KUOPION YLIOPISTO
YMPÄRISTÖTIETEEN LAITOS
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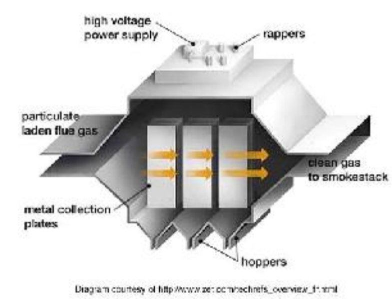
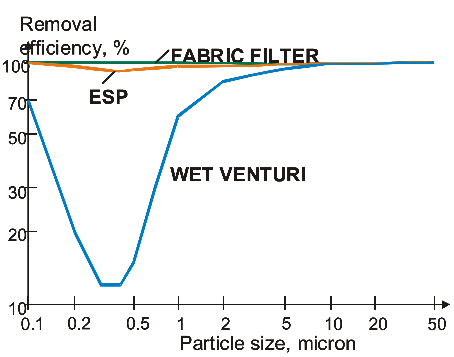
REDUCTION OF FINE PARTICLE EMISSIONS FROM RESIDENTIAL WOOD COMBUSTION
Workshop in Kuopio on May 22 – 23, 2006

Kati Hytönen and Jorma Jokiniemi (Eds.)





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7 OPTIMISATION OF AIR DELIVERY IN A SMALL HOUSE FURNACE

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7.1 INTRODUCTION

Small-scale batch-type wood combustion furnaces are widely used in heating of houses and saunas in Finland. Lately harmful emissions have been paid considerable attention, because remarkable amounts of fine particles are produced in combustion. It has been observed that the fine particles can cause serious health effects such as lung cancer etc (Salonen et al., 2006).

In small-scale batch-type furnaces carbon monoxide (CO), unburnt hydrocarbons (HC) and fine particles are the major emission components. At the beginning of year 2008 in Finland, a new emission standard is coming into force for new small-scale batch-type firewood combustion furnaces. According to the standard, the CO level must be below 0.17%. The aim of the standard is to limit the CO to a suitably reduced level. When comparing poor and good combustion, CO, HC and fine particle emissions are all reduced in the case of good combustion (Tissari et al., 2006). The CO level indicates well how complete the combustion is. However, in good combustion conditions there is no correlation between CO, HC and fine particle emissions.

The following factors influence to the amount of CO emissions in small-scale batch-type combustion:

- place of ignition
- moisture content of firewood
- size of firewood
- position of fire-woods in grid
- construction of furnace
- air delivery system

The goal of the research was to develop an air delivery system for a small-scale batch-type firewood combustion furnace in which CO emissions are as low as possible. Traditionally in this kind of furnace all the combustion air is supplied as primary air under the grid. In the new type of air delivery system a part of combustion air is supplied as a pre-heated secondary air over the firewood batch and rest of the air normally as a primary air under the grid. In this way pyrolysed gases from the fire woods burn out better and also other emissions will remain low compared to the emissions from furnace which has traditional construction. In the research the main objective was to find out and optimise a proper air supply ratio, how much air needs to be supplied as the primary and secondary air into the furnace in order to reduce the CO emissions to the minimum level. In addition, considerable attention was paid to the previously listed factors which affect the formation of CO.

7.2 METHODS

The research was divided into the three stages. First, the amount of air needed and flue gas produced was calculated when a typical 5.0 kg firewood batch was burnt based on the birch's elementary analysis (Kurki-Suonio, 1980). Using a typical burning time and excessive air ratio of the firewood batch mentioned it was possible to calculate the average air flow during the combustion. Also the adiabatic temperature of the gas was calculated for estimation of the maximum flame temperatures which could appear, if radiation of the gas and soot is neglected.

Secondly, so called cold model of the small-scale batch-type combustion furnace, the real sized visualisation test model, was built up of transparent plastics in the laboratory of TUT. In this visualisation test model, the primary and secondary air flows were independently adjustable. There was a blower with which the pressure of the chamber was adjusted to the typical level appearing in the real furnaces. On both side walls there were secondary air holes from which the secondary air and visualisation smoke mixture jets came into the furnace as shown in Figures 11a, 11b. The number and size of the holes varied in the visualisation tests in order to know how the hole size influences the penetration of the jet. The basic idea of the use of secondary air jets was to enhance the mixing of pyrolysed gases and air and to enhance combustion by jets just above the firewood batch in the so called secondary combustion zone. Secondary air jets from both sides have to at least reach the middle part of furnace. Also the air flow through the hole was calculated for the different hole sizes based on the certain discharge coefficient (Daugherty et al., 1982) and the pressure difference over the hole (Fagerholm, 1986). This knowledge was used in the dimensioning of the secondary air pipes in the real furnace.

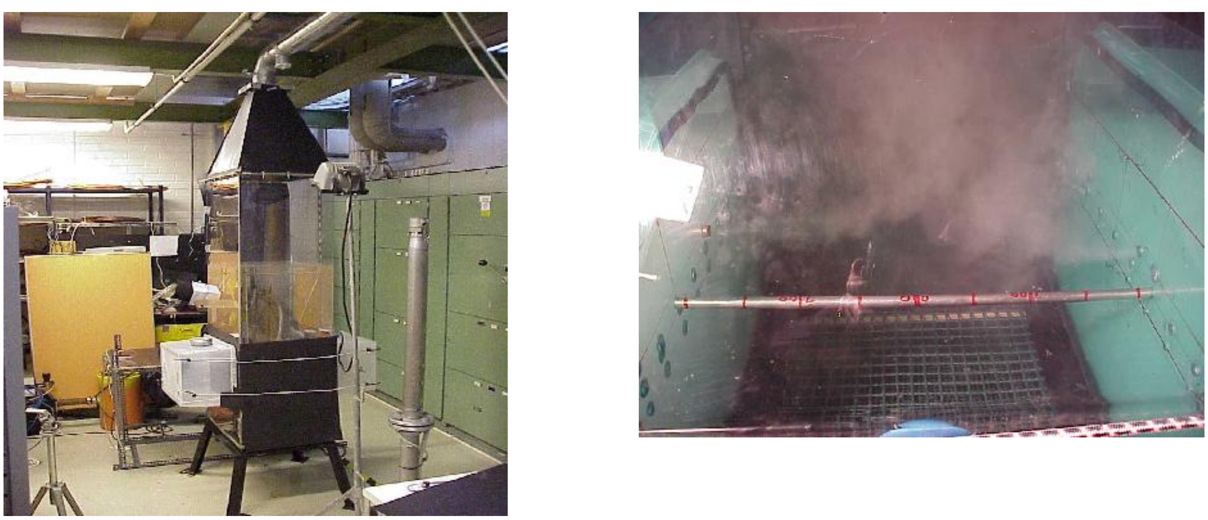


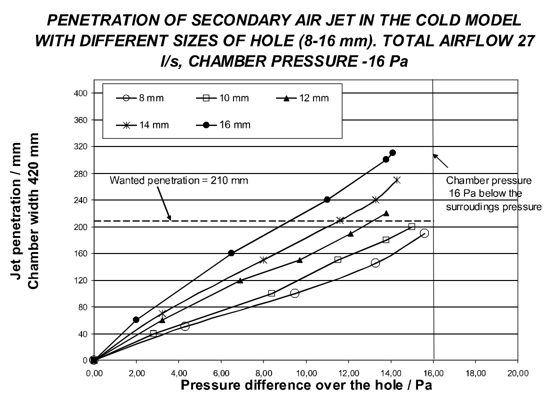
Figure 11. *General view of secondary air jets visualisation model at TUT on left (a), view of secondary air jets behaviour and measuring of penetration with rod in a certain test (b).*

Thirdly, many combustion tests were carried out with the real small-scale batch-type combustion furnace made at Tulisydän Oy by varying the primary/secondary air supply ratio. In the combustion tests, the place of ignition and the size of firewood were also tested. A test where there was a narrowed furnace at the grid level was tested in order to see the effect of free space between the furnace side wall and the firewood batch. Pyrolysed gases easily go near the side of the firewood batch to the flue gas channel without burning out and thus forming a lot of emissions.

7.3 RESULTS

7.3.1 Visualisation tests

The effect of secondary air hole size as a function of pressure difference over the hole at the 16 Pa chamber pressure below the surrounding pressure on the secondary air jet penetration is shown in Figure 12a. The calculated air flow through the different size of hole can be seen in Figure 12b.



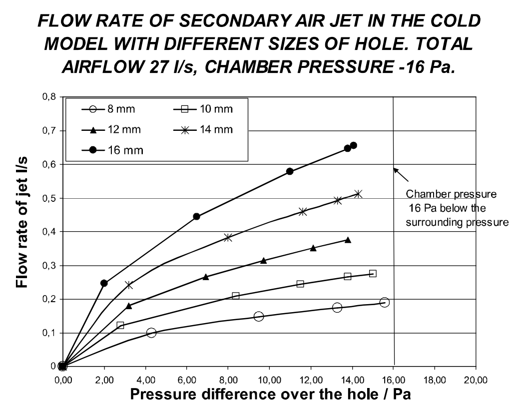


Figure 12. *Secondary air jet penetration on left (a), air flow through the different sizes of hole on right (b) at chamber pressure 16 Pa below the surrounding pressure.*

7.3.2 Combustion tests

According to the combustion tests made in order to reduce CO-emissions, the firewood batch has to be ignited from the top using small firewood splints as shown in Figure 13a. The firewood has to be as dry as possible and its size should be large enough to avoid the release of a large amount of pyrolysis gases. Also in the combustion tests it was observed that the fire woods should not lean to the sidewalls of furnace because they block the airflow near the batch and consequently combustion is inefficient in that area. Fire wood should be placed in the furnace in such a position that the combustion air is able to flow easily in the space between the logs. Then the combustion proceeds downwards fast enough and the whole firewood batch heats up and ignites properly. Also the grid must not be too wide so that the primary air could flow between the sidewall and the batch to the flue gas channel and extract the pyrolysed gases at the same time.

Since small-scale batch-type combustion furnaces use so called natural draught, in ignition and early combustion phase an unavoidable large amount of CO and HC is formed because a lot of pyrolysis gases are formed but the draught of air is still weak and hence the combustion is incomplete, as seen in Figure 13b. During the main combustion stage when the draught of air is large enough but not excessive, the pyrolysed gases burn out almost completely as can be seen in Figure 13b. If the draught is too strong it is possible that the pyrolysed gases go directly to the flue gas channel without burning due to too short a residence time in the hot combustion zone of the furnace.

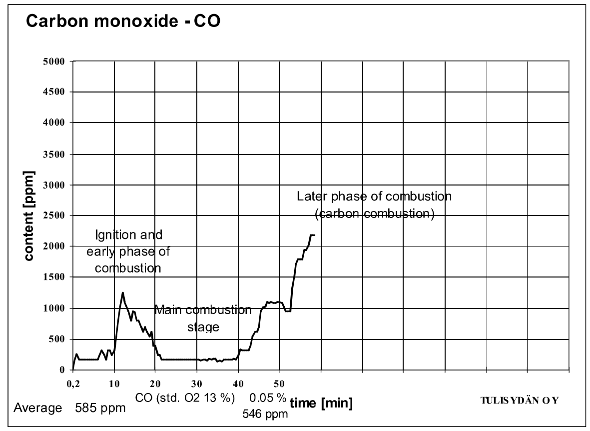


Figure 13. *On the top of batch ignition and combustion proceeding downwards on left (a), CO-emissions in different combustion stages on right (b).*

Using the secondary air supply above the firewood batch ensures that the pyrolysed gases will have sufficient air for combustion. Also the secondary air should be preheated as hot as possible so that it does not cool unburnt gases in the reaction zone and hence slow the combustion reactions. This kind of situation can happen in the later phase of combustion when the residual carbon of fire woods form CO and this does not burn properly because the temperature of gas mixture is too low. In this stage a lot of CO can be produced as can be seen in Figure 13b. The preheated secondary air supplied near the embers promotes the CO burn out.

By varying the primary/secondary air ratio in many of the combustion tests made at Tulisydän Oy, the number distribution of tests which yield a certain CO concentration was obtained (Figure 14a). Based on the results, it was found that when the primary/secondary air ratio is about 0.5, i.e. the secondary air flow over the batch is about double compared to the air flow through the grid, the optimised situation is reached in respect to the CO-emissions. In this case, the average from the ten tests obtained was 0.081 % CO which is less than the target level of the project (0.1 %) and clearly below the new emission standard level mentioned before (0.17 %). According to the reference (Hyytiäinen et al. 2007), if the secondary air is not used at all and all the combustion air is supplied as a primary air, the CO-emissions will be about three times higher. The flame which gets secondary air has different structure compared to the structure of flame in the traditional furnace. As can be seen in Figure 14b, the flame over the firewood batch becomes narrow at the beginning but after that it spreads in upstream due to secondary air jet flows and gases expanding at high temperature combustion.

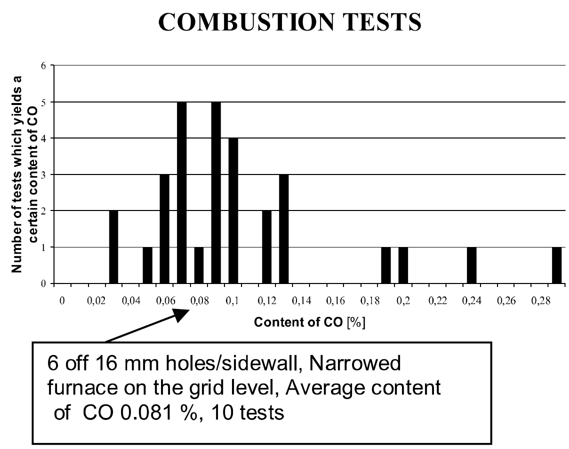


Figure 14. *Number of tests at certain primary/secondary air ratio as a function of CO-emission on left (a), the flame structure in using secondary air on right (b).*

7.4 CONCLUSIONS

CO-emissions have been reduced by more than 65 % from the original level by developing a new and optimised air delivery system into a small-scale batch-type combustion furnace using knowledge of visualisation tests results. Based on the knowledge of other emission component behaviour with respect to CO, such as HC and fine particles, it can be concluded that they have also been reduced in the same way without doing different measurements.

Also the way of using this kind of furnace influences the emissions produced considerably. Emissions formed as a result of incorrect use of furnace can be many times greater than the emissions from well operated furnace. With this in mind, informing users how to use furnaces correctly is also very important.

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