23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

NUMERICAL ANALYSIS FOR OPTIMAL LOCALIZATION OF GAS INLET IN A VENTURI MIXER

M. Romańczyk*, W. Elsner**

Abstract: *The research is devoted to numerical analysis for the optimal localization of gas inlet in a Venturi mixer. Performance of the gas engine depends heavily on the quality of mixing of air and fuel, and therefore homogeneity of the mixture. In addition, there must be a suitable, adapted to the current load of fuel, air ratio* λ*. Responsible for the fact, among others is the mixer located before entering the combustion chamber of the engine. Incorrect parameter value* λ *can lead to unstable operation of the engine as well as higher emissions going beyond current environmental standards. The Air-Fuel Ratio (AFR) was calculated for an air-fuel mixture of lean combustion gas engine for* $\lambda = 1.6$ *where the stoichiometric AFR for methane* CH_4 *equals* $\rightarrow 9.52\ \frac{m^3 air}{m^3 CH_4}$*. In this study, three-dimensional computational fluid dynamics (CFD) modelling has been used to investigate and analyze the influence of different positions of the gas inlet on mixer characteristics and performances. Attention was focused on the air-fuel ratio changes, pressure loss and improvement of the mixing quality in the Venturi mixer.*

Keywords: Venturi mixer, Air-fuel ratio, Pressure loss, Turbulence, CFD.

1. Introduction

Performances of industrial gas engines depend heavily on the quality of mixing of air and fuel, and therefore homogeneity of the mixture. Air-fuel ratio characteristic has a large influence on the exhaust emissions and fuel economy in industrial gas engines. With increasing demand for high fuel efficiency and low emissions, the need to supply the engine with a well-defined, homogeneous mixture under all circumstances has become more and more essential for better engine performance (Gorjibandpy et al., 2010). An ideal Venturi mixer provides a mixture of appropriate Air-fuel ratio (AFR) to the engine over its entire range of operation, from no load to full load conditions (Devarajan, 2008). To ensure correct performance of the engine, the Venturi mixer should be equipped with a gas inlet in optimal position, which causes a better mixing and a smaller pressure loss. Additionally an incorrect parameter value of λ can lead to unstable operation of the engine as well as higher emissions going beyond current environmental standards. For industrial gas engines the combustion anomalies differ highly from conventional combustion processes and can lead to strong impairments of the engine operation as well as to several engine failures (Han, 2010). On how the combustion process develops, has a huge impact the proper mix of fuel and air. If the mixture is optimal prepared appears an optimal combustion and an environmental friendly power generation. If the mixture is to lean (more air then necessary), it can lead to misfire. Misfire results with unburned gas-fuel cams in the exhaust. Another problem what can occur is the slow combustion. In effect there would be high CO-Emissions, high instability of the whole combustion process. On the other side, if the mixture is to rich (more gas then necessary) there may occur undesired processes such as pre-ignition and glow-ignition. They occur often during high load operations. Glow Ignition causes a very high instability of the combustion process, and is very danger for the engine. Different reasons for pre-ignition have been suggested previously, especially the mixture composition of the gas-air phase itself and also the particle-droplet-induced ignition (Günther et al., 2013). In addition can occur abnormal combustion knock which has a strong impact of the deterioration of engine durability and a negative environmental impact by exhaust emissions.

* MSc. Mathias Romańczyk: Institute of Thermal Machinery, Czestochowa University of Technology, Armii Krajowej 21; 42-201, Czestochowa; Poland, mathias@imc.pcz.czest.pl

** Prof. Witold Elsner: Institute of Thermal Machinery, Czestochowa University of Technology, Armii Krajowej 21; 42-201, Czestochowa; Poland, welsner@imc.pcz.czest.pl

As seen, a very important "component" in the combustion process is an optimal preparation of good quality air-fuel mixture. Therefore in this paper the numerical investigations were performed on a basic Venturi mixer, to compare different positions of gas inlet and determine the optimal localization of it.

2. Mixer design and modeling software OpenFOAM

In modern gas engines more often the manufacturers trying to design gas mixers based on the Venturi effect. The Venturi effect is caused by the drop in fluid pressure that results when a fluid flows through a constricted section of a pipe. In fluid dynamics, a fluid's velocity increases, as it passes through a constriction in according with the principle of the mass continuity, while its static pressure decreases in according with the principle of conservation of the mechanical energy. In place of the constriction, due to the decrease of static pressure (negative pressure), is sucked in gas, and in this way the gas is mixed with air. The flow through a Venturi mixer is a turbulent flow, so there was used a turbulence model in the numerical calculations. Therefore a k-ε transport equation turbulence model was used to study the turbulence kinetic energy (TKE). The different Venturi mixer geometries of models used in these CFD simulations were designed in Autodesk Inventor, while the numerical calculations have been performed using the software OpenFOAM. This software is an open source CFD tool which gives very good results in validation with experimental data. This program is a package for solving a wide range of engineering problems, from complex CFD among other things, including chemical reactions, turbulence flows etc. In these CFD analyzes the *reactingFoam* was used. *ReactingFoam* is one of the standard OpenFOAM Solvers, which using a VOF (Volume of Fluid) method to capture the mixing interface between analyzed gases. In this paper were analyzed the mixing between methane CH_4 and air. The composition of air was set in the CFD simulations by 21 % of oxygen, and 79 % of nitrogen. In Fig. 1 were shown on the left hand side the Venturi mixer and on the right hand side the analyzed cases 1 – 6 with the dimensions of the Venturi mixer.

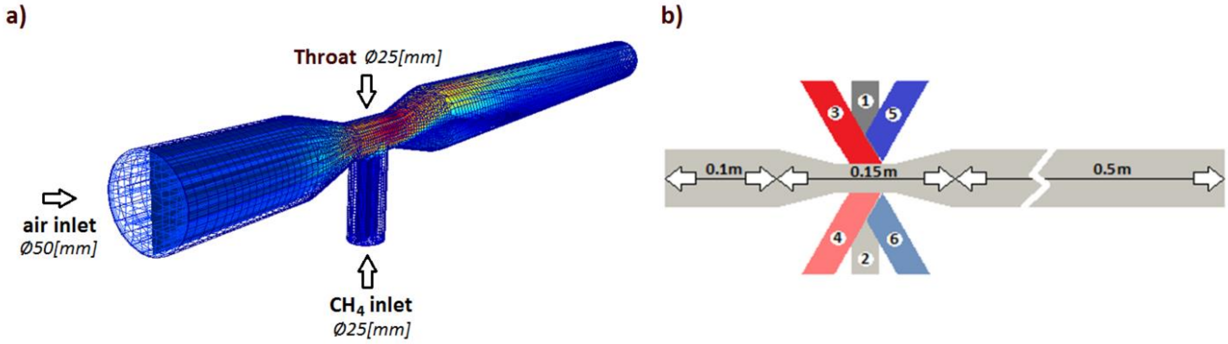

Fig. 1: a) Venturi mixer; b) Analyzed cases 1–6 with the dimensions.

The Venturi mixer constructed in Autodesk Inventor was equipped with the following dimensions. The air inlet diameter was set on 50 mm, while the gas inlet diameter on 25 mm. At the constriction point of the Venturi mixer (Throat) the diameter equals 25 mm. The length of the analyzed Venturi mixer types in all cases was set on 750 mm.

The analyzed cases in this paper were presented below:

- Case 1) **normal↓** – normal location of the gas inlet from the top,
- Case 2) **normal↑** – normal location of the gas inlet from the bottom,
- Case 3) **30 °↘** – location of the gas inlet from top on left side at an angle of 30°,
- Case 4) **30 °↗** – location of the gas inlet from bottom on left side at an angle of 30°,
- Case 5) **30 °↙** – location of the gas inlet from top on right side at an angle of 30°,
- Case 6) **30 °↖** – location of the gas inlet from bottom on right side at an angle of 30°.

3. Results and discussion

The results presented in this paper show the comparison between six analyzed cases of the gas inlet localization in the Venturi mixer. The Air-Fuel Ratio (AFR) was calculated for an air-fuel mixture for lean combustion gas engine with $\lambda = 1.6$ where the stoichiometric AFR for CH_4 equals $\rightarrow 9.52\,\frac{m^3 air}{m^3 CH_4}$ (Ražniewić, 1966). The calculation has been presented below:

$$AFR = \frac{m_{air}}{m_{fuel}}$$

$$AFR_{stoich} = 9.52\,\frac{m^3 air}{m^3 CH_4}$$

$$\lambda = \frac{AFR}{AFR_{stoich}}$$

$$1.6 = \frac{AFR}{9.52} \Rightarrow AFR = 15.232\,\frac{m^3 air}{m^3 CH_4}$$

$$for\ AFR = 15.232\,\frac{m^3 air}{m^3 CH_4} \Rightarrow \frac{0.9384\, m_{air}}{0.0616\, m_{CH_4}}$$

Therefore the concentration of methane mass fraction CH_4 equals $\Rightarrow 0.0616\, m_{CH_4}$ while the concentration of air mass fraction equals $\Rightarrow 0.9384\, m_{air}$. The concentrations of methane mass fraction CH_4 and air through the Venturi mixer were shown in Fig. 2.

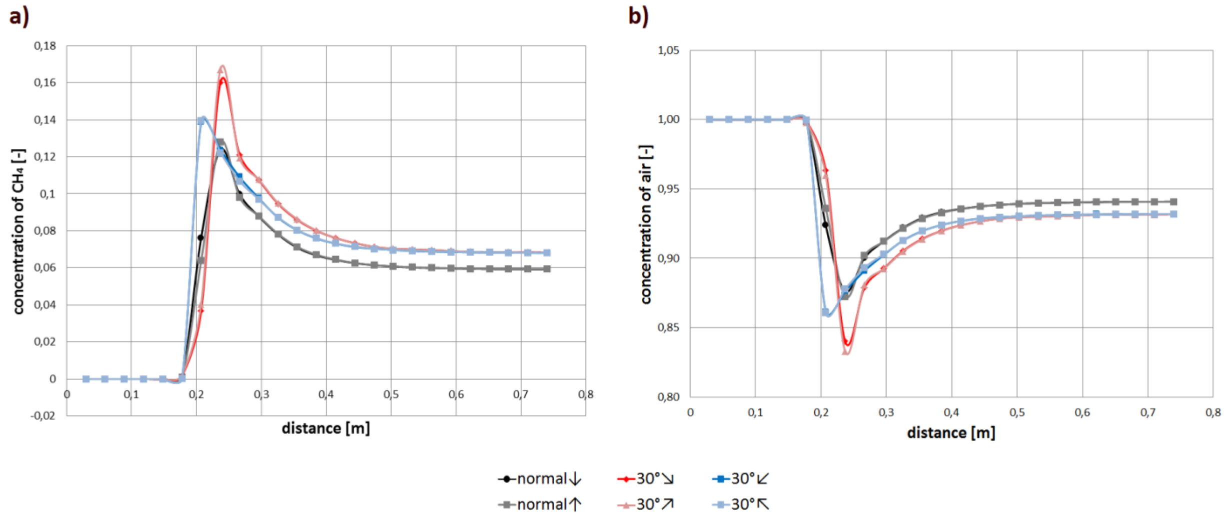

Fig. 2: Concentration of methane mass fraction CH_4 - a) and air - b) through the Venturi mixer.

Analyzing Fig. 2 it is seen, that the suction of methane appears earlier and faster in the gas inlet located indirectly to the flow stream (blue colored lines). The gas inlet located directly to the flow stream (red colored lines) show that the suction of methane appears a little bit later and initially slower, but in the end more methane CH_4 is sucked in, which results in a better mixing process of the two components – air and gas. These drops are also seen on the concentration of air through the Venturi mixer. The normal position of the location of gas inlet has been optimally simulated for $\rightarrow \lambda = 1.6$. It is seen in both cases (left and right side of the location of gas inlet) – that the mixture preparation is richer in the end (more gas) what causes a smaller value of $\lambda < 1.6$. Here we could observe the air-fuel ratio changes, which could be explained with the angle of the gas inlet flow which causes more suction of gas into the flow stream of the Venturi mixer, at identical inlet conditions for all analyzed cases.

In Fig.3 were presented the distributions of turbulence kinetic energy (TKE) and pressure loss [Pa] through the Venturi mixer. In fluid dynamics the turbulence kinetic energy (TKE) is defined as the mean kinetic energy per unit mass, related with eddies in a turbulent flow. Physically, TKE is characterized by measured root-mean square (RMS), therefore velocity fluctuations. In Reynolds-averaged Navier Stokes equations (RANS), the turbulence kinetic energy (TKE) can be calculated based on the closure method, i.e. a turbulence model. As it was mentioned before, in the numerical simulations the turbulence model k-ε was applied. Turbulence kinetic energy (TKE) can be generated by fluid shear, friction or buoyancy, or through an external force at low-frequency eddy scales (Absi, 2008).

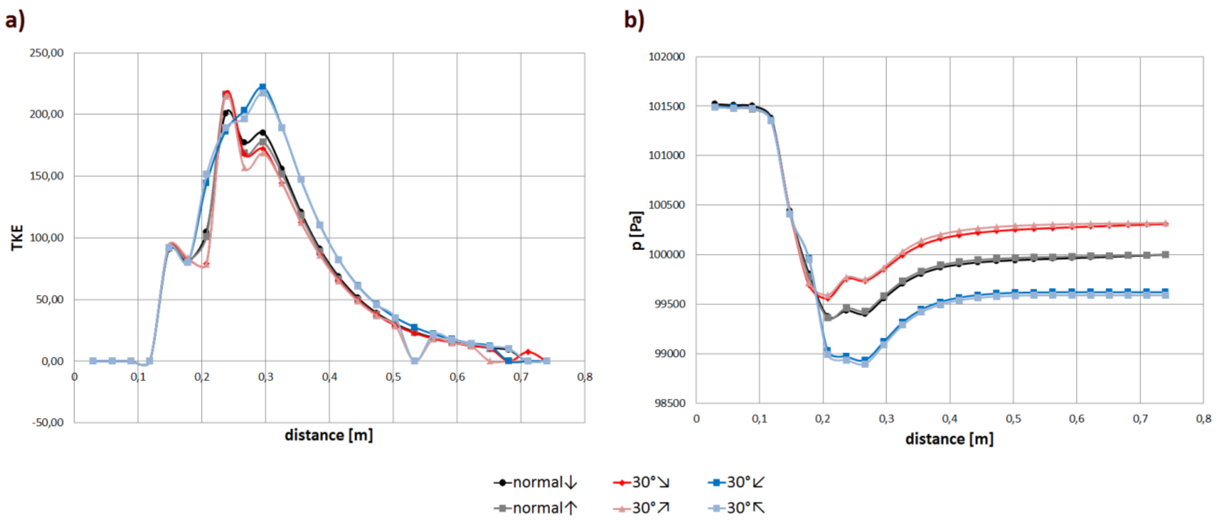

Fig. 3: Distribution of turbulent kinetic energy - a) and pressure loss [Pa] - b) through the Venturi mixer.

Analyzing the distributions of pressure loss [Pa] through the Venturi mixer it is clearly seen that the smallest drop in pressure appears for red colored lines – in the location of the gas inlet on the left side at an angle of 30 °. The reason for this is, that the gas entering the Venturi mixer flows directly into the flow stream and is mixed with air without much resistance from the air itself, due to the fact that the analyzed flow through the Venturi mixer is from left to right. The biggest pressure loss is seen for the blue colored lines, where the gas enters the Venturi mixer in the opposite direction to the flow.

4. Conclusions

The research shows that the best localization for the gas inlet in the Venturi mixer is case 3 and 4 (red colored lines), where the gas inlet is located on the left side at an angle of 30 °, where the gas CH_4 is supplied directly into the flow stream of air.

Acknowledgement

This research is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691232-Knocky-H2020-MSCA-RISE-2015/H2020-MSCARISE-2015.

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