REVERSED COMBUSTION OF WASTE IN A GRATE FURNACE – AN EXPERIMENTAL STUDY

M. MARKOVIC*, G. BREM* and E. A. BRAMER*

** Energy Technology, University of Twente, P.O.Box 217, 7500 AE Enschede, The Netherlands*

SUMMARY: Most widely used concept for municipal solid waste (MSW) incineration is combustion on a moving grate with energy recovery. In MSW incinerators fresh waste stacked on a grate enters the combustion chamber, heats up by radiation from the flame above the layer and ignition occurs. Ignition front propagates downwards producing heat for drying and devolatilisation of the fresh waste below until it reaches the grate. The present project is investigating the so called reversed combustion of waste on a grate. In this new concept the fuel layer is ignited by means of preheated air from below without any external ignition source. As a result a combustion front will be formed close to the grate and will propagate upwards. In order to investigate reversed combustion an experimental set-up that is able to simulate a real moving grate furnace is designed. Experimental study was conducted to determine the influence of different factors (amount of primary air, fuel moisture content etc.) on process parameters. In this paper, the detailed description of setup, as well as the results from experiments will be presented.

1. INTRODUCTION

According to the OECD factbook 2010 (Figure 1), the average person in EU generates 560 kg of municipal solid waste per year. This means that around 280 million tons of waste is generated each year.

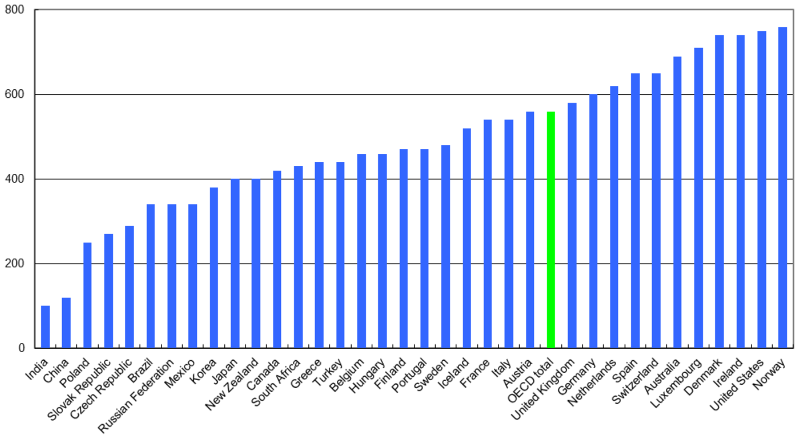

Figure 1. Municipal solid waste generation in kg per capita

Concerning the current situation and local directives for waste disposal, majority of mentioned amount is incinerated with energy recovery.

In MSW incinerators fresh waste stacked on a grate enters the combustion chamber, heats up by radiation from the flame above the layer and ignition occurs. Typically, the reaction zone from the top of the waste layer propagates downwards, producing heat for drying and devolatilisation of the fresh waste below it until the ignition front reaches the grate. The control of this industrial process is mainly based on empiricism.

MSW is a highly inhomogeneous fuel with continuous fluctuating moisture content, heating value and chemical composition. The resulting process fluctuations may cause process control difficulties, extra maintenance, unplanned stops, and fouling and corrosion issues.

The present project is investigating the so called reversed combustion of waste on a grate. In this new concept the fuel layer is ignited by means of preheated air from below without any external ignition source. Previous experiments on a lab scale setup showed that a fuel layer can be ignited by a preheated primary air stream without any external ignition source. An air temperature of only 230 ^{o}C is needed to ignite wood chips. As a result a combustion front will be formed close to the grate and will propagate upwards. That is why this approach is denoted by reversed combustion. Understanding the controlling process steps, optimum design and consequences of applying this method in existing MSW incinerators are the focus of this research. Expected results are an increased process stability, better char burn-out, lower NOx, less fouling and a better understanding of the conversion process.

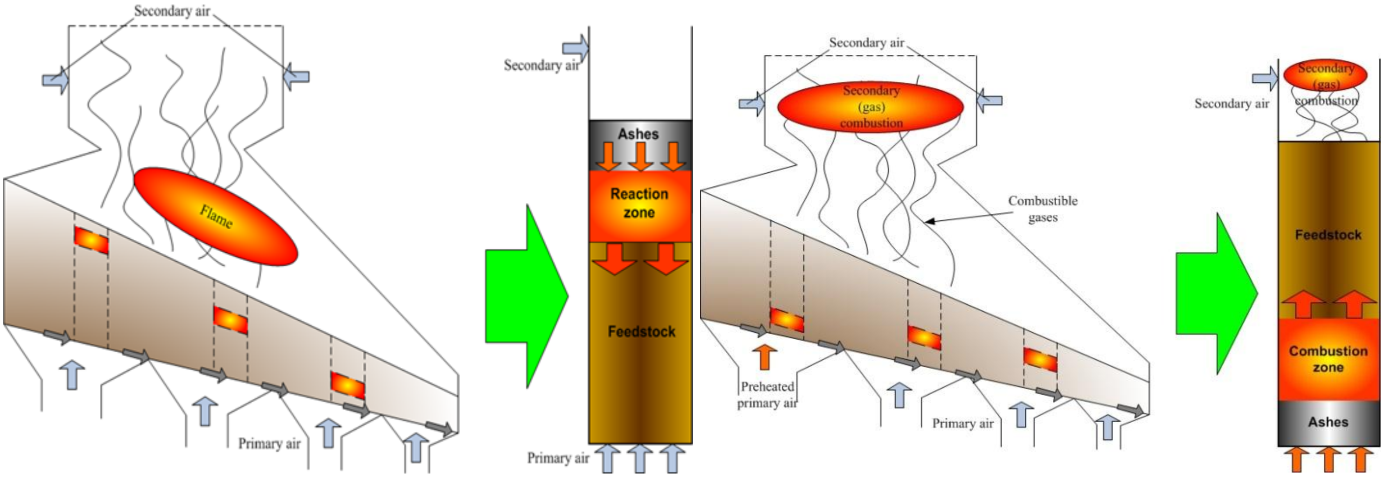

Figure 2. Ignition from "above" vs. "reversed" combustion: The cross section of the waste layer showing the reaction front both on a grate and in the built experimental setup when ignited from above(left) and from below by preheated air (right). The time during the batch experiment corresponds with a location on the full-scale grate.

This project includes mathematical modeling of both the combustion of the waste in the fuel layer and the unburnt gases in the furnace, and an experimental investigation of both conventional and reversed combustion in a new built pilot-plant.

2. EXPERIMENTAL STUDY

2.1 Experimental setup

The behaviour of waste layer in combustion chamber of waste incinerator can be simulated by a batch type fixed bed reactor. The states that a waste layer slice undergoes along the length of the grate are indentical to the ones of the fuel layer in the batch reactor in time. This means that we can easily scale up the experimental results to the real scale incinerator because time elapsed in the batch reactor corresponds to the residence time of the fuel in the moving grate (Figure 2).

The reactor (Figure 3) is designed for fuel layer heights up to 100 cm, and overall height of 455 cm. This also enables easy scaling up to a real scale facilities in vertical direction. Reactor consist of five pieces made out of stainless steel tube with outer diameter of 60 cm, and the inner diameter is 20 cm. Insulation is installed from the inner side and is made out of two components: high temperature resistant vacuum formed ceramic tube, and insulation blanket around it. Both of the insulation components have very low thermal mass. That ensures very low heat losses during experiments.

Fuel is stacked on the peforated grate made from thermaly resistant material, so the air is distributed evenly along the cross-section. Air is fed to the system as primary (below the grate) and secondary (above the fuel layer). Primary air can be supplied in two ways : preheated to desired temperature by electrical heater, or in room temperature by bypassing the heater using the three-way valve. Furthermore, primary air can be diluted by nitrogen to reduce oxygen concentration to desired level. Secondary air is distributed via nozzles 35 cm above the bed. Both air streams are controled by mass flow controllers.

Above the secondary air inlet, in the freeboard, a gas burner is installed. The purpose of this burner is to preheat the freeboard of the reactor creating the real scale incinerator conditions, and to ignite the combustible gasses leaving the layer.

Thermocouples are installed to obtain temperature profile inside the reactor, in the layer as well as the freeboard region. Thermocouples in layer are more densely set (every 5 cm on first 20 cm, followed by every 15 cm until full height of 100cm) than in the freeboard region (every 30 cm). Gas composition can be observed on two places: directly above the bed and at the top of the reactor. For monitoring of the mass reduction during the experiment, a counterweight construction with a load cell is made. In that way, a load cell with low maximal load can be used, providing high accuracy.

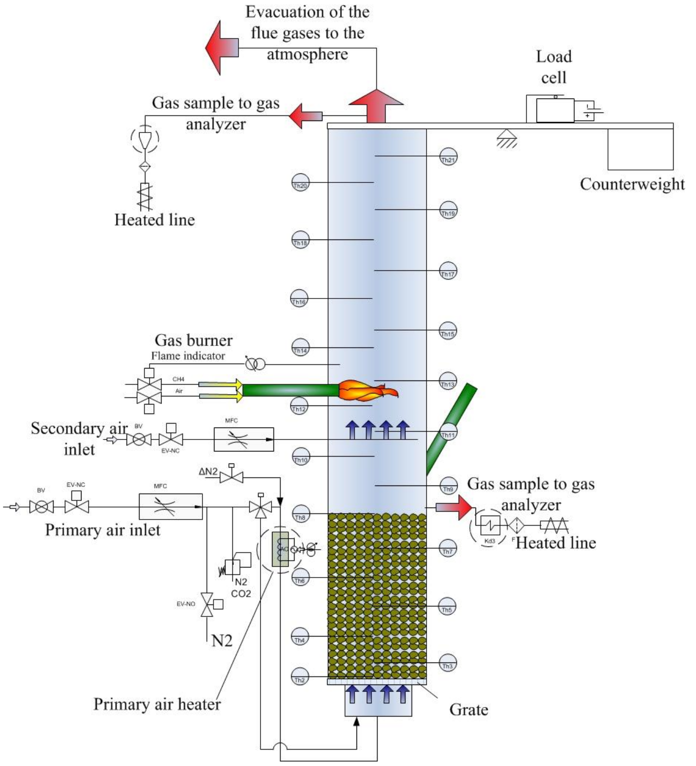

Figure 3. Schematic of experimental set-up

Exhaust system is connected to existing fluidized bed setup, in order to ignite all combustible components eventually present in flue gasses, before releasing into the atmosphere. During the experiments inside of the reactor is constantly held under a mild underpressure, preventing the possible leakage from unburnt gases to the environment.

2.2 Experimental procedure

The goal of the testing was to determine the impact of varying primary air flow, fuel moisture content and inert content on process parametars i.e. temperature in the layer and freeboard, concentration of gas, conversion time etc. Previously, a set of experiments with ignition from above was conducted. The results were consistent with literature (Figure 4).

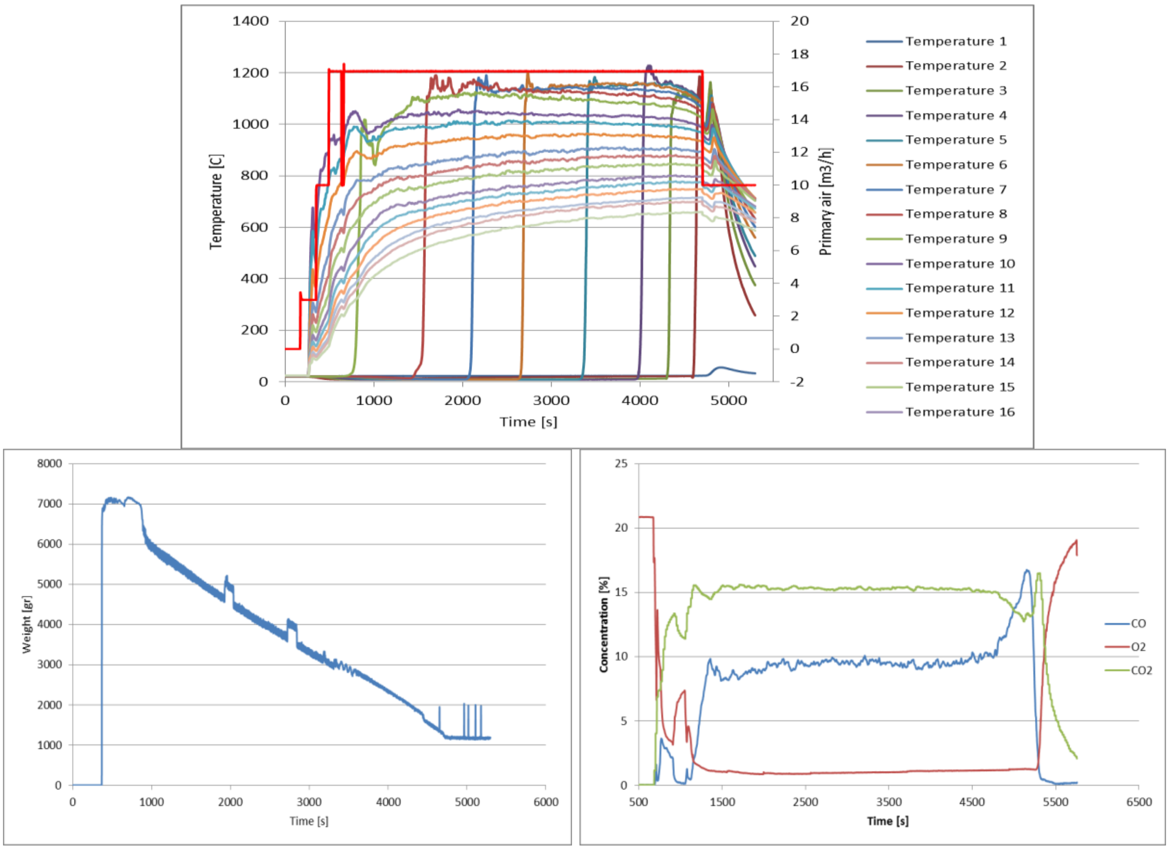

Figure 4. Experimental results with ignition from above: temperature profile along the height of the reactor(top), weight decrease (bottom left) and flue gas concentrations (bottom right). Primary airflow: 16.95 m3/h (corresponds to air velocity of 0.15m/s); Moisture content: 20 wt %; Inert material: 0 wt %

For reversed combustion experiments following parametars were varied: primary air flow (corresponding to air velocities of 0.1 and 0.15 m/s), moisture (20 and 30 wt. %) and inert content (5 and 10 %). Fuel used for both experimental series was beech wood chips (Figure 5), particle size 6-12 mm, and inert material used was construction type gravel with particle size 10-20 mm.

In these experiments primary air was diluted with additional nitrogen to 3% oxygen content

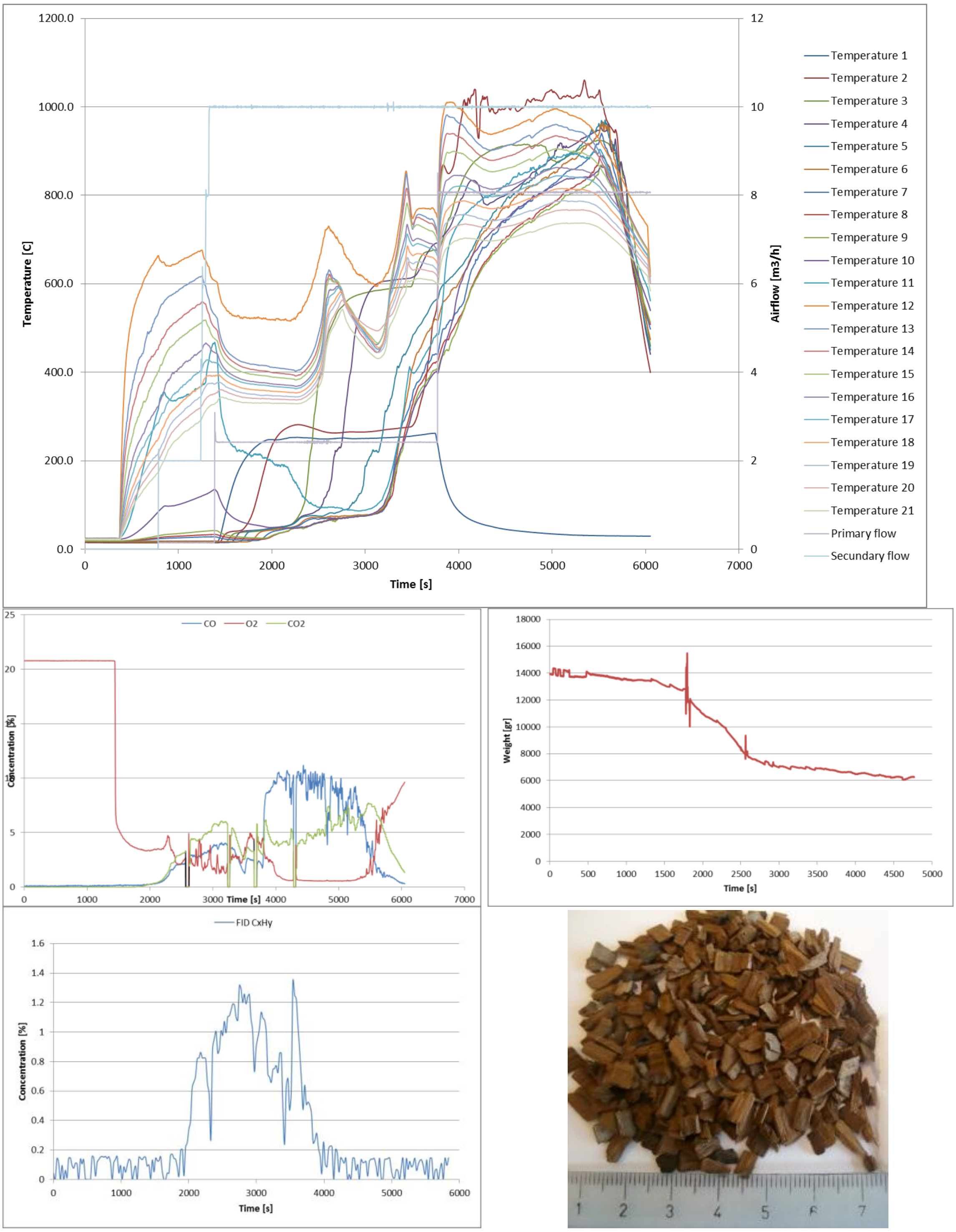

Figure 5. Reversed combustion experimental results: temperature profile along the height of the reactor(top), flue gas concentrations (middle left), weight decrease (middle right), hydrocarbon content in gas sample (bottom left) and beech wood chips used in experiments (bottom right). Primary airflow: 16.95 m3/h (corresponds to air velocity of 0.15m/s); Moisture content: 20 wt %; Inert material: 5 wt %

and preheated to 250 °C during drying and devolatilisation, and changed to 10% dilution without preheating during char combustion. Secondary airflow was kept constant in amount of 10 m^3/h.

Continuous sample of the gasses leaving the fuel layer was taken and analysed by IR spectrometers and FID hydrocarbon analyzer. The gas produced in the fuel contained heavy hydrocarbons which occasionally blocked the gas sampling system filter. For this reason, filter had to be changed during the experiments which resulted in slight weight measurement disturbance, and minor gas concentration analysis discontinuity.

3. RESULTS AND DISCUSSION

During the reversed combustion experiments, three stages of the process could be distinguished (Figure 6): drying – I, rapid devolatilization – II and char combustion – III.

Figure 6. Stages of reversed combustion

In the first stage drying of the layer occurs under the convective and thermal influence of primary air. Part of the layer close to the grate is starting to devolatilize, and when the volatile to air ratio is right and temperature of that mixture is high enough ignition occurs. Beginning of second stage is characterized by steep gradient of the layer temperature in the area 3-5 cm above the grate (Figure 5). Reaction (combustion) zone is formed that produces heat as a sort of engine for the process. As a consequence of this heat production as well as very effective insulation (heat produced is employed in the process rather then lost to the surroundings), devolatilization process accelerates. In this stage around 75 % of the mass is converted to gas in very short time period resulting high emission of combustible gasses into the freeboard of the reactor. In order to slow down the process of devolatilisation, primary air is diluted with nitrogen to 3% oxygen content.

Start of the third stage can be detected in two ways: mass decrease gradient is not so steep and temperature in the freeboard is rapidly decreasing due to decrease in production of volatiles. Now, in order to speed up the process of char combustion, concentration of oxygen is increased to 10%. However, to prevent too high temperature in the layer primary air is not preheated from this point. This results in char combustion temperatures of around 1000 ^{o}C.

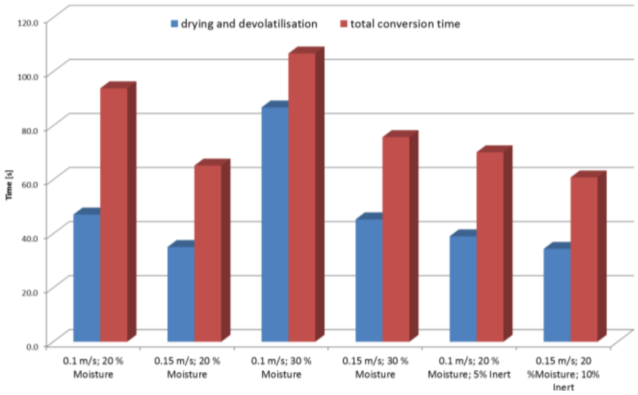

Figure 7. Time needed for drying and devolatilisation of the layer vs. total conversion time for varying parameters in reversed combustion

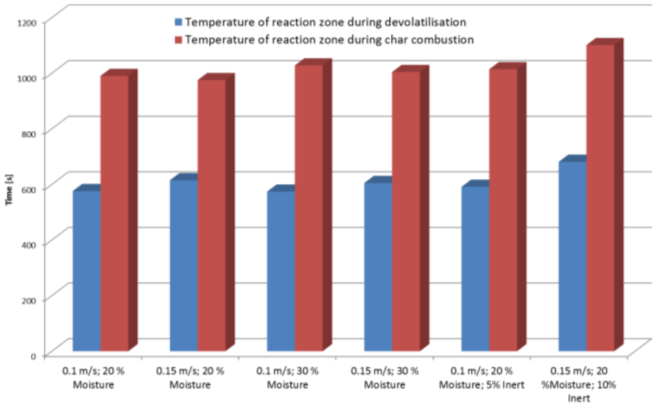

Figure 7. Temperatures of reaction zone during devolatilization of the layer vs. temperatures of reaction zone during char combustion for varying parameters in reversed combustion

4. CONCLUSIONS

Increasing the amount of primary air results in decreasing the time needed both for drying and devolatilization and total conversion for all fuel moisture and inert content. However, there is very little influence on the temperature of the layer during devolatilization and char combustion. The reason is in cooling effect of the reaction zone by nitrogen in primary air feed. By increasing the amount of primary air oxygen feed to the reaction zone is increased, but also is the amount of nitrogen. Result is almost identical temperature of the layer for both air feeds (0.1 and 0.15 m/s).

Increasing the moisture content is increasing the time needed for drying and devolatilization and the total time for conversion. Again, there is no influence on the reaction zone temperatures because the fuel is already dried when transported to the reaction zone. The only influence is in prolonging the drying time and delaying the ignition.

Increase in inert content is resulting in shorter times for drying and devolatilization and total conversion. This is because the inert material is taking the place of reactive fuel so less fuel is in the process, and also because inert material once heated up is behaving like a thermal bridge for heat distribution. Increase in inert content is slightly increasing temperatures in reaction zone because of changed air to fuel ratio.

ACKNOWLEDGEMENTS

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