

Organic Rankine cycle power plant by low-temperature slag washing water of blast furnace

Xiaoyu Chen^{1a}, Yanna Liu^{2b}, Song Xiao^{1c, †}

¹Faculty of Metallurgical and Energy Engineering, Kunming University of Science and Technology, Kunming, 650093, China

² Faculty of Chemical Engineering, Kunming University of Science and Technology, Kunming, 650093, China

^a690569390@qq.com, ^bnuo2004lyn@163.com, ^cxskmust@163.com

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Abstract. Three typical organic fluids for Organic Rankine power cycles utilizing low-temperature slag washing water of blast furnace is presented. With the aim of making the best use of the energy contained in a stream of 60–80°C slag washing water of blast furnace. The available heat flux of R125 is the highest, and the value of the minimum can reach 70%. When the temperature of initial slag washing water temperature is lower than 70°C, the work fluids R125 and R245fa have the equal theoretical power and higher than the work fluid R143a.

Introduction

Due to the increasingly severe energy crisis and environment pollution, the waste heat recovery of industries is significant as it can reduce energy consumption and reduce CO₂ emissions. Organic Rankine cycle (ORC) is a promising solution because of its flexibility, safety, low maintenance requirements and outstanding economical performance [1, 2].

Compare with the conventional steam Rankine cycle, ORC can get relatively high efficiency for the conversion of low-grade heat into power [3-5]. The choice of working fluids is of key importance for the performance of an ORC. For example, HCFC123, HFC-245fa, HFC-245ca, isobutene are as organic fluids have been studied for use in ORC systems [6-8].

In this paper, three typical organic fluids for organic Rankine power cycles utilizing low-temperature slag washing water of blast furnace is presented. In this system, the thermal efficiency, efficiency of utilization of slag washing water of blast furnace, power and temperature of injected slag washing water of blast furnace will be analyzed by different temperature of slag washing water of blast furnace. The results can help us to choose the suitable organic fluids for organic Rankine power cycles.

Model and assumption

In this section, the schematic of the ORC and T-S diagram of the cycle are shown in Figs. 1 and 2, respectively. The present ORC system consists of heat exchangers (preheater and vaporizer), a vapor turbine, a condenser and a pump. For all work fluids the starting point for the energy analysis is the assumption that slag washing water is available at temperature T_{SWW1} (60–80°C) and at a constant flow rate of 30kg/s. It is assumed that the condensing temperature of the work fluid and the pinch point in the slag washing water heat exchange process are 20°C and 5°C, respectively.

When the rejection temperature for slag washing water is equal into 30°C (i.e., $T_{SWW2}^{\min} = 30^\circ\text{C}$), the greatest utilization of slag washing water energy will be obtained. The slag washing water heat flux available for utilization can be defined as:

$$Q_{SWW} = m_{SWW} C_{P-SWW} (T_{SWW1} - T_{SWW2}^{\min}) \quad (1)$$

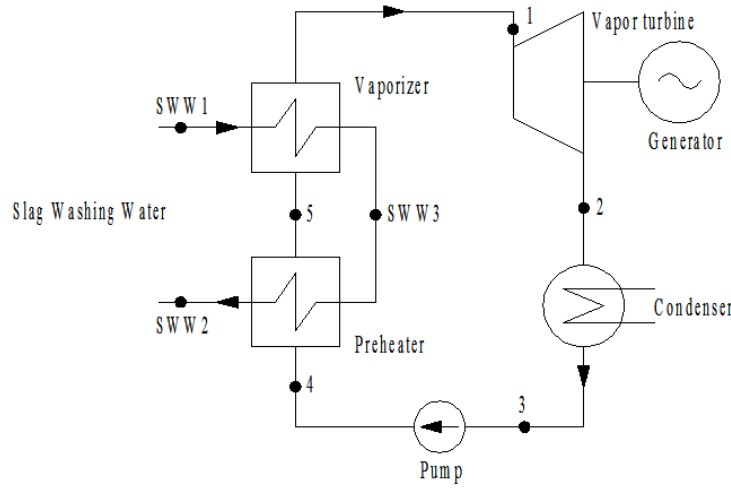


Fig. 1. Schematic of an organic Rankine cycle power plant

Where m_{SWW} is the slag washing water mass flow rate (kg/s), C_{P-SWW} is the specific heat of slag washing water (kJ/kg K), T_{SWW1} is the slag washing water temperature ($^{\circ}$ C).

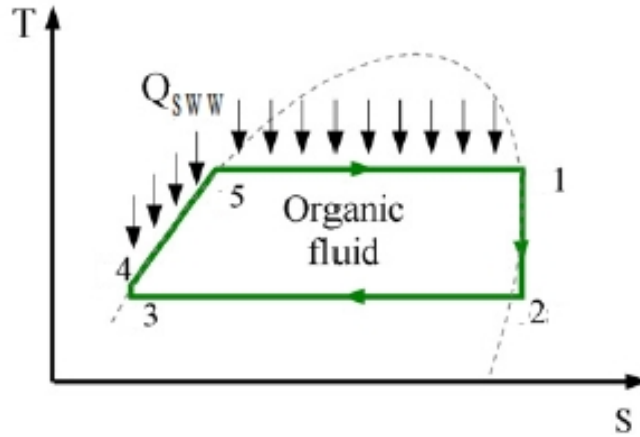


Fig. 2. T-s process diagram of the organic Rankine cycle

This quantity is useful in determining the extent of utilization of the energy contained in the slag washing water, f is the quotient of heat flux actually used in the power plant to the amount of available heat flux:

$$f = \frac{Q_{SWW}^{ORC}}{Q_{SWW}} \quad (2)$$

Where Q_{SWW}^{ORC} is the slag washing water heat flux utilized in the power plant, and it can be expressed as:

$$Q_{SWW}^{ORC} = m_{SWW} C_{P-SWW} (T_{SWW1} - T_{SWW2}) \quad (3)$$

Then from the energy balance for the preheater, the injected slag washing water temperature T_{SWW2} can be determined:

$$T_{SWW2} = T_{SWW3} - \frac{m_{ORC} (h_5 - h_4)}{m_{SWW} C_{P-SWW}} \quad (4)$$

According to the scheme shown in Figs. 1 and 2, the working fluid flux m_{ORC} can be determined from the energy balance for the vaporizer:

$$m_{ORC} = \frac{m_{SWW} C_{P-SWW} \Delta T_{vap}}{h_1 - h_5} \quad (5)$$

$$\Delta T_{vap} = T_{SWW1} - T_{SWW3} \quad (6)$$

For every working fluid, depending on its thermodynamic properties, the optimal value of the temperature drop of the slag washing water in the vaporizer (ΔT_{vap}) that gives the maximum power can be determined [9]. Here in order to simplify the analysis the same temperature drop $\Delta T_{vap} = 20^\circ\text{C}$ was assumed for all working fluids. The thermal efficiency and theoretical power of ORC power plant can be calculated as:

$$h_{th} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4} \quad (7)$$

$$N = m_{ORC} [(h_1 - h_2) - (h_4 - h_3)] \quad (8)$$

Results

The temperature of the slag washing water pumped back into the reservoir for the different work fluids are presented in Fig. 3(a). This figure shows that use of an ORC power plant is associated with rather high injection temperatures T_{SWW2} , which are affected by the nature of the organic fluid used in the ORC plant, but to a small extent. In these three work fluids, the injection temperature of R245fa is the highest, and R125 is the lowest. The temperature of slag washing water pumped back into the reservoir has a direct impact on the extent of utilization of this water in the power plant. As can be seen from Fig. 3(b), the different work fluids can use at least 50% of the available heat flux. With the temperature of initial slag washing water increasing, the available heat flux decreases. The available heat flux of R125 is the highest, and the value of the minimum can reach 70%.

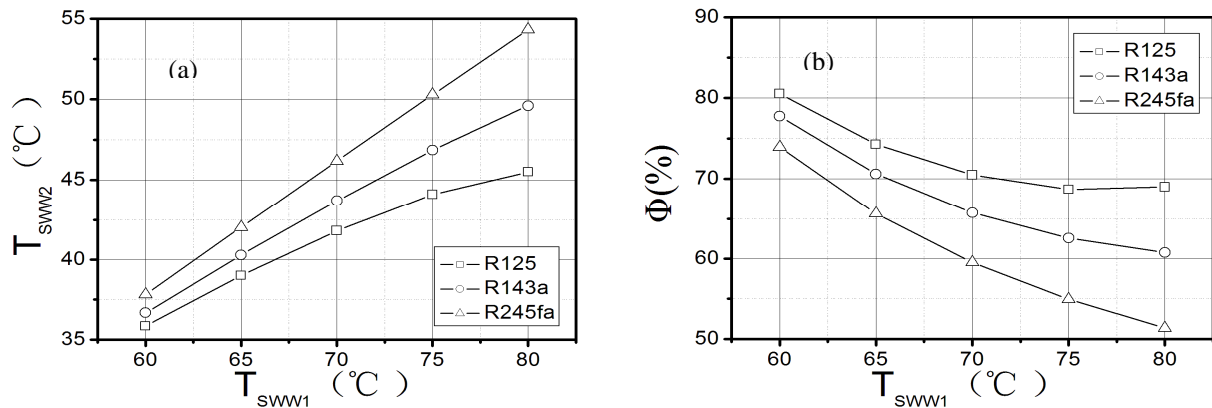


Fig. 3. (a) Temperature of injected slag washing water as a function of T_{SWW1} for different work fluids. (b) Utilization of slag washing water energy for the different work fluids as a function of T_{SWW1}

The highest efficiency and thermal power of the ORC of each work fluids depends on the initial temperature of the slag washing water are shown in Fig. 4. According to Fig. 4(a), the highest thermal efficiency is shown by work fluid R245fa, and with the initial slag washing water temperature increasing, the thermal efficiency increases, too. Interestingly, the thermal efficiency of work fluids R125 and R143a are much closed. In Fig. 4 (b), the highest theoretical power is shown by work fluid R125, and with the initial slag washing water temperature increasing, the theoretical power increases, too. Interestingly, when the temperature of initial slag washing water temperature is lower than 70°C , the work fluids R125 and R245fa have the equal theoretical power. However, when the temperature

of initial slag washing water temperature is equal into 80° C , the work fluids R143a and R245fa have the equal theoretical power.

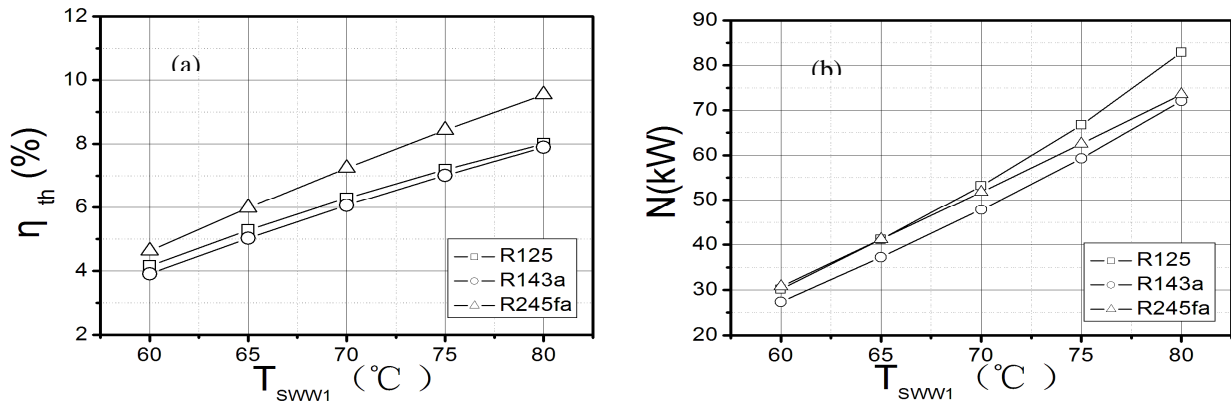


Fig. 4. (a) Thermal efficiency of different work fluids as a function of T_{SWW1} . (b) Theoretical power of different work fluids as a function of T_{SWW1} .

Conclusions

- (1) The different work fluids can use at least 50% of the available heat flux. With the temperature of initial slag washing water increasing, the available heat flux decreases. The available heat flux of R125 is the highest, and the value of the minimum can reach 70%.
- (2) When the temperature of initial slag washing water temperature is lower than 70° C , the work fluids R125 and R245fa have the equal theoretical power. However, when the temperature of initial slag washing water temperature is equal into 80° C , the work fluids R143a and R245fa have the equal theoretical power.

Acknowledgements

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