Performance of Different Working Fluid In Power Generation From Waste Heat of DG Set Using ORC: A Simulation Study

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Abstract- *Temperature change, ecological regulation and binding for renewable energy, alongside an increased focus on the economic benefits of energy and fuel conservation, are pouring the acceptance of new aids as sources of energy. With these changing aspects, it is understandable that waste heat recovery technologies can play vital role in decreasing the dependence of fossil fuels and in meeting future energy needs. This paper focused on the simulation study of the Organic Rankine Cycle (ORC) and as an effective technology for low to medium temperature heat recovery to generate power with different organic fluid*

Keywords- Organic Rankine Cycle (ORC), organic fluid, Heat Recovery, power

I. INTRODUCTION

Waste heat is heat, which is produced in a process by fuel combustion or chemical reaction, and then discarded into the environment. It could still be reused for some useful and economic purpose. Large extent of hot flue gases is generated from boilers, kilns, ovens and furnaces also renewable energy sources, such as solar thermal and geothermal, biomass, municipal solid waste and huge amounts of industrial waste heat are potentially promising energy sources [1–3]. If some of this waste heat could be recovered then substantial amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, the low grade heat from these sources cannot be converted efficiently to electrical power by using the conventional power generation methods [4–6]

The organic Rankine cycle (ORC), whose major feature is the option of using different low temperature heat sources for small and medium power generation. The ORC unit is a system based on a closed-loop thermodynamic cycle for the generation of electric and thermal power, especially suitable for distributed generation. ORC systems can generate electric and thermal power exploiting multiple sources, such as renewables (biomass, geothermal energy, solar energy), traditional fuels and waste heat from industrial processes, waste incinerators, engines or gas turbines.[10-15] In ORC's the problems encountered with water can be partially mitigated by selecting an suitable organic fluid, characterized by higher molecular mass and lower critical temperature than water [7–9]. In the other words, the organic Rankine cycle (ORC) is a non-superheating thermodynamic cycle utilizing an organic working fluid to rotate an expander and generate power. The main objective in ORC systems design mainly involves the selection of the appropriate working fluid for the operation condition[18, 19]. Suitable working fluids permit proper volume flow rates which is essential for optimum sizing of the turbine for any power level [20], and also determines the proper type and size of the pump, heat exchangers.

In this paper, a simulation study of ORC give us the idea that waste heat from DG set can be used to produce power and how power is vary by using different organic fluids.

II. ORC (ORGANIC RANKINE CYCLE)

The Organic Rankine cycle (ORC) is named for its use of an organic, high molecular mass fluid with a liquid-vapor phase change, or boiling point, occurring at a lower temperature than the water-steam phase change. The Organic Rankine Cycle (ORC) uses an organic fluid such as n-pentane or toluene [16] etc in place of water and steam. This allows use of lower-temperature heat sources, such as solar ponds, which typically operate at around 70–90°C. The efficiency of the cycle is much lower as a result of the lower temperature range, but this can be worthwhile because of the lower cost involved in gathering heat at this lower temperature. Alternatively, fluids can be used that have boiling points above water, and this may have thermodynamic benefits. [17]

The Rankine cycle is a thermodynamic cycle which converts heat into work. The heat is supplied externally to a closed loop, which usually uses water as the working fluid.

This cycle generates about 80% of all electric power used throughout the world, including virtually all solar thermal, biomass, coal and nuclear power plants.

III. SIMULATION STUDY OF POWER GENERATION USING ORC PROCESS WITH DIFFERENT FLUIDS

Here following inputs are consider
DG Set Model : KG 600 WS
DG Set Exhaust
Gas Temperature : 600 degree C
Flowrate : 153.3 m3/min
Organic fluid : R245, Toluene, i-Butane, i-Pentane and n-Pentane
Composition of
Exhaust gas : Nitrogen = 77%
Oxygen = 13%
Carbon dioxide = 5%
Water = 5%
Pump efficiency : 60%
Expander efficiency : 80%

CHEMCAD Simulation software is used to study how power varies by using different organic fluid. Simulation design is concluded after several trial and error ways. Detail results shown in Expander summary, pump summary and stream summary for different fluids.

Table 1: Expander Summary

Organic Fluid	R245	Toluene	i-Butane	i-Pentane	n-Pentane
Equip. No.	1	1	1	1	1
Pressure out bar-G	2.2	2.2	2.2	2.2	2.2
Type of Expander	1	1	1	1	1
Efficiency	0.8	0.8	0.8	0.8	0.8
Actual power kW	-141.3273	-19.924	-141.4	-44.015	-34.7084
Cp/Cv	1.3961	1.1119	1.6131	1.2191	1.2004
Theoretical power kW	-176.6591	-24.905	-176.75	-55.0187	-43.3855
Ideal Cp/Cv	1.0624	1.0633	1.0779	1.0615	1.0619
Calc Pout bar-G	2.2	2.2	2.2	2.2	2.2

Table 2: Pump Summary

Organic Fluid	R245	Toluene	i-Butane	i-Pentane	n-Pentane
Equip. No.	4	4	4	4	4
Name					
Output pressure bar-G	25	25	25	25	25
Efficiency	0.6	0.6	0.6	0.6	0.6
Calculated power kW	23.5028	32.8199	50.53	45.6352	45.2871
Calculated Pout bar-G	25	25	25	25	25
Head m	191.5919	267.5441	411.9146	372.0127	369.1756
Vol. flowrate m3/h	22.0564	30.8001	47.4203	42.8267	42.5001
Mass flowrate kg/h	27000	27000	27000	27000	27000

Figure1 shows the flowsheet used for the simulation of organic Rankine cycle. Table 3 to 7 shows the stream summary of different organic fluid. Stream 3 in the table shows different organic fluid in each table.

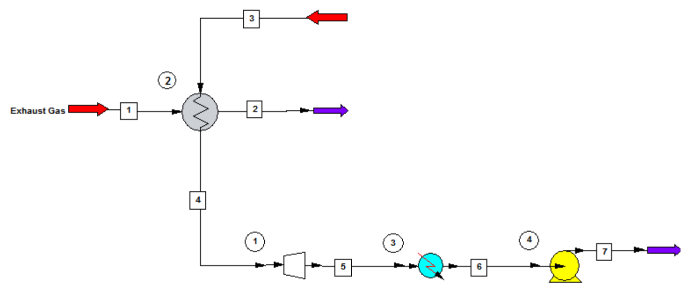

Fig1: Flowsheet of organic Rankine cycle simulation

Table 3: Stream Summary when R245 is used as organic fluid.

Stream No.	1	2	3	4	5	6	7
Stream Name	Exhaust Gas		R245				
Temp C	600.00	60.00	13.41	116.07	52.05	11.00	13.41
Pres bar-G	1.50	1.50	25.00	25.00	2.20	2.00	25.00
Enth MJ/h	-4329.00	-9737.6	-228130.0	-222720.0	-223230.0	-228220.0	-228130.0
Vapor mass fraction	1.00	1.00	0.00	1.00	1.00	0.00	0.00
Total kg/h	8973.00	8973.00	27000.00	27000.00	27000.00	27000.00	27000.00
Component mass %							
Nitrogen	77.00	77.00	0.00	0.00	0.00	0.00	0.00
Oxygen	13.00	13.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	5.00	5.00	0.00	0.00	0.00	0.00	0.00
Water	5.00	5.00	0.00	0.00	0.00	0.00	0.00
1-1-1-2-2-pentaf	0.00	0.00	100.00	100.00	100.00	100.00	100.00

Table 4: Stream Summary when Toluene is used as organic fluid.

Stream No.	1	2	3	4	5	6	7
Stream Name	Exhaust Gas		Toluene				
Temp C	600.0	60.0	13.4	122.2	120.9	11.0	13.6
Pres bar-G	1.5	1.5	25.0	25.0	2.2	2.0	25.0
Enth MJ/h	-4329.0	-9737.6	3038.8	8447.5	8375.8	2930.4	3048.6
Vapor mass fraction	1.0	1.0	0.0	0.0	0.0	0.0	0.0
Total kg/h	8973.0	8973.0	27000.0	27000.0	27000.0	27000.0	27000.0
Component mass %							
Nitrogen	77.0	77.0	0.0	0.0	0.0	0.0	0.0
Oxygen	13.0	13.0	0.0	0.0	0.0	0.0	0.0
Carbon Dioxide	5.0	5.0	0.0	0.0	0.0	0.0	0.0
Water	5.0	5.0	0.0	0.0	0.0	0.0	0.0
Toluene	0.0	0.0	100.0	100.0	100.0	100.0	100.0

Table 5: Stream Summary when i-Butane is used as organic fluid.

Stream No.	1	2	3	4	5	6	7
Stream Name	Exhaust Gas		i-butane				
Temp C	600.0	60.0	13.4	89.1	21.7	11.0	13.8
Pres bar-G	1.5	1.5	25.0	25.0	2.2	2.0	25.0
Enth MJ/h	-4329.0	-9737.6	-72256.0	-66848.0	-67357.0	-72411.0	-72229.0
Vapor mass fraction	1.0	1.0	0.0	0.0	0.5	0.0	0.0
Total kg/h	8973.0	8973.0	27000.0	27000.0	27000.0	27000.0	27000.0
Component mass %							
Nitrogen	77.0	77.0	0.0	0.0	0.0	0.0	0.0
Oxygen	13.0	13.0	0.0	0.0	0.0	0.0	0.0
Carbon Dioxide	5.0	5.0	0.0	0.0	0.0	0.0	0.0
Water	5.0	5.0	0.0	0.0	0.0	0.0	0.0
Isobutane	0.0	0.0	100.0	100.0	100.0	100.0	100.0

Table 6: Stream Summary when i-Pentane is used as organic fluid.

Stream No.	1	2	3	4	5	6	7
Stream Name	Exhaust Gas		i-pentane				
Temp C	600.0	60.0	13.4	94.5	66.1	11.0	13.7
Pres bar-G	1.5	1.5	25.0	25.0	2.2	2.0	25.0
Enth MJ/h	-4329.0	-9737.6	-67297.0	-61889.0	-62047.0	-67443.0	-67279.0
Vapor mass fraction	1.0	1.0	0.0	0.0	0.2	0.0	0.0
Total kg/h	8973.0	8973.0	27000.0	27000.0	27000.0	27000.0	27000.0
Component mass %							
Nitrogen	77.0	77.0	0.0	0.0	0.0	0.0	0.0
Oxygen	13.0	13.0	0.0	0.0	0.0	0.0	0.0
Carbon Dioxide	5.0	5.0	0.0	0.0	0.0	0.0	0.0
Water	5.0	5.0	0.0	0.0	0.0	0.0	0.0
Isopentane	0.0	0.0	100.0	100.0	100.0	100.0	100.0

Table 7: Stream Summary when n-Pentane is used as organic fluid.

Stream No.	1	2	3	4	5	6	7
Stream Name	Exhaust Gas		n-pentane				
Temp C	600.0	60.0	13.4	93.7	74.4	11.0	13.7
Pres bar-G	1.5	1.5	25.0	25.0	2.2	2.0	25.0
Enth MJ/h	-4329.0	-9737.6	-65608.0	-60199.0	-60324.0	-65755.0	-65592.0
Vapor mass fraction	1.0	1.0	0.0	0.0	0.1	0.0	0.0
Total kg/h	8973.0	8973.0	27000.0	27000.0	27000.0	27000.0	27000.0
Component mass %							
Nitrogen	77.0	77.0	0.0	0.0	0.0	0.0	0.0
Oxygen	13.0	13.0	0.0	0.0	0.0	0.0	0.0
Carbon Dioxide	5.0	5.0	0.0	0.0	0.0	0.0	0.0
Water	5.0	5.0	0.0	0.0	0.0	0.0	0.0
N-Pentane	0.0	0.0	100.0	100.0	100.0	100.0	100.0

IV. RESULT

It is observed from above simulation analysis that all working fluids considered in this paper can be used as organic fluid in ORC. When R245 and i-Butane is used as organic fluid around 141.3 kW of power can be generated by expander by considering 80% expander efficiency. In case of Toluene, i-Pentane and n-Pentane low power can be generated. Power consumption of pump for R245 and i-Butane will be 23.50 kW and 50.53 respectively at 60% pump efficiency. So the power consumption in case of i-Butane is higher than that of R245. Also for Toluene, i-Pentane and n-Pentane pump power consumption is high.

V. CONCLUSION

From above simulation study it is observed that R245 is the best organic fluid which can be used in organic rankine cycle compare to i-Butane, Toluene, i-Pentane and n-Pentane. R245 thermo-physical properties make it a suitable working fluid for organic Rankine cycle applications. Also the heat capacity of R245 results in improved theoretical cycle efficiency. For effective energy management Organic Rankine cycles is the one of the best option in developing countries like India. ORC simulation has confirmed that suitable amount of power can be achieved from DG set exhaust gas.

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