HYDROGEN PRODUCTION OPTIMIZATION IN REFINING INDUSTRY

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Abstract

In current economic and environmental situation in refining industry it is very important to increase crude oil conversion to produce more valuable light products. The key factor to deeper conversion is hydrogen, which is mostly produced in refineries by steam reforming technology. These processes belong to most energy consuming, and produce large amount of excess steam, which is not usually utilized on site, but it is exported to refinery steam network. A new hydrogen production plant is to be built in SLOVNAFT refinery. In this contribution, four investment proposals capable of solving the resulting anticipated steam excess are presented and their impact on steam balance, fuel consumption and electricity production is evaluated.

Introduction

Slovnaft refinery is relatively small, but complex refinery processing mostly Russian export blend crude oil. Conversion of crude oil to light products usually exceeds 90%, therefore high amount of hydrogen production is needed to fulfil hydrocracking units' consumption. Two quality grades of hydrogen are produced by steam cracker, catalytic reformer, PSA purification of off-gases and two steam reforming units, but lately, their maximal hydrogen production capacities are reached more often. In future hydrogen demand in Slovnaft refinery is expected to grow due to:

- Decreasing Russian export blend crude oil quality
- Increasing ratio of heavier and sourer feedstock
- Continual revamp of existing units to increase crude oil conversion to lighter products and to meet tightening fuel quality standards

Therefore, commissioning of a new hydrogen production unit based on steam reforming is considered in Slovnaft refinery. As a by-product of steam reforming technology, excess of steam arises [1], therefore, unit connection to refinery steam network is important to reach optimal economical operation of hydrogen production.

Steam balance in Slovnaft refinery

Steam in Slovnaft refinery is produced by two main sources. First one is thermal power plant, TPP, which is currently part of the refinery. Secondary steam sources on different pressure levels utilizing waste heat are found directly on production units.

TPP is not only producing steam but also generates electricity to cover part of refinery's consumption. It is equipped with five boilers, which are producing very high-pressure steam. This steam is in turbines, where electricity is produced, or in reduction station, reduced to three steam pressure levels: high-pressure, HP, medium-pressure, MP and low-pressure, LP [2]. Four turbines, with different configurations of steam extractions are located in TPP. Three of them are condensation turbines and one is back-pressure turbine. Typically, 2 – 3 of them, depending on season, are in operation. It is common, that turbines´ extractions are not able to fully satisfy demand of each pressure level, therefore rest of steam's need is reduced on reduction stations, which are able to produce to all other levels from very high-pressure steam level , but no electricity is produced and therefore energy difference between levels is wasted.

HP steam consumption is highly depended on refinery operation configuration and amount of steam from TPP is often fluctuating. The new hydrogen production plant, HPP3, is estimated to export 43.2 t/h of HP steam to network in average [3], while the old HPP1 plant currently exports just 10 t/h of HP steam in average. As depicted in Figure 1., there will be average surplus of 16.2 t/h of HP steam to refinery steam network after HPP3 commissioning and HPP1 shutdown . Without any intervention, this steam will be reduced to MP steam level and energy difference between HP and MP steam will be lost. Therefore, four alternatives were considered to reduce this economical loss.

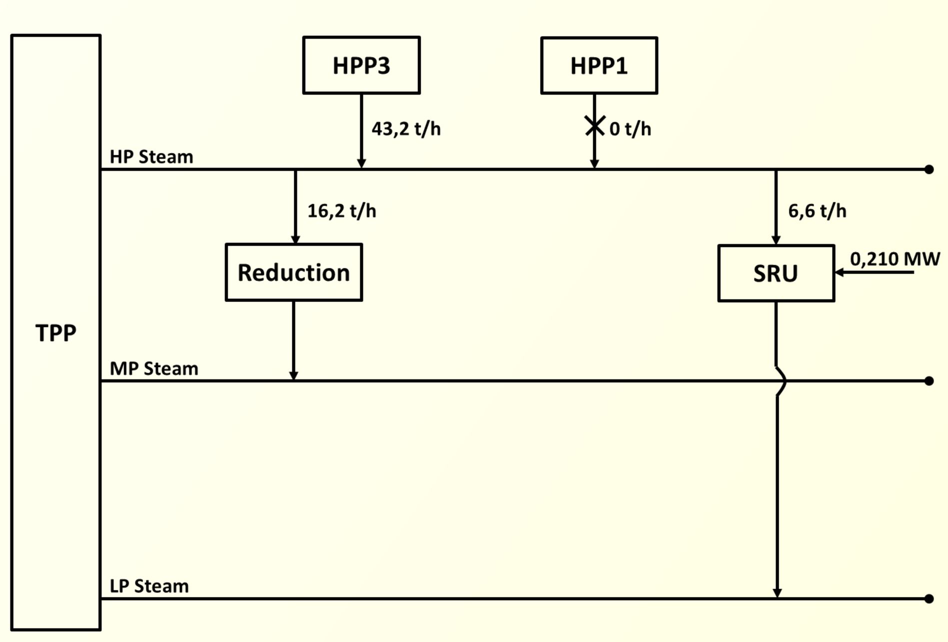

Figure 1. Steam network after HPP implementation

Replacement of steam drives on Sulphur Recovery Unit

Sulphur Recovery unit, SRU, operates two steam drives, which are reducing HP steam to LP steam, while generating shaft energy to drive pumps directly on unit. Their average steam consumption of turbines is 4.7 t/h and 1.9 t/h, respectively. Originally, they should be in operation as much as possible to lower low quality HP steam export from unit, but due to decreasing reliability of steam-driven position, their average operation time in present reaches 66 % and 42 %, respectively.

Replacement of those steam drives for new ones, which will be operating between HP and MP steam level, is one of the solutions how to solve HP steam surplus situation. Due to smaller pressure difference between HP and MP steam, compared to HP and LP steam, new steam drives will consume more HP steam than the existing ones [4], lowering the unwanted reduction between HP and MP steam level to minimum, as it is depicted in Figure 2.

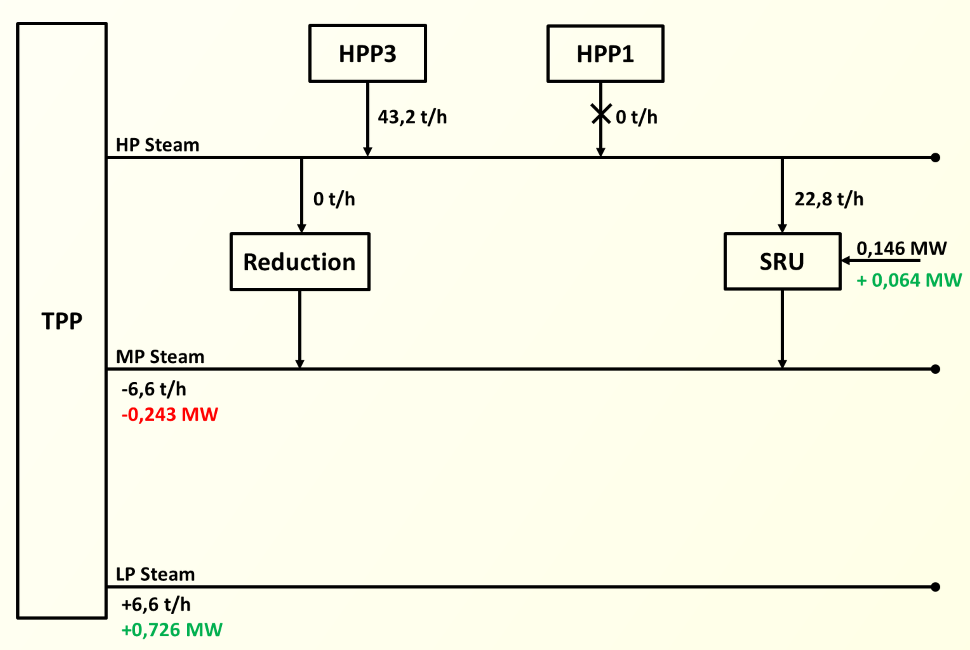

Figure 2. Steam network balance change after replacement of steam drives on SRU

Total steam export from TPP maintains at the same level. Also, HP steam supply from TPP maintains at the same level. However, MP steam supply from TPP will decrease, causing loss on electricity production directly on TPP turbines. This loss will be lowered by fact, that 30% of produced MP stream on TPP is reduced without generating any electricity at present. Lack of LP steam, which was originally supplied from SRU unit, will be replaced by TPP production of LP steam, where it will produce additional electricity. Increase of LP steam production from TPP will also help in summer season. Higher operation time of turbine positions, which is expected to reach 79 % in this configuration , will lower average electricity consumption of electromotor positions. In total, installation of new turbines at SRU will cause increase of electricity production by 0.547 MW on average.

New stand-alone backpressure turbine installation

The basis of this solution is replacement of reduction station by back pressure steam turbine, which will be processing HP steam to MP steam and producing electricity. Enthalpy difference between HP and MP will be much lower than in TPP; therefore, this small turbine will have lower specific electricity production than the large turbines in TPP. Due to fact, that 30 % from total production of MP steam is reduced from HP, this turbine can be used also to avoid this reduction and to produce additional electricity. After data analysis, it was calculated, that in average additional 5 t/h can be processed on this turbine instead of being reduced in TPP. In total, this turbine will be processing 21.2 t/h of HP steam in average and will yield 0.65 MW power output. This situation is depicted in Figure 3.

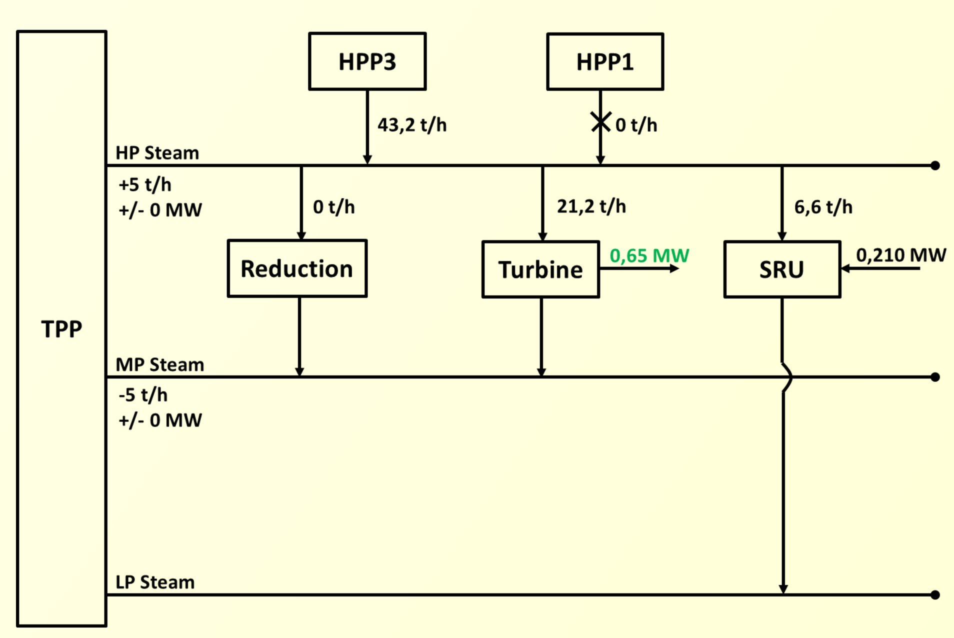

Figure 3. Steam network balance change after new back pressure turbine installation

From the viewpoint of TPP, total steam export will be maintained. More HP steam instead of MP steam, 5 t/h, will be supplied to network to by process on new turbine, but because it is usually reduced on TPP, it will not cause any losses.

Change in design of Hydrogen Production Plant 3

Hydrogen Production Plant 3 is still only in initial commissioning phase, so there is still option to change its design easily. The contractor was asked to propose new design solution, which will decrease HP steam production of unit. Their proposal was to add an EHTR reactor, which will recover part of heat from steam reformer effluent for enhanced reforming whereby less heat will be available for HP steam generation. This configuration will decrease HP steam production by 11.2 t/h on average. Fuel consumption reduction was estimated from enthalpy of HP steam and estimation of 90 % efficiency of steam generation on HPP3. Lower HP delivery to steam network from HPP3 will be covered by TPP and will boost electricity generation on turbines. Altogether, approximately 4 GJ/h more fuel will be consumed but 0.871 MW more electricity will be produced, as results from Figure 4.

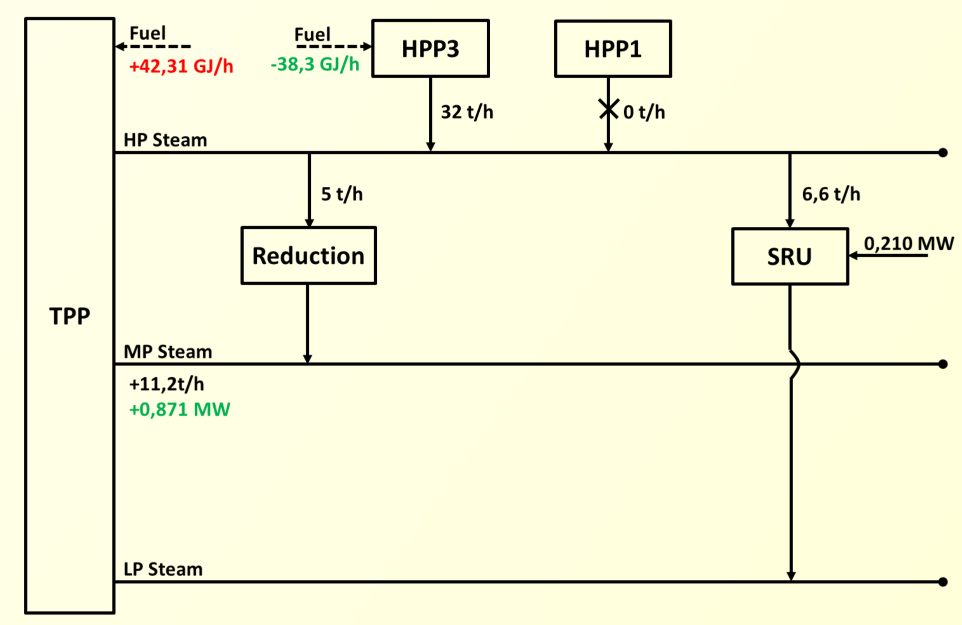

Figure 4. Steam network balance change after EHTR implementation

Usage of HP steam in reboilers in RREF unit

Higher consumption of HP steam directly on units in refinery is also one of the solutions how to handle HP steam surplus in network in future [4]. Reformate splitter unit, RREF, is using reboiler furnaces at present , where refinery fuel gas is burned, to heat process streams in distillation columns. The advanced age of furnaces and their technical condition cause, that they can reach maximal 85 % efficiency. Their replacement by HP steam reboilers, will serve as new HP consumer in refinery, and more electricity will be produced on TPP turbines from this steam. However, this additional steam needs to be produced on TPP, therefore, fuel consumption on TPP will increase.

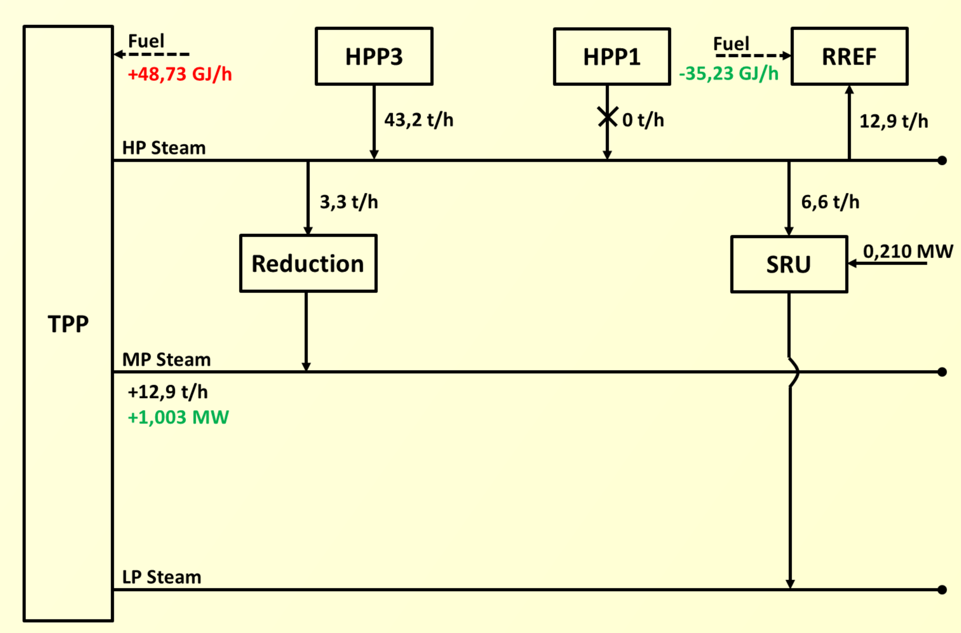

Figure 5. State of steam network after RREF reboiler installation

To sum it up, in average 13.5 GJ/h more fuel will be consumed but power production of TPP increases by around 1 MW.

Conclusions

In this case study, four proposal, how to solve surplus of HP steam in network after HPP3 implementation were presented. All of them help lowering the operational costs of the energy system of the refinery. However, in cases of new steam drives on SRU, new stand-alone backpressure turbine and design change of HPP3 capital expenses are very significant, and payback period exceeds 7 or even more years. This is not acceptable at present. The economic feasibility of HP steam reboilers on RRED project, is closely connected with condensate recovery system project. Without its simultaneous realization only a change in utilities' prices could yield positive benefit from this project. With condensate recovery project in operation, simple payback was calculated to 4 years, which is an acceptable value [5]. However, this project solves the HP to MP steam reduction only party.

Acknowledgement

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