environment

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# PIV METHOD AS A MEANS OF OPTIMIZATION AND VALIDATION OF FLUID FLOW IN FLUE GAS PATH

**Abstract**

*The production of flue gases and particulate matters also take part in combustion process. Solid particulate matters are dragged into the air with fumes and adversely affect the air quality, environment, human and animal health. Reducing of particulate matter emissions is very important not only for large particle sources but also for small sources that are involved in environmental pollution, too. Those small producers are for example small heat sources. In this paper reduction of particulate matter production in small heat source by modification of the flue gas path by using CFD simulation and PIV method is considered.*

**Keywords**: CFD simulation, gas path, PIV method

## 1. Introduction

One of the most significant factors which affect normal function of the whole ecosystem and health of people is air quality. In many European countries problems with particulate matter concentration in ambient air, which also contribute to deterioration of air quality were recognized. There are many sources which produce particulate matter pollution. One group of them are small combustion appliances with biomass combustion.

The most developed and the most frequently applied thermochemical conversion technology of biomass into the energy is already mentioned combustion. Therefore, biomass boilers and small combustion installations could be potentially a significant source of pollutants. In those appliances the stream of burnt gas drags solid particles as soot, fly ash and tar and together it comes into the air. The domestic heating appliances have a big potential because there is a huge number of them in populated areas and especially during winter heating season they contribute to particulate matter pollution. Those combustion appliances are uncontrolled and not monitored, therefore, on a large scale contribute to the air pollution and it is estimated that those small sources produce from 20% to 90% of the total emission of particulate matter in the winter [1, 2].

Various ways of reducing can be used in heat sources with regard to decrease of particulate matter pollution. For example filters, external separators and similar devices are used. However, their disadvantage is price and, therefore, solution which are effective enough and are not so costly are searched for. One of the ways how to achieve it appears to make modification straightaway on the source of particulate matter. It can be construction change of combustion chamber or flue gas path. In this work was paid attention to changes of flue gas path by simulation and particle image velocimetry method.

## 2. Particulate matter

Solid particles from biomass combustion are soot, organic and inorganic substances. Soot is 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 dependent on the combustion conditions and on stability of temperature in the combustion chamber [1, 2].

Solid particles or particulate matter have various sizes. Attention is paid mainly to particulate matter of smaller diameter. A group of the smallest particles consists of particles PM10 with diameter under 10 micrometer and particles PM2.5 with diameter less than 2.5 micrometer. Those particles are able to infiltrate into the lungs and cause serious damage. Exposure to such particles can affect both lungs and heart, especially fine particles, containing microscopic solids or liquid droplets that are so small that they can get deep into the lungs, some may even get into the bloodstream and cause serious health problems. They contribute to rising of cardiovascular and respiratory problems, too. Moreover, they are able to keep longer in the atmosphere and could be drifted hundreds of kilometres from the source of pollution. In contrast to fine particles are course particles (bigger than 10 microns) filtered in human body during breathing by natural process in a top part of respiratory system and do not charge the organism. Bigger particles with diameter above 100 microns are relatively quickly settled down near the source of pollution [3–6].

## 3. Simulation of particulate matter in flue gas path

Modelling of physical changes by simulation program is the advantage for science and technology. It is safer, more economical and more environmentally friendly and it may significantly reduce the “trial and error” development time needed if experiments only are used for design optimization. For example, it can be used as an option to observe influence of construction changes on the flue gas flow [1].

There is possibility to observe the behaviour of flow, velocity, turbulence etc. and also influence of construction changes by minimum cost. For this purpose simplified model of small heat source was done. Few assumptions are taken into account in the simulation. The first assumption is that there is no combustion, in the model just fluid flow is assumed. Fluid in the model is air with properties of 25°C air. It is very important to consider gravity force, which has a major impact on the particulate matter separation in this case. One of the results from simulation is vector map that shows direction of flow inside of flue gas path.

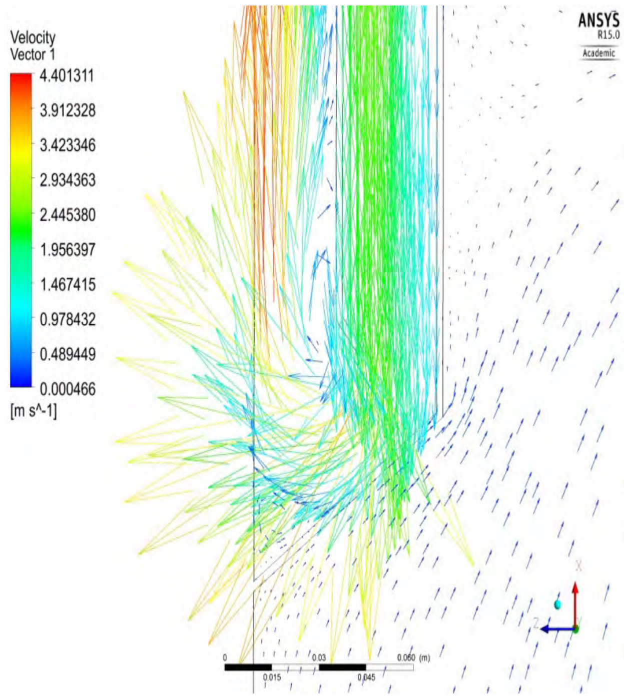


Fig. 1. Vectors of Fluid Flow

## 4. Validation and verification

A verification of simulation can be observation of fluid flow by the same conditions. For this observation appropriate measurement by PIV method is used. After validation and verification of simulation results real model can be prepared and final verification of construction changes can be done by gravimetric method during combustion. From measurements we receive data on particulate matter concentration which can be compared with those from measurement of original construction.

## 5. PIV method

Particle Image Velocimetry (PIV) is a whole-flow-field technique providing instantaneous velocity vector measurements in a cross-section of a flow. Two velocity components are measured, but use of a stereoscopic approach permits all three velocity components to be recorded, resulting in instantaneous 3D velocity vectors for the whole area. The use of modern digital cameras and dedicated computing hardware, results in real-time velocity maps [7].

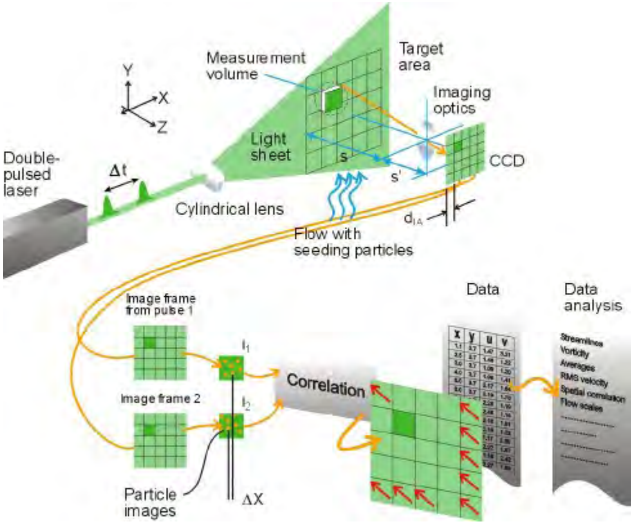


Fig. 2. PIV method scheme [7]

The experimental setup of PIV system typically consists of several subsystems. In most applications seeding particles have to be added to the flow. These particles have to be illuminated in a plane of the flow at least twice within a short time interval. The light scattered by particles has to be recorded either on a single frame or on a sequence of frames. The displacement of the particle images between the light pulses has to be determined through evaluation of the PIV records. In order to be able to handle the great amount of data which can be collected employing the PIV technique, sophisticated post-processing is required [8].

Principle of velocity measurement in fluid flow by PIV method is based on recording of particles movement in flow and subsequent evaluation of this motion. The seeding particles in the target area of fluid flow are illuminated by few short laser pulses with defined time difference. Positions of seeding particles are recorded on digital camera. The camera is able to capture each light pulse in separate image frames [7, 9]

Evaluation of those recordings is based on elementary equation:

$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$

where *distance* is movement of particle in fluid flow per time interval (*time*) [9].

The images are divided into small subsections called interrogation areas. The interrogation areas from each image frame are cross-correlated with each other, pixel by pixel. The correlation produces a signal peak, identifying the common particle displacement. An accurate measure of the displacement – and, thus, also the velocity – is achieved with sub-pixel interpolation. A velocity vector map over the whole target area is obtained by repeating the cross-correlation for each interrogation area over the two image frames captured by the camera [7].

## 6. Experiment

According to the simulation model the real model will be prepared from plexiglass for measurement by PIV method. For experiment is necessary to prepare the same condition as was set up in the simulation. It is necessary to use approximately 25°C air (as in simulation) and set up the same chimney draft. Position of devices for PIV measurement will be done according to the scheme of the experiment in Figure 3.

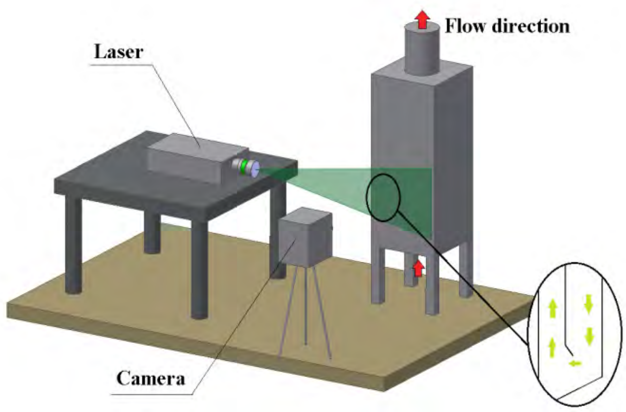


Fig. 3. Scheme of the experiment

After successful completion of the experiment we should obtain a velocity vector map over the whole target area as result.

## 7. Conclusions

Increasing use of the biomass also brings some problems for example mentioned earlier particulate matter production from biomass combustion devices, especially in the small domestic heat sources. The amount of those appliances is rising so also particle pollution produced by those devices is increasing, too.

Reduction of particulate matter is therefore important. Using of CFD simulation together with PIV measurement method can be appropriate solution how to find out how flow of particulate matter in combustion devices is influenced and see how particulate matter concentration can be dependent on construction changes. That can also help to do right decision about construction changes with regard to decrease of particulate matter pollution.

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