INDUSTRIAL COMBINED HEAT AND POWER PLANT REPOWERING PROPOSAL

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Abstract

Industrial combined heat and power plants (CHP) in Middle Europe face the problem of tightening emission limits and decreasing thermal efficiency resulting from their ageing. At the same time, focus and financial support for renovation activities are directed on ageing thermal power plants nowadays, while the need for revamp of industrial CHPs is a less discussed topic generally. To highlight the need for action in this sector a model case study is presented. It showcases an industrial CHP, fueled with heavy fuel oil, producing steam for industrial use and electricity on a condensing-extraction turbine. Several technologies are considered that could augment its actual performance and lead to cleaner heat and power production. Among those, internal combustion engines (ICE) and gas turbines (GT) are the most frequently applied solutions in scientific studies as well in real repowering activities. Both technologies are suitable for industrial use as well. General features and pros and cons of industrial CHP repowering by those technologies are discussed; system balances are set up and resulting improvement of the repowered CHP is obtained.

Introduction

Global climate change highlights our obligation to reduce greenhouse gas coming from the thermal power plants fired by fossil fuels. The fundamental method is partial repowering, when a new component is incorporated to the CHP as mentioned above. Even though repowering by internal combustion engines (ICE) is a reasonable option, heat in hot water is a by-product. Repowering by gas turbines (GT) is more feasible, yielding hot flue gas as the only by-product which can further serve for steam production. All facts considered; GTs are more suitable for this study's purposes mainly due to the higher overall efficiency potential [1].

Study objectives

The aims of this contribution are in particular:

- analyzing the model operation of an old heavy fuel oil power plant both for winter and summer
- introducing the usage of GTs
- deciding the more convenient repowering option

CHP unit description

In this section, more detailed description of the original plant model scheme and calculation assumptions are presented. Main equipment is displayed in figure 1, where streams in gaseous state are depicted in dashed lines, while solid lines represent liquid streams. The main task of this CHP is to produce at least 60 MW of electric energy and high-, intermediate- and low-pressure (HP, IP, LP) extraction steam in desired amounts for export as well as for own consumption.

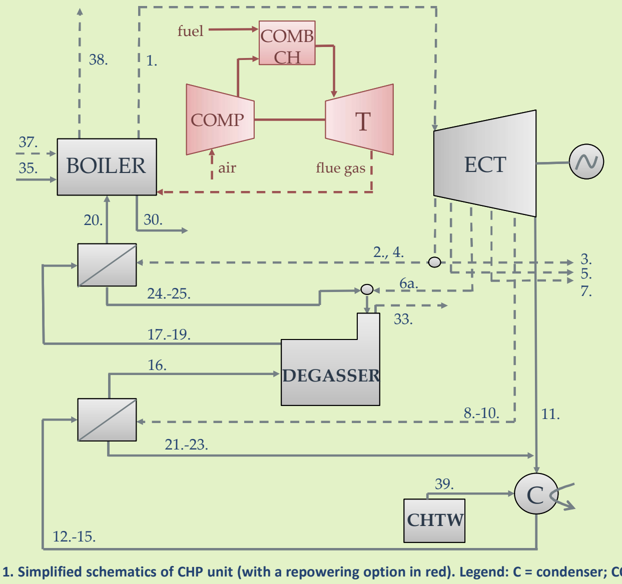

Figure 1. Simplified schematics of CHP unit (with a repowering option in red). Legend: C = condenser; COMB CH = combustion chamber; COMP = compressor; CHTW = chemically treated water; ECT = extraction-condensing turbine; T = turbine.

The scheme consists of several technological units:

- ECT – extraction-condensing turbine driven by high pressure steam (stream no. 1) produced in steam boiler; Besides electricity cogeneration, HP IP and LP extraction steam is produced concurrently for export and for own consumption.
- C – condenser; Vapor-liquid mixture (wet steam) from the turbine (stream no. 11), condensates from low temperature water heaters and CHTW (chemically treated water) flow into the condenser. Condenser is operated in broad load range between 20 and 90 t/h of inlet wet steam. Condensate exits after condensation at 30°C and is pumped as feed water to a sequence of three LTWH.
- LTWH – low temperature water heaters (depicted as one in schematics for clarity); Each one requires separate extraction steam stream from ECT with the condensation temperature of the inlet steam of 5°C above the temperature of outlet feed water. This way a sufficient heat-exchange driving force is ensured. In each LTWH, the temperature of feed water is increased by 30°C, exiting at 120°C to the degasser.
- CHTW – chemically treated water; While there are a few streams considered as material loss such as blowdown from the boiler, degasser exhaust, even export steam, those need to be replaced.
- DEGASSER – embodies two purposes - feed water degassing and feed water heater; Inlet water (stream no. 16) is mixed (into an outlet feed water (stream no. 17) at the temperature of 120°C) with steam from another turbine extraction (stream no. 6a), expander steam, condensates from fuel and air pre-heating and also condensates from HTWH.
- HTWH – high temperature water heater; Fullfiling the same role as LTWH with a sequence of two HTWH simplified into one in the scheme.
- BOILER – unit transforming feed water into steam (stream no. 1) at the temperature of 530°C and the pressure of 9 MPa; Combustion of pre-heated fuel (stream no. 35) with air (stream no. 37) takes place resulting in exhaust gas production.

Repowering proposals

After we identified the operation conditions of the CHP, the decision-making process concerning altering the CHP unit takes place. Incorporating ICE with a system of heat exchangers shows promising results. ICE is a machine that produces thermal and electric energy by converting chemical energy contained in fuel into mechanical work of a moving piston [2]. Nevertheless, such solution is more suitable in cases with significant hot water demand. In the analyzed plant, however, there is little use for hot water, as it is steam, not hot water, that is exported from the CHP unit.

In GT, compressed air from its compressor module and fuel are combusted. Results are gases that expand through a turbine leaving it at a high temperature [3]. High rate of used excess air indicates larger amount of oxygen in flue gas. This offers the possibility of using the flue gas as a combustion air mixed with the fresh air in the boiler.

In this paper, option with GT using flue gas as a combustion air was chosen, which shows promising results as can be observed in table 1:

Table 1. Comparison both for existing (E) and repowered (R) CHP

	Winter (E)	Summer (E)	Winter (R)	Summer (R)
$\dot{m}_1 (t/h)$	453.7	394.9	453.7	332.6
$Q_{fuel} (MW)$	333.9	289.7	361.0	249.4
$\dot{m}_{11} (t/h)$	20	87.2	20	46.7
$\dot{m}_{CO_2} (t/h)$	92.6	80.6	95.7	71.2
$Q_{export} (MW)$	222.2	143.1	222.2	143.1
$P_{el,total} (MW)$	64.3	60	82.1	60
η_{cog} (%)	85.8	70.1	84.3	80.7
η_{el} (%)	19.6	21	23.11	27.8

Discussion and Conclusions

The aim of this case study was to describe the old thermal power plant functioning with the repowering options evaluation.

In summer, cogeneration and electricity production efficiency appears to be lower. The reason is reduced demand for export steam, which means higher amount of steam expanding in the low-pressure part of the turbine resulting in more waste heat production. This stresses the need to considerate the seasonal impact on CHP operation [4]. Repowering yields an increase of cogeneration efficiency, and, as a result, lower fuel consumption and CO_2 emissions.

According to study conducted in Departments of Mechanical Engineering of various universities in Iran, using GT is an essential repowering method used for energy production improvement and operating lifetime of the unit extension [5]. As the results in table 1 show, it is obvious that adding GT to the cycle leads to more efficient electricity production.

This study presents one of the many methods how to balance between the increasing energy production demand and the need for a cleaner environment.

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