Dynamic Simulation of a Fluidized Bed Incinerator
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Abstract
A computer aided tool for the dynamic simulation of fluidized bed incineration processes is developed. SIMAPI (SIMulateur Aquitain de Procédés d’Incinération) is particularly dedicated to the training of operators working on such processes. The main aspects of the model and the user-friendly graphical interface are presented. The tool abilities are illustrated with the shut down procedure of an industrial unit.

Keywords: fluidized bed, incineration, simulation, dynamic, real time

1. Introduction
Because of the higher regulation of landfill in European countries from 2002, incineration is expected to play a major role in the disposal of municipal waste. However, the formation of toxic solid and gaseous by-products during the incineration of municipal waste can lead to a limitation in the use of incineration as well as to an increase in the cost. That is why, improvements in the design of incinerators as well as in the level of knowledge of operators is required. In order to fulfil these two objectives, we have chosen to construct real-time simulators, able to predict the behaviour of the process. Such a tool can then be used for design purposes, or, together with a teacher and specific scenarios, it can be used as a learning tool for operators running the unit. Our first choice has been to apply these considerations to a fluidized bed incineration process. We will neither, in this paper, present the mathematical model used to represent the physics and chemistry involved by the process nor the numerical algorithm used to solve it. Instead we will give the key steps that have been drawn up in order to reach our objective. Thus, we will firstly give some information about the model for fluidised bed incinerator and some about the model used to represent the steam to electricity process. Then we will present the industrial unit on which we have carried out numerical experiments in the case of the stop of the unit.

2. Description of the Incinerator Model
The composition of the waste entering the process is supposed to be known with respect to its main components: moisture, inert material, wood, cardboard and PVC. As suggested by Shafizadeh (1982), flash pyrolysis of the waste is expected to occur in a hot fluidized bed. Thus the waste is decomposed into:

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• a high heating value gas composed of light hydrocarbons and pollutants (H2, CH4, CO, CO2, HCN, H2S, HCl and C6H6)
• a pyrolysis residue composed of fixed carbon and ashes (with the same size distribution as the initial waste),
• a fraction of inert material

Yields and compositions are computed using chemical element and energy balances (Marias et al., 2001).

Another important point is the hydrodynamic model. Our model is based on previous works dedicated to combustion of coal in a fluidized bed: Wildegger-Gaissmaier and Agarwal (1990), Stubington and Chan (1990) and Hannes (1996). Because of its high volatile content, we expect the incineration of waste to be mainly driven by volatile combustion, which is of diffusion type. Hence, we need a hydrodynamics description of the bed that allows the description of this particular trend. That is why, because of its film concept, the choice has been made to use the model proposed by Werther (1980). This model is modified using a two dimensional description of the film between bubbles (buffer zone) and emulsion. Finally, it is completed to take into account phenomena occurring in the freeboard. Figure 1 gives a good representation of the global hydrodynamic model (including gaseous and solid materials except inert material).

Figure 1: Hydrodynamic model of the fluidized bed incinerator.
Additional assumptions are: chemical equilibrium for gaseous species O2, N2, CH4, H2, H2O, CO, CO2, C6H6, HCl, Cl2, SO2 and SO3; kinetic control for HCN and NO; reactive particle oxidation is limited by external heat and mass transfer and kinetics. Then we are able to write a full model for waste incineration within a fluidised bed (Braianov et al., 2003). It is able to take into account stiff variations of operating parameters (Mass flow rates of waste, primary and secondary air of extra gas, temperature of the fluidising air).

3. Description of the Steam to Electricity Process
For environmental and economic reasons, the energy released during incineration of waste needs to be recovered. Such a recovery is often performed through a steam cycle as briefly depicted in Figure 2.

The cycle is composed of a main loop and of some auxiliary loops: desuperheating loop, funnel, heating of the feed tank and bypass of the turbine. The main units are: the feed tank BA01 (its level is controlled by the valve VCCA01 and its temperature is raised to 110°C using MP vapour), the steam drum BCh01 where saturated vapour is produced, the turbine TU01 where thermal energy is converted into electricity, the aero-condenser AER01 and the condensate tank BC01 which is kept under atmospheric pressure using steam jet ejectors.

A dynamic mathematical model has been written to represent the behaviour of this unit. Basically, it is composed of mass and enthalpy balances, an equation of state for pure water (Wagner and Kruse, 1998) and valve and pumps characteristics. The model results in a system of 121 differential and algebraic equations and it is solved using a

Figure 2: Steam unit.
Gear method. Operating parameters such as valve opening can be modified interactively during the simulation.

4. The Industrial Unit
In order to keep our simulator attractive, we have designed interface of control as can be found in the industrial world. These interfaces represent 3 different views of the whole process: furnace view (figure 3), boiler view and expender view. Opening of manual valves can be modified directly.

The furnace view has been selected in this paper since it describes more in depth how these two processes are connected. Both the incinerator and the steam to electricity process are connected in a sequential way: the power received by the boiler and the heat exchangers are output variables of the fluidized bed incinerator model.

The industrial unit under investigation has a nominal input of 3.3t/h of municipal waste (7.3 MW of input power), previously shredded. In these conditions, 8000Nm³/h of fluidizing air are supplied at the bottom of the furnace while 6000Nm³/h are supplied in the post combustion chamber. The cross sectional area of the bed is 1.3m² and the mass of fluidized sand inside the furnace is approximately 620kg. In addition, in order to raise the temperature at the start-up of the unit, and in order to keep the thermal level in the post combustion chamber up to 850°C when a low heating value waste is incinerated (environmental regulation), two extra burners can supply 80Nm³/h of propane each.

Figure 3: Interface used for the control of the process (furnace view).

5. Numerical Results
The shut down of the process is now presented. The waste and secondary air flow rates entering the process are progressively driven to zero (FCDA01 and VASA01). In order
to always keep legal conditions (temperature of the post-combustion chamber more than 850°C and oxygen level within the post combustion more than 6% while waste is present within the furnace) there is a need for extra gas: both VABA01 and VABA02 valves are first open and then closed at t=1100s.

Moreover, as the furnace is extinguished the pressure of the superheated vapour will decrease. Thus we need to shut off the expender: first the expender is by-passed (VCTA01 is half opened at t=1000s) and next, the expender is isolated (VITM01 is closed at t=1200s). Finally, the valves VCCA01 (condensate flow rate), VAA01 (feeding water flow rate) and VDA01 (desuperheating loop) are progressively closed.

Figure 4: Results of the simulator

(VCTA01 is half opened at t=1000s) and next, the expender is isolated (VITM01 is closed at t=1200s). Finally, the valves VCCA01 (condensate flow rate), VAA01 (feeding water flow rate) and VDA01 (desuperheating loop) are progressively closed.

The results of the model are shown on Figure 4. As it is required, we can observe that legal conditions always prevail within the furnace while waste is fed to the incinerator. Nevertheless, we can observe that temperature of the post combustion decrease under
850°C (approximately at time 1200s) while some solid waste remains within the furnace. Thus the operator can see that the extra burner have been stopped to early. From the steam cycle side, we can note some important variations for the level of liquid within the steam drum. This emphasises the need for automatic control of this level which is of great importance.

Pollutants emissions are computed at the exhaust of the furnace. The low value of temperature leads us to say that no thermal NO is produce within the furnace (Zeldovic’h mechanism is taken into account within the fluidized bed model). Moreover, we can see that the main part of the nitrogen held in the initial waste is converted to HCN. This can be of importance because this species is expected to be absorbed by flue gas treatment technologies.

6. Conclusion
In this paper we have presented our virtual incinerator SIMAPI. Based on two knowledge models coupled through heat exchanger data, it is able to represent the stop of an industrial unit of 3.3 t/h of waste input.

Such a tool can be used for at least two purposes. The first one is linked to formation of operators who daily drive such a plant. With our tool, they can be trained in the case of working conditions, but also in the case of start-up or stop of the unit. Given some specific scenarios (imposed by the teacher) they can be trained to react under specific conditions, and the teacher can analyse how the operator behave, which is quite important. Secondly such a simulator might be used in order to design new units or revamping old ones. Indeed important characteristics such as pressure at the steam drum, temperature in the furnace, pollutants emissions can be computed dynamically, and this can be of help for designers of incineration plants.

Gas treatment units and control loops of the complete process are now under development. Liquid level in steam drum, temperature after SUR02 and pressure of stream entering the turbine are respectively controlled by valves VAA01, VDA01 and VCTA01.

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References