CHEMICAL ENGINEERING TRANSACTIONS

VOL. 70, 2018

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Timothy G. Walmsley, Petar S. Varbanov, Rongxin Su, Jiří J. Klemeš

ISBN 978-88-95608-67-9; **ISSN** 2283-9216

DOI: 10.3303/CET1870187

Optimised Integrated Steel Plant Operation Dependent on Seasonal Combined Heat and Power Plant Energy Demand

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The steel industry is energy intensive with large corresponding contributions of fossil CO_2 emissions, which accounts to around 7 % of the global emissions. This presents great challenges, and continuous work is therefore done to reduce energy consumption and CO_2 emissions. This work evaluates ways of decreasing the total energy demand and CO_2 emissions in a system containing integrated steel plant connected to a combined heat and power plant (CHP), through optimised production operation with respect to seasonal-dependent energy demands.The studied system, which includes SSAB EMEA Luleå (integrated steel plant) and LuleKraft (CHP), is located in the municipality of Luleå in northern Sweden. The CHP produces the base demand of district heat (DH) for the community, with process gases from the integrated steel plant as its main fuel. Oil is used as an extra energy source when the amounts of process gases are insufficient to meet the DH demand, which happens mainly in the cold winter periods. Therefore, this study aims to find production guidelines to minimise the additional energy consumption of oil through matching cold winter periods with high production of process gases. Optimisation of the system is performed with a mixed integer linear programming (MILP) model based on process data for a normal year. The year is divided into periods based on varying DH demand, to give the model possibility to choose how the integrated steel plant is best operated in each period. The main variables in the integrated steel plant for the study are coke production and usage of recirculated materials, which are bound by yearly demand and availability. Optimisation of this setting is then evaluated in comparison to an optimisation where the integrated steel plant is operated in a constant manner the whole year. Results show that an optimised use of recirculated materials and coke production decreases yearly oil consumption with up to 8 GWh and increases yearly electricity production with up to 8 GWh.

1. Introduction

The steel industry is energy intensive with large corresponding contributions of fossil CO_2 emissions, which accounts to around 7 % of the global emissions. This presents great challenges, and continuous work is therefore done to reduce energy consumption and CO_2 emissions, which is also the aim for this work.

The system studied in this work includes SSAB EMEA Luleå (integrated steel plant) and LuleKraft (combined heat and power plant (CHP)) that are located in the municipality of Luleå in northern Sweden. The municipality has a district heat (DH) demand that is provided mainly by LuleKraft. Two different optimising process integration models have been developed and used for this system. The first model describes SSAB EMEA Luleå and LuleKraft, which is described by Larsson and Dahl (2003), Larsson et al (2006). The second model describes LuleKraft and the DH system in the municipality of Luleå described by Olofsson et al. (2013).

LuleKraft is obliged to produce up to 185 MW DH and obliged to produce electricity to SSAB so that less than 30 MW is imported. The fuels used in the CHP are process gases from SSAB and oil. Oil is mainly used when the conditions demand it, which happens in the cold winter or when SSAB has a stop in their production.

The integrated steel plant of SSAB EMEA Luleå includes coke plant, blast furnace (BF) and steel plant for steel slab production. Production of coke in the coke plant, production of hot metal in the BF and production of steel in the basic oxygen furnace (BOF) at the steel plant produces process gases that are used as fuel in the CHP.

Please cite this article as: Orre J., Bellqvist D., Nilsson L., Alstrom L., Wiklund S., 2018, Optimised integrated steel plant operation dependent on seasonal combined heat and power plant energy demand , Chemical Engineering Transactions, 70, 1117-1122 DOI:10.3303/CET1870187

How much process gas energy is produced depends on steel slab production rate, operation praxis' and incoming material to the processes.

This study aims to increase the utilisation of process gases and thus decrease the oil demand, which results in decreased energy demand and CO_2 emissions. This is done through optimizing one year operation of the integrated steel plant together with the CHP plant. The optimization model is constrained to use the same amount of incoming materials to the integrated steel plant at yearly basis but with the possibility to vary when to produce coke used in the BF and when to use scrap and briquettes made from internally recycled by-products.

2. Method

2.1 Modeling

Description of the optimisation problem is done in reMIND, a graphic modelling environment for the MIND-method. The mathematically described optimisation problem is then solved by a Mixed Integer Linear Programming (MILP) solver.

2.2 Model

The model describing the integrated steel plant is based on the model described by Larson and Dahl (2003) and Larsson et al (2006). That model has then been developed with a more precise CHP model and addition of time steps with constraints for the whole modeled time period. The new CHP model is a simplified version of the one used by Bellqvist and Olofsson (2012).

A schematic figure showing the main parts of the model together with energy flows and system boundaries is shown in Figure 1. The models are used in the following way in this project:

- Coking plant: Coking coal demand, energy demand and coke oven gas (COG) production is calculated depending on coke production.
- Blast furnace: Demand of raw materials and blast furnace gas (BFG) production is dependent on hot metal production and operation praxis.
- Steel plant: The steel plant contains basic oxygen furnace (BOF), secondary metallurgy and continuous casting, but only BOF operation praxis is varying. Demand of hot metal, scrap and other materials together with the basic oxygen furnace gas (BOFG) is varying depending on operation praxis of the BOF.
- Combined heat and power plant: Electricity production is dependent on the district heat production and the fuel input.

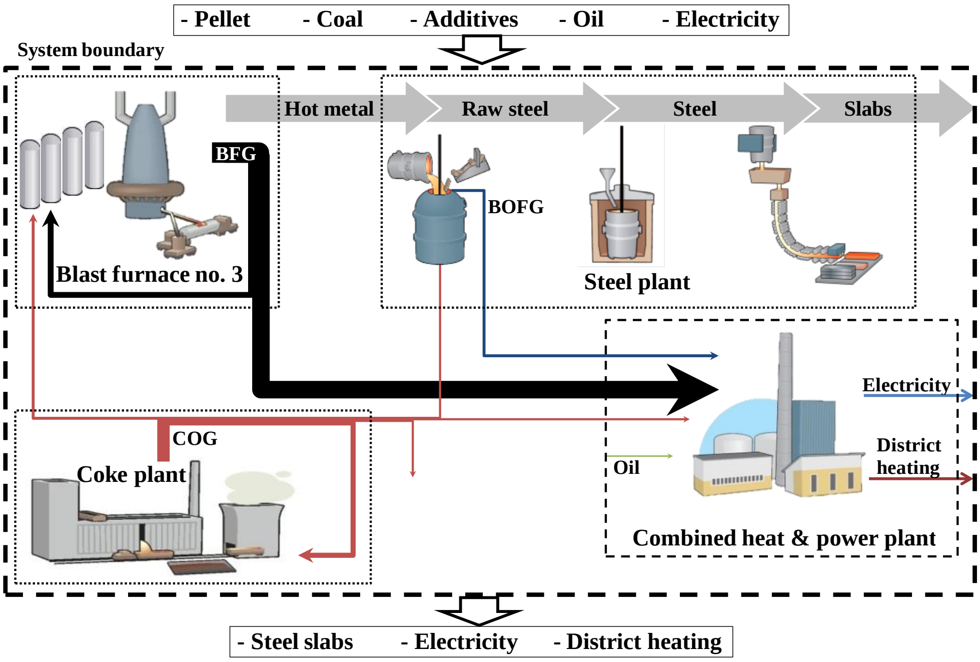


Figure 1: Schematic description of model with system boundaries and energy flows, where thickness of lines for process gases is proportional to normal energy flows.

2.3 Boundary conditions

System

A normal year with respect to integrated steel plant operation and outdoor conditions for DH demand is modeled. The year is divided into 15 periods with varying lengths based on DH demand and when there is production stop at CHP and/or integrated steel plant. The division into periods is done to enable varying operation dependent on external conditions. Table 1 shows the modeled year divided into 15 periods with different lengths, which are based on DH data from 2014-2016 and information about normal production stop lengths. Period 1-3 consists of periods with production stop at LuleKraft and/or integrated steel plant. Periods 4-15 are divided by DH intervals, where colder periods with higher DH demands have smaller intervals.

Table 1: Table title using style

	Period length (h)	Outdoor temperature (°C)	DH (MW)	Commentary	Season
Period 1	594			No production in LuleKraft	-
Period 2	30			No production in LuleKraft and steel plant	-
Period 3	210		97	No production in steel plant	-
Period 4	1680	16.3	28	0-40 MW DH	Summer
Period 5	1512	8.6	60	40-80 MW DH	Summer & spring/autumn
Period 6	792	4.0	91	80-100 MW DH	Spring/autumn
Period 7	1080	1.5	111	100-120 MW DH	Spring/autumn
Period 8	1200	-0.7	128	120-140 MW DH	Spring/autumn & winter
Period 9	480	-4.1	148	140-155 MW DH	Winter
Period 10	264	-7.3	161	155-165 MW DH	Winter
Period 11	264	-7.6	170	165-175 MW DH	Winter
Period 12	198	-9.9	180	175-185 MW DH	Winter
Period 13	168	-14.3	190	185-195 MW DH	Winter
Period 14	192	-18.0	200	195-205 MW DH	Winter
Period 15	96	-23.1	209	205+ MW DH	Winter
Total/average	8760	3.6	97		

The following variables are bound for the whole year but variable in each period:

- Coke plant produces the coke used in the blast furnace, if possible by the production boundaries.
- On average, 97.4 kg/t hot metal briquettes produced from by-products is used in blast furnace
- On average 6.3 kg/t hot metal scrap is used in blast furnace
- Scrap use in the BOF is bound to average 14 % of incoming iron carriers

It is by redistributing the coke production, scrap and briquette usage in the blast furnace and scrap use in BOF over the year that gives variable amount of process gases to the CHP.

Coke plant

The coke production is allowed to vary between 67.8 t/h and 83.8 t/h coke, but with the yearly limitation to produce the coke used in the BF, if possible by the production limitations.

Blast furnace

Hot metal production varies over the year depending on the hot metal demand in the BOF. Blast furnace is bound to produce less than 280 t/h hot metal. The operation praxis of the blast furnace can vary through briquette usage of 50 - 150 kg/t hot metal and 0 – 30 kg/t hot metal scrap. Pellets, coke and injection coal use depends on the use of scrap and briquettes.

Steel plant

Production of steel slabs is constant over the year, which gives constant crude steel production because of constant production praxis in secondary metallurgy and continuous casting. Scrap addition in the BOF is allowed to vary between 12 % and 22 % of iron carrying materials. The need for hot metal is thus varied through addition of scrap.

Combined heat and power plant

The production of DH is predefined for each period according to Table 1. Electricity production is dependent on the fuel to the CHP and DH production. Electricity production is limited to produce at least 25 MW. Oil is used as extra fuel when energy in the process gases to the CHP is too low for producing DH and 25 MW electricity. When oil is used it is limited to be at least 20 MW.

2.4 Scenario description

Four modelling cases are designed to show the potential of optimal strategy with respect to process gas production and DH demand for high and low production at the integrated steel plant. These cases, which are seen in Table 2, consists of a base case and an optimised case for low (38 kt/week) and high (43 kt/week) production. The base cases (B38, B43) are constrained to have constant operation over the whole year in coke plant, blast furnace and steel plant. The optimised cases (O38, O43) are allowed to vary the operation over the year in coke plant, blast furnace and steel plant. The CHP is modelled in the same way in all cases with predefined DH demands for each period.

Table 2: Case descriptions

Case	Production (kt/week)	Comment
B38	38	Constant coke production and operation
B43	43	praxis in blast furnace and BOF.
O38	38	Varying coke production and operation
O43	43	praxis in blast furnace and BOF.

2.5 Optimization objective

The optimization is done with the objective to minimize energy consumption. The design of the boundaries is formed to give optimal solution with respect to CO_2 emissions and cost at the same time. Yearly import of materials to the system will be equal for the base and optimized case for both production levels. Therefore it is only oil and electricity import that varies for the whole year.

3. Results

3.1 General results (yearly)

The yearly figures seen in Table 3 show that there is potential to decrease oil consumption and increase electricity production with an optimized production strategy. The lower production level has larger potential for both oil consumption decrease and electricity production increase, which is also seen in Figure 2. One reason for this is that oil consumption for the low production level base case is higher to start with, 50 GWh/y compared to 30 GWh/y. Gas production is equal for base and optimized case on a yearly basis at same production level. This shows that the gas utilization is higher in the optimized cases. The equal gas production shows also that scrap and briquette addition to blast furnace and BOF has similar effect on the processes regardless of when it is added, within the given boundaries. Optimized production strategy decreases the CO_2 emissions due to the oil with 2 kt/y in the low production case and 0.5 kt/y in the high production case.

Table 3: Main results on yearly base

	Unit	Base38	Opt38	Δ38	Base43	Opt43	Δ43
Slab production	kt/y	1927	1927	0	2181	2181	0
Electricity production	GWh/y	494	502	8	585	588	3
DH production	GWh/y	788	788	0	788	788	0
Total fuel CHP	GWh/y	1962	1967	5	2203	2207	4
Oil to CHP	GWh/y	50	42	-8	30	29	-2
Gas to CHP	GWh/y	1912	1925	13	2173	2179	6
Gas production	GWh/y	4330	4330	0	4846	4846	0
Gas internal use	GWh/y	1959	1959	0	2176	2176	0
Gas flare	GWh/y	290	278	-13	330	324	-6
CO_2 Oil	kt/y	13.5	11.4	-2.1	8.3	7.8	-0.5

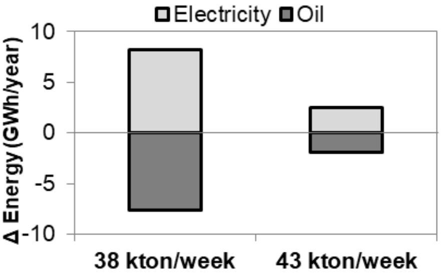


Figure 2: Δ yearly electricity production and oil consumption between Base and Optimized cases

3.2 Specific results (period)

The optimized cases show that process gas production should be adjusted for less gas production in the low DH demand periods or when SSAB has a stop in production (period1 and period 4-8). More gas should be produced in the periods with high DH demand (Period 11-15), which is seen in Figure 3. The adjustment of gas production is mainly done by adjusting scrap in BOF and BF, where BOF scrap addition that has greatest impact is seen in Figure 3.

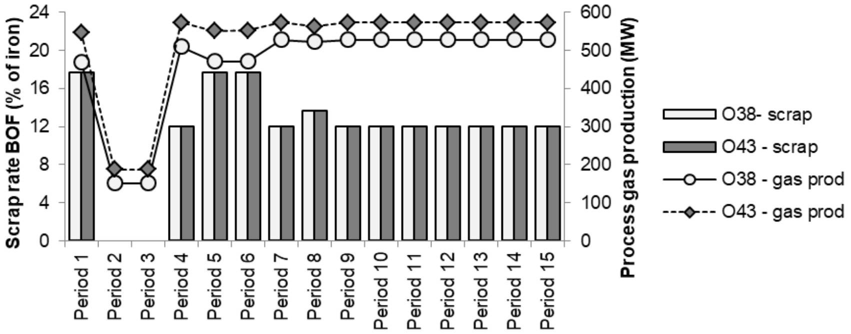


Figure 3: Process gas production and BOF scrap usage for the cases O38 and O43

Figure 4 shows the fuel usage and electricity production in the CHP. In this low production case oil is required in period 11-15 for B38 and period 12-15 for O38. This shows that oil consumption reduction in the optimized case for 38 kt/week slab production comes from shorter time of oil usage and less oil at the highest DH demands (period 14-15).

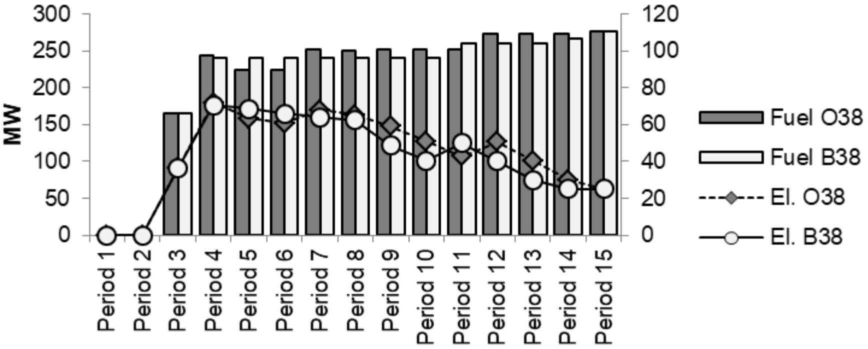
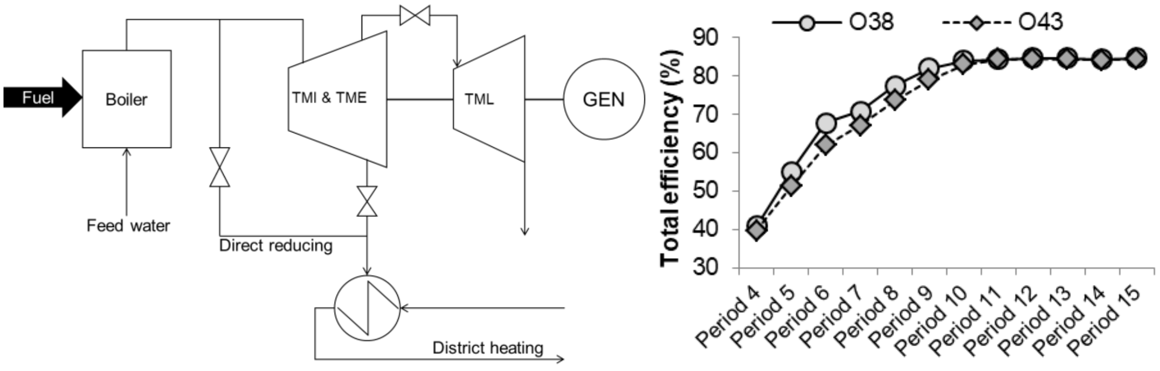


Figure 4: Fuel (process gas + oil) use and electricity production in the CHP.

The yearly process gas amount to the CHP is higher for the optimized cases because process gas production is minimized in period 1 when there is no usage of the gas. Then maximal amount of gas is delivered when there is a high DH demand to either replace oil or produce electricity at a higher efficiency. The increased efficiency for electricity production can be seen through comparing period 7 and period 10 in Figure 4, where the fuel to the CHP is equal in both periods while the difference in electricity production between the base and optimized case is larger in period 10. The reason for this is that the most efficient operation of the CHP is when all steam goes through the high and medium pressure part of the turbine for electricity production and after that used for DH production. This happens at α (electricity/DH) around 0.43. Optimization of the model gives therefore a minimization of electricity production via the low pressure turbine and direct reduction of steam for DH production. Figure 5a show a schematic description of the CHP plant that consists of a boiler where feed water is boiled to superheated steam through fuel combustion and a three stage turbine (TMI – high pressure, TME – intermediate pressure and TML – low pressure) for electricity production. The CHP plant District heat is produced in condensers, where heat from steam condensation and cooling is transferred to the district heating system. Steam to the DH condenser can be taken directly from the boiler before turbine (direct reducing) or from TME (back pressure). In Figure 5b that show the total efficiency ((electricity + DH)/fuel) of the CHP it is seen that higher DH demand gives higher efficiency, which is a reason for the model to give more process gas to the CHP in the winter.



(a) (b)

Figure 5: (a) Schematic description of LuleKraft. (b) Total efficiency ((electricity + DH)/fuel) of CHP in periods with normal production.

4. Discussion

This work shows the possibilities for redistributing gas production in the integrated steel plant to increase energy efficiency and decrease use of fossil fuel, when the raw materials for the integrated steel plant is constant on a yearly basis. Because of constant use of raw materials over the year it is important to have right constraints for how much the material usages can vary in the year. One uncertainty of this kind in this model is that the energy balance limits the highest amount of scrap addition to 17.7 % in the BOF, which is not always the case. At the same time the range of scrap addition to the BOF has large impact on the results.

There are also other possibilities to adjust the process gas production in an integrated steel plant that has not been included in this work. One of these possibilities is to operate the BF in a way to require more Injection coal or coke, which will increase BFG production. The results from this work are used by SSAB and LuleKraft.

5. Conclusions

Process gas production should be minimized in the summer and when LuleKraft has stop in production, which is done through high scrap usage in BF and BOF. Process gas production should be maximized in the cold winter when the DH demand is high, which is done through no or low scrap usage in BF and BOF. This increases the utilization of the process gas through replacing oil or producing electricity with higher efficiency. This work shows that there is gain from increasing system boundaries for systems that are connected.

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