Comparison of R134a and R245fa used in Organic Rankine Cycle and Organic Flash Cycle for Waste Heat Recovery

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Abstract: Bottoming cycles like Organic Rankine Cycle (ORC), Organic Flash Cycle (OFC), Kalina Cycle System (KCS) etc. are employed with primary vapour cycle to recover waste heat and increase work output. The result depends on the working fluid being put to use. Calculations for R134a and R245fa were done separately considering ORC and OFC (with two flashing chambers with temperature ratios of 0.5 and 0.3) operating between 10 bar and 4.14 bar. On overall basis, R245fa was considered to be a better working fluid and OFC for maximum work output.

Keywords: ORC, OFC, R245fa, Power output, R134a

I. INTRODUCTION

New methods for waste heat recovery have been highlighted in the recent past due to the increasing demand of energy and depleting energy resources. Different approaches to recover the waste heat from an ordinary steam plant have been taken in order to cut production cost and make a system more efficient. Shaaban [1] analysed integration of ordinary Rankine cycle(ORC), Organic Rankine cycle and gas power cycle with solar combined steam cycle and concluded that integration of an ORC with primary cycle led to an effective cooling on air compressor and net power output was gained after utilizing the thermal energy obtained from cooling the compressor.

Many studies were conducted to figure out the best working fluid for ORCs under the optimized conditions. Kang et al. [2] studied 10 different zeotropic mixtures and found R245fa/R600a most preferable. Maizza and Maizza [3] suggested R401C as the best industrial working fluid for recovery in ORC in year 2001. Shu et al. [4] proposed a dual looped organic Rankine cycle and R1234yf as the best working fluid for the same. Feng et al. [5] compared performances of low grade ORCs and recommended R245fa. Desideri et al. [6] studied R245fa and SES36 and recommended R245fa keeping power generation in mind. Varma et al. [7] studied comparison between ORC, OFC and Kalina cycle system (KCS) and recommended OFCfor overall power generation. R124 was used as a working fluid for this study. Calculations were made for ORC and OFC with R134a and R245fa separately and the two working fluids werecompared under research parameters.

II. ORC AND OFC

Fig 1. shows a simple organic rankine cycle (ORC). The waste steam from the primary steam cycle into the Heat Recovery Vapour Generator (HRVG) and it exchanges heat with the working fluid in the organic rankine cycle. HRVG consists of 3 parts namely, economiser, evaporiser and superheater. In organic Rankine cycle, the fluid simply passes through HRVG and then sent to isentropic turbine. Turbine expands the fluid isentropically and releases it at compressor pressure. Compressor condenses the outlet vapour/vapour mixture from turbine to saturated state and sends it to the pump which compresses it to HRVG pressure. Hence, the cycle continues.

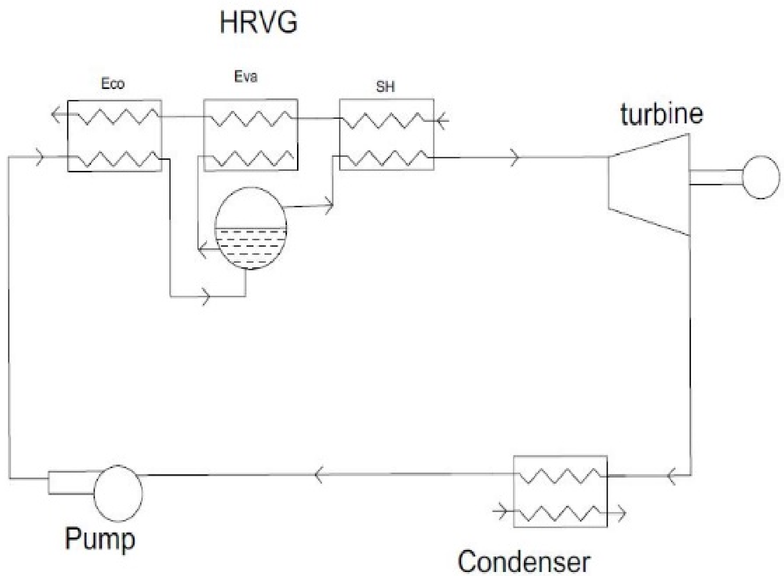

Figure 1 Organic Rankine Cycle

An OFC or organic flash cycle is basically an ordinary ORC in which flashing chamber(s) operating at pressure between the interval of HRVG and compressor pressure. Fig 2 shows an OFC with 2 flashing chambers.

The waste heat enters HRVG from primary cycle and exchange of heat takes place. While the fluid is at economiser stage, a certain mass of fluid is bled out to High Pressure Flasher (HPF) and rest of the fluid reaches turbine. Inside HPF, throttling process takes place and vapour and liquid at saturated states are separated. The saturated vapour is sent to turbine and saturated liquid is passed to Low Pressure Flasher (LPF) where this separation again takes place. The waste fluid from turbine condenses through condenser and then pumped to the pressure of LPF to mix with saturated liquid from second flashing. Finally, entire fluid is together pumped by another pump to HRVG pressure.

The flashing occurs at constant temperature that lies between boiler and condenser temperature. Varma et al. [7] gave following method to calculate T_{HPF} and $T_{LPF.}$

$$\theta_{HPF} = \frac{T_{HPF} - T_{LPF}}{T_b - T_{LPF}}$$

$$\theta_{LPF} = \frac{T_{LPF} - T_c}{T_{HPF} - T_c}$$

Here θ_{HPF} and θ_{LPF} are the temperature ratios of HPF and LPF. In OFC, not all the fluid flowing in the cycle reaches the turbine instead only a fraction of it does.

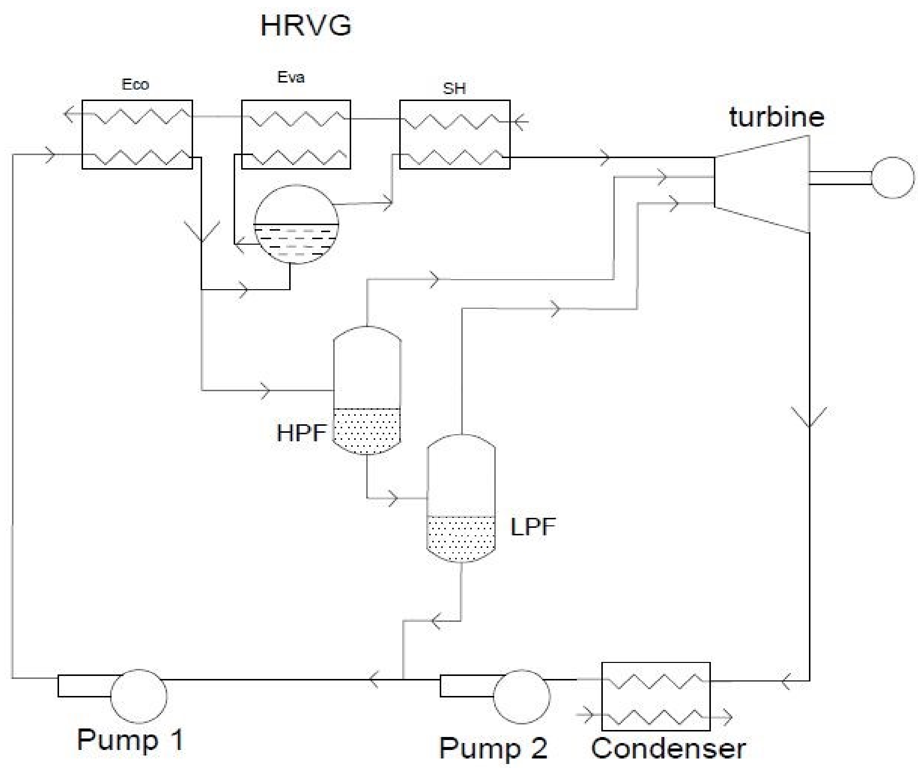

Figure 2 Organic Flash Cycle

III. RESULTS AND DISCUSSIONS

Power output and efficiency for R134a were calculated first. For ORC, the turbine work per kg of inlet fluid was calculated to be 18.01 kW when the cycle operated between pressure limits 10 bar and 4.14 bar respectively. The efficiency calculated to 8.50%.

For OFC, with temperature ratios of HPF and LPF as 0.5 and 0.3, the turbine power output under similar pressure limits and flashing mass fraction of 0.5 came out to be 16.63 kW and efficiency of 7.7404%. Calculations for R245fa were made under the same pressure limits and temperature ratios. For ORC turbine, poweroutput and efficiency came out to be 16.31 kW and 8.12% respectively. For OFC, power output and efficiency were calculated as 16.48 kW and 8.1%.

IV. CONCLUSION

The literature showed that there is still a lot of study to be done on modifications in more efficient alternatives like OFCs. R245fa has been recommended as a working fluid keeping in mind industrial and ecological parameters. Use of transcritical power cycle [8] is also a potential field of study. Between ORC and OFC, OFC is recommended for more turbine power output and industrial use in compliance with present market conditions. Temperature ratios and flash mass ratio for an OFC should be optimized according to the primary cycle and working fluid in order to gain maximum output.

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