

Benefit analysis of organic Rankine cycle power generation by using waste heat recovery in Refinery

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Abstract. Under the goal of achieving "carbon neutrality", increasing energy-saving and reducing emissions has become a long-term strategy to ensure the sustainable development of China's social economy. The unrecycled waste heat leads to a high energy penalty in refinery. This paper presents an Organic Rankine Cycle (ORC) power generation technology, which through the thermodynamic cycle to recover the waste heat from the Aromatics Complex units. This process is simulated and analysed from the environmental point. The results indicate that the application of ORC in aromatics combined units can indirectly save 41040 tons of coal every year. The annual emission of CO₂ is reduced by 94455 tons. The proposed ORC system provides technological route for refineries to achieve waste heat recovery, thus advancing the green transition of the petrochemical plants.

1. Introduction

Nowadays, the increasing pressure with regard to energy security and environmental pollution (especially CO₂ emissions), requiring nations to seek lower-carbon development path. CO₂ emissions cause a major concern [1,2] and are responsible for various extreme weather events [3]. The international community has reached a consensus on CO₂ reduction to build a low-carbon future. As a traditional energy producer and major carbon emitter, China's carbon neutrality commitment puts forward new requirements for domestic refineries to fulfill their "carbon" responsibilities. As a producer and consumer of traditional energy, refinery has always been the top priority in the field of energy conservation and emission reduction [4]. According to incomplete statistics, refineries' energy consumption accounts for 16% of China's total energy consumption [5,6], ranking in the forefront of major energy consumers. Studies have shown that compared with Japan's energy utilization rate (60%), China's energy utilization rate is only about 30% [7]. The main reason for this difference is that China does not make full use of waste heat.

The waste heat accounts for a large proportion of the total energy consumption of the refinery, and some are even as high as 60% [4]. If it cannot be well utilized, it is bound to cause a waste of energy, resulting in the high comprehensive energy consumption and environmental pollution of the refinery. So that the economic benefits cannot be optimized, which is contrary to low-carbon direction. In the refining and chemical fields, this low-grade energy that has not been reutilized mostly

discharged into the environment at the cost of consuming cold utilities.

With the complex development of petroleum processing process, resulting in the Aromatics Complex has become a high energy consuming unit in the refinery [4]. As part of the CO₂ mitigation strategy, introduction of waste heat recovery technology in refineries would considerably reduce CO₂ emission indirectly. Therefore, it is imperative to find some technological options to recover this huge fraction of the energy that is untapped and the potential gain from efficiently utilizing the waste heat is appreciable for refineries' low-carbon development.

Organic Rankine Cycle (ORC) is a state-of-the-art technology for converting the low-grade heat to power via the work of organic working fluids, which has proven to be promising for waste heat recovery [8,9]. In recent years, it is being progressively adopted as commercially-matured technology since there have been many applications in recovery waste heat from industrial processes, such as biomass or coal fired combined heat and power (CHP) plants [10], geothermal plants or micro-CHP [11,12]. However, few studies have focused on waste heat recovery in refineries. This work is motivated by recognizing the gap and provide targeted solution to promote the reutilization of refineries' waste heat, thereby improving the energy efficiency and reducing the emission of the refineries.

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2. Model and methodology

This section illustrates the modeling of the ORC system. Besides, the key performance indicators to evaluate the impact of the ORC power generation system on energy conservation and emission reduction of refinery.

2.1 Model description

As shown in Figure.1, the modeling process consists of condenser, evaporator, organic expander and working fluid pump. The saturated liquid working fluid is pumped to a high-pressure state in the working fluid pump and heat exchanged with the waste heat source in the evaporator. The organic working fluid is heated and becomes saturated or superheated vapor. Then, it enters the expander and drives the expander to rotate to generate electricity. Finally, the exhaust gas after work enters the condenser and it is condensed into saturated liquid through cooling water, followed by pressed into the evaporator via the pump for the next cycle.

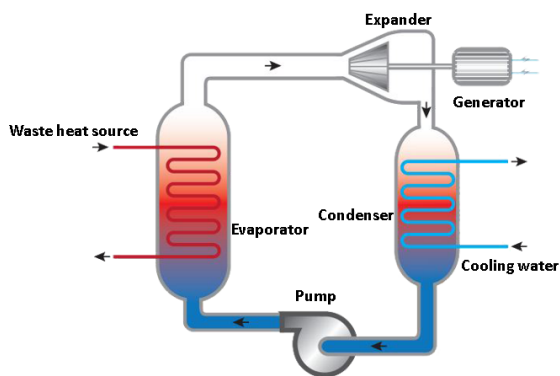


Figure 1. Process diagram of ORC system.

2.1.1 Waste heat sources.

Based on the research and summary of the waste heat distribution of key process units (Aromatics Complex) in refinery, the main waste heat sources of ORC system as shown in table 1.

Table 1. The waste heat from the aromatic's combination unit

Item	Waste heat sources	T _{start} (°C)	T _{target} (°C)	Heat load (MW)	Heat-capacity flow rate (kW/°C)
H1	Distillation column	197.8	190.5	83.4	11426
H2	Xylene column	247.8	226.2	57.3	2655
H3	O-xylene column	201.8	189.3	11.66	933.19
H4	Extraction column	140	83	27.7	486.62
H5	Raffinate column	129	101.3	54.37	1963
H6	Deheptane column	235.7	175	13.96	229.8
H7	Toluene column	125.6	115.3	17.03	1650.78
H8	Heavy aromatics column	177.7	167.8	10.84	1095.2

2.2 Key performance indicators

It is assumed that the mainly energy consumption of the refinery is coal. The CO₂ reduced by using the electricity output by ORC system can be calculated by equation as followed:

$$M_{coal} = hP_{net} C_{coal} \quad (1)$$

$$E_{CO_2} = E_{substitution} - E_{generation} = hP_{net} \beta_{CO_2} \quad (2)$$

Where, h is the annual operation time of ORC system, 8000 h. P_{net} is the net power output of ORC system, M_{coal} is coal consumption and C_{coal} is coal coefficient based on standard coal power generation. β is the carbon emission coefficient of each emission, which represents the emission to the atmosphere per unit of electricity produced, and the unit of power is kW · h.

$$E_{NO_x} = hP_{net} \beta_{NO_x} \quad (3)$$

$$E_{CH_4} = hP_{net} \beta_{CH_4} \quad (4)$$

$$E_{CO} = hP_{net} \beta_{CO} \quad (5)$$

3. Results and discussion

We focus on the evaluation of the contribution of ORC system to refinery energy conservation and emission reduction. We take coal power as the benchmark and calculate the emission reduction effect based on the emission factor methods. For the waste heat power generation system of high energy consumption units in refinery, the total power generated by waste heat utilization is 15.17 MW and the net power output is 13.54 MW. If the net power output is converted into standard coal consumption and unit coal consumption for power generation is 380 g/kW · h [13], the recovery of waste heat of aromatics combined units in refinery can indirectly

save 41040 tons of coal per year (Calculated by equation 1-2). In addition, if these waste heat sources are not utilized, it can only be cooled by air cooling or water cooling. According to the calculation of circulating water cooling, more circulating water (about 11630 t/h) is required, which can save 18.61 million yuan per year (0.2 yuan / ton) [14]

The greenhouse gas emission factors of coal are shown in table 2 [15]. According to the equations (2-5) defined in section 2.2, the energy consumption saved and the carbon emission reduced are shown in Table 3. The results show that through recovery of waste heat in aromatics combined units the annual emission of greenhouse gas CO₂ is reduced by 94455 tons, followed by NO_x and CH₄, which are reduced by 1418 tons and 312 tons, respectively. It can be seen that the ORC system can significantly reduce the heat load that dissipated to the environment, thereby increasing the overall efficiency of the system. Those results demonstrate that the recovery of waste heat is of great significance to promote the development of low-carbon refinery, which achieving energy conservation and emission reduction.

Table 2. Carbon emission coefficients for coal

Parameters	β_{CO_2}	β_{CH_4}	β_{CO}	β_{NO_x}
Carbon emission coefficients (kg/kW·h)	0.87 2	2.89*10 ⁻³	1.05*10 ⁻³	1.31*10 ⁻²

Table 3. Emission reduction evaluation of the ORC waste heat recovery system

Working fluid	Power output	Save coal consumption	CO ₂ reduction	NO _x reduction	CH ₄ reduction	CO reduction
R600	1.08*10 ⁸ /kWh	41040/t	94455/t	1418/t	312/t	113.4/t

4. Conclusion

In this study, we proposed an ORC power generation system to recover the waste heat of the refinery. It can indirectly save 41040 tons of coal in the refinery every year. The annual emission of CO₂ and NO_x are reduced by 94455 tons and 1418 tons, respectively. It can be seen that the reutilization of waste heat contributes to refineries' transition toward a cleaner and lower-carbon future, which provides technical support for the global push of "carbon neutrality".

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