Methods for efficiency improvement of the semi-closed oxy-fuel combustion combined cycle

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Abstract. The paper presents thermal schemes of the semi-closed oxy-fuel combustion combined cycle with preliminary cooling of the coolant flow. The first scheme involves the coolant flow preliminary cooling in a surface heat exchanger. The heated agent is a part of condensate taken from the steam turbine circuit. The net efficiency improvement against the base cycle is 3.2% for the working fluid initial temperature of 1700°C. The coolant flow temperature is reduced down to 150°C. The second scheme involves injection of the water taken from the cooler-separator. In this case the power facility net efficiency improvement may be up to 1.5%.

1. Introduction

Efficiency improvement and environmental harm reduction are the main goals of power facilities manufacturers. The most efficient gas firing facilities are the combined cycle power plants ones. Large facilities of this type may reach over 60% net efficiency [1]. Different emission mitigation methods reduce the environmental harm down to its minimum. On the other side the hydro-carbons combustion in atmospheric oxygen produces enormous amounts of carbon dioxide that is difficult to precipitate from flue gas because of its small partial pressure. The carbon dioxide emission increases its atmospheric content and may be one of the probable sources of the earth temperature increase during the last 70 years [2].

The carbon dioxide may be efficiently captured in oxy-fuel combustion cycles [3]. This technology differs from the traditional ones mostly by oxy-fuel combustion and multi-component working fluid that consists mostly of carbon dioxide and water vapor. The water component may be thermodynamically extracted by condensing in a cooler-separator.

The semi-closed oxy-fuel combustion combined cycle (SCOC-CC) [4–7] is widely known. It has a simple configuration and may be considered as a Bryton-Rankine cycle with oxy-fuel combustion and carbon dioxide recirculation.

The combustion chamber is supplied with gas fuel, high purity oxygen and the carbon dioxide flow that limits the maximal temperature. The combustion products main contents are carbon dioxide and water vapor at 1100-1700°C. The products enter the gas turbine that drives the power generator. The
working fluid expands in the gas turbine and enters the heat recovery steam generator. The produced superheated steam is supplied to the steam turbine that also produces power. The flue gas leaves the heat recovery steam generator and enters the cooler-separator where most of the water contents is separated by condensing at nearly atmospheric pressure. Then a part of the carbon dioxide flow is removed from the cycle for its further storage. The remaining flow that consists mostly of carbon dioxide increases the compressor pressure and re-circulates. The gas turbine is cooled with the working fluid flow bleeding from the compressor.

The cycle net efficiency considering the air separation unit (ASU) penalty and the carbon dioxide storage may be over 47% [8–10]. Here the gas turbine coolant flow varies from 20 to 40% depending upon the inlet temperature.

The paper describes investigation of the semi-closed oxy-fuel combustion combined cycle efficiency improvement by means of the gas turbine coolant flow reduction.

2. Efficiency improvement of the semi-closed oxy-fuel combustion combined cycle

The most effective method of the turbine coolant flow reduction is the flow temperature decrease at the cooling channels entrance. This may be reached by the cooling flow preliminary cooling in a surface heat exchanger or by the water injection into the coolant flow.

The first method scheme of is shown in figure 1. In terms of use of the heat taken from the coolant flow some condensate from the steam turbine exit may be heated. The main condensate flow is heated in the pre-cooling surface heat exchanger and returned into the steam turbine flow. This increases the heat recovery steam generator steam production and the steam turbine power.

The water injection reduces the coolant flow temperature by evaporation. The water may be taken from the cooler-separator so the expenses for its preparation are minimal. This method scheme is presented in figure 2.

![Figure 1. The coolant flow preliminary cooling in a surface heat exchanger for the SCOC-CC.](image)
3. The analysis of simulation results

The basic and developed versions of the SCOC-CC were modeled with the AspenONE code. Figure 3 presents the net efficiency evaluation obtained from the calculation.

The higher is the working fluid turbine inlet temperature the larger is the coolant pre-cooling effect. In the investigated temperature range the maximal net efficiency improvement of 3.8% is reached by the coolant temperature reduction down to 100°C in the surface heat exchanger. On the other side the coolant temperature reduction below 150°C is not recommended because of the risk of water condensate formation in the coolant flow. The maximal net efficiency increase at cooling to 150°C is 3.2%.

The maximal net efficiency improvement with the water injection is 1.5%. The injection water massflow varies from 0.4 to 2.2% for the turbine inlet temperature from 1100 to 1700°C respectively. The small water massflow values produce small changes of the coolant chemical composition. The cycle efficiency increase is mostly due to the coolant massflow reduction and the resulting reduction of cooling losses.

4. Conclusions

The semi-closed oxy-fuel combustion combined cycle thermal efficiency may be improved by two methods of preliminary cooling of the gas turbine coolant taken from the compressor.

In the case of deep coolant cooling down to 150–250°C it is reasonable to use cooling in a surface heat exchanger with the steam turbine unit condensate. The net efficiency increase may be up to 3.2%.

In the case of pre-cooling to temperature above 250°C may be recommended injection of the water taken from the gas cycle cooler-separator. The power facility net efficiency increase may be up to 1.5%.
Figure 3. Influence of the pre-cooling methods upon the cycle net efficiency.

Acknowledgements
This study conducted by National Research University “Moscow Power Engineering Institute” was supported by the Russian Science Foundation under Agreement No. 17-79-20371 dated July 28, 2017.

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