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Secondary Combustion Chamber with Inbuilt Heat Transfer Area – Thermal Model for Improved Waste-to-Energy Systems Modelling

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The paper presents method for thermal calculation of secondary combustion chamber (SCC) containing inbuilt tubular heat transfer system of municipal waste treatment unit for purpose of improvement of calculation monitoring of the complex and actual material and energy balance of the whole municipal waste treatment unit. Mathematical model is based on worldwide recognized method for thermal calculation of boilers, developed by Gurvich, published for example in (Kakac, 1991). Method is reformulated and adapted for calculation purposes of in-house developed software W2E (Tous et al., 2009) taking into account specific design and operating features of secondary combustion chamber installed in real municipal waste incinerating plant.
Developed model for calculation of heat transfer in the SCC with inbuilt tubular heat transfer system is applied together with above mentioned software W2E for determination material and energy balance of municipal waste incineration plant at different operating conditions. Obtained results are confronted with real parameters obtained from operating of municipal waste incinerating plant.

1. Introduction to secondary combustion chamber systems

The combustion of municipal wastes is the most often realized in the combustion chambers of two different types. First, often realized arrangement of combustion chamber for combustion of municipal wastes is the rotary kiln followed usually by heat recovery steam generator (HRSG). This two-stage incineration system (a typical arrangement of unit see on Figure 1), performed to achieving of a perfect combustion, is also the most common unit in case of the thermal treatment of industrial and hazardous solid and liquid wastes. Second, very frequently used type, is the standard fixed combustion chamber equipped by traveling grate (stoker furnace).
This type of combustion chamber mostly contains inbuilt tubular heat transfer system for steam generation. A typical arrangement of unit for thermal treatment of municipal wastes with the standard fixed combustion chamber is shown in Figure 2. Simplified scheme of typical arrangement of fixed combustion chamber to part of secondary combustion chamber (SCC) and primary combustion chamber (PCC) with traveling grate of such waste incinerator is schematically shown on Figure 3.

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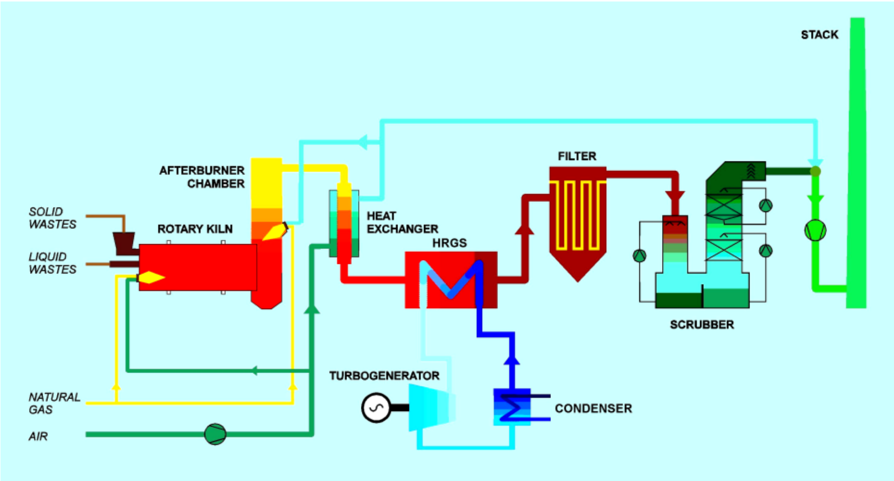

Figure 1: Typical layout of municipal or industrial waste incinerator with rotary kiln

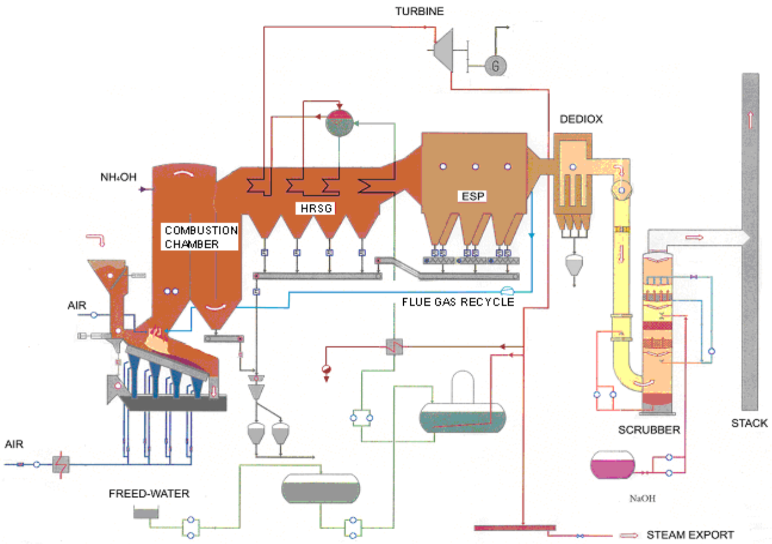

Figure 2: Typical configuration of municipal waste incinerator with fixed combustion chamber (Courtesy of TERMIZO Inc.)

2. Motivation for development of thermal model of SCC

Necessity of application of different thermal calculation methods for design or rating of different types of combustion chambers described in previous paragraph very complicates a situation in the cases when the complex and actual material and energy balance of the whole municipal waste treatment unit have to be calculated. In the area of simulation and balancing of complex waste-to-energy systems we use our in-house developed software W2E (Tous et al., 2009).

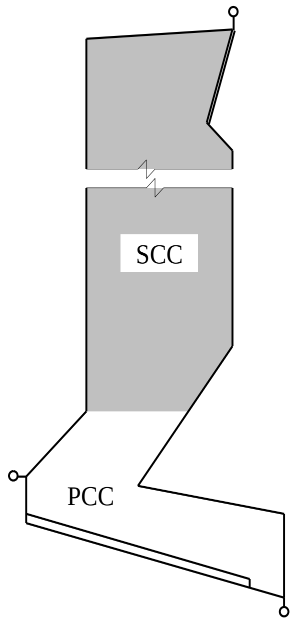

Figure 3: Typical arrangement of SCC and PCC with travelling grate

When the combustion chamber is arranged as rotary kiln (see Figure 1) the flue gas temperature at combustion chamber outlet can be calculated from the simple material and energy balance. In contrast of rotary kiln, the standard (fixed) combustion chamber with inbuilt tubular heat transfer system (see Figure 2) represents much more complicated case from thermal calculation point of view. The presence of inbuilt heat transfer system significantly influences determination of heat flows and temperature profile in the space of secondary combustion chamber (SCC) together with determination of flue gas outlet temperature from SCC (SCC is placed just above the primary combustion space (or primary combustion chamber - PCC) as illustrated on Figure 3.) Therefore, in case of standard (fixed) combustion chamber it is necessary to consider heat transfer from flue gas to inbuilt heat transfer area, taking into account both radiation and convection heat transfer mechanism of flue gas. The present simplified approach to calculation of heat transfer conditions of this type of combustion chamber used in software W2E is based on operating data and knowledge obtained from real plant (unit) for municipal waste incineration. However, this approach is not generally applied to other incineration unit (even if similar conceptions of inbuilt heat transfer system). Thus, for extension and universality of calculation capability of software W2E for different incineration plants with different arrangements of (fixed) combustion chambers, the thermal model of secondary combustion chamber has to be disposable.

3. The role of SCC in waste-to-energy incinerator

The SCC is enclosure just close to primary combustion space (around the firing equipment), which provides adequate volume to permit completion of combustion, that is, to meet the residence time requirement to burn the waste. Moreover, SCC provides also adequate surfaces to cool the flue gases to an acceptable level to enter the downstream surface - usually it is a (slag) screen or super heater section - without the fear of ash deposits or tube overheating. For purpose of software W2E the thermal model of SCC is developed as rating calculation tool of existing SCC.

Heat transfer in SCC is almost entirely by radiation mechanism. The arrangement of heating surfaces in SCC and so called active volume of SCC play important role in the model behaviours. Active volume of the SCC is the volume of the open chamber that surrounds the firing equipment (it is generally grate, combustor, bed or burner) and extends from the top of stoker, bed, ash pit, or floor to the exit plane at which the next surface (usually screen or super heater) starts. Projected radiant surface of the SCC is the heating surface that participates in cooling of the flue gases. It comprises all areas of the walls of the SCC enclosure including the area of the exit plane. Effective projected radiant surface is the adjusted projected radiant surface that takes into account the fuel, types of walls (membrane, spaced etc.), extent of refractory covering on walls, effect of possible slagging, etc.

Flue gas outlet (or exit) temperature from SCC (defined as the average gas temperature at the middle of the SCC exit plane) is then calculated with help of effective projected radiant surface. The dimensions of SCC are usually designed by residence time required of individual fuel and type of firing equipment. Residence time is required for a fuel particle to reach the midpoint of the SCC exit aperture from the firing equipment (center of heat input, to be precise), assuming the whole SCC to be at the isothermal temperature of flue gas exit temperature of SCC. In case of municipal waste incinerators, the required residence time ranges typically from two to three seconds and the flue gas exit temperature of SCC ranges typically from 850 °C to 1100 °C (both parameters depend on type of waste and firing equipment).

4. Basic principle of developed thermal model of SCC

The developed thermal model of SCC is based on the worldwide recognized method for thermal calculation of furnace part (radiation chamber) of boilers, developed by Gurvich and published for example in (Kakac, 1991). This method is reformulated and adapted for calculation purposes of our in-house developed software W2E (Tous et al., 2009) taking into account specific design and operating features of secondary combustion chamber installed in real municipal waste incinerating plant. The basic formula of Gurvich method has the following form (Kakac, 1991):

$$\frac{T_{gFe}}{T_{ga}} = \frac{Bo^{0.6}}{Bo^{0.6} + M \cdot a_F^{\ 0.6}} \tag{1}$$

where, after adaptation to situation of SCC, it can be considered that

T_{gFe} is the flue gas exit temperature at the SCC outlet;

T_{ga} is the adiabatic temperature of combustion;

Bo is the Boltzmann number;

M is a coefficient relating to the pattern of the temperature field in the SCC;

a_F is a coefficient of thermal radiation of the SCC.

In equation (1) the parameters Bo, M and a_F are the complex functions depending on fuel type, combustion equipment type, conditions of combustion process, volume, geometry and arrangement of heat transfer surfaces of SCC. Moreover, the parameters *Bo* and a_F are also functions of temperature T_{gFe}. Therefore, the typical solution of equation (1) is performed by iterative way based on successively refinement of initially assumed value of T_{gFe}. However, for calculation purposes of our in-house developed software W2E the eq. (1) is solved by no iterative way due to fixated (required) value of T_{gFe}, which leads to evaluation of rated fuel consumption as unknown parameter in Boltzmann number *Bo*.

5. Confrontation of results of developed model with real plant data

Developed model was applied together with above mentioned software W2E for determination material and energy balance of the most modern and latest municipal solid waste (waste-to-energy) incinerator (MSWI) TERMIZO Inc., located in town Liberec, Czech Republic.

Incineration of waste in this plant (see plant configuration in Figure 2) in the amount of 12 t/h is performed in a combustion chamber equipped by moving grates. During plant operation flue gas outlet temperature from SCC reaches commonly value between 850 °C and 1050 °C. The heat potential of the waste is utilized in a waste heat boiler for generation of superheated steam with pressure of 4 MPa and temperature 400 C.

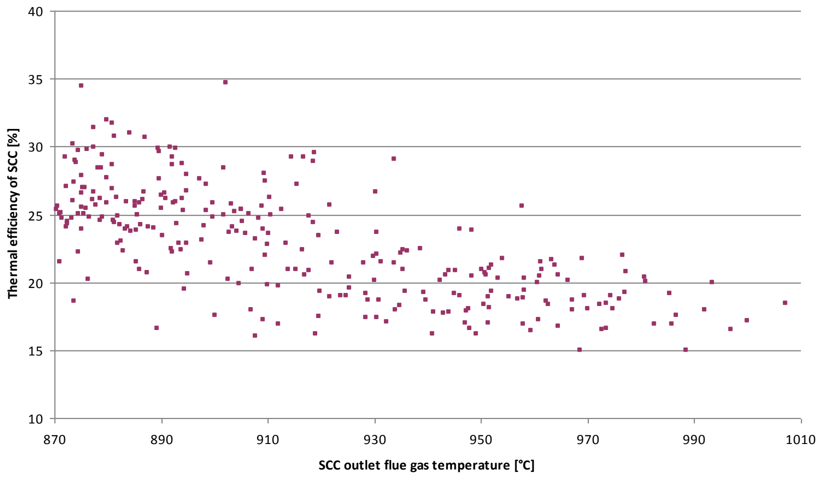

Figure 4: Thermal efficiency of SCC as function of SCC outlet flue gas temperature evaluated from plant data of MSWI TERMIZO Inc.

The flue gases are cooled in the boiler down to about 250 to 280 °C and concurrently, most of the fine particulates (fly ash) carried by the flue gas from combustion area is collected here. Collection of the remaining fly ash from the flue gas down is performed in electrostatic precipitator (ESP). Part of the flue gas (about 16% of total amount) is recycled from the ESP outlet (see Figure 2) back to the combustion chamber using a recycle fan and the remaining flue gas goes to the flue gas cleaning part of the plant. The SCC (see Figure 3) consists of lining steel membrane walls with heat transfer area

of 366 m^2, performed from tubes 57 x 5 mm with pitch 80 mm. At the outlet of SCC is placed (slag) screen consists of tubes 108 x 6 mm with heat transfer area 10 m^2.
Collection of real plant data for different operating conditions represented by the percentage of heat absorbed by water walls in SCC from heat released (i.e. thermal efficiency of SCC) as function of SCC flue gas outlet temperature (ranges from 870°C to 1010°C) is illustrated in Figure 4. Based on evaluation of plant operating data the balanced trend of thermal efficiency of SCC for average operating conditions of MSWI was evaluated. Based of these average operating conditions (such as average LHV of waste 10.76 MJ/kg, etc.) the calculation of thermal efficiency by developed model of SCC was performed. Comparison of results of SCC model with average plant data is illustrated in Figure 5. A very good agreement between the SCC model results and results of heat balance of average plant data of MSWI TERMIZO Inc has been found.

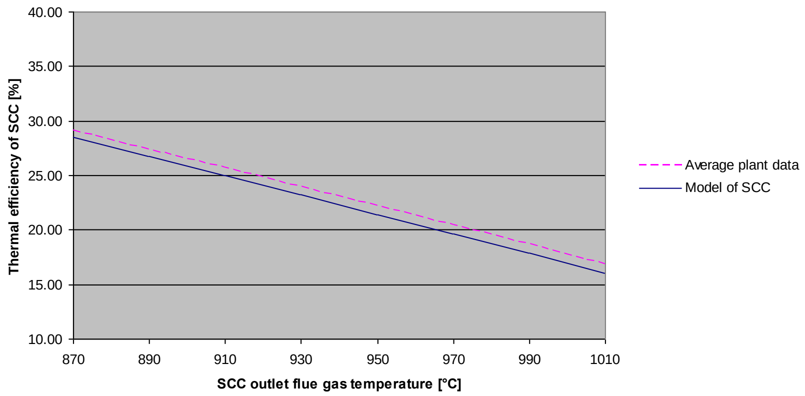

Figure 5: Thermal efficiency of SCC obtained by developed model in comparison with heat balance based on evaluation of plant data of MSWI TERMIZO Inc.

6. Conclusion

It was developed thermal model for calculation of heat transfer in the SCC with inbuilt tubular heat transfer system for purpose of in-house developed software W2E for material and energy balance of municipal waste incineration plants. Obtained results were confronted with real plant data of MSWI plant and very good agreement is found.

Acknowledgement

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