Efficiency of HRSG within a Combined Cycle with gasification and sequential combustion at GT26 Turbine

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Abstract While most attention of Integrated Gasification Combined Cycles (IGCC) developers focus on the gas turbine, only a few papers turn into the gasifier processes and the steam cycle beginning with the Heat-Recovery Steam Generator (HRSG). Therefore, in this paper we have undertook the problem of optimal utilisation of both the chemical energy of coal and the flue gas recovery heat within a HRSG. For selected advanced ABB GT26 gas turbine composed with a triple-pressure HRSG and a coal gasifier, the combined cycle have been analysed parametrically using own computer code COM-GAS. The efficiency of IGCC, with respect of steam turbine parameters like power, live steam pressure, has been find for the HRSG designed by the pinch point technique.

Introduction. Power generation concepts involving the combustion of coal-derived fuels in heavy duty gas turbines put forward two major actors of the energy market: the first is Coal with proven clean technologies, the second is the modern Gas Turbines. Today, advanced energy schemes associating coal with gas turbine are serious candidates for the power generation concepts that will require, besides the classic availability, reliability performances, operation flexibility and environmental friendliness [1-5].

This paper aims at presenting thermodynamical analysis of a syntetic gas-fired combined cycle plants based on the ABB GT26 engine. Our analysis will be performed using a home-code COM-GAS for multi-variant design of an advanced combined cycle in different configurations of the plant's apparatus. The combined cycle assumed here is a 1-2-1-1 configuration with one gasification plant of LUERGI type, two GT26 engines, one HRSG of RAFAKO type, one Steam Turbine of 200MW type. Figure 1 shows the main apparatus with the triple steam cycle with High-, Intermediate- and Low-Pressure parts of the HRGS. Steam turbine part, on this stage of researches, will be modelled "roughly" without any apparatus [17,23].

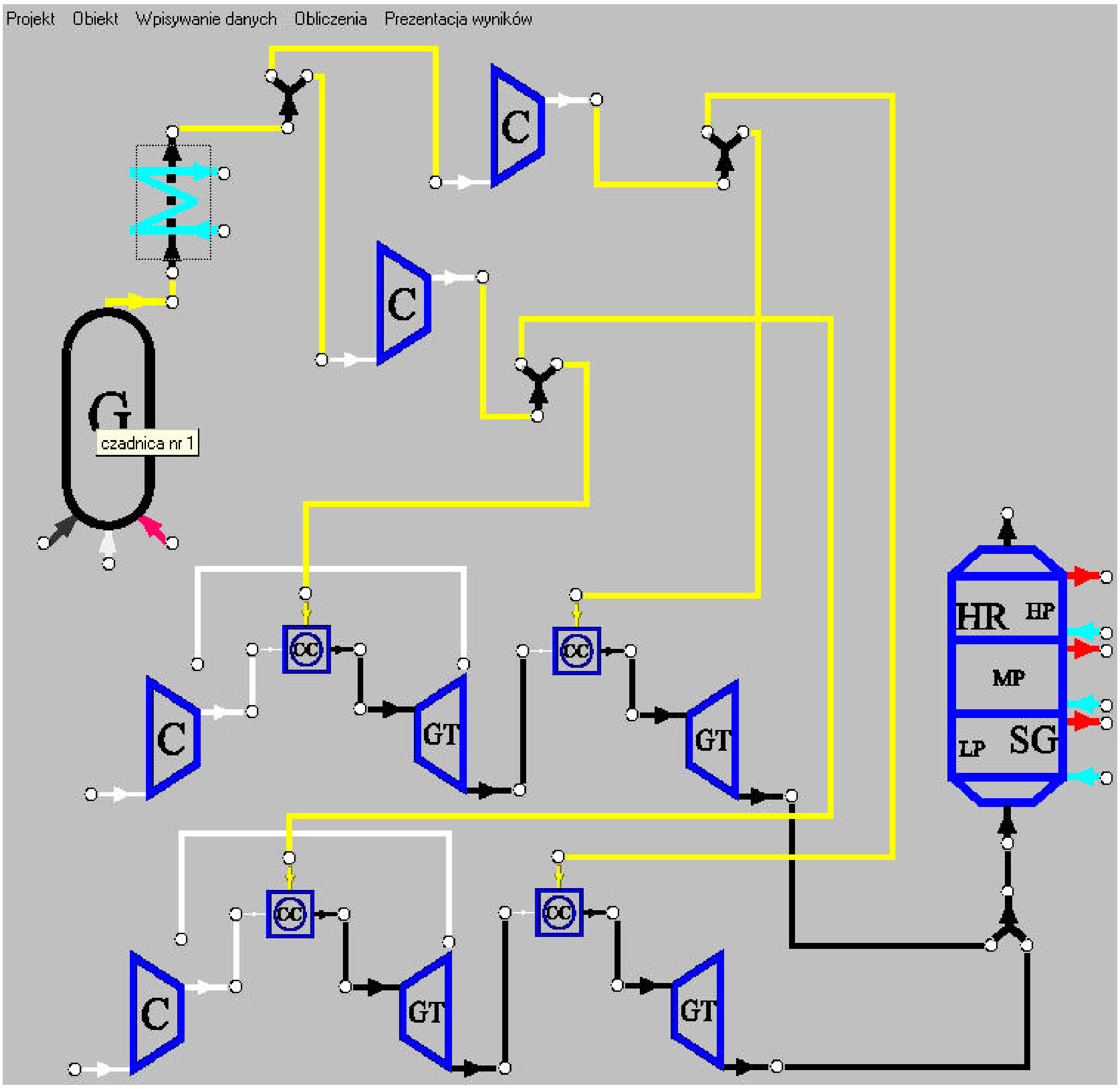

Figure 1. Plant schemes of IGCC type

Usually the gasification concept involves the addition of large pieces of hardware to the power plant, including, beyond the gasifier itself, an air separation process, syngas cooling and hot-gas-clean-up, compressors, etc. In this stage of development, our code could calculate a cycle without the hot- and cold-gas cleaning and the air separation process.

The Gas Turbine GT26. The ABB GT26 engine has been selected for this study because it has particular characteristics such as the exhaust temperature being about 30°C higher then in competing machines [6,7]. The GT26 at 240MW is the largest 3000 rev/min gas turbine now available for the 50 Hz market. It holding out the prospect of 37.8% simple cycle efficiency and 58.5% in a combined cycle [11,20]. With a sequential combustion it ensures that both a high exhaust gas temperature and a high power conversion per kilogram of air drawn in are achieved [21]. The sequential combustion realised in low-emission EV and EVS- burners, respectively, characterising by flame-less oxidation on the second stage of an annular combust chamber [22].

Advanced Heat Recovery Steam Generator (HRSG). Besides continuous development in design and performance of gas turbines for power generation, tremendous progress is being made in HRSG technology [22,8,9,10]. Increasing sizes, exhaust gas turbines (t>600°C) and mass flow ($\dot{m}_{flue\ gas} > 540$ kg/s) of the recent gas turbines are having a major impact on new advanced HRSG design. Nowadays' designs need to incorporate many more features to ensure optimum efficiency [18]. Therefore, in the paper we want to consider a triple-pressure HRSG which is particularly patterned on the RAFAKO's production [22], NEM Energy [8], EVT Energie-und Verfahrenstechnik [12] (Figure 2).

Our HRSG is a most advanced triple pressure generator which consists three (LP+IP+HP) evaporator systems designed for parallel flow operation, three drums, IP economiser, two HP economisers and LP, IP, HP, superheaters. Different interlining between heating surfaces of LP-economiser, IP-economiser, HP-economiser as well as between the evaporators and superheaters leads, in general, to quite different distribution on the heat consumption diagram and unexpected localisation of the pinch point. The assumptions for the HRSG are as follows [4,5,19]

- Maximum HP steam superheat temperature is 535°C - this corresponds to temperature of live steam using in the domestic ST of 200MW-type.
- Minimum pinch point temperature difference is 10°C
- Minimum stack temperature: 75°C
- Maximum working pressure : 200 bar

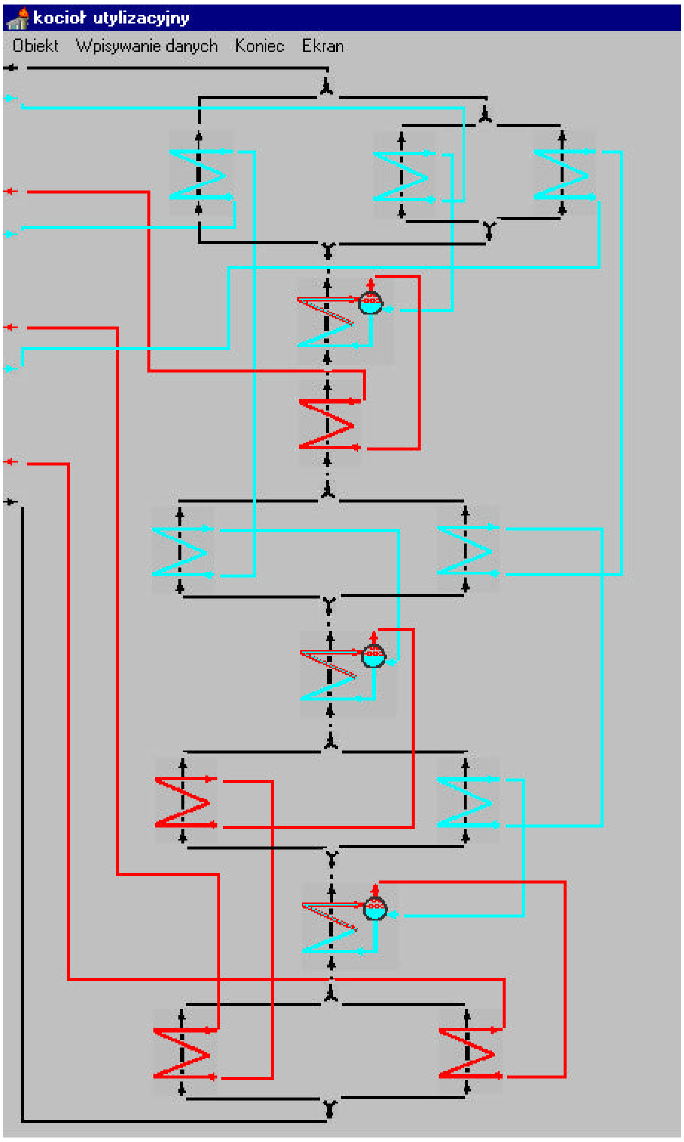

Figure 2. Scheme of a triple-pressure HRSG

Description of the COM-GAS code. In order to do quickly and multiple calculations of combined cycle power plant during of multi-variant design process we have developed a computer code combined with so-called friendly using of graphical mode for preparation and change of a scheme of cycle [13-16]. The COM-GAS code algorithm is based on the fulfilment of the basic governing balances of mass, momentum and energy in discrete points of a cycle [13,14]. Such an approach, which also has been used in other commercial codes [1,2,3], leads to a system of non-linear algebraic equations with unknowns pressure, temperature, mass flow, mass fraction, enthalpy, etc. Discrete points are usually localised on the inlet and outlet from a single apparatus.

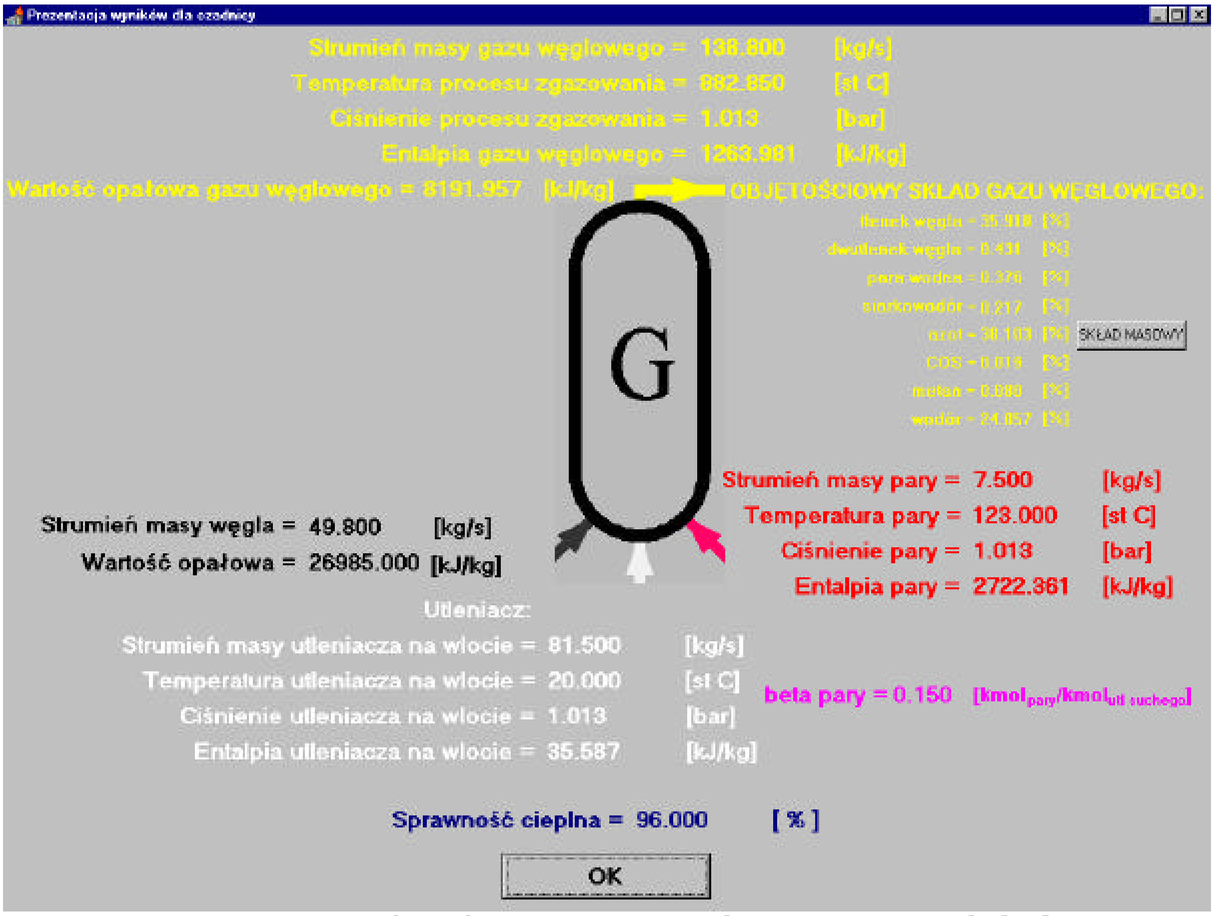

FIGURE 3. Typical results presentation in the COM-GAS code [19].

Our code, in its present form, can calculate plants that contain such apparatus as follows: compressors, combustion chambers, mass flow separators, pumps, ventilators, stages of gas turbines, heat exchangers (parallel- and counter flow type and parallel or sequentially arranged), feed water-tank, steam drum, coal gasifier, mass flow and total energy flow changes (heat losses, heat supplies).

Example of Calculations.

In order to find an optimal scheme of the combine cycle plant it should be defined the thermal efficiency of a plant. Here, knowing enthalpy of the working fluid and the efficiency of any particular apparatus the net efficiency is calculated for every arbitrary part of the cycle according to the following procedure

*thermal efficiency = (output power + mass flow of steam*available specific enthalpy)/chemical energy*

The following data are taken for calculations: **Gasifier:** Coal composition (by weight) Carbon 64.44%, Hydrogen 3.95%, Oxygen 7.40%, Sulphur 0.85%, Nitrogen 1.49%, Ash 12.49% Moisture 9.2% , Coal HHV - 26.985 MJ/kg, Coal LHV - 24.66 MJ/kg, Coal input mass flow 49.80 kg/s, air inlet mass flow 81.50 kg/s, air temperature and pressure 20°C, 1.013 bar, inlet steam flux 7.50 kg/s, temperature and pressure of steam 123.00°C and 1.0138 bar, heat loss (%of input LHV) 0.40, gasifier pressure 1.013 bar, steam/dry air ratio 0.15. **GT26:** Air input mass flow 472.6 kg/s, air temperature and pressure 15°C, 1.013 bar, Compressor pressure ratio 30.
HRSG: Water inlet temperature (°C), pressure (bars) 60,178 – HP, 60,30 – IP, 60,4 – LP.
Live steam outlet temperature (°C) 535 – HP, 535 – IP, 200 – LP.

The following results have been calculated :

Gasifier : outlet temperature 882.85^oC

Syngas composition: CO – 35.918%, C_2O – 0.431%, H_2O – 0.376%, H_2S – 0.217%, N_2 – 38.103%, COS – 0.019%, CH_4 – 0.08%, H_2 – 24.857%

Unclear syngas LHV value – 8.192 MJ/kg

Syngas mass flow - 138.8 kg/s

GT26 : gas turbine compressor

Outlet temperature – 529.66 ^oC

Outlet pressure – 30.39 bar

Outlet entalpy – 573.06 kJ/kg

Outlet mass flow – 467.6 kg/s

Gas turbine combustior (I stage)

Outlet temperature – 1159.63 ^oC

Outlet pressure – 30.39 bar

Outlet mass flow – 517.92 kg/s

Outlet flue gas composition: N_2 – 74.842%, CO_2 – 4.843%, H_2O – 4.795%, SO_2 – 0.001%, O_2 – 14.688%, Ar – 0.831%

Gas turbine (the first one stage)

Entalpy difference - 240.89 kJ/kg

Outlet pressure - 15.19 bar

Outlet temperature – 967.07 ^oC

Gas turbine combustior (II stage, flameless)

Outlet temperature – 1162.56 ^oC

Outlet pressure – 15.19 bar

Outlet mass flow – 542 kg/s

Outlet flue gas composition: N_2 – 74.175%, CO_2 – 6.439%, H_2O – 5.860%, SO_2 – 0.001%, O_2 – 12.722%, Ar – 0.803%

Gas turbine (the second four stages)

Entalpy difference – 728.49 kJ/kg

Outlet temperature – 573.7 ^oC

Outlet pressure – 1.06 bar

HRSG:

Live steam outlet pressure (bars) 169.28 – HP, 28.53 – IP, 3.82 – LP

Live steam mass flow (kg/s) 67 – HP, 66 – IP, 58.5 – LP

Outlet flue gas temperature - 81.13^0C

Pinch point $\Delta T = 11^o C$

Since certain parameters within HRSG are free and can varies within technological constrains, we have analysed efficiency of HRSG with respect on changing enthalpy of the live steam, or the pressure of HP steam.

From calculations, it follows that the inter-linking is necessary in all three stages to achieve similar temperature levels on the cooling medium side. This result in HP economiser heating surfaces being split into three separate sections. As follows from FIGURE 4, it is necessary for optimal temperature distribution both on the flue gas side and on the cooling medium side.

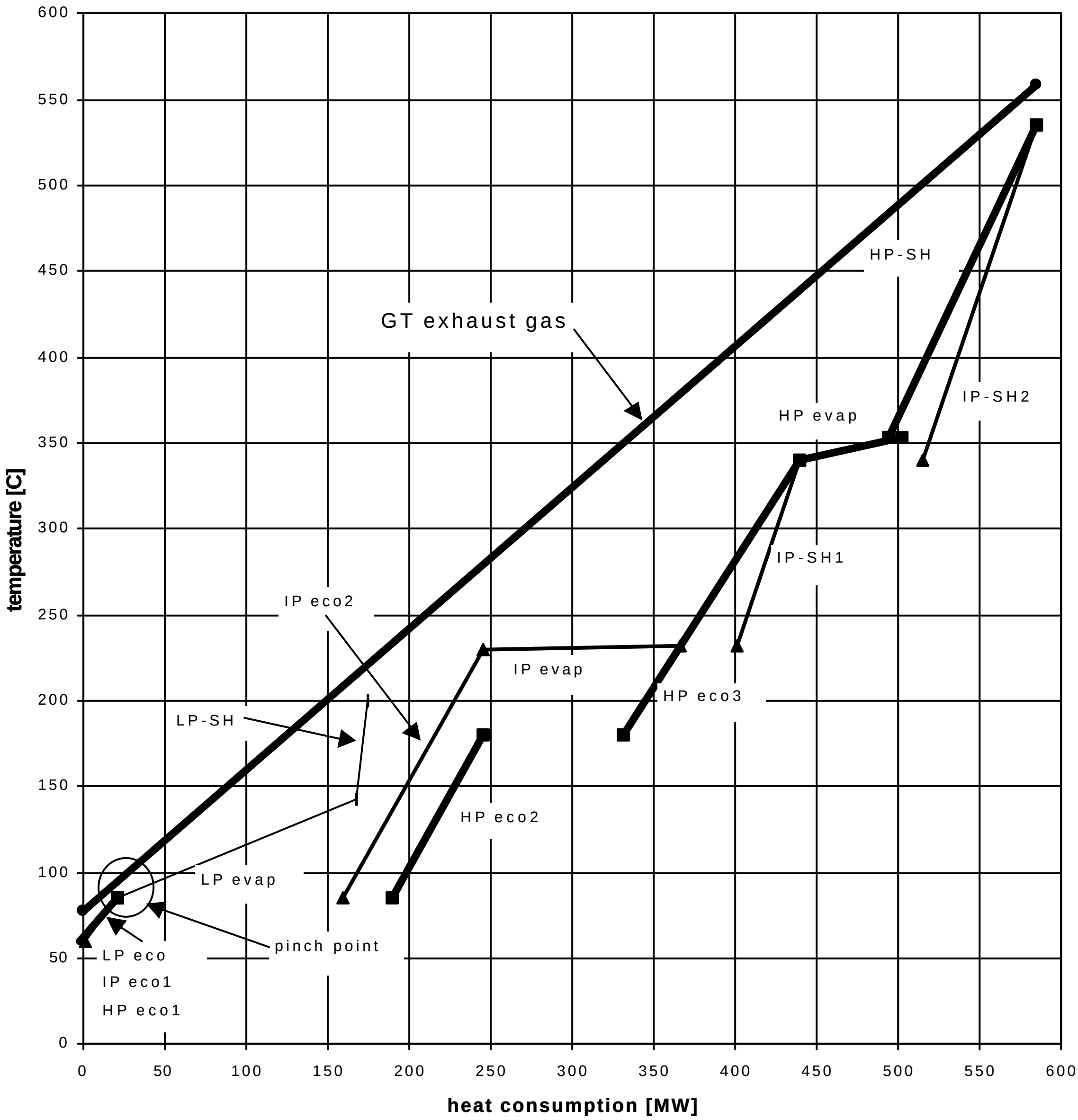

FIGURE 4. Heat consumption versus temperature diagram for the HRSG

Conclusion

The performances of the COM-GAS code are shown in this report. The code is underdevelopment, nevertheless, as a first general consideration, one can say that gasification schemes, even if including a conservative steam cycle can surpass the efficiency in some cases by several percentage points.

Concerning HRSG, the traditional HRSG design is essentially based on manufacturer experience and heuristics in order to obtain convenient matching of temperatures drop, pressure drop and exchange surface area. Taking advantage of the fact that HRSG is thermodynamically determined by the knowledge of working fluid temperature and their enthalpies, it is possible, using a computer code like the COM-GAS, to find more optimal and consistent exchangers arrangement. The authors study [23] shows that some kind of optimisation analysis has is required that in the case when the exchangers arrangement is not to far from optimum.

It has to be noted that the COM-GAS code, having open form, could be to develop a procedure for identifying temperature pinches in critical zones. In contrast to power boiler plants HRSG feature is one or several temperature pinches. An in-deep reconsideration of the optimisation process is needed due to fact that there can be contradiction between optimum of individual components of the HRSG and its overall efficiency.

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