SIMULATION OF A STEEL FACTORY'S CLOSED GAS CIRCULATION

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Abstract

This paper presents the simulation possibilities of a steel factory's closed gas circulation (the project name is "ReGenGas"). A real composition of a steel factory gases is used. The main aim in this project is to decrease carbon dioxide emission into the air and/or to re-use it to produce more hot metal or some chemicals. Actual processes will be compared to the developed system in this project. Trial runs in laboratory scale help to establish a use of non-ideal gases and potentiality to recirculate these gases.

The simulation tool will be done with Matlab's Simulink® and will be based on the data collected from the test campaigns. The real measurements of the experimental data and the simulated results will be compared. Simulation will consist of models for the mixing of pure gases and for the mixed real process gases like coke oven and blast furnace gases. In laboratory trials the variables are for example the composition of the gas, the operating temperature, recirculation rate, catalyst's dimensions and composition and the characters of the iron charge.

The test equipment and trials are based on the calculated results of Outokumpu Technology's HSC-software done in the same research group's earlier "CO_2H_2"-project. In this project the lab scale test runs are made to verify earlier calculations. Expert knowledge and an experimental design matrix will be utilized.

The goal of simulation and dynamic modelling is the preliminary information of a re-using of gases in a steel factory and designing of trials. As a result of this research it is possible to decrease a steel factory's carbon dioxide emissions and at the same time the production of hot metal increases. The feed gases in test runs will be H_2, N_2, CO, CO_2, H_2O, CH_4 and O_2.

This ReGenGas -project is financed by the National Technology Agency of Finland (TEKES), Outokumpu Technology Oy, Neste Oil Oyj and Ehovoc Oy. Research partners in this consortium are University of Oulu (3 laboratories) and Åbo Akademi (Turku, Finland).

1 Introduction

Project's background is in the idea of applying closed or semi-closed water cycles, successfully implemented e.g. in pulp and paper industry and in steel industry, to different gas-intensive processes to create closed or semi-closed gas cycles by recycling, refining and upgrading. In earlier project the energy balances were calculated using HSC Chemistry simulation software. Thermal energy required in each of the reforming cases has been evaluated by performing material and energy balances for each case. [Turpeinen 2005]

Processes are considered gas-intensive if they either consume or produce relatively high volumes of different types of gases in their normal operation. Such processes are commonly found in metals industry like coke and iron making processes and in energy production by combustion processes.

Ideally with closed gas loops one could decrease either total or relative CO_2 and other harmful gaseous emissions like Green House Gases from the processes. This would in principle take place due decrease in total or relative energy consumption or due a shift to less carbonaceous gas forming materials, like natural gas instead of coal. By recycling process gases one could save some primary energy sources like fossil fuels, even reforming the gases requires some extra energy. [Turpeinen 2005]

In iron and steel industry costs of CO_2 separation (based on physical absorption) are estimated to amount of 10.3–18.8 US$/t CO_2 depending on the iron production process. Thus, this cost level is similar or even lower than the cost level for CO_2 removal for coal fired power plants. [Gielen 2003] Blast furnace gas contains about 20 % CO_2. One of the advantages of CO_2 removal from blast furnace gas is improving of the heat value.

2 Application examples

Recycling gas streams to increase production or decrease emissions and coal or energy consumption has been studied intensively with blast furnace, the main iron making process. To improve the economy of the blast furnace recirculated top gas is one quite extensively studied method, for example in Full oxygen blast furnace (FOBF) [Jianwei 2003], A numerical study of reaction of coal with temperature exhaust gas [Miyagawa 1992], Process characteristics of a commercial-scale oxygen blast furnace with shaft gas injection [Ohno 1992], Prediction of blast furnace performance with top gas recycling [Austin 1998], A flow-chart for iron making on the basis of 100 % usage of process oxygen and hot reducing gases injection [Tseitlin 1994] and Mathematical Analysis on Exergy Consumption and Carbon Dioxide Discharge in Ironmaking Systems [Yagi 1992].

In a research an industrial side-fired steam reformer in a hydrogen plant is simulated under dynamic conditions. The dynamic model is used to study the effects of a few (planned) disturbances that reduce the production of hydrogen and steam. The operation of the steam reformer is simulated in the presence of three idealized disturbances in (1) the inlet feed temperature, (2) the inlet feed rate of natural gas, and (3) the furnace gas temperature. The model is then used to obtain optimal operating conditions required to negate the effects of two disturbances using several control or decision variables. Two objective functions are minimized simultaneously: the cumulative (integrated over time) deviation of the flow rate of hydrogen and the cumulative deviation of the steam flow rate. The elitist non-dominated sorting genetic algorithm NSGA-II leads to non-dominating Pareto-optimal solutions of this multi-objective optimization problem. [Nandasana 2003]

LURGI® -processes aim to avoid the need for expensive coke making, and reduce capital and operating costs as well as the impact on the environment. Processes include a high automation degree and NO_x-emissions are low (<50 mg NO_x/Nm^3). In the combination of Lurgi reformer and Lurgi catalytic autothermal reformer for the production of reformed gases having a high C/H ratio, the most favourable reforming processes are those in which surplus hydrogen is converted to water during steam reforming accompanied by partial oxidation.

The MIDREX® -reformer is a proprietary, tubular style natural gas reformer. The Midrex® -process was over the last decade the most successful direct reduction process, reducing iron ore lumps or pellets with gas in a shaft furnace. In production gas the H2:CO –ratio is 1 and the feed is natural gas.

$$CH_4 + CO_2 \Rightarrow 2\ CO + 2\ H_2 \quad (1)$$

$$\text{Coke gas} + CO_2 + H_2O\ (g) \Rightarrow \text{products} \quad (2)$$

DANAREX® incorporates an "autoreforming" process that uses oxygen to raise the reducing-gas temperature. It has lower investment and reduced production costs. In Danarex there is a possibility to recirculation of the feed gas.

In HYL III® –process the production gas's H_2:CO –ratio is 3 and natural gas is in feed gas (20 bar pressure). HYL offers two product options Traditional DRI (cold product in pellet or lump form) and HBI (Hot Briquetted Iron)

$$CH_4 + H_2O \Rightarrow CO + 3\ H_2 \quad (3)$$

It is possible to use alternative fuels, so called bio fuels, to some amount in limestone burning. Bio fuel research is very extensive in the industrialized countries. Coke gas, which caloric capacity is about 16 MJ/Nm^3, could also be replaced with blast furnace gas (about 3.5 MJ/Nm^3) or with converter gas (about 8.5 MJ/Nm^3) or with the mix of these gases. In this research, it is estimated that the level of 6 MJ/Nm^3 would be effective enough in the lime stone burning. Carbon dioxide recovery from converters would decrease the total amount of CO_2. It is possible that a mixture of bio fuels, direct reduction of off-gas and natural gas would be useful in replacing the coke gas. Carbon dioxide recovery from a steel factory's converters would decrease the total amount of CO_2 about 100 000 ton CO_2/year. It is possible to operate with a wide range of feed gas mixes.

In the forest products industry they are able to generate over half of their own energy from wood waste products and other renewable sources of fuel. Gasification technologies using biomass by-products from the pulp and paper industry improve chemical recovery and generate process steam and electricity at higher efficiencies and with lower capital costs than conventional technologies.

The industrial sector produces thermal output and electricity from biomass primarily from combined heat and power (CHP) facilities in the paper, chemical, and food-processing industries. Power plants that generate electricity also produce useful heat and steam using the CHP - technology. The power plant controls the delivery of blast furnace gas. It has financial values that coke gas, which has a high caloric value, ends as little as possible to straight to air. The H_2:CO –ratio (approximately 1…6) can be used to control the flue gas delivery. That requires among others temperature and concentration measurements of the flue gas. Some more information (measurements) of blast furnace moisture could be helpful in the controlling of the gas flows.

3 Test plant and test runs

In this paper, the main demand for the new planned reforming plant was that the capacity would be sufficient and, even more important, flexible. The aim is to minimize or even to eliminate the number of excess gas burners. Comparison of different process options and the demands of different reforming plants are necessary. Also the composition of gas mixture needs to be flexible ($C/CO_2/CO/H_2/O_2$–ratios varies). The new reformer plant should be able to start-up and stop easily.

In this project an actual processes will be compared to the developed system. Trial runs in laboratory scale help to establish a use of non-ideal gases and potentiality to recirculation these gases. As a result of this research it is possible to decrease a steel factory's carbon dioxide emissions and at the same time the production of hot metal increases. The feed gases in the test runs will be hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O), methane (CH_4) and oxygen (O_2).

The test equipment and trials are based on the calculated results of Outokumpu Technology's HSC-software done in the same research group's earlier "CO_2H_2"-project. In this project the lab scale test runs are made to verify earlier calculations. Expert knowledge and an experimental design matrix will be utilized.

The gas bottles will feed the process gas. The gas flows are measured and controlled. Before the reformer unit the feed gas needs to be heated in a pre heating unit. From the reformer unit the gas flows forward to the reduction part. In Figure 1 there is presented a simplified process layout, which shows also the main circulation possibilities of the gases. It has been taken a little longer time to build the laboratory device than it was expected, so the simulation part has not been done so far. In Table 1 there is presented conditions of test runs and the feed gases. The compositions of gases are alike in a steel factory.

National Instrument's LabView®-program will be used in the controlling of the whole process equipment. All the valves are controlled by a logic part, so the process gas flows are possible to change rapidly based on the measurements.

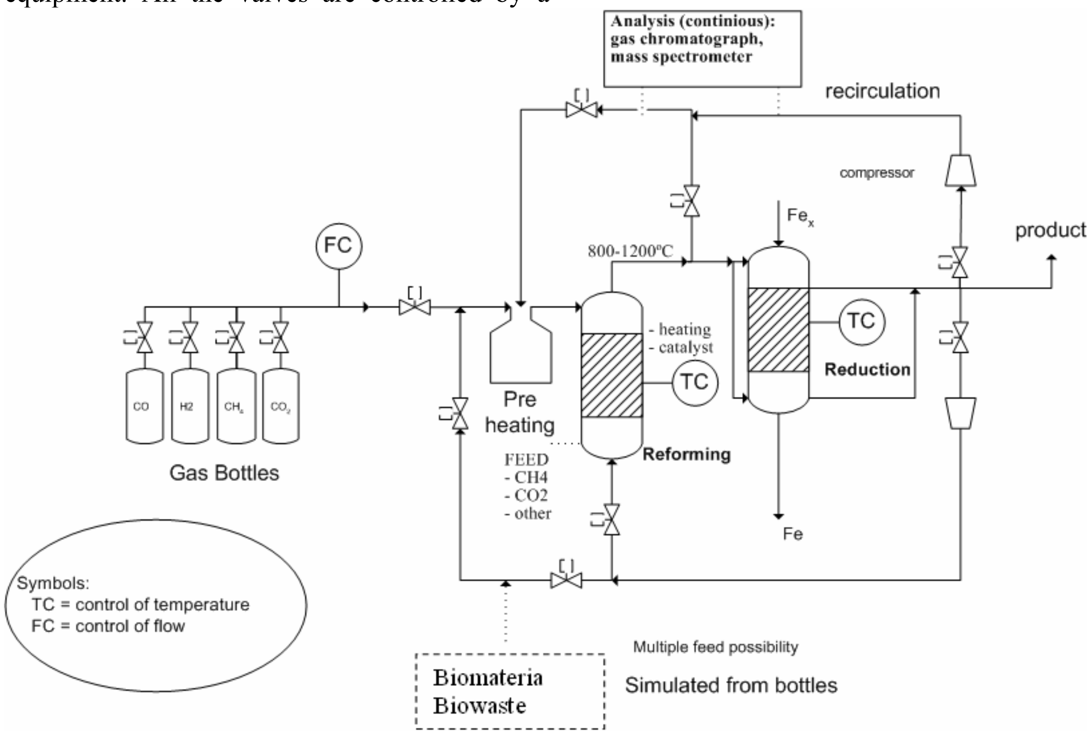

Figure 1. A simplified process layout.

Table 1. Test batches conditions and the feed gases.

Volume per gas: 0 - 2 l/min Temperature: 800, 900, 1000, 1100,1200 °C COG COG+BFG (2:1) COG+BOFG (1:1) COG+O_2 (11.8 %) COG+CO_2 (23.8 %) COG+H_2O (19 %) COG+BFG+BOGF (proportion 3:0.7:1) NG+H_2O (alike Hyl-process) NG+CO_2 (alike Midrex-process) NG	COG means coke oven gas BFG means blast furnace gas NG means natural gas BOFG means converter gas

4 Dynamic modelling and simulation

The goal of simulation and dynamic modelling is the preliminary information of a re-using of gases in a steel factory and designing of trials.

Dynamic modelling and simulation will be done with Matlab Simulink®. In Figure 2 there is presented a simplified picture of Simulink model of this process.

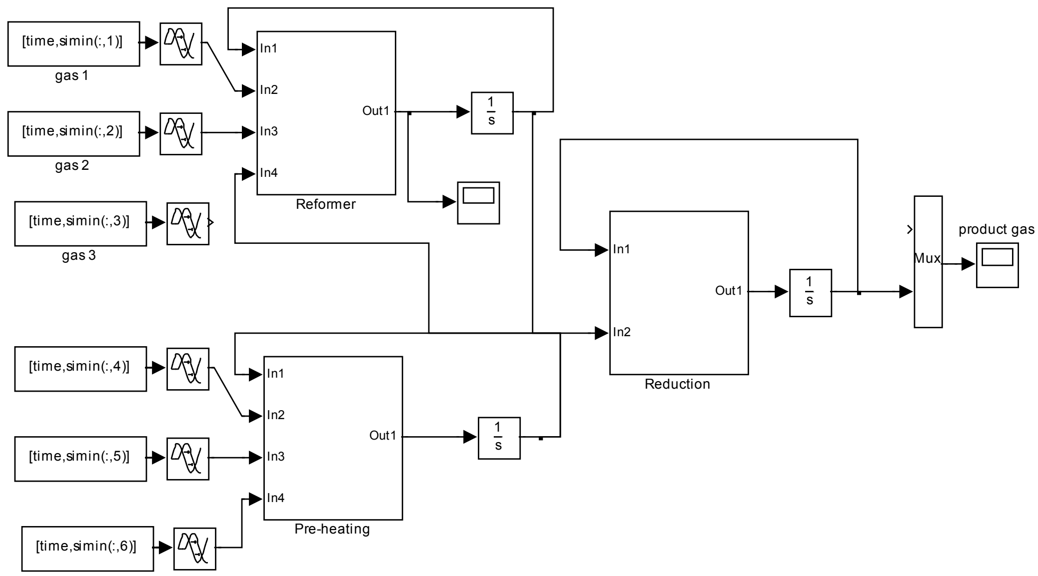

Figure 2. A simplified picture of Simulink® -model.

The amount of circulation is an important function in this simulation. By changing the circulation rate it is possible to control the composition of the product gas. The reaction equations and equilibrium are based on literature and are known beforehand. By simulation it is possible to get more information of ideal reaction compositions and conditions.

The test batches will be started in the beginning of year 2006 and after that the modelling will be started, so the simulation models and the testing of the models are incomplete so far.

Process integration techniques are methods, which aim to optimize and analyze the use of energy and material on the system level. There are basically three process integration methods; pinch analysis, energy analysis and mathematical programming. In pinch analysis the aim is to find possible changes in an industrial system to minimize the external cooling and heating demand. Exergy analysis is based on the quality levels (usefulness) of energy and quantifies the losses in individual processes and system in respect to this. Mathematical programming consists of different types of optimization methods. [Tari 2002]

Controllability is a tool that integrates process control issues into process design. The controllability analysis has to be done with the intrinsic property of a process system, which makes it possible to control all the process output variables with the available input variables.

A static or dynamic system, which makes use of fuzzy sets or fuzzy logic and of the corresponding mathematical framework, is called a fuzzy system.

A system can be defined, for instance, as a collection of if-then rules with fuzzy predicates, or as a fuzzy relation. An example of a fuzzy rule describing the relationship between a heating power and the temperature trend in a room may be:

If the heating power is high

then the temperature will increase fast

Dynamic fuzzy models can be constructed on the basis of state-space models, input-output models or semi-mechanistic model [Babuska 1997].

The most common structure for the input-output models is the NARX (Non-linear AutoRegressive with eXogenous input)-model which establishes a relation between the collection of past input-output data and the predicted output. MIMO systems can be built as a set of coupled MISO models. Delays can be taken into account by moving the values of input variables correspondingly. [Juuso 1998]

The Takagi–Sugeno fuzzy modelling method was proposed by Takagi and Sugeno as a framework for generating fuzzy if–then rules from numerical data. A TS fuzzy model consists of a set of fuzzy rules, each describing a local linear input–output relationship [Babuska 1996].

5 Results

COG reforming by CO_2 clearly consumes most carbon dioxide (over 23 kmol/100 kmol COG). In this reforming case also the biggest amount of synthesis gas is generated. If CO_2 is available free of charge and pure enough, then this is the most promising reforming case. Mixing of BFG and COG in reforming to produce more valuable synthesis gas is a respectable case. There usually is a surplus of BFG available. The problem is the high nitrogen concentration in synthesis gas. Accumulation of nitrogen increases total gas volume and thus decreases the efficiency of the process. BFG reforming by natural gas is not realistic option and it is attractive only then, when natural gas is obtained without expenses. [Turpeinen 2005]

Using alternative fuels in lime stone burning, heating furnaces and power plant decreases carbon dioxide emissions in a steel plant. Bio fuels can replace process gases to some extent in limestone burning. It is possible that a mixture of bio fuels, direct reduction off-gas and natural gas would be useful in replacing coke gas.

6 Conclusions

The design of experiment is done. Modelling will be started after the first test runs. The aim of simulation and dynamic modelling is the preliminary information of a re-using of gases in a steel factory and the designing of the trials.

Simulation gives some new information for the further test batches. Simulation results can be used to confirm the design of test runs.

In future it is possible to increase or decrease the configuration, so the simulation will give for example more information of a factory scale process.

One uncertainty is a measuring accuracy in the test drives. A new kind of configuration in this project is not in use as far as we know. The most challanging part of the pilot plant is the recirculation of hot gases. Short enough response time from the measurements is essential to a fluent control.

There might be one or more unknown factors in test drives that are uncontrollable. In that case the earlier results that based on HSC- Chemistry simulation software will be even more useful in the simulation and modelling.

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