Development of A High Pressure Compressed Natural Gas Mixer for A 1.5 Litre CNG-Diesel Dual Engine

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Abstract: The Computational Fluid Dynamics (CFD) analysis software was used to study the flow behaviour of compressed natural gas (CNG) and air in a CNG-air mixer to be introduced through the air inlet of a CNG-Diesel dual fuel stationary engine. The results of the simulation show that the Venturi mixer with more holes gives superior engine performance compared to the 4-hole Venturi mixer. Further analysis is done on the different holes mixer to investigate the effect of engine speed on the mass flow rate of CNG and the equivalence ratio Lambda. The second part of the paper represents a comparison results between the performances of a single cylinder research Compression Ignition CI engine fuelled with CNG-diesel system and conventional CI engine fuelled by conventional diesel. The engine was equipped with the simulated Venturi mixer, the result showed significant reduction in the exhaust gas emission compared to the conventional diesel engine. The average power output generated by dual fuel engine was slightly higher than that diesel one at different engine speeds.

Keywords: Compressed natural gas, mixer, 1500cc four stroke engine, computational fluid dynamics

I. INTRODUCTION

Internal combustion engine mixture preparation and utilization are mainly governed by fluid flow. A clear understanding of the fluid motion and dynamics processes are needed to improve the design of each of components involved. CFD can be used to give information on the properties of the fluid flow in the respective engine components. A four-stroke engine is designated for conversion into bi-fuel version to use compressed natural gas and gasoline respectively. In Figures 1 and 2, the mixer was developed based on several assumptions with the engine air flow requirements of a 1500 cc engine [1]. The simulation exercise can be used to predict the amount of CNG consumed by the engine [2].The model is done by using boundary conditions of a high pressure inlet obtained by adjusting the CNG gas regulator. The model is hoped to have better control of the CNG intake of the engine.

II. MODEL DEVELOPMENT

The best approach is to mix CNG and air just before entering the air intake valve [3]. Since both fluids are in gaseous state, they can easily mix without any external force. UMP has begun focusing on lean-premixed (LP) combustion to reduce the emissions formed during combustion. LP combustion requires that fuel (natural gas) and air be thoroughly mixed before combustion takes place so that stoichiometric values are achieved. This premixing ensures that the flame temperature will never exceed levels above which high pollutant formation rates occur. More conventional combustion techniques (with higher pollutant formation) mix the fuel and air flows at the same time that combustion is occurring [4]. The result is regions within the flame of inefficiently high temperatures and high pollutant emissions. Nitrogen Oxide, NOx, emissions are dependent on flame temperature; higher flame temperatures increase the level of NOx emissions. The primary objective is to create a uniform mixture of air with fuel in order to lower the flame temperature required for complete combustion by utilizing the existing high pressure in the CNG tank.

In the market venturi mixers are available in all sort of sizes and need minor modification in order to be setup on a vehicle CNG system. The venturi mixer has inlets for the fuel gas (natural gas, propane) and the air (and/or oxygen). Inside the mixer body, the venturi shape of the mixer mixes these gases properly and distributes them through the outlet [5]. This mixing ratio is controlled by the sizing of the jet and the throat that are part of the mixer body. Figure 1 shows the design done for the prototype of the high pressure CNG mixer.

When the higher pressure air or oxygen is brought into the mixer, it must pass through the jet. By limiting the size of the jet, the mixer controls the amount of air that is capable of entering the mixing chamber. The fuel gas enters through its side inlet unrestricted into the mixing chamber. The pressure of the air pushing through the jet mixes the gases together and forces them out through the Throat at the proper ratio. In this case a slight adjustment of the pressure regulator is required to adjust the CNG gas leaving the tank to the stoichiometric condition.

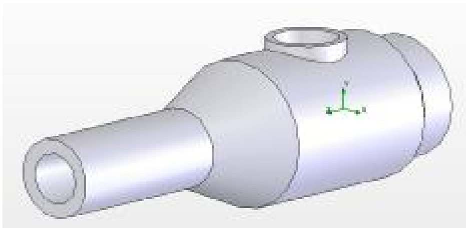

Figure 1: Isometric view

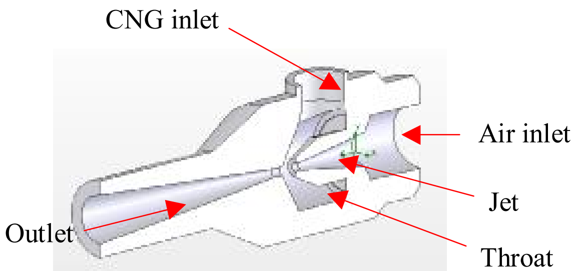

Figure 2: Cross-section view of the Mixer

III. BOUNDARY CONDITIONS

The boundary condition as shown in Figure 3 is important to represent the flow in the mixer for CFD analysis to begin. CFD results are usually related to the number of cells used to model the flow. If it is insufficient and the boundary conditions not appropriate enough, the turbulence model will not match for flow at high speeds [6]. Proper boundary condition is determined for the simulation and after the design of the CNG mixer is finished, the design is transferred to COSMOS Flow Works for analysis [7]. Before the analysis was done, a set of the boundary condition of the air and methane is established. The CFD software utilizes the Navier Stokes equations to solve the flow behaviour [8].

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_k}(\rho u_k) = 0 \qquad (1)$$

$$\frac{\partial \rho u_i}{\partial y} + \frac{\partial}{\partial x_k}(\rho u_i u_k - \tau_{ik}) + \frac{\partial P}{\partial x_i} = S_i \qquad (2)$$

$$\frac{\partial (\rho E)}{\partial y} + \frac{\partial}{\partial x_k}((\rho E + P)u_k + q_k - \tau_{ik} u_i) = S_k u_k + Q_H \qquad (3)$$

These are some boundary condition that has been setup during the analysis:

The outlet volume flow : $0.2738\ m^3/s$
Methane pressure : 151.325 KPa
Air pressure : 169.325 KPa

After keying in these input parameters, calculation were done with 227 iteration before the result were out.

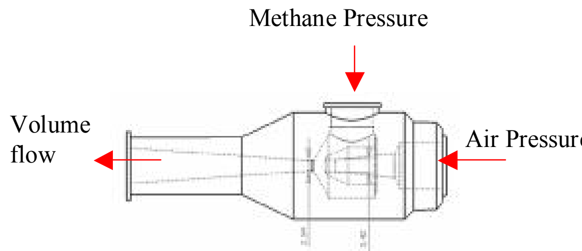

Figure 3 Boundary Inputs for the Mixer

The design must also follow the criteria of mixing of air and fuel is 17.4 ratios, this call stoichiometric ratio which means the mixing of the CNG and air achieve the most efficient mixing ratio. This stoichiometric ratio also we can get from chemical composition of methane (CH_4) and air which is oxygen (O_2) [9].

IV. RESULTS AND DISCUSSION

Analysis of pressure was done by increasing the air inlet pressure to see the workability of the system; this caused the content of air flow through the mixer outlet to increase. The condition need to analyse because if the pressure of air is high at the orifice, it will cause less methane to flow and mix with the air. Figure 4 to 6 shows that the air flow is increased by the use of the high pressure in the mixer to get a leaner mixture. The higher pressure input causes the opening of the mixer to have a suction pressure so that CNG may be introduced in proportion to the air. Apart from this the result also is used to obtain the overall pressure drop that occurs at the mixer. For an increase of pressure of 9KPa, the pressure drop is 118.322 KPa and for increase the pressure 7 KPa the pressure drop is 39.62 Pa.

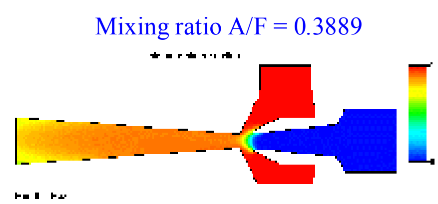

Figure 4: Analysis with using pressure 151.325KPa

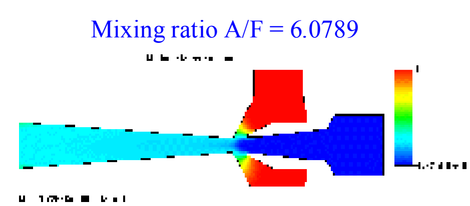

Figure 5: Analysis with using pressure 160.325KPa

Mixing ratio A/F = 16.7005

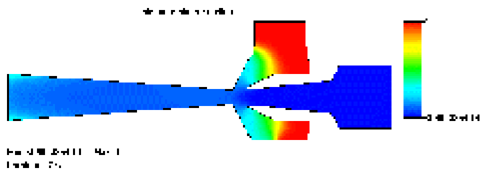

Figure 6: Analysis with using pressure 167.325 KPa.

The pressure decreases because of the restriction imposed by the design. This means that the methane decreases proportional to the pressure drop. Thus, giving more suction as the inlet pressure is increased [10].

After pressure analysis is done the simulation moved to determine the CNG and air mixing ratio. From the simulation products of flow rate are obtained at an integral surface perpendicular to the flow. This flow rates are for the air and methane flow. Both of the values are used to determine the air to fuel mixing ratio.

Jet = 1.66mm
Throat = 1.66mm

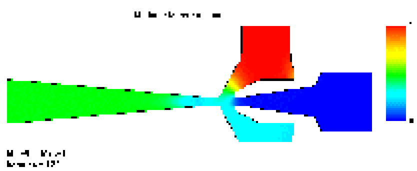

Figure 7: Analysis 1st model of mixer

Jet = 1.66mm
Throat = 3.44mm

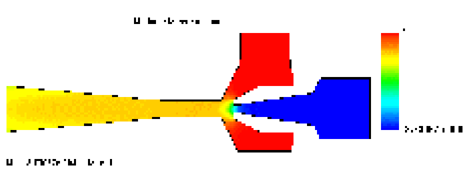

Figure 8: Analysis 2nd model of mixer

Jet = 3.42mm
Throat = 2.84mm

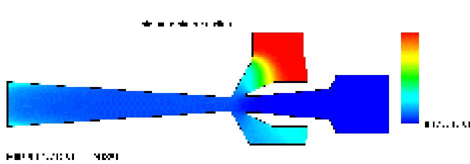

Figure 9: Analysis 3rd model of mixer

These are the result of computer simulation using COSMOS software with the variable diameter of the throat and the jet. Referring to Figure 7 from the simulation, the mass flow rate of the air is -0.00122892 kg/s and the mass flow rate of the methane is -0.00122892 kg/s. The negative symbol denotes suction of methane. The A/F ratio which is mass flow rate of air over mass flow rate of methane and this equal to 1. These mean that the volume of air and methane which flows through the outlet is same and not compatible with the A/F ratio.

Figure 8 shows the result for the second model. The mass flow rate of air is equal to -0.000852849 kg/s and the mass flow rate of methane is -0.00202187 kg/s. The A/F ratio is equal to 0.4218. This ratio also is not compatible with the stoichiometric ratio which is 17.4. This result means that the volume of methane that flow through the outlet is larger amount than the air volume.

Figure 9 shows the result for the third model. From the simulation, the mass flow rate of air is equal to -0.061334 kg/s and the mass flow rate of methane is -0.0035618.This result means that the volume of air that flow through the outlet is larger amount than the volume of methane. The A/F ratio is equal to 17.22 which can consider satisfied with the stoichiometric ratio. Thus, the design for the third model is compatible with the stoichiometric A/F ratio.

V. CONCLUSION

The characteristic of the air, compressed natural gas and the mixture of air and gas flow in the mixer have been discussed on theory and being proved by computer simulation COSMOS Flow Works. Air flow is one of the areas that need to be considered seriously when a CNG mixer is designed, as it not only reduce the pollution by automobile vehicle but also improves the vehicle performance. The engine emissions level is also very important as we designed and created the engine by using methane as a fuel and this will improve the emission as we discussed earlier. A high quality mixer should provide the very optimum environment for the engine operating condition. In the process of designing the CNG mixer, it can be deducted that the design has reached the objectives. A CNG mixer in the same application as venturi mixer was designed for 1500cc four stroke engine application.

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