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PERFORMANCE ANALYSIS OF ORGANIC RANKINE CYCLE (ORC) WORKING ON DIFFERENT FLUIDS HAVING LOW BOILING POINT

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Abstract:

Organic Rankine Cycle is the best way to recover heat from low grade energy source. The working principle of ORC is same as Rankine cycle. The selection of the working fluid is of key importance in low temperature Rankine Cycles. Only difference is low boiling point temperature is used as working fluid. In this paper four different working fluids R-124 (2-chloro-1, 1, 1, 2 - Tetrafluoro-ethane), R-134a (1, 1, 1, 2 - Tetrafluoroethane), R-152a (1, 1 - Difluoroethane) and 245fa (1, 1, 1, 3, 3 - pentafluoropropane) has been taken for performance analysis of Organic Rankine Cycle. Here condenser and evaporator temperature is kept on 46°C and 100°C respectively.

Key Words: Organic Rankine Cycle, R-124, R-134a, R-152a & 245fa

Introduction:

ORC technology is similar to a traditional steam turbine, but with a single, important difference. Instead of using water vapour, the ORC system vaporizes a high-molecular-mass organic fluid having low boiling point. This allows the ORC to extract energy from low temperature sources. Solar energy, hot exhaust gas from coal furnace, ocean energy, geothermal energy is the source of low grade energy. Solar power has low density per unit area (1 kW/sq.m. to 0.1 kW/sq.m.) Hence it is to be collected by covering large ground area by solar thermal collectors. Solar thermal collector essentially forms the first unit in a solar thermal system. It absorbs solar energy as heat and then transfers it to heat transport fluid efficiently. The heat transport fluid delivers this heat to evaporator. Oceans cover about 71 percent of earth's surface. They receive, store and dissipate energy through various physical processes. Recoverable energy in oceans exists mainly in the form of temperature difference between surface and deep layers. Geothermal energy originates from earth's interior in the form of heat. As such the geothermal resource is estimated to be more than 2.11 x 1025. Most geothermal resources produce low-grade heat at about 70-90°C, which can be used directly for thermal applications. Main advantages of geothermal energy are: is a reliable and cheap source of energy, is available 24 hours per day, availability is independent of weather, has inherent storage feature so no extra storage facility required and require little land area. Exhaust gas have sufficient temperature for generating electricity by ORC. Thermal efficiency of internal combustion engine is 30-35%. Large amount of heat is rejected through exhaust gas. This energy can be used by utilized by evaporator for increasing the pressure and temperature of working fluid. In this paper ORC is working between evaporator temperature at 100°C and condenser temperature at 46°C. Compare of performance analysis of ORC has been done by using four different working fluids. Operating temperature has been kept constant for all fluids.

2. Organic Rankine Cycle:

Operating temperate of organic rankine cycle (ORC) is lower than Rankine cycle. Energy is received from low grade energy source to evaporate the fluid from evaporator. For using low grade energy boiling point of fluid should be low.

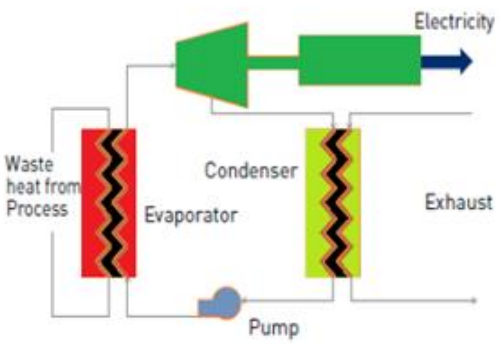

Figure 1: Schematic Diagram of ORC

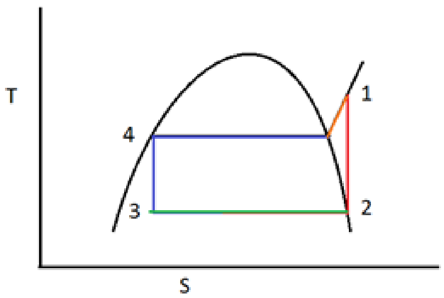

Figure 2: T-S Diagram of ORC

2.1 Scope of ORC in India: India has large potential for the application of organic Rankine cycle system. The total potential of electric generation from this technology in India, including all sectors is 4.4 GW. 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. 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 Ultra Tech 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

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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.

3. Mathematical Modelling:

Energy required for heating unit mass of steam = (h1-h4) kJ/kg
Work output from turbine = (h1-h2) kJ/kg
Heat rejected from condenser = (h2-h3) kJ/kg
Work done by pump = (h4-h1) kJ/kg $=\nu\int dp$
Efficiency of ORC $\eta = \frac{(h_1-h_2)}{(h_1-h_4)}$
Properties of working fluid at 46°C and 100°C

Table 1: Properties of refrigerant R 124(2-chloro-1,1,1,2-Tetrafluoroethane)

Temp T°C	Pressure (bar)	Density Liquid (kg/m3) ρ	Sp. volume, (m3/kg)ν	Enthalpy h		Entropy s		specific heat c	
				hf	hg	sf	sg	cf	cg
46	6.9845	1278.8	0.02327	252.17	385..51	1.175	1.5928	1.193	0.906
100	23.787	1001.8	0.00569	323.5	405.2	1.3766	1.5955	1.665	1.607

Table 2: Properties of refrigerant R 134a(1,1,1,2-Tetrafluoroethane)

Temp T°C	Pressure (bar)	Density Liquid (kg/m3) ρ	Sp. volume, (m3/kg) ν	Enthalpy h		Entropy s		specific heat c	
				hf	hg	sf	sg	cf	cg
46	11.903	1120.6	0.01687	265.47	421.92	1.2186	1.7089	1.537	1.202
100	39.724	651.2	0.00268	373.3	407.68	1.5188	1.6109	17.59	25.35

Table 3: Properties of refrigerant R-152a(1,1-Difluoroethane)

Temp T°C	Pressure (bar)	Density Liquid (kg/m3) ρ	Sp. volume, (m3/kg) ν	Enthalpy h		Entropy s		specific heat c	
				hf	hg	sf	sg	cf	cg
46	10.639	842.6	0.03004	282.76	534.16	1.2766	2.0643	1.926	1.443
100	35.05	618.5	0.00686	403.59	536.28	1.6151	1.9707	3.495	3.776

Table 4: Properties of Refrigerant 245fa(1,1,1,3,3-pentafluoropropane)

Temp T°C	Pressure (bar)	Density Liquid (kg/m3) ρ	Sp. volume, (m3/kg) ν	Enthalpy h		Entropy s		specific heat c	
				hf	hg	sf	sg	cf	cg
46	3.0394	1279.3	0.05873	260.77	438.05	1.2048	1.7603	1.373	1.036
100	12.646	1093.3	0.01374	339.78	474.26	1.4308	1.7912	1.59	1.356

4. Results and Discussion:

Table 5: Enthalpy of Refrigerants.

kJ/kg	R 124	R 134a	R 152a	245fa
h_1	410.05	430.10	565.23	480.2
h_2	385.51	421.92	534.16	438.05
h_3	252.17	265.47	282.76	260.77
h_4	253.50	268.18	285.74	261.49

Table 6: Efficiency of ORC

kJ/kg	R 124	R 134a	R 152a	245fa
Q_E	174.55	161.92	279.49	218.71
W_T	24.540	8.18	31.07	42.15
Q_C	133.34	156.45	251.4	177.28
W_P	1.33	2.482	2.987	0.7232
η(%)	14.05	5.05	11.11	19.27

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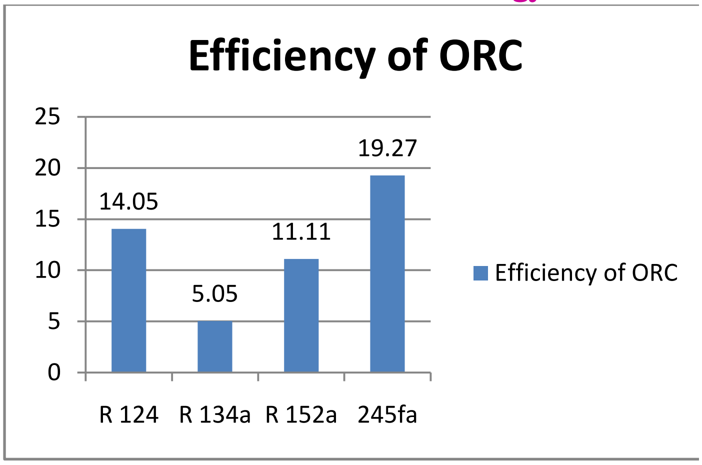

Figure 3: Compare of efficiency

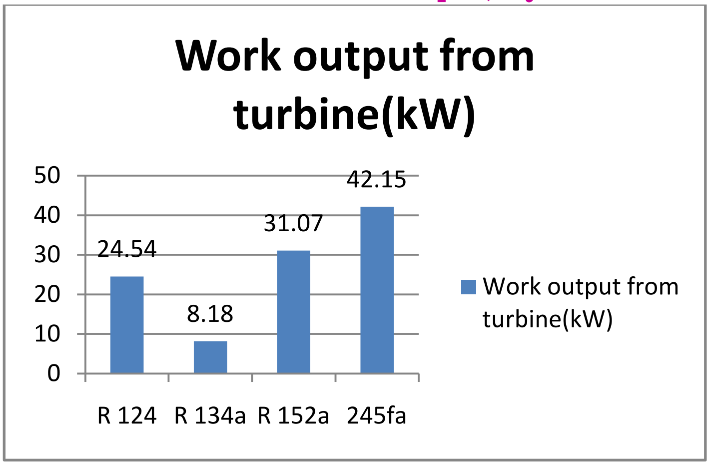

Figure 5: Work output from turbine (kW)

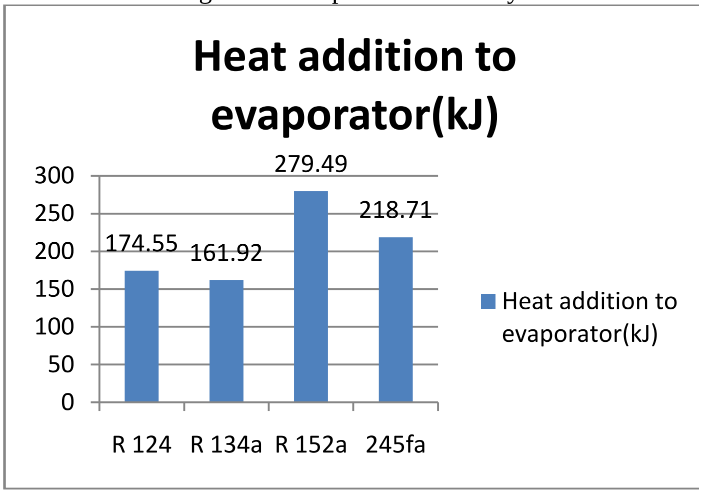

Figure 4: Heat addition to Evaporator (kW)

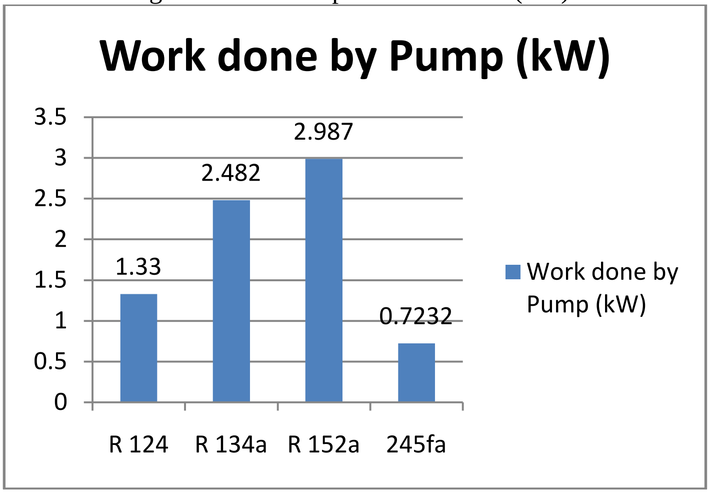

Figure 6: Work done by pump (kW)

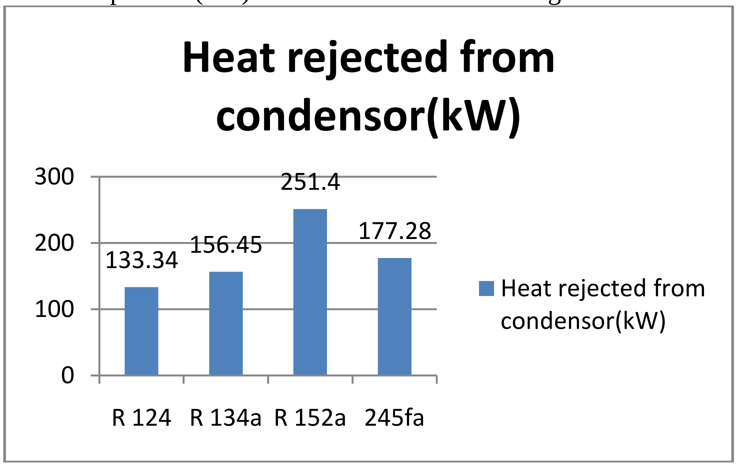

Figure 7: Heat rejected from condenser (kW)

5. Conclusion:

From the above result it is concluded that efficiency of the ORC is highest when working fluid is 245fa. And also work output is highest and pump work is lowest when 245fa is used as working fluid. So, refrigerant 245fa is more suitable out of these four fluids. It is the best method to use the low-grade energy for electric power generation.

6. Future Scope:

Efficiency of ORC can be increased by improving the thermal conductivity of fluids. Thermal conductivity of fluids increases when nanoparticles are mixed with fluid & this fluid is called nanofluids. Generally, Al203, TiO2 & CuO are used for making nanofluids. Thermal conductivity of Nano fluids depends on various parameters like size of the, material, sphericity and type of of Nano particles. It is also largely affected by the volumetric fraction. It increases linearly when volume fraction increases.

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