Nowadays, internal combustion engines (ICEs) are the major motive power source for the society. Internal combustion engines are used widely in transport, construction, agriculture, etc. However, the environment problems caused by the fuel consumption in internal combustion engines are also severe. Nearly half of the total transportation fuel is consumed by internal combustion engines. Whereas, the thermal efficiency of the ICEs is only 30-45% [1], leading to energy waste and the environment pollution. As a result, finding sustainable ways to fully utilized the fuel energy in the ICEs has attracted more and more attention of the researchers.

Previous researchers mainly focused on recycling waste heat from the exhaust gas which is in high temperature state. Many works have been carried out to utilize the energy in exhaust gas with the help of organic Rankine cycle (ORC). In 2010, Vaja et al. [2] matched an organic Rankine cycle to the internal combustion engine to recovery the waste heat. Later, further studies were carried out to improve the performance of the electricity generation system. Shu et al. [3] designed an organic Rankine cycle to harvest the exhaust waste heat of engines. Rita et al. [4] optimized a shell and louvered fin heat exchanger in the organic Rankine cycle driven by the internal combustion engine gas. Beside the exhaust gas, the coolant of the ICEs also has the potential to be utilized, considering the large amount of the mass flow rate and the relatively high temperature.

Research works about utilizing the exhaust gas and jacket water have been developed by many researchers. Zhang et al. [5] modeled a novel system combining a dual loop ORC and a vehicular light-dual diesel engine. The exhaust gas, intake air and the coolant were analyzed. They compared the power output of the high-temperature loop and the low-temperature loop and found that the low-temperature loop can produce more power. To avoid the complexity of the conventional multi source ORC system, a confluent cascade expansion ORC system was introduced by Chen et al. [6]. Thermodynamic simulation method was employed to calculated the parameters of the system. By comparing the results, they concluded that the architecture of the novel system is simper, the net power output of the system is larger (generating 8% more net power) and the thermal efficiency of the novel system is higher (improved to 49.5% from 45.3%). A dual-loop organic Rankine cycle was developed by Ge et al. [7] to recover the waste heat of the ICEs. In that study, isobutane and isopentane are mixed as the working fluid for the low-temperature loop (LTL) and cyclopentane and benzene mixtures are selected as the working fluid for the high-temperature loop (HTL). Comparing between mixed organic working fluid and pure organic working fluid was carried out and they drew the conclusion that less exergy destruction rate was achieved in the mixture using system. Seyedali et al. [8] studied a two-parallel-step organic Rankine cycle driven by the waste heat of the IEC. Comprehensive thermodynamic performance analysis and the optimization of the system were carried out by analyzing the key design parameters of the system. The got the result that 468 kW electricity power was produced by the system with an exergy efficiency of 21 %.

With the variation of the customers’ demand, more products other than electricity power were required. A number of studies began to pay attention to the combined systems. The design of combined cooling and power (CCP) system as a result was carried out by many researchers [9-11]. Chen et al. [12] investigated an ammonia-water combined cooling and power system using the waste heat from the ICEs. A gas engine with the power output of 300 kW was selected as the data source. By calculating the thermodynamic performance of the system, they concluded that the equivalent power output of the system is 92.86 kW and the exergy efficiency of the combined cooling and power system is 33.69%. In order to gain a large cooling capacity, ammonia-absorption cooling cycle was utilized by many researchers. Whereas, the capital investment of the system components and the operation cost was relatively high. Ejector refrigeration systems which were low in capital cost and simple in operation therefore were combined with the electricity generation cycles. And the economic analysis of a system has attracted the attention of studiers in recent years.

To better evaluate the thermodynamic and economic performance of a system, exergoeconomic (thermoeconomic) analysis methods were established. It provided a new aspect to design and operate the energy systems. YD Lee et al. [13] evaluated an SOFC-Engine hybrid power generation system. Exergoeconomic analysis methods were employed to analyzed the economic performance as well as the thermodynamic performance of the system. They found that the internal combustion engine accounted for the largest exergy destruction and followed the heat exchanger and the SOFC stack. An ejector refrigeration system driven by homogeneous charge compression ignition (HCCI) engine was designed by Mohsen et al. [14]. Exergoeconomic and thermodynamic performance of the system was calculated in MATLAB software. Multi-objective optimization was carried out with the objective function of exergy efficiency and the product unit cost of the system. Conclusion was obtained that in the highest exergy efficiency and the lowest product unit cost, the generator, condenser and the evaporator should work at temperature of 94.54 oC, 33.44, and 0.03, respectively. A combined cooling, heating and power (CCHP) system was analyzed by Wang et al. [15] using exergoeconomic methods. Energy costs of products in the system were calculated considering the natural gas price. They found that the cost of electricity increased from 0.537 to 1.077 Yuan/kWh with the change of the power output range (100-20%).

In most of the study, the exhaust gas was utilized directly by working fluid in organic Rankine cycle without considering the chemical stability. In general, the decomposition temperature is about 200 to 300 oC for many kinds of the organic working fluid. However, the exhaust gas temperature can get as high as 600 oC, causing the potential of the decomposition for the working fluid during the long working process. As a result, there is contradiction between the thermal stability of the system and the maximum utilization of the thermal energy when combining the organic Rankine cycle with the ICEs.

To solve the problems mentioned above. A CO2 Brayton cycle is employed to utilized the high temperature of the exhaust gas in this study. To fully make use of the thermal energy of the exhaust gas, an organic Rankine cycle is employed which is driven by the exhaust gas after the Brayton cycle. Considering the high temperature of the exhaust CO2 gas in the Brayton, another organic Rankine cycle is added. Therefore, a dual-pressure organic Rankine cycle with the exhaust CO2 gas as the high-pressure heat source and the secondary exhaust gas as the low-pressure heat source is introduced. Because of the large mass flow rate and relative high temperature of the jacket water, it is utilized to preheat the organic working fluid before the separating of the working fluid in the dual-pressure ORC cycle. Besides, an ejector refrigeration cycle is added to the system for the cascade utilization of the jacket water. To consider the system comprehensively, thermodynamic and exergoeconomic analysis of the system is employed. Optimization for the system based on the exergoeconomic analysis is obtained by means of genetic algorithm.

Figure





























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| exhaust gas temperature | 500oC |  |
| gas mass flow rate | 0.546 |  |
| jacket water temperature | 90-80 |  |
| water mass flow rate | 4.304 |  |
| cooling capacity | 34.74 | 27.72 |
| net power | 14.76 | 47.39 |
| exergy efficiency | 33.69 | 50.04 |
|  |  |  |