Optimization of Geometric Parameters of Wood Stove

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Abstract. The combustion process of wood in heat sources is accompanied by the production of flue gases and particulate matters. Solid emissions get into the air with fumes and adversely affect the environment, human and animal health. It is very important to reduce the amount of emissions emitted into the atmosphere not only for large sources of heat, but also for small sources that are also involved in environmental pollution. The paper deals with the reduction of particulate matter in small heat source by modification of geometric parameters of the flue, namely by adjusting the tunnel labyrinth located in the flue gas path.

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INTRODUCTION

At the present time is laid stress on air purity. Previous observation shows that many European countries have a problem with particulate matter concentration. As a consequence of those facts legislation, which regulate amount of emitted particulate matter into the air, is getting stricter. This legislation step has ambition to support general decrease of particulate matter concentration in an ambient air. [3][4]

One of the factors which influences air quality is exactly concentration of particulate matter. It is coming into the air inter alia also from combustion processes of solid fuels and biomass. Stream of burnt gas drag solid particles as a soot, fly ash and a tar. [10]

Bigger attention is paid to particulate matter with smaller diameter. Into the group with the smallest particles belong particles PM10 with diameter under 10 micrometer and particles PM2,5 with diameter less than 2,5 microns. Those particles are able to infiltrate deep into the lungs and cause serious damage. They contribute to rising of cardiovascular and respiratory problems too. Moreover they are able to keep longer time in the atmosphere and could by drift hundreds of kilometers from the source of pollution. In contrast to fine particle are course particles (bigger than 10 microns) filtered during breathing by natural process in a top part of respiratory system and don`t charge the organism. Bigger particles with diameter above 100 microns are relatively quickly settled down near the source of pollution. [4][2][10]

With the intention to minimize particulate matter production and improve the air quality are used various ways of their reduction. The devices, that product particulate matter are connected for example with filters or separators. Their implementation costs and operation costs can significantly financially charged owners or consumers and also usually maintenance is difficult. Therefore are researching solutions which will be satisfy requirements for decreasing of particulate matter production enough and at the same time will be costly as least as possible.

One of the possibilities how to do that this way is to make changes straightaway on the source of particulate matter. More accurately it is change of geometrical parameters of a combustion chamber and a flue gas path. In this work were done changes of a special tunnel labyrinth which is located in the flue gas path. The special tunnel labyrinth is device that decrease amount of particulate matter emitted into the ambient air from process of wood combustion in the small heat sources in addition to the current simply maintenance. This device is made of few parts that together create tunnel. Construction of this tunnel also make second combustion zone and work as built-in mechanical separator too.

PARTICULATE MATTER AND POSSIBILITY OF THEIR REDUCING

Solid emission – Particulate matter have harmful influence to the human health or to other organism, damage environment and decreases air quality. Solid particles from biomass combustion are soot, organic and inorganic substances.

Soot are solid carbon particles excluded from gaseous products of ideal and non-ideal oxidation of combustible by unexpected temperature drop of the flame in a combustion chamber or temperature drop of the burnt gas in some parts of exchange surface of heat source. Their amount is clearly depending on the combustion conditions and on stability of temperature in the combustion chamber.

It is very necessary to trap solid particles before their leaving into the air. To the effect are used various devices for disposal of pollutant, that are called separators. This type of devices are placed between devices that products pollution and their outlet into the ambient air. A carrying medium together with pollution are flowing through this device where are particles of pollution separated. [5] [10]

The separation of solid and liquid pollutants from gas takes place in separation devices by several phases. As a first step is necessary to take solid particles and liquid particles from gas stream towards a wall of separator into the collecting place or a sediment area, that are placed in the inner part of separator. In this phase are used various physical principles and forces. Is concerned the force of gravity, inertia force, centrifugal force, diffusive force, electrostatic force and more. In the second phases of separation process is very important to deliver pollutants that are taken towards the wall into the collecting (trapping) zone. In the closing phase of separation process, that also could have more parts, is trapped pollution in collecting zone necessary to take away to separator.

Combination of various forces and principles are used by separating, depending on actual type and sort of particles that we want to separate, depending on their density, concentration, adhesiveness, wettability, electric resistance and more. Selection of separating process also depending on technological condition by that are pollutant particles formed, on total volume, temperature of pollutant gas and more. [7] [11]

MEASUREMENT OF PARTICULATE MATTER

In this work were concerned just only with emission of particulate matter and therefore it will not more detailed paid attention to other emissions.

There are existing various method that are used for measurement of small solid particles during combustion process of biomass on the present. For this report was chosen gravimetric method that was used during experimental verification of simulations.

Gravimetric Method

The principle of measurement is to make multiple taking of sample during measurement by complex bleeding equipment by isokinetic conditions with gravimetric evaluation. Very important is that samples of burnt gas are taken isokinetically, it means that flow speed of gasses in a jet of bleeding pipe have to be the same as velocity of flow in the chimney.

Scheme of principle of gravimetric method is on the next picture Fig. 1.

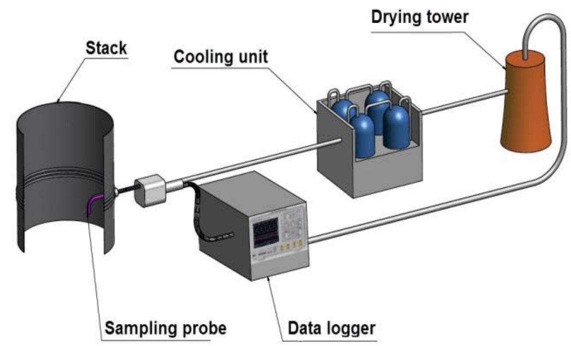

FIGURE. 1. Gravimetric Method Scheme**.**

This method is based on determination of mean concentration of particulate matter by manual taking of samples from time cross section of measurement and its consistent gravimetric interpretation. Taking of representative sample is realized by bleeding pipe (Fig.2) with proper shape right from stream of gas.

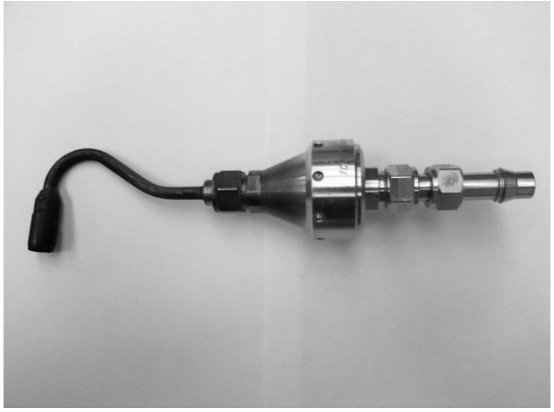

FIGURE. 2. Sonde for taking of particulate matter sample

Accuracy of the gravimetric method is depending, in significant size, on accuracy of meeting criteria of isokinetic, which is depending on accuracy of velocity measurement of burnt gas in the measuring division. Velocity of burnt gas is measured by Pitot tube based on measurement of difference of differential pressure. Problem can be that velocity of burnt gas in the small heat sources is approximately 2 m.s-1. It means approximately 3 Pa by measuring of differential pressure. This value is going up and down around level of measurement uncertainty of differential pressure.

SIMULATION OF PARTICULATE MATTER IN SMALL COMBUSTION APPLIANCES

Computational fluid dynamics (CFD) is tool which uses numerical methods to simulate fluid flow. It allows us to solve various problems with mass, heat and momentum transfer, interaction between solid and fluid etc. The CFD is very convenient way of optimization and solving different physical processes because it is economical and safety. As well there is possibility to simulate particulate matter`s flow in combustion appliances.

The way how particulate matter flows in small heat sources can be key aspect which influences particulate matter separation. From this point of view is very interesting to observe the flow of particles that exactly CFD simulation provides as the easiest way how to do it. Results of the simulation show velocity profiles, pressure layouts or previously mentioned flow of particles and other.

Description of the model

The model which is used in this work for simulation consists of big number of cells. In every cell are computed various equations.

With the intention to simplify the model of the flow as much as possible were taken into account more assumptions. The essential assumption is that there is not consider combustion, in the model is assumed just fluid flow and fluid in the model is air. The following assumptions are that processes are time independent and the fluid is incompressible. Very important is to consider gravity force, which has a major impact on the particulate matter separation in this case.

In order to have some results first it is need to get into the model input data. There was used pressure inlet and pressure outlet. Into the model was also placed source of particulate matter with some value of average mass flow. Those values were founded out in the previous measurements. Particle`s diameters were not determined just by one size. There were used various sizes to observe behaviour of the particles with different diameters. Other parameters as gravity force and barometric pressure were given as normally used values.

The next aspect which helps to simplify model was also minimum thickness of model, it was certain slice from observed area. It enables to divide model into more cells and so achieved more accurately results.

The simulations were done on a small heat source with special tunnel labyrinth located in the flue gas path.

Tunnel labyrinth

The special tunnel labyrinth is placed between combustion chamber and the chimney so burnt gas has to flow from combustion chamber trough this tunnel into the chimney. This tunnel changes aerodynamic of the flue gas and helps to separate particulate matter. There is one place in this tunnel labyrinth, where is big change of the direction of the flue gases and in this place are particles trapped. Attention was paid to this part of special labyrinth tunnel in this work.

The first simulation was done with previous construction. Other next simulations were done with a small construction changes. Because of many possibilities in those changes of construction parameters there were done just changes of one place in the special tunnel labyrinth.

RESULTS OF SIMULATION

As results of simplified simulation is visible the flow of particles in separation zone of tunnel labyrinth (Fig.3). This flow is more idealized; it is also without turbulence of particles. The bigger particles are almost all separated at the bottom, in the trapping place after wall crash and the smaller particles that are not influenced by wall crash are flying away with burnt gas into the chimney.

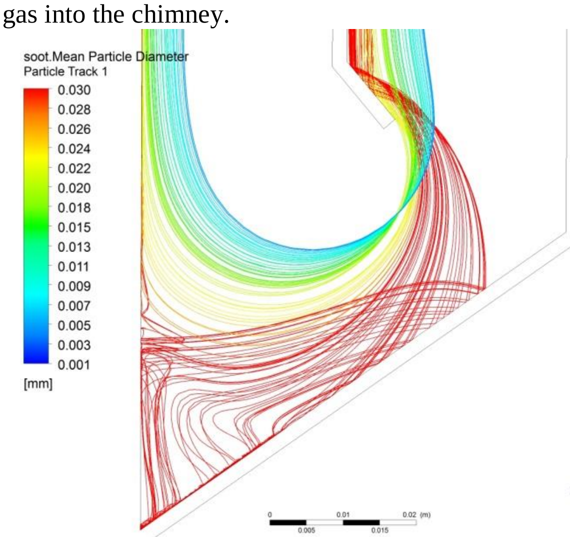

FIGURE. 3. Flow of particles in detail view

The influence of gravity and centrifugal force can be observed as well. There is possibility to trap more particles than trapped first observation with original construction. It is possible to reach higher separation by changing geometrical parameters of construction. Several simulations were done with modified construction too.

ANALYSIS OF RESULT AND CONSTRUCTION CHANGES

It is necessary to make various version of construction and compare it. After comparison of quantity of trapped particles in this various versions it is possible to choose the best construction. The best solution from simulation is made as real model and observes also in reality.

In this work was chosen modified construction which is compared to original construction. In the Fig. 4 is presented comparison of velocity of original and improved solution. On the left side is original construction and on the right side is improved construction where is changed vertical and horizontal distance up and on side. Also there is added extra barrier.

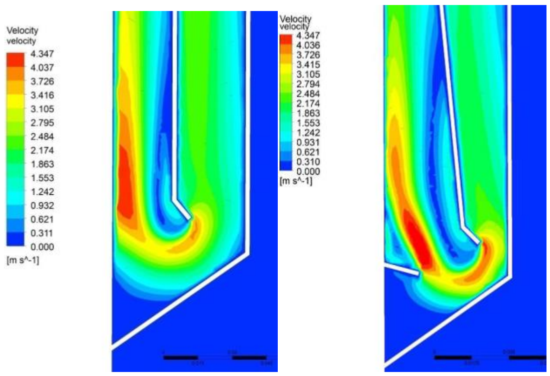

FIGURE.4. Flow of particles in detail view

On the velocity layout can be observed that aerodynamic in tunnel was changed. There was widen a place with smaller velocity in the bottom corner, where particles are trapped and the stream was speed up at the beginning of turning stream.

On the particle layout (Fig.5) is shown behaviour of particles in changed construction.

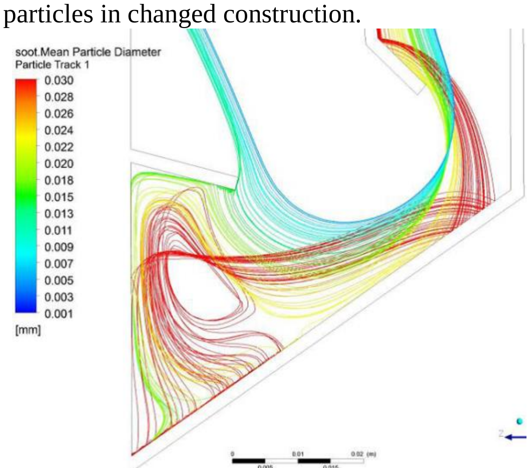

FIGURE 5. Flow of Particles in detail View

All red colored particles that are larger than 30 µm are trapped and also according color scale yellow and green particles with diameter around 17 µm are trapped by barrier. The results indicate that original construction is able to trap only particles bigger than 30 µm. It can be said that particulate matter concentration in the chimney will be smaller.

MEASUREMENTS ON THE HEAT SOURCE

In order to verify the numerical results, the experimental measurements were performed. Two series of measurements were carried out on the heat source. First was done with original construction and second round is done with modified construction.

Measurements were done on special made model, the heat source with tunnel labyrinth. The condition was the same by the first series of measurements and second series of measurements. Also both measurements were done with almost the same weight of wood.

The first series of measurements were done with first construction without changes. Results of concentration measurements are in Table 1. The second series of measurements were done with better construction according to simulation. The values of results are also in table 1. Average particulate matter concentration in the first series is 56,3mg/m3 by second series is average value 49,6mg/m3.

TABLE 1. Measurements of two different Constructions.

Number of measuremetn	First series of measuremetns	Second series of measuremetns
first measurement	58,3 mg.m^{-3}	47,9 mg.m^{-3}
second measurement	54,3 mg.m^{-3}	51,3 mg.m^{-3}
Average	**56,3 mg.m^{-3}**	**49,6 mg.m^{-3}**

There is visible a small different between those two series of measurements. It can be assumed, that it is caused by geometrical changes of special tunnel labyrinth.

CONCLUSIONS

The measured results indicate that changes of geometrical parameters influence particulate matter concentration. This can lead to reduction of emitted particulate matters. In the future more tests and experiments are necessary to do in order to improve construction of heat source and reduce particulate matter concentration.

Numerical simulation provides great opportunity for observing influences of various changes of geometrical parameters on reducing particulate matter concentration by minimum cost. It is possible observe individual changes in various construction and their influence on particulate matter trapping. This way of observation seems to be good possibility of finding optimal solution of various problems also decreasing of PM concentration. Using of numerical simulation is also financially more convenient than experimental searching by itself.

ACKNOWLEDGEMENTS

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