Development of ORC system which recovers wasted heat of metallurgy plants in China

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Abstract
In this study, Organic Rankine cycle (ORC) to recover wasted heat of metallurgy plants was evaluated. Several types of ORC systems, such as the direct evaporation, the indirect evaporation and their combined cycle were picked up and their operational parameters were optimized. The results showed all of these ORC systems indicated better gross power generation efficiency than that of the conventional steam power generation system. It is also indicated that the direct evaporation is most effective and the indirect evaporation is preferable to the combined cycle in case that the direct evaporation system cannot be installed.

Key words: ORC, Rankine Cycle, wasted heat, heat recovery, metallurgy plants

1. Introduction

Global warming is one of our great environmental concerns. Reduction of CO2 emission has the important role to solve the problem. Thus, effective use of energy, most of which is derived from fossil fuel, is necessary. Metallurgy is one of the energy consuming industries as its process for refining and production of metal requires a lot of heat. The energy of the temperature up to 300degC is emitted to atmosphere without utilized. China is the largest player in this field as it produces more than 45% of steel of the world. Hence making use of wasted heat energy in Chinese metallurgy is significant to CO2 emission reduction. This study focuses on the power generation for the heat utilization since the electric power can be transmitted long distance and can be supplied to the area where its demand is high.

2. Application of ORC

The targeted heat source condition of wasted heat in this study is shown in Table1. This comes from one of the metallurgy plants in China. Fig.1 shows the general heat source which is emitted from metallurgy plants in Japan. The condition of Table1 is plotted in the figure. This figure showed the targeted condition is not so far from the range of wasted heat of general metallurgy plants in Japan.

<table>
<thead>
<tr>
<th>Source</th>
<th>blast furnace.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>250degC</td>
</tr>
<tr>
<td>Flow rate</td>
<td>270,000 Nm³/h</td>
</tr>
<tr>
<td>Output power</td>
<td>2000kW</td>
</tr>
</tbody>
</table>
Fig. 1 Temperature range of wasted gas from metallurgy plants
(Japan Machinery Federation report, 2007)

Fig. 2 shows the schematic diagram of ORC. ORC generally consists of evaporator, turbine, condenser and pump as its basic components. Sometimes heat generators are equipped to transfer surplus heat of turbine outlet to the working fluid entering the evaporator. The working fluid of organic material circulates though the components above. The pressure and the temperature of the working fluid becomes high as it goes through the pump and evaporator respectively, and rotates the turbine as it expands at the low pressure side of turbine. The condenser generates its low pressure by condensing the working fluid. The organic material having low boiling temperature than water is generally chosen as the working fluid so that it evaporates effectively.

3. ORC design

3.1 Selection of ORC working fluid

3-2. ORC cycle variations

The selection of working fluid is important to acquire efficient thermal cycle. In this study, HFC-245fa is picked up because it is widely used as the working fluids. It has stability in the temperature range beyond 200\,degC and inflammability. Though its global warming potential (GWP) is high as 1600, currently low GWP materials having similar property to HFC-245fa have been developed. So substitution to these low GWP materials might be done easily.

HFC-245fa’s property is shown in Table 2.

<table>
<thead>
<tr>
<th>Name</th>
<th>HFC-245fa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical nomenclature</td>
<td>1,1,1,3,3-pentafluoropropane</td>
</tr>
<tr>
<td>Normal boiling temperature</td>
<td>15.14,degC</td>
</tr>
<tr>
<td>Critical temperature</td>
<td>154.01,degC</td>
</tr>
<tr>
<td>Critical pressure</td>
<td>3.651,MPa</td>
</tr>
</tbody>
</table>
3-2. ORC cycle variations

As Fig.2 shows basic ORC diagram, there can be cycle variations depending on several conditions such as the installation constraints. An example of the installation constraints is the location problem. If there is no space left or construction of ORC is not welcomed near the hot and operating heat source such as blast furnace, the ORC have to be located far from the heat source. This forces us to have longer pipes between heat source and ORC and the extra cost of working fluid. In this case, inexpensive material, such as water, is suitable as the heat transferring material from the heat source and the evaporator. That is, the indirect evaporation might be more cost effective than the direct evaporation which evaporates directly the organic working fluid as in Fig.2. Fig.3 shows two types of variations of ORC system which uses the water as heat transferring material. In the indirect evaporation shown in Fig.3 (a), the water flows into the boiler and it is heated and converted into the steam. The steam is transported to the evaporator in the ORC section where the working fluid is heated and evaporated. Fig.3 (b) shows the combined cycle where the ORC system and the steam system were separated and the steam gas composition and liquid composition (brine) are also separated by the flusher. The steam gas is supplied to the steam system and the liquid composition becomes the heat source of ORC system.

![ORC Variation Diagram](image)

(a) indirect evaporation  
(b) combined cycle  

Fig.3 ORC variation

3-3. ORC cycle optimization

ORC has several operational parameters. The most important parameters are turbine inlet temperature and pressure as they determine the cycle diagram as shown in Fig.4. They are optimized by scanning parameters in the plant simulator software to achieve the highest power generation efficiency (considering power consumption of working fluid pump and cooling water pump). The other parameters are set to fixed values.

![ORC Parameter Optimization Diagram](image)  

Fig.4 ORC parameter optimization
4. Results

Fig. 5 shows the result after the parameter optimization for the basic ORC system in Fig. 2. This figure shows the higher turbine inlet pressure performs the higher efficiency in power generation (considering pumps’ power consumption) as it has narrower temperature window to balance thermal cycle. Most efficient temperature was 20 degC lower than the heat source temperature. Fig. 6 shows the comparison of all ORC systems in Fig. 2 and Fig. 3 and the conventional steam power generation system. The results showed all of these ORC systems indicated better efficiency than that of the conventional steam power generation system. And it is also indicated that the direct evaporation system showed best performance of all the ORC systems compared in study and in the indirect evaporation is more effective than the combined cycle. That the direct evaporation showed the best performance is reasonable as the number of stages of heat exchange is fewer than others, which can minimize the heat exchange loss. The results that the indirect evaporation showed better performance than the combined cycle comes from that the working fluid in the indirect evaporation cycle can have higher temperature than that of steam in the combined cycle.

5. Conclusion

The result suggests that if the direct evaporation is possible to be installed it is the best way to have the direct evaporation system. And the indirect evaporation system is preferable to the combined cycle system in case that the direct evaporation system cannot be installed. In this study, the cycle systems are evaluated with their gross power generation efficiency, but as the next step, the net power efficiency and the cost or the system size/footprint should be also taken into account for the system parameter’s optimization and comparison with each other.

References

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