy inefficient, thereby losing a significant amount of heat to equipment inefficiencies.

This study focuses on waste heat recovery, especially the application of Organic Rankine Cycle (ORC) technology in the industrial sector in India. ORC is a technology that operates similarly as the Steam Rankine cycle, except that the former uses an organic working fluid instead of steam. This organic working fluid has a lower boiling point and a higher vapour pressure than water, and is, thus able to use low temperature heat sources to run a turbine for power generation.

ORC technology, although new to India, finds some very successful installations in the country. There are a few installations in India based on this technology, notably a 4 MW waste heat recovery plant by UltraTech Cements in Andhra Pradesh, India1 and the 125 KW system installed in Pune by Thermax India Ltd. and the Department of Science and Technology of the Government of India. The latter installation uses the steam generated from solar parabolic troughs during the sunny days, in hybrid mode with biomass boiler during low radiation hours. There are two more installations by Thermax Limited, only for experimentation and research purposes - one in house installation since 2010 and the other supplied to IISc, Bangalore to be commissioned at their new campus.

In India, there are many industries, as mentioned below, where the low temperature heat is expelled
in the atmosphere without putting it to any practical use. On the other hand, the ORC technology has been commercially utilized in these sectors, especially in the developed world, to extract this "waste" heat.

1. Industrial waste heat recovery applications (Iron and Steel, Cement and Glass)
2. Internal combustion engines (ICE) and gas turbines
3. Renewable energy power plants (solar thermal, biomass and geothermal)
4. Heat recovery from high temperature heater

Exhaust used in process such as textile, edible oil refineries, etc."

The total potential of electricity generation from ORC technology in India, including all the sectors, has been assessed during this study to be roughly around 4.4 GW by 2017. This potential is around 574 MW in the Iron and Steel industry, 35 MW in the Glass industry, 148 MW in the Cement industry, 1.4 GW in the solar thermal industry and 2.4 GW in the Biomass industry all till 2017.

Literature review

William John Macquorn Rankine 5th July 1820 to † 24th December 1872 a Scottish physicist and engineer invented the ORC, he is one of the founders of thermodynamics and he is an important contributions to the theory of steam engine.

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The reasons for such low penetration of this technology in India are the low overall conversion efficiency of the system to convert the heat from external source to electricity (owing to low waste heat source temperatures), the high system cost, the lack of indigenous manufacturing capability and the lack of proper incentives. In addition, most opportunities for the deployment of the technology exists currently for waste to heat recovery than for stationary applications that use biomass or geothermal energy directly. This is because both biomass (except bagasse based systems) and geothermal energy are not as popular in India as solar or wind energy. In the solar thermal installations, as a technology that is gaining a solid

foot in the Indian energy scenario, ORC can be used to exploit the medium to low temperature steam to generate electricity. Bagasse based cogeneration systems that are quite common in India, also have a promising future for ORC installations in India.

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From a broad industry analysis, it can thus be concluded that the potential for ORC technology is significant in the industrial and renewable energy sectors in India, but a detailed sector-wise analysis is needed in order to determine the exact potential of this technology accurately.

There are some technology providers in India for ORC technology that include both Indian as well as the multi-national companies, however the majority of the foreign companies who specialise in this technology, are yet to begin their work in India.

Different business models, such as the ESCO, RESCO, captive power plants, third party sale of power, sale of power to the DISCOMs etc., are making the mass scale adoption of many such new technologies easy and commercially viable. In addition, policy and financial incentives are also available in India, such as the NMEEE, SECF, NCEF etc., but further analysis is needed to find out how they would be applied for energy efficiency measures involving ORC systems.

Proper institutional set-up in India to promote such energy efficiency initiatives (such as the BEE) and the recent focus on off-grid power generation, can also help proliferate the deployment of this technology that not only contributes to the energy security of the country, but also helps mitigate the climate impact by reducing the carbon emissions, apart from mitigating the need for new investments to build captive power plants that may be fossil fuel based.

Objectives

1. Study the working process of ORC system.
2. Scope of implementing ORC.
3. Need of ORC in India.
4. To rehabilitate and modernise thermal power plants
5. To encourage the use of clean energy sources
6. To disseminate climate-friendly technologies on the energy supply and demand side.

Discussions

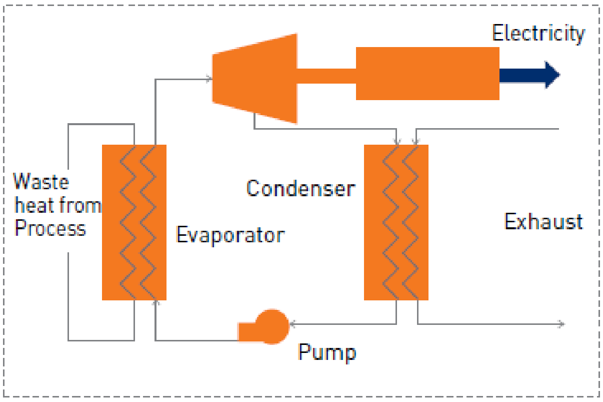
Heat losses arise both from equipment inefficiencies and from thermodynamic limitations of equipment and processes. Heat is generated by fuel combustion or by chemical reaction in a process in which part of the heat generated is used up, and the rest of the heat is “dumped” into the environment by means of an exhaust gas or steam. Although the total energy lost in waste gases/steam cannot be fully recovered, much of the heat could be recovered and be used for various useful and economic purposes. This would not only increase the efficiency of the process, but also reduce the fuel consumption, thereby reducing both the running costs and the carbon intensity of the process.

Waste heat can be utilized in two forms – utilising the waste heat in thermal applications or converting the waste heat in to electrical energy. Since the conversion of waste heat in to electricity involves efficiency losses at each stage, it is preferred to use the waste heat directly in thermal applications wherever possible, since the latter have comparatively lesser heat losses. In cases where this option is not viable, the waste heat is converted in to electricity.

This electricity generated is either consumed within the process or is transferred to the grid.

Generation of power from waste heat typically involves the conversion of the (otherwise) waste heat to mechanical energy to drive an electric generator.

Industries have different processes which in some way or the other involve dumping of heat into the atmosphere in the form of flue gases, hot water, steam etc. Heat can be recovered from these streams and utilized through different thermodynamic cycles to generate power. The most frequently used system for power generation from waste heat involves using the heat to generate steam to drive a steam turbine, a process commonly referred to as the Rankine Cycle.



Schematic of Steam Rankine Cycle

The traditional Steam Rankine Cycle (SRC) has been one the most efficient options for waste heat recovery from exhaust streams with temperatures above 650- 700°F [340-370°C]. At lower waste heat temperatures, this cycle becomes less cost effective because of the following reasons:

1. Low pressure steam generated from low temperature waste heat requires larger, bulkier

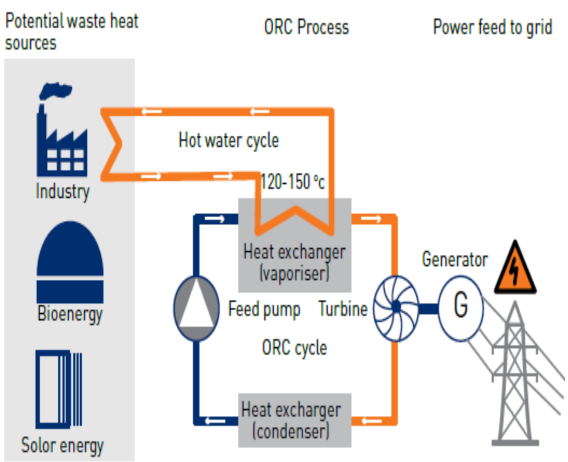
and costlier equipment.

2. Low temperature waste heat does not provide sufficient energy to superheat the steam, which causes steam to condense resulting in the erosion of the turbine blades and other metallic units.

For such low temperature waste heat recovery applications, a better technology that may be used is the Organic Rankine Cycle since this cycle uses organic fluids that not only have lower boiling point temperatures than steam has, but also do not corrode the metallic parts of the equipment.

The Organic Rankine Cycle (ORC) is similar in operation to the steam Rankine cycle, except the fact that the former uses an organic working fluid while the latter uses steam. Typical working fluids include(but not limited to) silicon oil, propane, haloalkanes (e.g. "freons" or hydro fluorocarbons), isopentane, isobutane, toluene etc., that have a lower boiling points and higher vapour pressures than water or steam have. This allows the cycle to operate at significantly lower temperatures — sometimes as low as 150ºF [66ºC] – a general characteristic of many waste heat streams. However, since the cycle functions at lower temperatures, the overall efficiency is only around 10-20%, depending on the temperature of the condenser and evaporator. This overall efficiency of conversion of heat into electricity of ORCs (10%-20%) is lower than that of steam cycle (30%-40%) because the SRC operates at higher temperatures than the ORC. This lower efficiency is due to the limitation based on thermodynamic principle called the Carnot Theorem.

Schematic of Organic Rankine Cycle



Advantages

1. Large inlet temperatures ranging from 100°C or lower to as high as 450°C;
2. ORC modules are easy to install (compact, skid mounted standard module) and very easy to operate;
3. ORC systems require low maintenance (no droplet erosion in the turbine, low pressure evaporator, automation), thereby reducing the running costs greatly, and need very little maintenance downtime (< 2% of the operational time per annum);
4. System sizes range from a few kWe (down to30kWe) to several MWe that make them perfectly suitable for tapping various thermal sources;
5. For power capacities lower than 2 MWe, steam power plants are usually not well adapted since the operation and maintenance costs of the equivalent Steam Rankine Cycle are higher and the system efficiency is lower;
6.The systems have very simple start up procedures coupled with automatic and continuous operation, which rules out the requirement of continuous operator attention;
7. Simple treatment of water is enough for supply to the system, for which no expense is there on special water treatment;
8.Since the organic compounds used have much higher molecular mass than water, the turbine blades rotate slowly resulting in a much lower vapour pressure of the system, which in turn results in much higher system stability.

Observations

The biggest weakness of the technology is the apparent low conversion efficiency of thermal
energy into electricity (between 10% and 25%). The main reason of this low

efficiency is the low operating temperature; but for the same operating temperatures, the SRC will not achieve any higher efficiency than the ORC given the thermodynamic limitations as explained above. However, the overall system efficiency can be increased to more than 95%, if the hot water (used to condense the hot organic fluid) in the heat exchanger can be used (for a variety of purposes such as for district heating or for cooling through vapour absorption machines or for cooking food or for preheating purposes or for various industrial purposes). It must be noted here that the temperature of this hot water is much lower than the heat stream on which the ORC system is running, but usable for other purposes.

The use of certain organic fluids needs more stringent security measures compared to the
steam cycle because of their higher flammability and, in some cases, toxicity compared to water or steam. However, given the large number of installations of varying sizes across the world, and the fact that the entire system is a closed system with very little or zero chances of leakage, the flammability or the toxicity issue can be deemed as quite negligible ones.

Conclusions

- Large inlet temperatures ranging from 100°C or lower to as high as 450°C;
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