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Simulation Modelling of Hydrogen Thermochemical Cu-Cl Cycle Integration in a Gas Steam Power Plant

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ABSTRACT

To increase the use efficiency of energy source production, the simulation modelling of hydrogen thermochemical Cu-Cl cycle integration into the existing gas-steam power plant is elaborated. The hydrogen produced is stored in tanks and consumed when the market price is favourable. The results of the modelling showed that the production and use of hydrogen, in combination with fuel cells, are expedient for the provision of tertiary services in the electricity system. In the event of a collapse of the electricity system, hydrogen and fuel cells could be used to produce electricity for the own use of the thermal power plant. The advantages of independent production of electricity are especially reflected in the start-up of a gas-steam power plant, as it is not possible to start a gas turbine without external electricity.

Keywords: Cu-Cl cycle, electricity system collapse, gas-steam power plant, fuel cells, hydrogen production, independent production

NONMENCLATURE

Abbreviations	
ANN	artificial neural network
GS-PP	gas-steam power plant
GT	gas turbine
HRSG	heat recovery steam generator
HTCu-Cl	hydrogen thermochemical Cu-Cl cycle

1. INTRODUCTION

The development of methods of producing and using hydrogen for energy purposes represents a greater environmental challenge and contributes to a more rational production and use of energy. Hydrogen technology has already been developed to such an extent that it can be also used in larger thermal power plants without any major complications.

A simulation model of analysis of the integration of hydrogen thermochemical Cu-Cl (HTCu-Cl) cycle into the existing gas-steam power plant (GS-PP) is elaborated. The simulation model consists of an artificial neural network (ANN) and a set of thermodynamic equations that cross-calculate the desired values.

The innovation, originality and contribution to the new knowledge gaps are expressed in the efficient analysis and payback investment by integrating the HTCu-Cl cycle into an existing GS-PP by real process data.

The structure of the paper is composed in a way that the operation of the system is presented first. Then is presented the simulation model of the HTCu-Cl cycle integration and the end, the results with the discussion are presented.

2. OPERATION OF GS-PP

The GS-PP consists of two parallel-running gas turbines (GT) marked SGT-800 [2] in which natural gas is burned, creating high-temperature flue gases. The flue gases from the burners travel through the turbine part of the GT, where they emit part of their internal energy for the production of electricity [1]. From GT, the flue gases of the temperature of approx. 850 K and pressure approx. 0.12 MPa enter a heat recovery steam generator (HRSG).

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In HRSG, flue gases emit the rest of their internal energy, which is used to produce high-pressure steam, intermediate-pressure steam and hot water for district heating. From the HRSG, the flue gases are discharged into the environment at a temperature of approx. 350 K. Most of the high-pressure steam is discharged from the HRSG to the high-pressure part of the steam turbine, and the rest of the high-pressure steam can be discharged into the HTCu-Cl cycle to produce hydrogen. Depending on energy needs, intermediate-pressure steam from HRSG can be used for various purposes: for industrial purposes, it can enter and expand into the intermediate part of the steam turbine.

The construction design of the steam turbine enables two operating regimes of the steam turbine, namely the backpressure and condensing operating regime. In the backpressure regime, the steam turbine operates without exhaust steam, in the condenser, there is no steam condensation, and the thermal efficiency of the process increases. The condensing mode operation of a steam turbine is when the needs for thermal energy for industrial purposes are lesser than the need for electricity. Exactly the condensing mode operation of the steam turbine is the mode of process operation where the hydrogen can be intensively produced with the HTCu-Cl cycle.

Steam turbine has three turbine extraction: high-pressure, intermediate-pressure and low-pressure turbine extraction. Steam from the high-pressure steam turbine extraction can be taken to the HTCu-Cl cycle for hydrogen production, while steam from the low-pressure turbine extraction can be also taken to the HTCu-Cl cycle for hydrogen production. The remaining steam, which does not leave the steam turbine via the turbine extraction, also expands in the low-pressure part of the steam turbine [3].

In addition to the above, GS-PP also contains a hydrogen storage tank and fuel cells for the production of electricity, when the market price is favourable. A schematic representation of the GS-PP with the integrated HTCu-Cl cycle and marked thermodynamic states of the fluids is shown in Fig. 1.

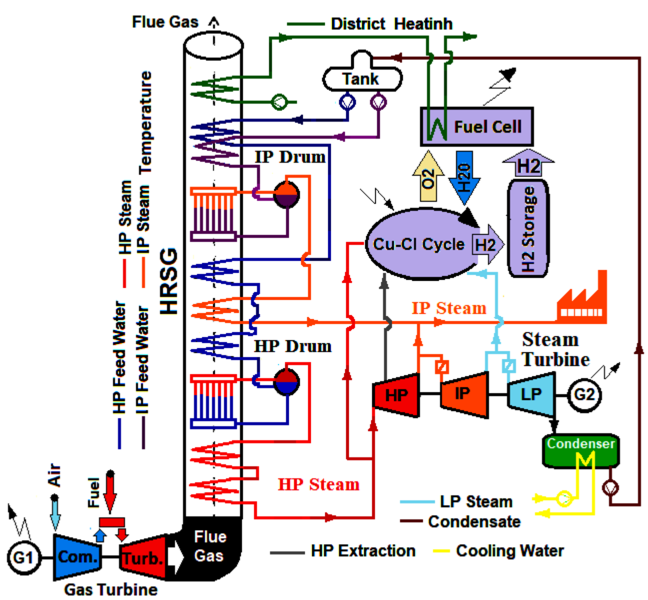

Fig. 1. Schematic representation of the GS-PP with integrated HTCu-Cl

3. SIMULATION MODEL OF THE HTCU-CL CYCLE

The architecture of the simulation model consists of an input unit, two ANN, four sub-models, and results report monitoring. The input unit contains five groups of input data. Two groups of input data, which are the ambient temperatures and the natural gas mass flow for the GT drive, are the input data groups in the ANN GT unit. The output data groups from the ANN GT unit are the mass flow and temperature of the flue gas from the GT.

So, the previously learned and validated ANN GT unit with real process data obtained from the supervisory control and data acquisition system, based on the ambient temperature and the mass flow of natural gas required to drive the GT calculates the mass flow and temperatures of the flue gases from the GT. The remaining three groups of input data, which are: pressure, temperature and mass flow of intermediate-pressure steam is the input groups of data in the ANN

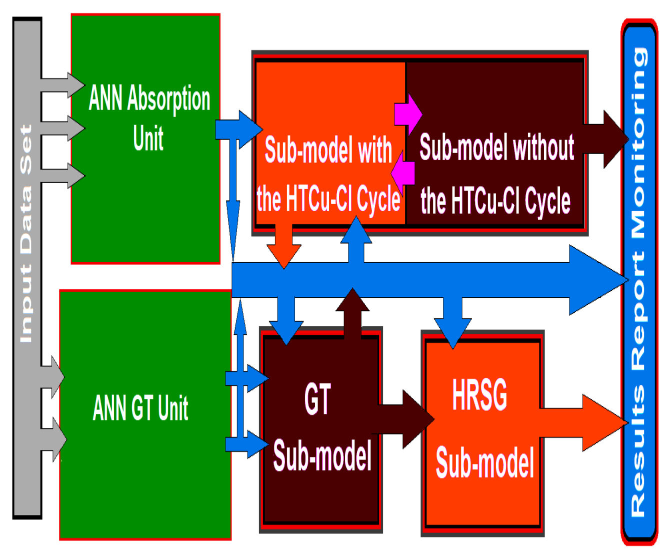

Fig. 2. Architecture of the simulation model of the HTCu-Cl cycle

absorption unit. The architecture of the simulation model of the HTCu-Cl cycle is shown in Fig. 2.

The GT simulation model using thermodynamic equations calculates thermodynamic quantities, power useful efficiencies, and economically evaluates GT performance. The output data groups from the GT simulation model serve as input data groups to the remaining models and are simultaneously stored in the results report monitoring unit.

With the help of previously calculated data groups, the HRSG simulation model calculates the generated amount of high-pressure steam, intermediate-pressure steam, district heating power, flue gas temperatures, the energy efficiency of the HRSG, etc. Steam turbine simulation models with and without HTCu-Cl cycle using mathematical equations calculates the operation parameter of a steam turbine with and without HTCu-Cl cycle.

4. RESULTS WITH DISCUSSION

Results presentation of the GS-PP simulation modelling is arranged with and without the HTCu-Cl cycle. So that first the mass steam balances for the production of hydrogen and the quantity of hydrogen produced are presented, followed by power analyses and comparative useful efficiency analyses of the GS-PP with and without the HTCu-Cl cycle. Finally, the results of hydrogen production with the HTCu-Cl cycle with payback periods of investment are presented.

Simulation, modelling results of required steam mass balances hydrogen production and the quantity of producing hydrogen are shown in Fig. 3.

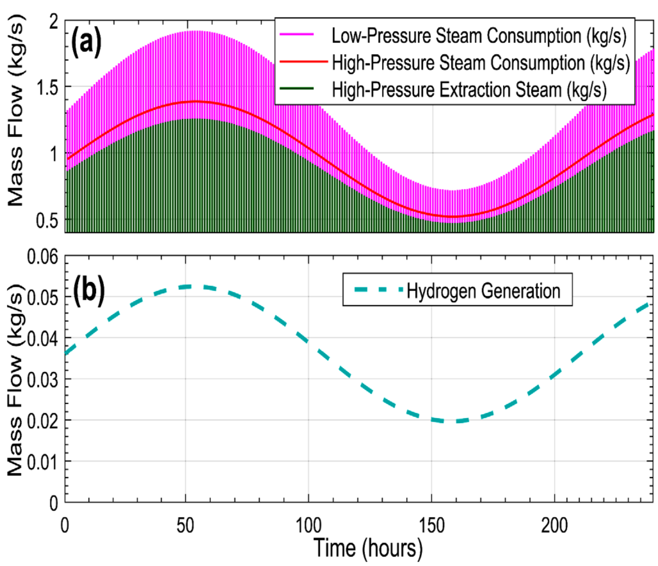

Fig. 3. (a) Steam mass balances for the production of hydrogen and (b) the quantity of hydrogen produced

Three different qualities of steam are needed to produce hydrogen. The high-pressure steam needed to produce hydrogen is taken directly from HRSG. This means that in the case when the HTCu-Cl cycle is operating, a smaller quantity of high-pressure steam enters the steam turbine than otherwise. High-pressure extraction steam is discharged from the steam turbine via the high-pressure turbine extraction.

The low-pressure steam required for the operation of the HTCu-Cl cycle also discharges from the steam turbine via the low-pressure turbine extraction, Fig. 1. As the steam flows are slightly reduced due to the operation of the HTCu-Cl cycle, a smaller amount of steam expands in the steam turbine and less work is done by the steam turbine. Fig. 4 shows useful power efficiencies of the entire GS-PP with or without considering the HTCu-Cl cycle.

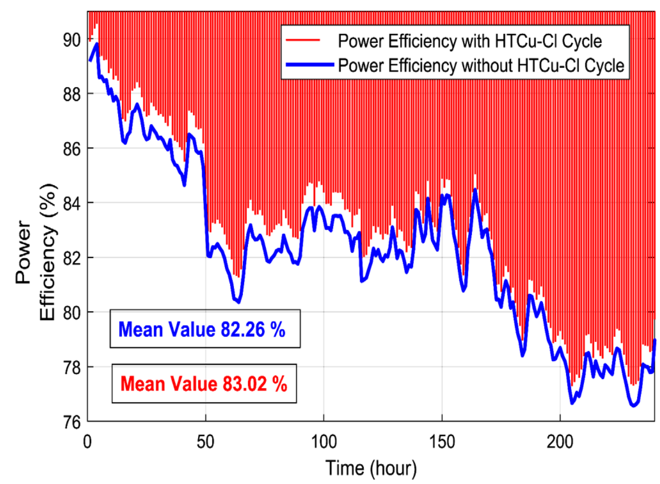

Fig. 4. Useful power efficiencies of the entire GS-PP with or without considering the HTCu-Cl cycle

From Fig. 4 it is evident that the power useful efficiency of the total GS-PP without taking into account the HTCu-Cl cycle on average in the analysed period amounts to 82.26 %. The power efficiency of the entire GS-PP cycle, taking into account the HTCu-Cl cycle on average in the analysed period amounts to 83.02 % and is 0.76 % higher. The higher power useful efficiency of the entire GS-PP, with taking into account the HTCu-Cl cycle, is mainly attributed to the increase in the amount of steam leaving the turbines via turbine extractions, which is further usefully spent for other purposes.

On account of the increased amount of steam to the turbine extractions, the amount of exhaust steam that travels to the turbine condenser and then is uselessly discharged into the environment is reduced.

In calculating the payback period of the investment, in addition to energy prices, the simulation model also takes into account a 7 % discount rate, 20 % tax rate, 2.5 % maintenance costs in relation to investment costs. The total investment costs of integrating the HTCu-Cl cycle and the cost of fuel cells are estimated at 30,000,000 monetary units [4], [5].

The purpose of calculating the payback period of the investment is to calculate the net present value, which is a basic indicator of the economy of the investment. Only when the net present value is positive, the investment is economical. The payback period of the investment into the integration of the HTCu-Cl cycle into the existing GS-PP at constant hydrogen production of 0.03 kg/s is shown in Fig. 5.

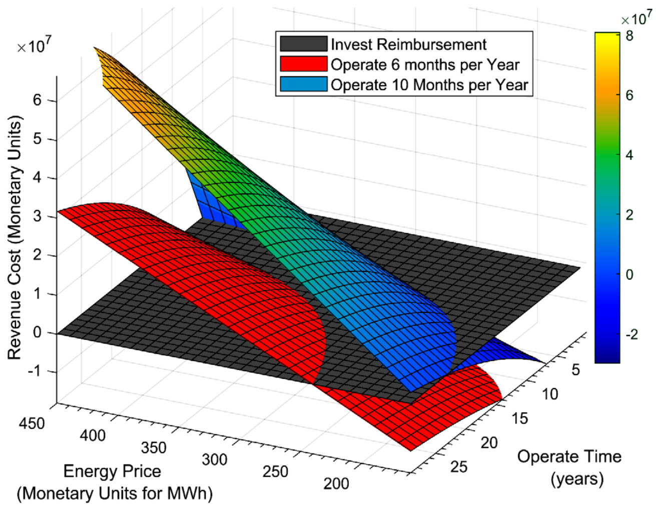

Fig. 5. The payback period of the investment into the integration of HTCu-Cl cycle into existing GS-PP at constant hydrogen production of 0.03 kg/s and at 6 months and 10 months of continuous operation

In Fig. 5, the upper curve surface of greenish-blue colour shows the net present value of 10 months of continuous operation of the HTCu-Cl cycle, the middle curve surface of red colour shows the net present value of 6 months of continuous operation of the HTCu-Cl cycle and the horizontal surface of grey shows the investment payback period limit. Only when the curve surface of the net present value green-blue colour and red colour intersects the horizontal surface plate of black colour, the investment is paying off.

In the case of 6 months of uninterrupted operation of the HTCu-Cl cycle per year and at a selling price of hydrogen energy of 450 monetary units per MWh, the payback period of the investment is 8 years. The minimum selling price of hydrogen energy is 280 monetary units per MWh, so that the investment pays off in 30 years. In the case of 10 months of uninterrupted operation of the HTCu-Cl cycle per year and at a selling price of hydrogen energy of 450 monetary units per MWh, the payback period of the investment is 4 years.

In case the investment pays off in 7 years, the selling price of hydrogen energy is 290 monetary units per MWh. The payback period of the investment therefore largely depends on the price of the hydrogen technology plant.

5. CONCLUSION

Integration of the HTCu-Cl cycle into the existing GS-PP improves the power useful efficiency of the entire plant.

The power useful efficiency of the whole with the integration of the HTCu-Cl cycle in the existing GS-PP increases on average by 0.76%.

The economic analysis of the payback period of the investment shows that the investment of the integration of the HTCu-Cl cycle in the existing system is profitable only when the system operates at an annual level for at least 10 months.

Hydrogen production in thermal power plants is currently quite unfavourable due to high investment costs. However, in the event of an increase in the prices of ecological taxes, CO_2 coupons and a decrease in the prices of the hydrogen plant, hydrogen technology will also become more cost-effective for integration into existing thermal power facilities.

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