LUND UNIVERSITY
LUND INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CHEMICAL ENGINEERING
THESIS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING

DYNAMIC MODEL OF A NID-SYSTEM

E. Nilsson

Abstract

To learn more about the dynamic behaviour of the NID-system, a simulation model was designed. Dynamic mass and energy balance equations were established to describe the NID-system and Simulink, an extension of Matlab, was used for modelling. The validation of the simulation model showed good agreement between output from the simulation model and measured process data of temperature and relative humidity. With a validated model, simulations can improve the knowledge of the dynamic behaviour of the NID-system. Simulations were performed to see how the NID-system reacts when rapid changes of the input data were made. The results of the simulations showed that the system adjusted within hours or minutes to changes in temperature or relative humidity, but changes in lime injection took days before stabilized.

Introduction

Background

When fossil fuels like oil or coal are used in combustion processes the fuel often contains sulphur, which will be released into the atmosphere as sulphur dioxide. Another contributor to released sulphur dioxide into the atmosphere is waste incineration. The emission from waste incineration varies due to the inhomogeneous composition of the fuel. After further oxidation of sulphur dioxide to sulphuric acid, it will contribute to the acidification of the Earth's surface. Acidification has adverse effects on forests, water and human health. One main problem is that the acidity releases aluminium from the soils which is toxic to many aquatic species. Human health problems could be worsening of respiratory and cardiovascular diseases. [1], [2]

Because of the adverse effects sulphuric compounds have on the environment and on the health the emissions has to be cut. This could be done using the dry scrubber technology on plants that burn fuels containing sulphur. One technology that uses the dry scrubber technology is the NID-system (Novel Integrated Deacidification).

Formulation of the relevant issues

To improve an existing, operational system one way is to design a model of the system. The idea is that a model of the NID-system will improve the understanding of the dynamic behaviour so that the system response could be predicted, given inlet conditions. Having a functional model make it possible to implement and evaluate changes of the system which in the future might lead to an operating unit with improved skills.

The NID-system

The NID-technology, short for Novel Integrated Deacidification, is used to lower the emissions of sulphuric compounds and hydrogen chloride in the flue gas.

The main components of the NID-system are the mixer, where dust, water and lime are mixed, the reactor, the fabric filter that separates the gas from the solid material and the hopper/trough where dust is stored before recirculated to the mixer, see figure 1. For the removal of sulphur dioxide (SO_2), hydrogen chloride (HCl) and hydrogen fluoride (HF), calcium hydroxide, $Ca(OH)_2$, is used. [3]

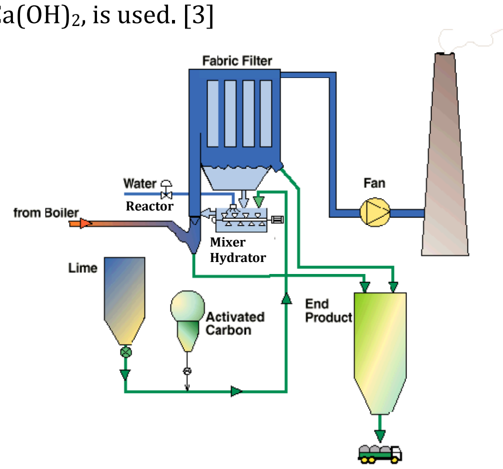

FIGURE 1. SCHEMATIC SCETCH OF A NID-SYSTEM. [3]

In the mixer is hydrated lime ($Ca(OH)_2$) added to recirculated dust. The solids are sprayed with a thin layer of water in the mixer before transported to the reactor. The amount of water added is only a few percent which means that the dust remains dry. Compared to semi-dry systems, the amount of water is the same but the amount of solid compounds is larger. A more efficient reshuffle of the dust is reached with the fluidized bottom of the mixer. [3]

Hydrated lime, $Ca(OH)_2$, and acid compounds in the flue gas, mainly sulphur dioxide, SO_2, and hydrogen chloride, HCl, reacts in the NID-reactor. High turbulence is important to make the dust material and the flue gas mix well and consequently make it possible for the reactions to take place in the whole volume of the reactor. A thin layer of water on the dust particles vaporizes which makes the temperature of the flue gas decrease and the humidity to increase. The temperature of the flue gas is usually 130-140°C when it leaves the fabric filter and the relative humidity is 5-7 %. These conditions are suitable for the desired reactions to take place in the reactor:

$$\boldsymbol{Ca(OH)_2 + SO_2(g) \rightarrow CaSO_3(s) + H_2O\ (g)} \quad \textbf{R1}$$

$$\boldsymbol{Ca(OH)_2 + 2\ HCl(g) \rightarrow CaCl_2 \cdot 2\ H_2O(s)} \quad \textbf{R2}$$

These simplified reactions results in that the gaseous compounds, SO_2 and HCl, are bound to the solid material, $Ca(OH)_2$, that circulates the system. Reactions between other compounds in the system do occur, but R1 and R2 are the main reactions of the system. [3]

After the reactor, the flue gas, together with the dry dust material, enters the fabric filter. In the fabric filter is dust collected on fabric filter bags. The dust material has a composition of reaction products, fly ash and hydrated lime and when a layer on the bags is thick enough, the material is removed by short pulses of compressed air entering the bags. After a short pulse of compressed air, dust falls down into a hopper. After the fabric filter, the cleaned flue gas leaves the NID-system through the fabric filter plenum. [3]

Dust material enters the trough through the hopper. In the trough, fluidized air is fed from the bottom to keep the dust that enters the trough well mixed. Most of the solid material is recirculated to the mixer by a rotary feeder with variable speed and is reused in the system. The system has a high recirculation ratio of the dry dust material before it leaves the system. When the dust material in the hopper exceeds a certain value some of the material is removed to an end product silo. Finally the end product is landfilled. [3]

Simulation of the NID-model

To formulate the mathematic equations for the NID-system an energy balance equation was formed together with a mass balance equation. The simulation was performed in Simulink, an extension of MATLAB which is a computer program for numeric computations, data visualization and analysis. Simulink is used to build dynamical models with block diagram notation. The use of block diagram notation makes a model of a complex system relatively easy to overview since subsystems often are used to combine the blocks into groups.

Validation of the model

To validate the model, data from an existing waste incineration plant, was used. The design of the NID-system, such as the volume and surface area of the sections, mass of the steel and dust amounts in the fabric filter and in the hopper, was used in the simulation to make the model look like the operating system.

Output from the Simulink model was compared to the measured outflow temperature from the fabric filter and the relative humidity after the fabric filter that was calculated from measured data. Figure 2 show the measured and simulated temperature after the fabric filter, as a function of time. The simulated temperature seems to follow the shape of the measured temperature well. Simulated values are slightly higher, about 1 %[1], something that could have to do with the losses from the steel to the isolation of the NID-system and from the isolation to the surroundings that is not included in the model. If this was included in the model the simulated temperature would be lower and possibly closer to the measured temperature.

When the model is validated the simulated relative humidity is somewhat lower than the measured relative humidity. This can be explained by the fact that the measured temperature is lower than the simulated temperature.

[1] Calculated in Kelvin (K)

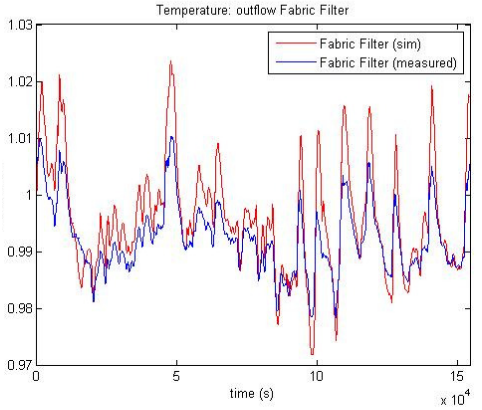

FIGURE 2. NORMALIZED TEMPERATURE OF THE GAS FROM THE OUTFLOW OF THE FABRIC FILTER AS A FUNCTION OF TIME.

Simulation results

Temperature Decrease

The NID-system is simulated with constant input values except for the temperature that is constant the first period of time but then decreases rapidly at time t=0 s, blue line in figure 3. After the decrease, the temperature is constant for the remaining simulation period. In figure 3, the simulation results are plotted as a function of time. During steady conditions, the temperature drop over the NID-system is 4,1 %[2]. The initial temperature of the gas out of the reactor and the fabric filter are almost equal. This means that the temperature decreases in the reactor. This corresponds with the theory since the evaporation of water, an energy consuming process, takes place in the reactor. Reactions between acid compounds in the flue gas and hydrated lime are exothermic reactions that contribute to an increase of the temperature. Since these reactions mainly occur in the reactor, the heat is released there.

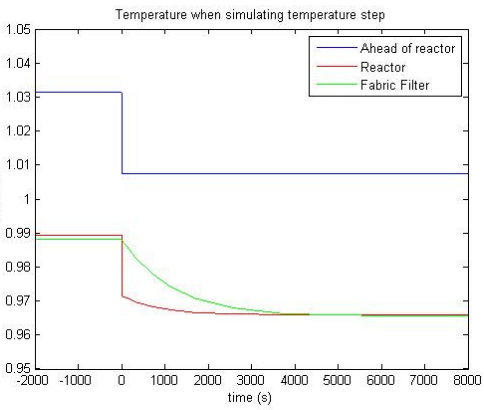

FIGURE 3. NORMALIZED TEMPERATURE OF THE GAS AS A FUNCTION OF TIME. AT TIME T=0 S, THE INLET TEMPERATURE OF THE GAS DECREASES RAPIDLY.

[2] Calculated in Kelvin (K)

When the inlet temperature of the gas decreases rapidly, the gas temperature out of the reactor will decrease but with a delay of 3000 s (0,83 h). The temperature of the outflow from the fabric filter will decrease with a delay of 5000 s (1,39 h).

Relative Humidity Increase

This simulation was preformed with the inlet gas composition kept constant at t<0. At time t=0 s was the inlet relative humidity increased which made the relative humidity out of the reactor increase as fast as the inlet relative humidity, see figure 4. The increase of the relative humidity out of the fabric filter will take 60 s. The large volume of the fabric filter damps the rapid impact of the relative humidity increase. The simulation of the relative humidity out of the reactor has a peak short after the rapid increase of the relative humidity. This has been seen in previous simulations when rapid changes are performed and is an unwished behaviour of the simulation model.

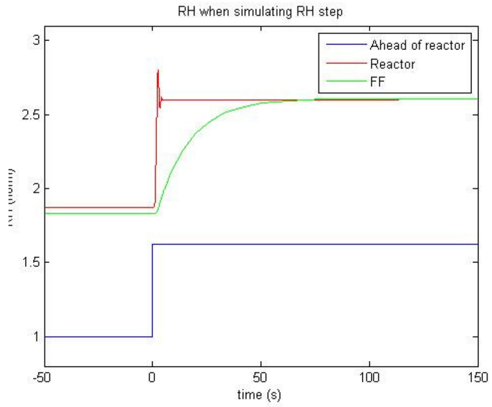

FIGURE 4. NORMALIZED RELATIVE HUMIDITY AS A FUNCTION OF TIME. AT TIME T=0 S, THE RELATIVE HUMIDITY INCREASES RAPIDLY.

Lime Adding increase

In figure 5, the mole flow of hydrated lime ($Ca(OH)_2$) is plotted as a function of time. The inlet lime addition to the mixer is kept constant for a period of 345 600 s (4 days) when a rapid increase rises the lime addition by 50 % (t=0 s). For the remaining simulation time the lime addition to the mixer is kept constant at the new, high level. After the rapid increase of make-up lime, it takes a long time for the output flow from the reactor and the fabric filter before a constant value is being reached. The output flow of the fabric filter is constant after 1 200 000 s (13,9 days) and the output of the reactor is constant after 1 400 000 s (16,2 days). The constant output flow is reached when the amount of lime added to the system is the same as the amount of lime consumed by the reactions and the amount of hydrated lime put in the end product silo.

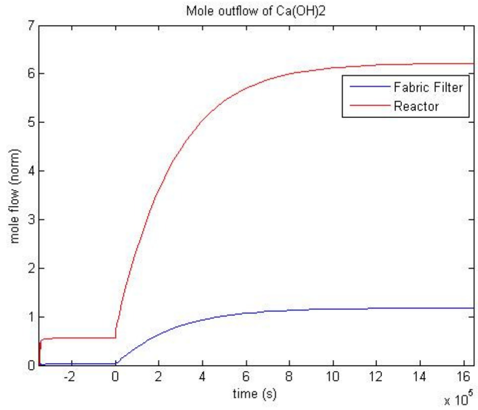

FIGURE 5. NORMALIZED MOLE FLOW OF HYDRATED LIME AS A FUNCTION OF TIME. AT TIME T=345 600 S (4 DAYS), THE LIME INJECTION IS RAPIDLY INCREASED.

When sulphur dioxide reacts with hydrated lime calcium sulphite is produced. The product of the reaction is plotted in figure 6. The blue line represents the mole flow out of the fabric filter and does not change much during the simulated time 1 987 200 s (23 days). When the level of make-up lime is rapidly increased after 345 600 s (4 days), t=0, the mole flow of calcium sulphite out of the reactor decreases during a time period of 1 300 000 s (15 days), see figure 6. When the hydrated lime injection to the system is increased, more dust is put in the end product silo. The production of calcium sulphite is not increased much, when more hydrated lime is added to the system, since the content of sulphur dioxide in the flue gas is low. More dust in the end-product silo and only a small increase in calcium sulphite production mean a decrease of calcium sulphite in the system.

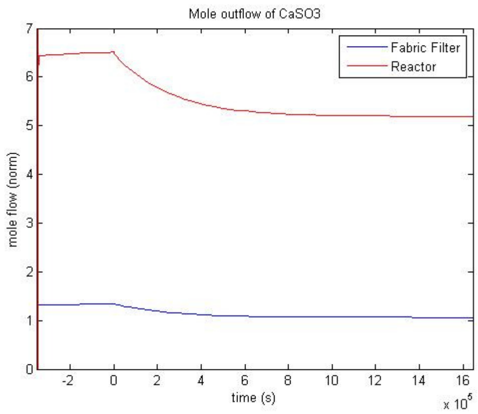

FIGURE 6. NORMALIZED MOLE FLOW OF CALCIUM SULPHITE AS A FUNCTION OF TIME. AT TIME T=345 600 S (4 DAYS), THE LIME INJECTION IS RAPIDLY INCREASED.

Discussion

The assumption that the fabric filter is continuously sending dust material to the hopper/trough make the simulation differ from the reality where dust is sent to the hopper when the compressed air cleans the fabric filter bags. In the same way the simulation model is assuming a continuous output from the trough to the end product silo, which is not a continuous process in the real system. In the simulation of the process will the mass of the system be an average of the reality. The efficiency of the fabric filter bags change slightly depending on the thickness of the dust layer so that they are more efficient when there is an existing dust layer. In the model the efficiency is always good.

Simulations were performed to get a better understanding of the dynamics of the system. A temperature step was simulated to see how long it takes for the system before the temperature of the outflow from the reactor and the fabric filter has reached a new constant value (0,8 resp. 1,4 h). The result show that changes in the inlet temperature of the system will take some time before affecting the temperature in the reactor and in the fabric filter. Changes in the relative humidity of the inlet gas result in rapid changes (0-60 s) of the relative humidity in the whole system. The short delay times make relative humidity easier to predict than temperature. The simulation of lime adding increase showed slow changes in the system. Hydrated lime and calcium sulphite reached constant values after 13-16 days. Slow parts of a system are harder to regulate since changes that are made affect the system with a great delay.

References

1. Acid Rain - The effects of acid rain. *U.S Environmental Protection Agency.* [Online] 4 Apr 2008. [Cited: 5 Nov 2008.] http://www.epa.gov.

2. **Jakobsson, et al.** *Energiläget 2007.* Eskilstuna : Statens Energimyndighet, 2007. ISSN 1403-1892.

3. **Alstom Internal Document.** *NID System Description.*