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Analysis and Performance Evaluation of Proposed Organic Rankine Cycle

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ABSTRACT

This paper provides a critical and analytical assay in the process vicinity of an Organic Rankine Cycle (ORC) resulting in a representation of a flow model as the best approach to implement an efficient Plant focusing on the robust and elegant energy production. There have been so many predictive and sensing process models presented for a gist and substantial control of the ORC plant in recent years but the proposed Model provides the robustness by performing all the roles in increments; e.g. in the insertion of efficient working fluid, analyzing turbine's output power, boilers efficiency and the rate of mass flow. The proposed model optimizes the performance of ORC by response simulating outputs under certain conditions which relegates the errors and sudden disturbance in the process flow. The selection criterion has been made by considering the temperature profile of northern areas in Pakistan. This study will be elaborating efficient model design and implementation to conjure up a well-designed working flow in an ORC plant.

KEYWORDS: Organic Rankine Cycle (ORC), Working fluid, Shaft Power, Energy efficiency

1. INTRODUCTION

Organic Rankine Cycle (ORC) is a process for elegant energy production by using an organic, high molecular mass fluid with low boiling point than the water- steam phase change. The organics fluid used allows Rankine cycle to use and recover heat from temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds etc. The heat is converted into useful work that can itself be converted into electricity. To convert excess heat of the system into electrical power using efficient generator and robust turbines; controlled by sensitive controllers and the process model which takes control the overall system. The ORC units and accompanying control system with associated equipment upgrade and present data, quantifying the energy saving benefit; which is also the main focus of the paper. The Rankine Cycle is a well known and understood thermodynamic cycle used to convert heat into work, most commonly applied in power generation. In the conventional Rankine Cycle, the working fluid (usually water) is heated to saturate in a boiler, traverse through a turbine while producing work, returns to the liquid state in a condenser and is pumped back into the boiler to repeat the cycle [1]. The ORC differs from the traditional Rankine Cycle because instead of water, a high molecular mass organic fluid is used as the working fluid. This organic fluid (normally selected organic fluids are R134a, R113, R425ca, R245fa, R123 is typically characterized by a lower boiling point than that of water, enabling the ORC to operate at lower temperatures and take advantage of waste heat generated at lower temperatures than other recovery methods [2].

As shown by different studies [2],[3] it has been proven that there is an unexpected increase in electrical consumption and load but the intensification in generating electric resources is less [4],[5]. The main objective of this paper is to optimize the control process of the plant by taking a deeper look onto the sudden disturbances which causes the problem and irregularity in energy production [6] and the desired time slots to ensure quality in defined time frames [7]. The proposed system to optimize the functionality of ORC with specification and customization provide the chance to take maximum benefit of the working fluids to the peak extent of theirs via heat recovery system of ORC. Table 1 shows some characteristics of temperature profile of Lahore City, high pressure, output generation requirement for a certain area like in Northern Areas of Pakistan:

Parametric Characteristics in Northern Areas Pakistan	
Parameters	**Description**/year
Average Low Temperature	3 C^{o}
Average High Temperature	7 C^{o}
Average Balanced Temperature	4 C^{o}
Average Atmospheric Pressure	468mmhg
Energy Generation Requirement	52000MW
Average Energy Generation	31000 MW

Table 1: Northern Areas Pakistan Region Characteristics [20], [21]

2. Selection of Process Model

The very first question arises in designing a novel process model is that are the previously designed models are not giving the outputs as per the expectations; as the most widely used strategies in thermal power plants use its simple structure with no precise modeling due to the uncertainty, non linearity, long delay and time-varying dynamics of the

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boiler-turbine systems and it cannot provide satisfactory performance with its monotonous control mechanism for various changing load demands and parameters variations of the complex process of thermal power plants [1, 8, 9].

Many developed countries like China and Japan are applying ORC to generate power due to great advantages of improving efficiency, efficiently saving energy and less generated pollution [1]. So it is essential to cope up the continuously varying Demand Response of electrical consumption while maintaining the temperature within a designed range.

3. Proposed Process Model

Organic Rankine cycle is used for explaining the optimal architecture of plant. It is best matching between the Rankine cycle and the heat source(s) and heat sink(s), best configuration of the components of the system), selecting the working fluid and determining performance of the system. Our model is simulated on MATLAB. There are thermodynamic properties of organic compound [10].

Particulars	**Values**
Compound	R-245fa
Name	1,1,1,3,3 –Pentafluropropane
Molecular weight	134.05
T_c(k)	457.20
P_c(MPa)	3.64
Vapor C_p (J/kg k)	980.90
Latent heat L(kJ/kg)	177.08

Table 2: Vital Parameters

This system is composed of Pump, boiler, turbine, evaporator, and generator.

State 1-2:The working fluid is pumped from low pressure to high pressure. Flow rate = 3600 kg/ Hr and pressure at 90 Atm.Ifm_b is the mass of the fluid in the boiler, m_{fi} is the mass of the fluid input and m_{fo} is the mass of the fluid output then the equation may become [11]:

$$m_b = m_{fi} + m_{fo} \qquad (1)$$

State 2-3: High pressure enters into boiler where it is heated then it became dry saturated vapors.
To change the phase of working fluid [12],[13] into vapors by using this equation:

$$Q = mH_v \qquad (2)$$

Where Q is energy, m is massH_v is the heat of vaporization. Out of total energy 50% of fluid may get evaporated in Cooled condenser [15]. So it means remaining working fluid converted into steam, which gets increased to 5200kg/hr. Here 60 degree is required to raise the temperature of steam due to the characteristics of the working fluid which has low boiling point.

$$f(t) = P_c * \sum_{n=1}^{\infty}(E) * \sum_{n=1}^{\infty}(T_{SHS} - T_B) \qquad (3)$$

$$E = f(t) * \sum_{n=1}^{\infty}(E) \qquad (4)$$

Where f(t) is the raise of temperature of steam, $P_c$is constant pressure, $E$is the total energy and T_{SHS} is the temperature to convert fluid into super-heated steam and $T_B$boiling point.

State 3-4: The dry saturated vapors expand through a turbine, generating power. This decreases the temperature and pressure of vapors and some condensation occur. Across turbine some temperature falls and energy is released [16], [17]. This temperature enthalpy shows how much energy released and what their exhausted temperature is the cycle efficiency which is 30% the following equation in the form of Energy extraction as given:

$$E_{ex} = 0.3 * Q_b \qquad (5)$$

Here $Q_b$is the heat added in the system or heat in the boiler which is explain in the later section in equation (7)

State 4-1: The wet vapors then enter into the cooled condenser to become a saturated liquid.

When superheated steam enters into condenser [18], which loses its heat to atmosphere and condensed fluid is fed back to boiler. The steam vapor releases the latent energy to the process fluid and condenses to a liquid condensate. The condensate retains the sensible energy the steam had. The condensate can have as much as 16% of the total energy in the steam vapor, depending on the pressure. Electric energy which is produced is mathematically written as:

$$P = 0.95 * E_{ex} \qquad (6)$$

State 4-5: The wastage heat passes through heat condenser and then to rise its temperature it passes through hot water and then it utilize [19].

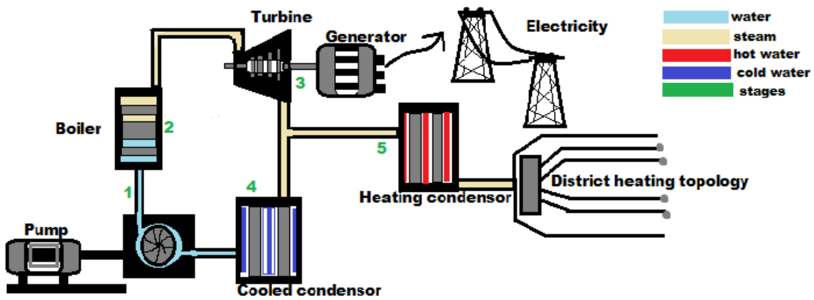

Figure 1: Proposed Organic Rankine Process Simulation

Figure1 represents the proposed organic rankine cycle with desired output schemes. The heating condenser absorbers energy when steam from 4500C cools down to 1000C and also becomes liquid. Remaining (increased steam '5200 kg/hr' – turbine exhausted steam) is passed through heating condenser. The temperature increased by passing through the heat exchange coil. By this designed model the waste heat used up for heating the building is nearly 500 M calories.

4. RESULTS AND DISCUSSIONS

A simulation is designed on the basis of the proposed model. The simulation demonstrates the working of the plant and its output characteristic curve with respect to the time and other parameters as shown below. There has been provided the simulated graphical representation of Shaft Power and Mass Flow Rate, Energy Available in Boiler and Energy Lost in Condenser, Ambient Temperature and Condenser Output [20], [21].

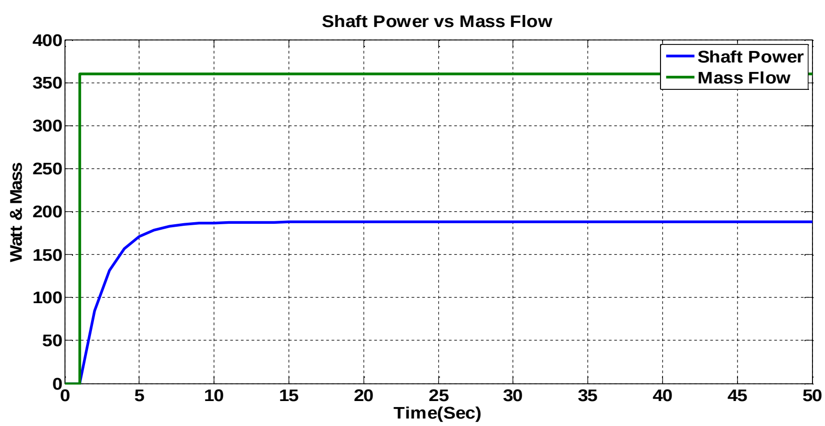

Figure 2: Graph of Shaft Power and Mass Flow

In the comparison of shaft power versus flow rate the nature of mass flow is found to have direct proportional relation with the shaft Power. At certain initial time the mass flow due to pump, gain some high magnitude in its flow rate so that this high velocity flow could be used up by the boiler to produce a high pressure steam which will be useful to drive the turbine with greater force. After driving the turbine the pressure drop arises in the steam and it when liquefy possess nominal flow rate which is again used to continue driving the turbine as used by Mehdi and Vahid in 2013 [22]. The nominal value of the flow rate is being adjusted according to the shaft power requirement. On the other hand shaft power in its initial stage of getting started therefore gaining some increasing magnitude with respect to time until it reaches the value of required Generation in Watts. Once the demanded power is achieved the turbine undergoes constant power generation. There might be some change occur in shaft power generation due to certain reasons in which the most promising issues can be the harmonics occurring across the turbine which may appear as under voltages or over voltages, Power factor issue can be considered but according to the present scenario these plots are taken on the ideal scenario where no such imbalance situation in shaft power occurs.

For making measuring the heat added to the system there is a need of the heat in boiler, mass of the fluid in the boiler and specific heat of the fluid. The following equation is derived for the simulation of the ambient temperature results:

$$Q_b = m_b * \left(H_{vap} + H_f * (100 - T_{amb}) + H_{fv}(100 - T_{amb})\right) \qquad (7)$$

Where Q_b is the heat added or the heat in boiler, specific heat of the fluid is 4180KJ/Kg Deg C, H_{vap} is the latent heat of vaporization which is 2268 KJ/Kg. Here mass of the fluid in the boiler is heated from T_{amb} to steam at 90atm at 450 Deg C

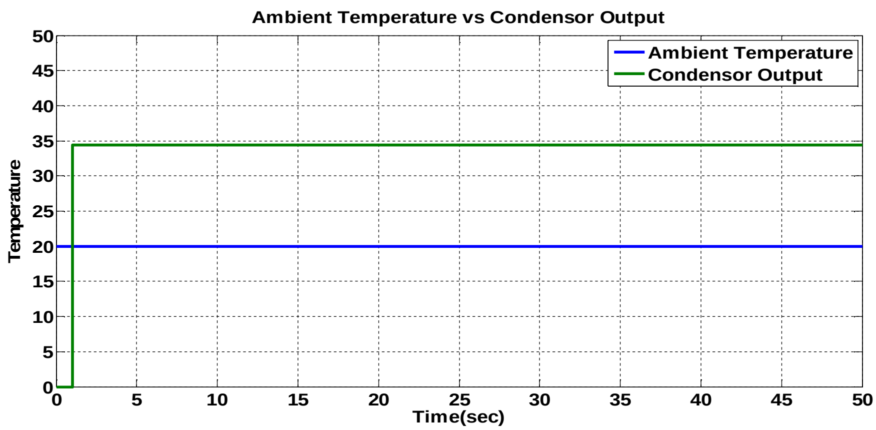

Figure 3: Graph of Ambient Temperature and Condenser Output

In the comparison of ambient temperature and condenser output it is evident from the result that tat constant ambient temperature the condenser output remain the same throughout the process. Ambient temperature and Condenser both give straight line as they show the constant result at certain temperature which is 35 [22]. The nominal value of the ambient temperature is not enhanced more than 35 degree as the fluid in the proposed model is R-245fa whose condensing temperature is very low which can be achieved easily. Hence ultimately the condenser output is sustained at the certain level as the temperature.

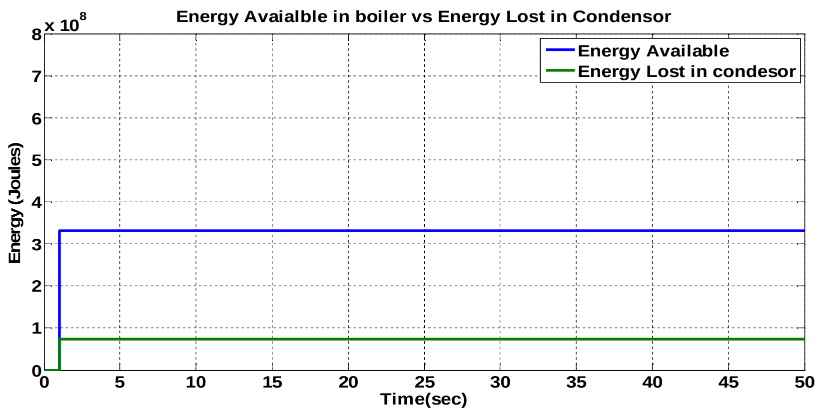

Figure 4: Graph of Energy Available and Energy Lost

The comparison of Energy Available in Boiler versus Energy Lost in Condenser it is clear from the result that energy lost and availability remain the same at certain level [23] because if the energy is achieved in the domain on the other hand there is an energy loss in the condenser also. Hence ultimately the energy is sustained at the certain level as the gain and loss.

5. CONCLUSION

ORC based system can easily implemented in industry due to their small foot prints to increase energy efficiency, reduce pollution and losses. The most popular cycle for power generation is Rankine cycle which contributes to almost 80% of power world generation. From the simulated work it is found that R-245fa gives the highest turbine work output and cycle efficiency. Condensing temperature of a fluid is very low which can be achieved easily. The simulated results clearly demonstrated the significant benefits of using the proposed system. Rankine cycle allows using and recovering heat from temperature sources. The recover heat is converted into useful work that can itself be converted into electricity. This proposed model having high thermodynamic cycle efficiency, there is absence of moisture during the vapor expansion, responsible for the erosion of the blades and having simple start up procedures. Thus it is the sign of hope for the industry to recover low grade heat energy.

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