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An Investigation of Air-Gas Mixer Types Designed for Dual Fuel Engines: Review

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Abstract: Diesel engines produce high emissions of smoke, particulate matter and nitrogen oxide. The challenge today is to reduce exhaust emissions without making any major modifications on engine. Therefore, adding alternative fuel will be the best practical pick to improve the performance and cut down emissions from diesel engines. The air fuel mixer plays an important role to convert diesel engine to work with dual fuel mode (alternative fuel-diesel) without any change in engine. One problem of gaseous mixers is the disabilityto prepare a homogeneous air-fuel mixture at a specific air-fuel ratio before entering the engine, thereby leading to high brake specific fuel consumption and exhaust emissions. This study offers an overview of air fuel mixer types. According to, overview in the dual-fuel engines, the combustion efficiency, engine performance and the emission reduction of gases are directly proportional to the degree of homogeneous mixing and air fuel ratio, all that depend on the design of mixer (size, shape, number of holes) and control mechanism that control on the mixer.

Key words: Diesel engine, dual fuel engine, AIR-CNG Mixer, exhaust emissions, fuel consumption, combustion efficiency

INTRODUCTION

The evolution of internal combustion engines has resulted in enormous benefit to the world, particularly in turning engines into essential prime movers for humankind. However, population growth and the enhancement of standard of living have led to a staggering rate of increase in energy consumption around the globe. Consequently, the world faces the twin problems of energy crisis and environmental degradation. The increase of fossil fuel burning in internal combustion engines and vehicles has led to several harmful effects to the environment and humans due to an increase in the emission of gases such as Carbon monoxide (CO), Carbon dioxide (CO_2), Hydro Carbon (HC) and Nitric Oxide (NOx) among others (Tang, 1995; Sun *et al*., 2012; Bora *et al*., 2013, 2014; Korakianitis *et al*., 2011).

By contrast, petroleum products including crude oil are assumed to become considerably expensive and scarce in 21st century. The enormous increase in the number of vehicles have increased the demand for fuel (Bose *et al*., 2013). The rapid depletion of fossil fuels and the continuous increase in oil prices are forcing engine manufacturers to develop a new alternative. In addition, alternative, reliable and environmentally friendly fuel should be developed due to the damage to the environment and human beings caused by the use of oil derivative fuels (Yang *et al*., 2015; Karagoz *et al*., 2016; Pichayapat *et al*., 2014; Liu *et al*., 2013). The majority of energy requirements in transportation are still addressed by fossil fuels. Various alternatives such as electric cars, fuel cells, biomass, hydrogen, LPG, methane, producer gas and solar-powered vehicles have been developed to reduce the emission levels from the transportation sector (Pichayapat *et al*., 2014). With new development in diesel engine technologies, Diesel Dual Fuel (DDF) is one of the solutions to reduce the overall emission levels from diesel vehicles (Yang *et al*., 2015; Karagoz *et al*., 2016; Pichayapat *et al*., 2014; Liu *et al*., 2013; Wang *et al*., 2016).

Although, on and off-road diesel engines are extensively used because of their high thermal efficiency and low HC and CO emissions, these engines are major contributors to NOx and Particulate Matter (PM) emissions. Various approaches to reduce NOx and PM emissions have been applied including the use of selective catalytic reduction and diesel particulate filter, respectively. However, these two approaches depend heavily on the use of expensive precious metals as catalysts and the devices are difficult to retrofit into

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in-use diesel vehicles. Accordingly, various alternative strategies have been proposed including dual-fuel combustion. The use of gaseous fuels (i.e., alternative fuels) in diesel engines under the dual-fuel mode (i.e., diesel and gaseous fuels as the pilot and main fuels, respectively) offers a simple method to reduce emissions and improve fuel economy (Yaliwal *et al*., 2016; Paul *et al*., 2015; Liu *et al*., 2015; Wei and Geng, 2016; Abagnale *et al*., 2014; Zhang and Song, 2016).

The most practical method of converting diesel engine without many modifications to accept alternative gaseous fuel is by installing a fuel-air mixer at the air inlet before the combustion chamber (Dahake *et al*., 2016; Gorjibandpy and Sangsereki, 2010). The mixing efficiency and accurate determination of flow characteristics are important in the design and control of mixing devices, particularly when turbulent flows are involved. For automotive, efficient mixing (i.e., homogeneity of the mixture) between fuel vapor and air is crucial for increased combustion efficiency and fuel saving (Abdul-Wahhab *et al*., 2015).

One problem of gaseous mixers is the inability to prepare a homogeneous mixture of air and fuel at a specific air-fuel ratio prior to entering the engine. This issue leads to high Brake-Specific Fuel Consumption (BSFC) and high exhaust emissions. Many studies have indicated that the mixture formation of gaseous fuel with air is more critical than liquid fuel due to the former's considerably low density and limited fuel penetration (Sharaf, 2013). Moreover, even though gaseous fuel can easily mix with air due to its high diffusivity property, this type of fuel may have insufficient time for mixing, particularly at substantially high engine speeds, thereby resulting in poor mixing formation (Chintala and Subramanian, 2013).

This study presents an overview of the diesel engine, dual-fuel engine and air fuel mixer. Moreover, this chapter presents the types of air fuel mixer and the influential factors in designing a mixer.

MATERIALS AND METHODS

Diesel engine: Diesel engines are used for power generation, mass and passenger transportation and off-road applications due to these engine's high thermal efficiency, high torque, reliability, durability and fuel economy (Chintala and Subramanian, 2013; Zhou *et al*., 2014). Diesel engine is an auto-ignition engine in which fuel and air are mixed inside the engine. The air required for combustion is highly compressed inside the combustion chamber. This process generates high temperatures that are sufficient for the diesel fuel to ignite spontaneously when it is injected into the cylinder. Thus, diesel engine uses heat to release the chemical energy contained in the diesel fuel and convert it into mechanical force (Resitoglu *et al*., 2015). Carbon and hydrogen construct the origin of diesel fuel which is similar to most fossil fuels. For the ideal thermodynamic equilibrium, the complete combustion of diesel fuel would only generate CO_2 and H_2O in the combustion chambers of the engine (Prasad and Bella, 2011). However, many reasons (e.g., air-fuel ratio, ignition timing, turbulence in the combustion chamber, combustion form, air-fuel concentration, combustion temperature and combustion with heterogeneous air-fuel mixture among others) make this process impractical and several harmful products are generated the during combustion. The most significant harmful products are CO, HC, NOx, SO_2 and PM (Fig. 1). NOx has the highest percentage of diesel pollutant emissions with a rate of over 50%. After NOx emissions, PM has the second highest proportion in pollutant emissions. Diesel engines are lean combustion engines and the concentrations of CO and HC are minimal. Moreover, pollutant emissions include a modicum of SO_2 which depends on fuel specifications and quality (Resitoglu *et al*., 2015).

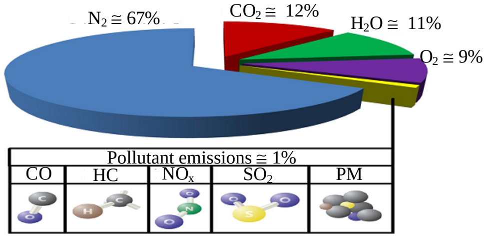


Fig. 1: Composition of the diesel exhaust gas (Resitoglu *et al*., 2015)

The HC and PM emissions in internal combustion engines result from the incomplete combustion process inside the engine whlie CO is created in internal combustion engines due to the incomplete combustion of a carbon-based fuel as a result of insufficient air (Wong, 2005; Sharaf, 2013; Dubey, 2014; Konigsson, 2014; Comino, 2012; Oliveira, 2016). Moreover, NO emissions is created due to high localized temperature in the cylinders (Resitoglu *et al*., 2015; Sharaf, 2013; Dubey, 2014; Larsen, 1966; Guo *et al*., 2015; Hussain *et al*., 2012).

At present, environmental protection has advanced to become a topic of central concern. Many agencies and organizations have attempted to prevent the damage on the environment and human health caused by greenhouse gases and pollutant emissions. Accordingly, governments introduced the requirements for permissible exhaust emission standards due to the adverse effects of

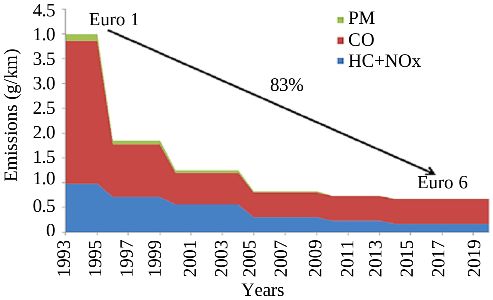


Fig. 2: Evolution of the Euro emission regulations (Tormanen, 2015)

Table 1: Euro standards of the European union for heavy-duty vehicles (Resitoglu *et al.*, 2015)

Variables	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM (g/kWh)
Euro I	4.5	1.10	8.0	0.61
Euro II	4.0	1.10	7.0	0.15
Euro III	2.1	0.60	5.0	0.13
Euro IV	1.5	0.46	3.5	0.02
Euro V	1.5	0.46	2.0	0.02
Euro VI	1.5	0.13	0.4	0.01

diesel emissions on health and the environment. Europe has developed the Euro standards (i.e., from Euro I-IV) which have been continuously lowered, since, 1993 (Fig. 2). Table 1 shows the Euro standards for heavy-duty vehicles. Regulations in the Euro standards have become progressively stringent in the ensuing years (Park *et al.*, 2013).

The emission values that have become substantially stringent have obliged vehicle manufacturers to work on reducing pollutant emission from vehicles. The desired emission levels for diesel engine can be reduced by using exhaust after treatment systems (e.g., Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF0, Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR). Vehicles are equipped with emission control systems to meet the actual emissions standards and requirements. Emission control systems facilitate the elimination of pollutants from the exhaust after these waste products leave the engine and just before they are emitted into the air. However, this method is based on the use of precious and expensive metals (Alrazen *et al.*, 2016a, b).

Dual fuel engine: The simultaneous utilization of gaseous fuel (alternative fuel) and diesel fuel is called dual-fuel engine (Fig. 3). The use of alternative fuel with diesel engine under the dual-fuel mode is one of the promising solutions to reduce the emissions of conventional diesel engines and will facilitate the improvement of the world economy (Yang *et al.*, 2015; Liu *et al.*, 2015). In a dual-fuel engine, the air intake and gaseous fuel is mixed before the intake stroke; thereafter, the mixture will be compressed during the compression stroke, similar to the process in diesel engines. The auto-ignition temperature of gaseous fuel is higher than that of diesel fuel thus, a small amount of the latter is injected at the end of the compression stroke (called pilot fuel) to ignite the mixture (Ochieng and Hawi, 2015; Walker, 2016). The dual-fuel engine is a conventional diesel engine that burns either diesel or diesel and gaseous fuel (simultaneous). This dual-fuel system is convertible to 100% diesel or a mixture of alternative fuel (gaseous fuel) with diesel (Oliveira, 2016).

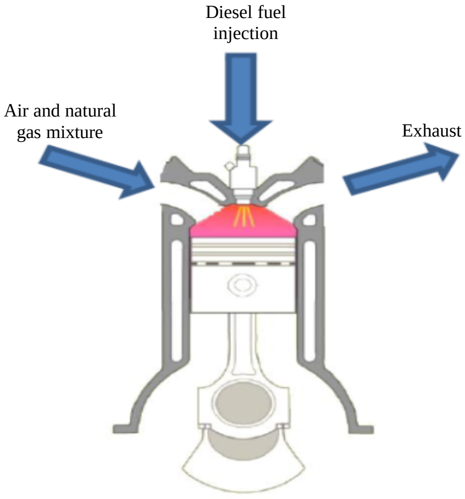


Fig. 3: Dual fuel engine

Alternative fuel injection methods in engines: The alternative fuel (natural gas or hydrogen) can be injected into the engine cylinder (Bakar *et al.*, 2012; Zastavniouk, 1997; Semin, 2011; Celik and Ozdalyan, 2010; Puttaiah *et al.*, 2012; Li, 2004) through an L gas mixer/carburetor injection, single point injection, multi-point injection or direct injection. Figure 4 illustrates the four methods of alternative injection.

Air-fuel mixer or carburetor is used to achieve a homogeneous mixture of air and fuel before air flow splits in the intake manifold. The air fuel mixer installs air intake before the manifold.

Single-point injection is used in gaseous fuel injectors to mix gaseous fuel with the intake air in the manifold at one location for all engine cylinders. Accordingly, fuel is injected at a single location similar to a gas mixer or carburetor. Single-point electronic injection offers the advantage of precise control of the amount of gaseous fuel that enters the intake charge of the engine as well as the economy of using a minimum number of injectors (Bakar *et al.*, 2012).

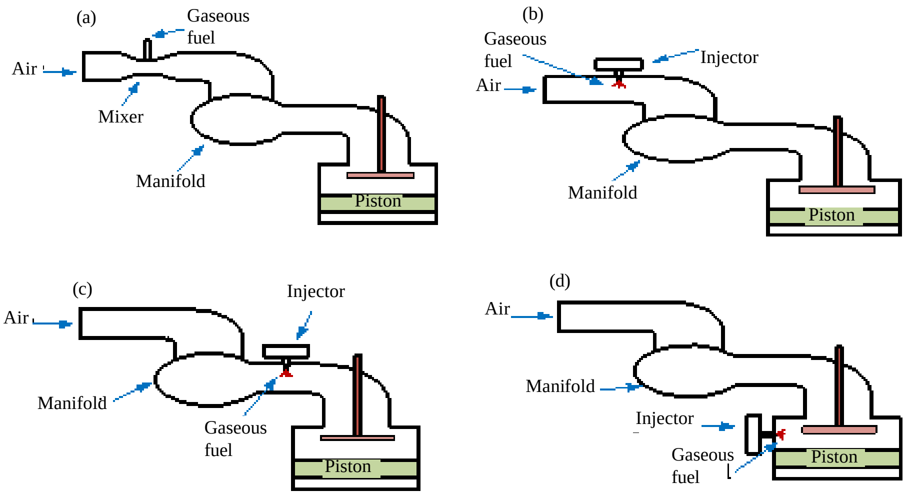


Fig. 4: Injection methods of alternative fuel into the diesel engine: a) Mixer/carburetor injection; b) Single point injection; c) Multipoint injection and d) Direct injection

Sequential injection systems or Multi-Point Injection (MPI) injects the fuel into each cylinder via. the intake port before the intake valve (Bakar *et al*., 2012; Zastavniouk, 1997). This system uses one or more fuel injectors for each cylinder intake port of an engine direct injection injects the gaseous fuel directly into each combustion chamber of the engine.

To convert diesel engine to work under dual fuel mode without additional engine modification, air fuel mixer is an easier and cheaper method to use compared with MPI and direct injection which require expensive engine modification. Combustion efficiency increases with the increase in the homogeneous mixing of fuel with air in the engine. The mixture formation of gaseous fuel with air is more critical than liquid fuel due to its lower density and lesser fuel penetration (Chintala and Subramanian, 2013). Gaseous fuel can easily mix with air due to its high diffusivity property, however, this fuel may have insufficient time for mixing at high engine speeds, thereby resulting in poor mixer formation.

The injectors in MPI and direct injection are mounted near the engine cylinder. Therefore, fluids do not mix appropriately due to the limited mixing time. The air-fuel mixer and single point injection allow additional mixing time because the distance between them and the engine cylinder is suitable to homogeneously mix fuel with air inside the engine.

Moreover, MPI and direct injection are more expensive because one or more fuel injectors are used for each cylinder intake port or direct injection in each cylinder. By contrast, the single point injection and air-fuel mixer are cheap because these methods do not need additional injectors or many air-fuel mixers. Moreover, no high-temperature effect is observed on the gas injector or mixer if the gas injector or mixer is mounted far from the intake valve/engine cylinder head because it is one of the durable problems. If the engine needs a port gas injection or direct gas injection, the gas injector should be of high-temperature resistive material. However, the system cost which includes maintenance and repair would increase. The gas injector or mixer mounting on the intake manifold is preferable because it is similar to a retrofit device that provides system flexibility and minimizes durable problems of injection systems (Chintala and Subramanian, 2013).

RESULTS AND DISCUSSION

Air-fuel mixer: A mixer is adevice for mixing the proper amount of fuel with air before admission to the combustion chamber. The most practical method of converting a gasoline and diesel engine without many modifications to accept an alternative fuel is by installing a fuel-air mixer at the air inlet before the combustion chamber (Abdul-Wahhab *et al*., 2015; Supee *et al*., 2014a, b; Dahake *et al*., 2016; Thipse *et al*., 2015). The design and development of the mixers depend on the following two main factors (Dahake *et al*., 2016; Danardono *et al*., 2011; Shaikh and Shukla, 2016).

Homogeneity of the mixture: The homogeneity of a mixture is one of the most important factors in designing a mixer. Combustion efficiency, engine performance and the reduction of emission of gasses are directly proportional to the degree of mixing homogeneity and depend on the design and shape of the mixer (Chintala and Subramanian, 2013; Thipse *et al*., 2015; Chang *et al*., 2007; Supee *et al*., 2014a, b).

Producing homogenous mixtures to achieve near complete combustion is a common goal that leads to the development of low-polluting engines (Deshmukh *et al.*, 2012; Serie *et al.*, 2016). Several investigations have reported that HC emissions were created as a result of incomplete combustion inside the engine. Most PMs are produced due to the incomplete combustion of HCs in the lube oil and fuel along with its combustion with the heterogeneous air-fuel mixture. Moreover, the amount of CO and NO emissions can be reduced in internal combustion engines by enhancing the combustion process. Thus, enhancing the combustion process and emission reduction inside the engine is related directly to enhancing the homogeneity of the mixture (air-fuel) inside the engine (Dahake *et al.*, 2016; Abdul-Wahhab *et al.*, 2015; Shaikh and Shukla, 2016; Robison and Brehob, 1967; Hairuddin *et al.*, 2014; Lu *et al.*, 2008; Chowdaiah *et al.*, 2015).

The mixture burns completely in the combustion chamber when the mixture inside the mixer is homogeneous, thereby, resulting in limited emissions. An air-fuel mixer that fails to provide a homogenous mixture causes significant cylinder-to-cylinder variations in AFR that lead to increased emissions, high brake-specific fuel consumption and possible knocking (Chintala and Subramanian, 2013).

Air-fuel ratio: AFR is a significant factor that affects engine performance. AFR is classified into three types: stoichiometric AFR, lean fuel mixture and rich fuel mixture. The minimum amount of air that is necessary for the complete combustion of fuel is called the stoichiometric AFR. The amount of more air than the stoichiometric is called excess air. The amount of air less than the stoichiometric amount is called air deficiency. Equivalence ratio is the ratio of the actual fuel-air ratio to the stoichiometric AFR (Kahraman, 2005).

$$\text{Equivlence ratio}(\phi) = \frac{\left(\frac{\text{Air}}{\text{Fuel}}\right)\text{Stoichiomrtric}}{\left(\frac{\text{Air}}{\text{Fuel}}\right)\text{Actual}} \quad (1)$$

Where:

$\phi = 1$ = Stoichiometric

$\phi<1$ = Lean (weak) mixture-excess air

$\phi>1$ = Rich mixture-air deficiency

$$\text{Stoichiometric } \frac{A}{F} \text{ ratio} = \frac{m_a}{m_f} \quad (2)$$

Where:

m_a = Mass of air

m_f = Mass of fuel

A lean air-fuel mixture contains a high volume of air and low volume of fuel. A slightly lean mixture is ideal for low fuel consumption and low exhaust emissions. Additional air in the cylinder results in complete combustion, that is all the fuel is burned. Problems such as lack of power, missing and even engine damage, may occur if the mixture is excessively lean.

A rich air-fuel mixture contains a high volume of fuel and low volume of air. A rich mixture tends to increase power but also increases fuel consumption and exhaust emissions considerably. A mixture that is excessively rich may result in reduced engine power, fouled spark plugs and incomplete combustion.

AFR of the generated mixture must be within the range determined by the operating condition of the engine. An out of range AFR leads to an unstable gas engine operation and the production of exhaust gas emission that will not meet the environmental standard. The AFR of the mixer only depends on the mixer design (Shaikh and Shukla, 2016). Therefore, the mixer must provide a suitable AFR based on different engine speeds and changes in the engine loads (Danardono *et al.*, 2011).

Types of air-fuel mixer: The literature review states that the air-fuel mixer can be classified depending on its shape (Fig. 5).

Venturi mixer: A Venturi gas mixer is a device that uses the Venturi effect which is a particular case of Bernoulli's principle of a converging diverging nozzle that converts the pressure energy of a motive fluid (air) to velocity energy at the throat to create a low-pressure zone. This low-pressure zone draws in and entrains the suction fluid (fuel) into the mixing chamber where the suction fluid mixes with the motive fluid (air). The Venturi mixer design should be compact with minimum pressure loss across the Venturi-mixer, the good suction pressure in the throat due to the Venturi effect from the pressure difference and homogeneous or good mixing quality (Dahake *et al.*, 2016; Danardono *et al.*, 2011). AFR and pressure loss of the Venturi mixer are affected by several specifications: the Venturi throat area, throat position, gas inlet area and gas inlet location. By contrast, the mixing effect of a Venturi mixer is affected by the Venturi throat diameter, fuel nozzle position, number of fuel holes and impingement angle. Many researchers have studied the air-fuel Venturi mixers to convert the engine to work under dual or bi-fuel engine (Table 2 and Fig. 6-22).

Non-Venturi mixer: This type of mixer depends on mechanical control on the amount of fuel and air that enter

Table 2: Review of the venturi mixer

Researcher	Work described	Software	Boundary condition	Output
Yusaf *et al.* (2013), Yusaf and Yusoff (2000)	The researcher designed two types of air-CNG Venturi mixers, mixer with four holes and mixer with eight holes to convert a diesel engine to a CNG-diesel/dual fuel engine (Fig. 6)	ANSYS Fluent was used	Air inlet: velocity CNG inlet: fixed pressure mixer outlet: fixed pressure k-e turbulent model (standards) was used	The results of the Computational Fluid Dynamic (CFD) simulation showed that the eight-hole Venturi mixer provided superior performance compared with the four-hole mixer (Fig. 7) Moreover, depending on the experimental work, the dual-fuel engine (CNG-diesel) reduced the emission gasses for NO and CO compared with the diesel engine (Fig. 8)
Bora *et al.* (2013)	The researcher designed and developed the new venture mixer to convert a diesel engine (power 3.5 kW) to a dual-fuel engine for using biogas (CH_4+CO_2) as the primary fuel and diesel as the pilot fuel. The result of the new mixer was compared with old mixers (mixers with a single nozzle inclined at angles of 45°(B) and 90°(C)) (Fig. 9)	ANSYS Fluent was used to investigate the flow behavior inside the mixers	Air inlet: velocity CNG inlet: fixed pressure mixture outlet: fixed pressure k-e turbulent model (standards) was used	The analysis results explained that the new mixer (C) performed homogenous mixing for biogas and air compared with the old mixers (mixers with a single nozzle inclined at 45° (B) and 90° (A) angles) (Fig. 10)
Ramasamy (2005)	The new CNG-air Venturi mixer was designed for two-stroke engines. The engine displacement is 150 cc Moreover, the new mixer was designed to convert the engine to work under the dual-fuel mode. Many factors were studied as inlet and outlet angles, number and size of the hole at the throat circumference and the effect of these factors on the performance of the mixer (Fig. 11)	Computer Aided Design and CFD Cosmos Software were used as tools for designing the new CNG-air Venturi mixer	Air inlet: pressure CNG inlet: pressure mixture outlet: mass flow rate	The results of the simulation indicated that the mixer with 12 holes can produce a homogenous mixture than that with eight and 10 holes Moreover, the new mixer with 12 holes gives suitable stoichiometry AFR 17 which corresponds to a particular engine speed (Fig. 12)
Sharma *et al.* (2014)	The researcher developed the new air-fuel mixer (mixer with two gas inlets) based on the existing mixer (mixer with one gas inlet). The new mixer was designed for a small capacity/two-stroke SI engine to improve the homogeneity of mixing. The flow characteristics of methane and air inside the two mixers was studied (Fig. 13)	ANSYS Fluent was used	Air inlet: velocity CNG inlet: fixed pressure mixture outlet: fixed pressure k-e turbulent model (standards) was used	The findings of the simulation explain that a two-hole mixer produces better fuel distribution than the one-hole mixer (Fig. 14)
Gorjibandpy and Sangsereki (2010)	The effect of geometrical dimensions and the number of holes of the mixer on the value of air-CNG ratio and the homogeneity of mixing inside the mixer were studied. Nine models of the mixer were tested to choose the best mixer model that gives AFR and the best distribution of mixing inside the mixer (Fig. 15)	ANSYS Workbench (Fluent)	Air inlet: velocity CNG inlet: fixed pressure mixture outlet: fixed pressure k-e turbulent model (standards) was used	The findings of the simulation explain that mixer with 12 holes gives good distributions for mixture compared with those of eight and six-hole mixers. Moreover, the stoichiometry air-CNG ratio of 31.5 was achieved with a 12-hole mixer according to the chosen engine speeds (Fig. 16)
Danardono *et al.* (2011)	Syngas venture mixer was developed based on an existing mixer (KIMM) The impact of the hole diameter and the location of holes on mixing quality was checked. The stoichiometric AFR of the syngas by weight is 1.624 and the syngas consists of 25% H2, 25% CO_2 and 50% N_2 (Fig. 17)	ANSYS Workbench Fluent software was chosen to check the mixing performance inside mixers	Pressure boundary conditions were applied on the air inlet, syngas inlet and outlet of the Venturi mixer. The k-e models, the Standard k-e model/high Reynolds number was selected	The results show that the Optimized design for venture mixer create a more homogenous mixture of air and Syngas than old mixer (KIMM) (Fig.18)
Supee *et al.* (2014a, b)	Three types of air CNG Venturi mixers (the mixer with two injectors, mixer with four injectors and mixer with six injectors) were developed to improve the performance of dual fuel engine (CNG-diesel engine). Moreover, the relation between the number of holes inside the mixer and a homogeneity of mixing was studied.Moreover, the levels of emissions were tested after connecting the new models of mixers to a real dual-fuel engine, and the results of the emissions from the engine were compared with the results the old dual-fuel system and diesel engine before the modifications (Fig. 19)	ANSYS Workbench (Fluent) was used to check the flow characteristic inside the mixer	Air inlet is defined as a velocity inlet equal to 15 m/s.CNG inlet is defined as the velocity inlet equal to 30 m/sec. Standard k-epsilon model Near-wall treatment was defined as the standard wall function	From the simulation points, the homogeneous mixture of CNG and air was produced by the CNG-air venture with four injectors compared with two and six injectors. This homogeneous mixture leads to high combustion efficiency (Fig. 20). Moreover, from the experiential tests, the exhaust gas concentrations of NOx, CO, CO2 and UHC reduced significantly when the mixer with four injectors was connected with the real dual fuel engine compared with other systems (diesel engine, dual fuel engine, direct injection (DDF), DDF mix injector 6 and DDF mix injector 2 (Fig. 21 and 22)

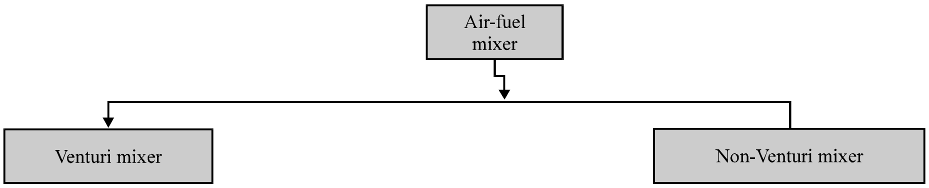


Fig. 5: Type of air-fuel mixer

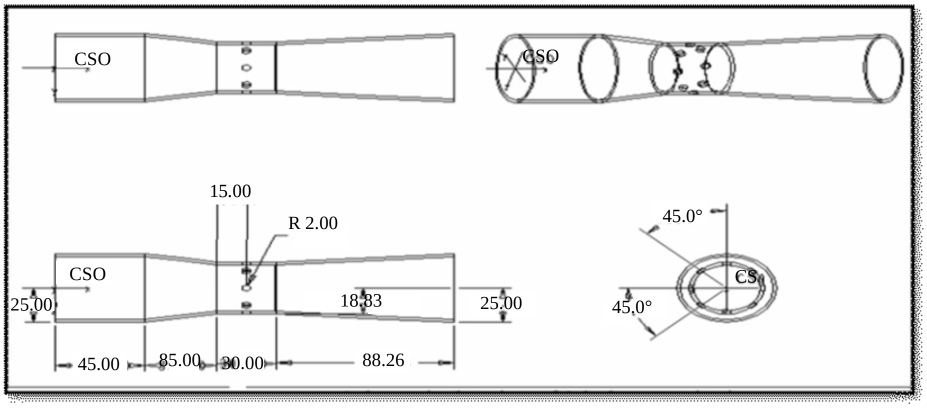


Fig. 6: Air fuel mixer designed based on Yusaf T

Table 3: Review about other mixers

Researcher	Work described	Software	Boundary condition	Output
Banapurmath *et al.* (2011)	The researcher studied the effect of mixer shape on the homogeneity of the mixture inside the mixer. Two different mixer shapes (Y-shape mixer and parallel flow gas entry mixer) were used to change the diesel engine 3.7 kW to a dual-fuel engine (diesel-producer gas) (Fig. 23)	GAMBIT and ANSYS Fluent/CFD were used to investigate the flow characteristic inside the mixer	The inlet boundary condition for air and producer gas is the mass flow rate. The boundary condition for the mixer outlet is of different mass flow rates	The simulation results show that the parallel flow gas entry mixer conducts homogeneous mixing for the air and fuel (producer gas) (Fig. 24)
Anil1 *et al.* (2006a, b) Ani *et al.* (2009)	The producer gas mixer was designed to convert the diesel engine 25 kW capacity to the dual-fuel engine. The amount of fuel that entered inside the mixer was controlled using butterfly a valve (Fig. 25)	ANSYS CFD/CFX software was used to draw, mesh and simulate the flow	Flow rate boundary conditions were applied on the air and syngas inlets. The boundary condition for the mixer outlet is of different mass flow rates A standard k-e Model has been chosen with isothermal heat transfer condition at 300 K to simulate the turbulence parameters	The results of the simulations explain that a producer gas mixer provides good mixing efficiency (Fig. 26-28)
Reddy and Reddy (2014), Vinay *et al.* (2008), Suryawanshi and Yarasu (2014)	A producer gas mixer was designed and analyzed to convert the diesel engine 25 kW capacity to a dual-fuel engine (producer gas and diesel) (Reddy and Reddy, 2014) The amount of fuel was controlled using a butterfly valve (Fig. 29)	The geometry of the mixer was drawn and meshed using ANSYS (CFX)	Mass flow rates at the air and PG inlets and the pressure outlet at the outlet boundary were used. A standard k-e Model was chosen with isothermal heat transfer condition at 300 K to simulate the turbulence parameters	The study reported that producer gas mixer gives good mixing efficiency based on the simulation results (Fig. 30)

such mixer. Most mixtures in this category depend on the butterfly valve which connected directly with an accelerator pedal (diesel) for controlling the amount of air and fuel that enters the mixer. Moreover, other types of mixers depend on the force of air to control an amount of fuel. The shapes of the mixers also differ from the shape of the Venturi mixer in this category. Many researchers have studied and designed air-fuel mixers for dual-fuel engines (Table 3 and Fig. 23-30).

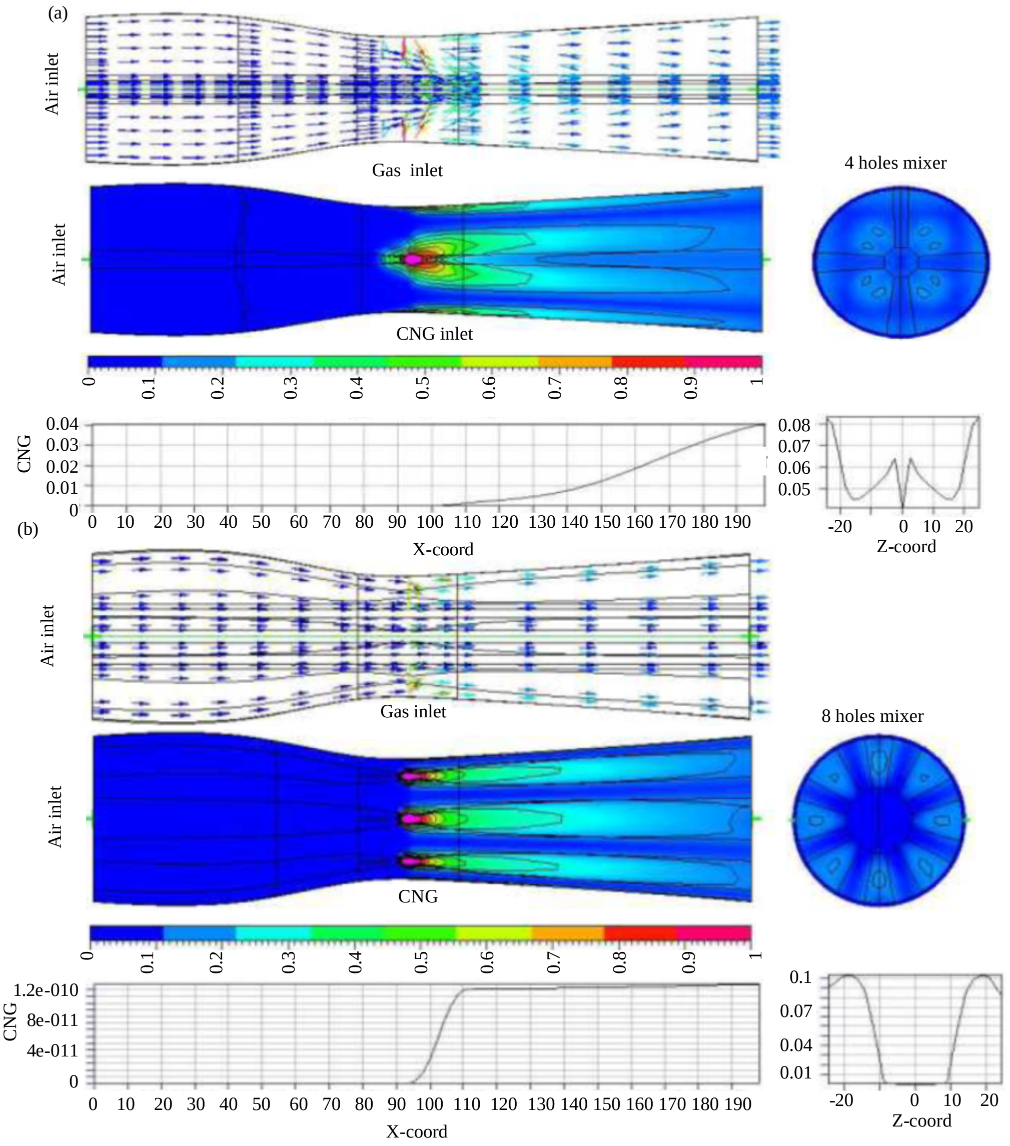


Fig. 7: CNG concentration inside the four and eight-hole Venturi mixers which were designed based on Yusaf T: a) 4 holes mixer and b) 8 holes mixer

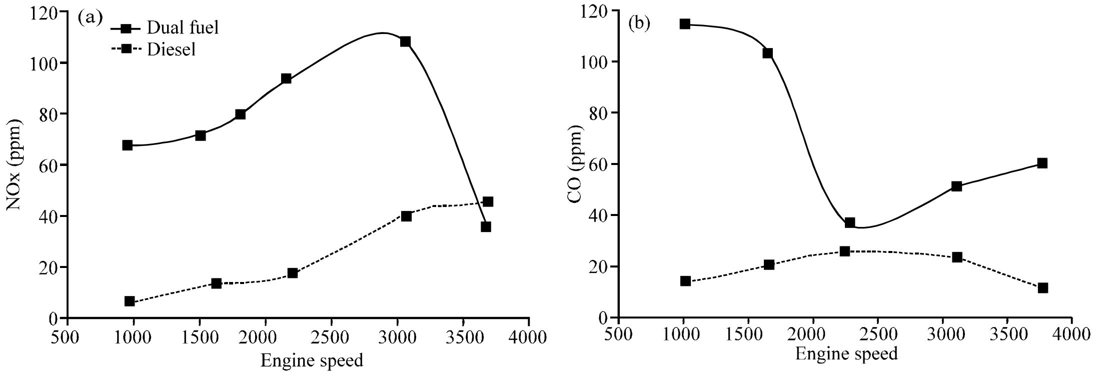


Fig. 8: a, b) Nitric Oxides (NOx) and CO concentrations at different engine speeds under full load based on Yusaf T

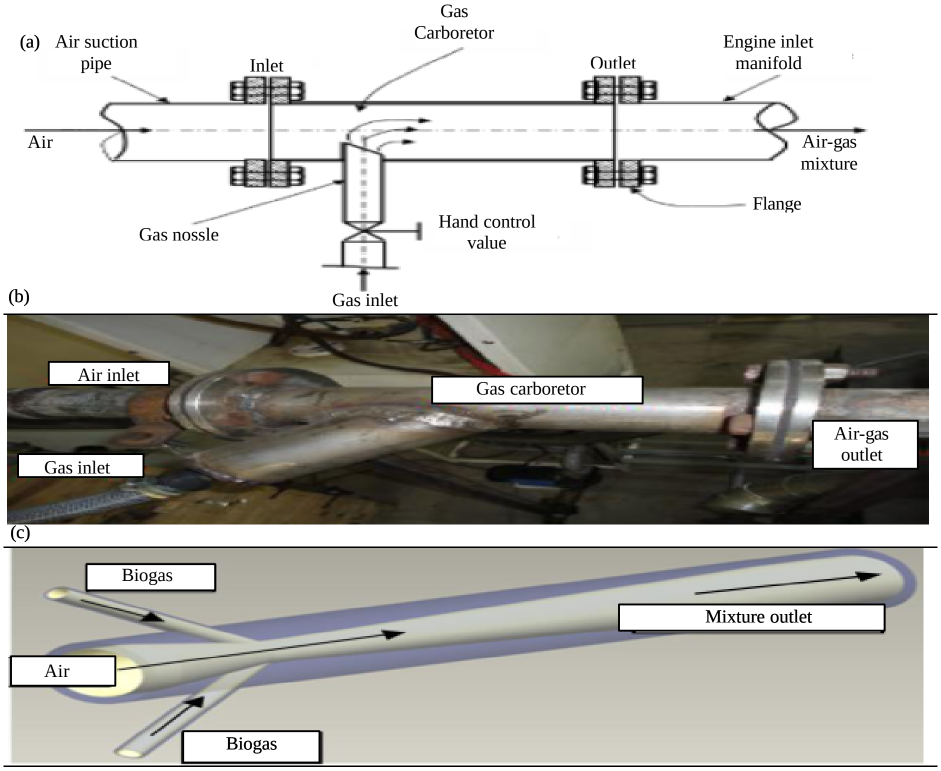


Fig. 9: a-c) Air fuel mixers which was designed according to Bora

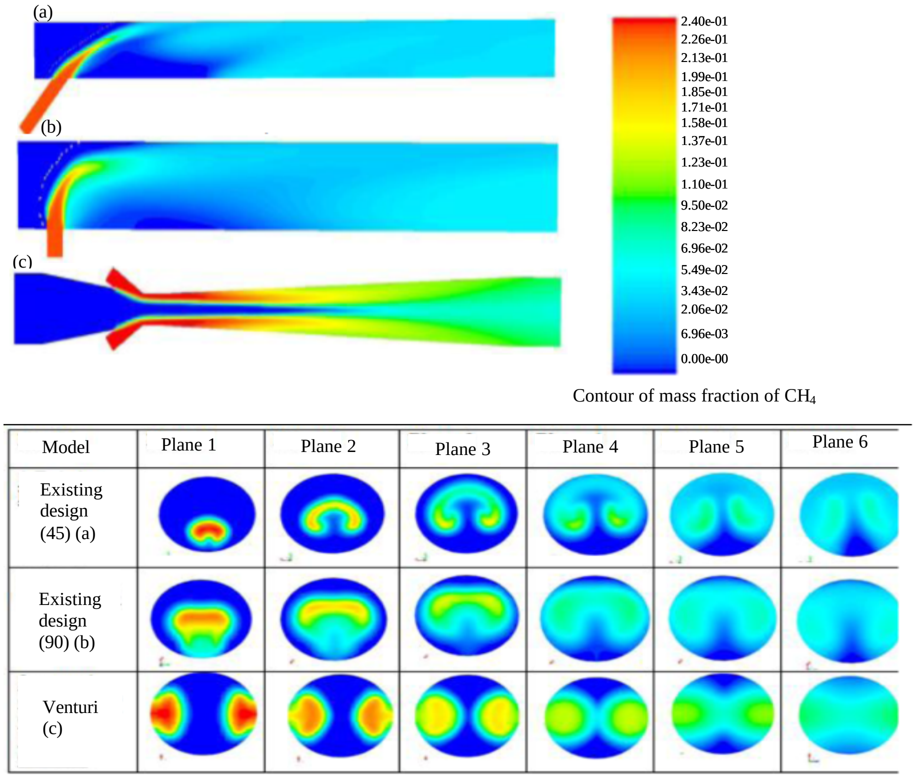


Fig. 10: a-c) CH_4 contour for the air-fuel mixer designed based on Bora

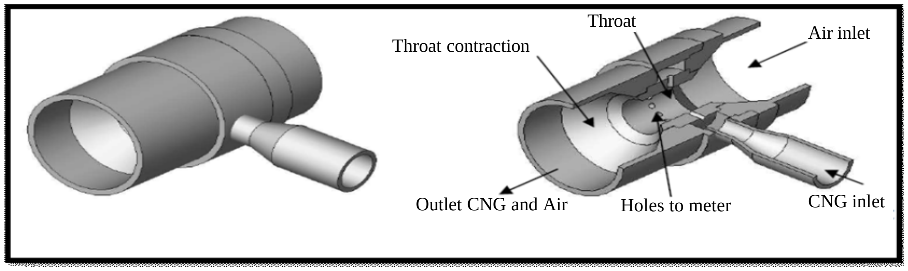


Fig. 11: Air fuel mixer designed based on Ramasamy

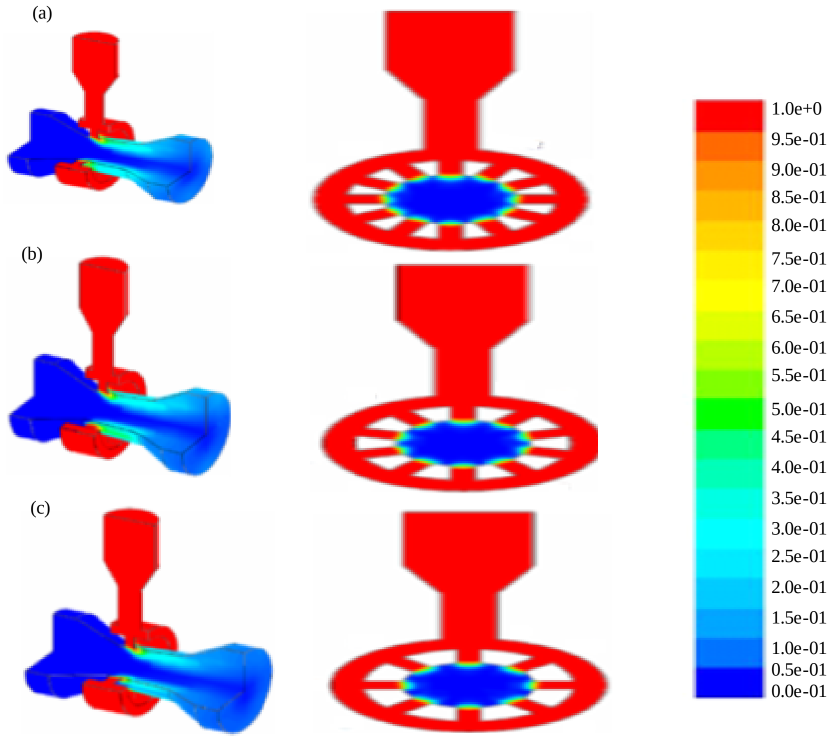
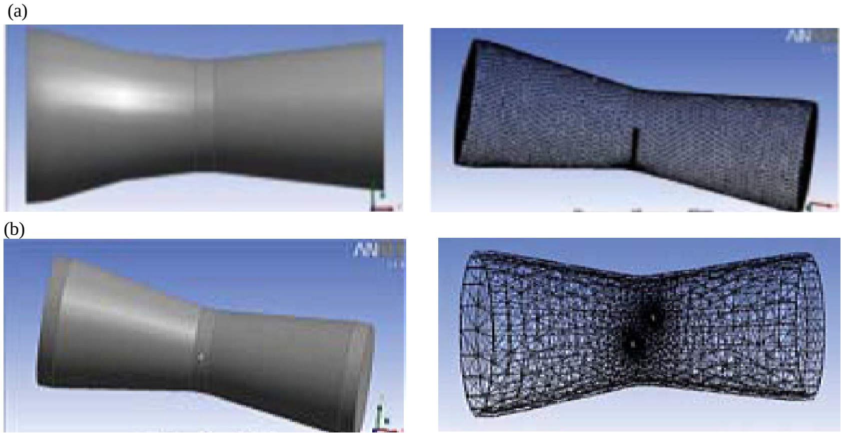


Fig. 12: CH_4 contour for the air-fuel mixers based on Ramasamy: a) 12 holes; b) 10 holes and c) 8 holes



3D Model

Mesh

Fig. 13: Air-fuel mixer designed based on Sharma: a) Existing mixer and b) New mixer

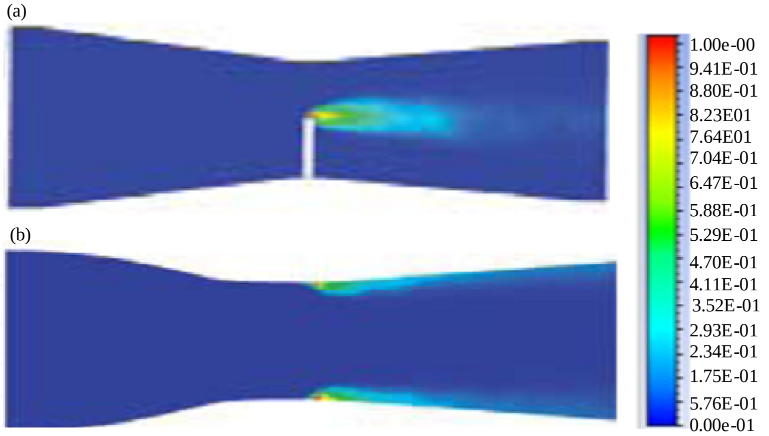
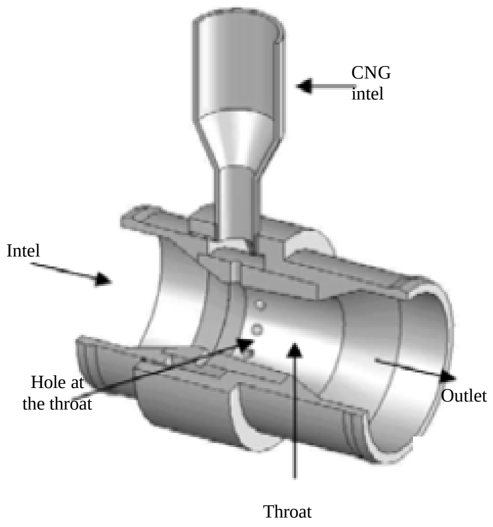


Fig. 14: CH_4 mass fraction distribution inside the mixers that designed based on Sharma: a) Existing mixer and b) New mixer



Mixer names	Intel lenght (mm)	Convergence lenght (mm)	Throat lenght (mm)	Divergence lenght (mm)	Outlet lenght (mm)
A_{12}	600	600	100	300	600
B_{12}	600	450	100	450	600
C_{12}	600	600	100	600	600
A_8	600	300	100	300	600
B_8	600	450	100	450	600
C_8	600	300	100	600	600
A_6	600	600	100	300	600
B_6	600	450	100	450	600
C_6	600	300	100	600	600

Fig. 15: Air-fuel mixers designed based on Gorjibandpy

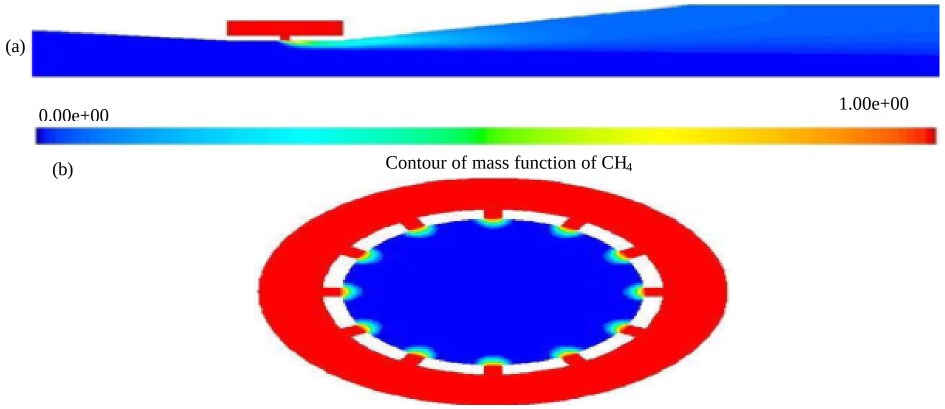


Fig. 16: a, b) CH_4 mass fraction distribution inside the mixers with 12 holes based on Gorjibandpy

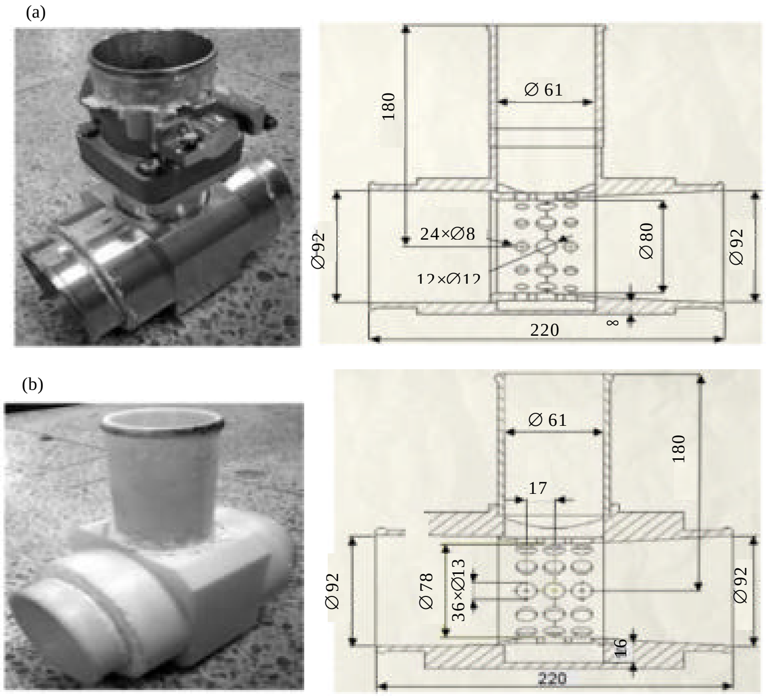


Fig. 17: Air-fuel mixers designed based on Dominicus: a) KIMM mixer prototype and b) Optimizede design prototype

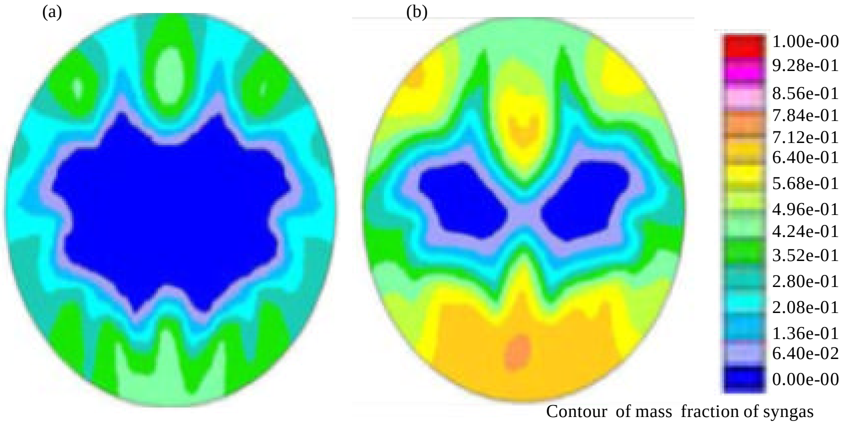


Fig. 18: Mixing characteristics on the mixer outlet cross-sectional view of the KIMM and optimized model at air flow rate 100 m^3/h based on Dominicus: a) KIMM mixer prototype and b) Optimizede design prototype

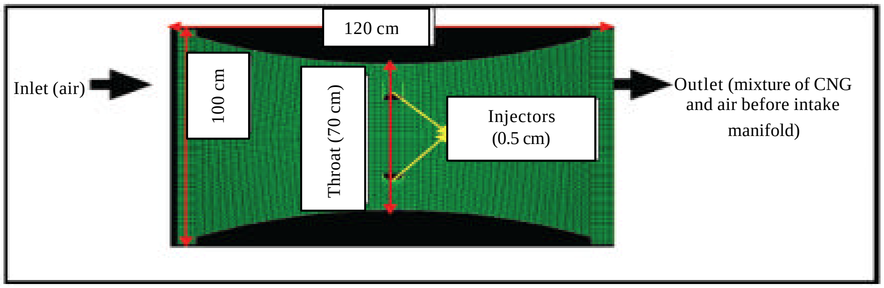


Fig. 19: Air fuel mixers which was designed according to Supee, Shafeez

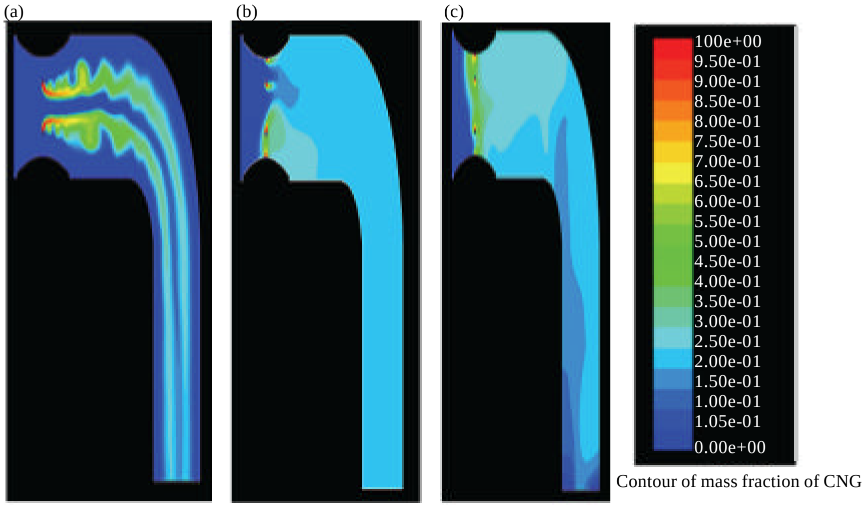


Fig. 20: CNG-air concentrations inside Venturi mixjectors based on Supee, Shafeez: a) 2 holes; b) 4 holes and c) 6 holes

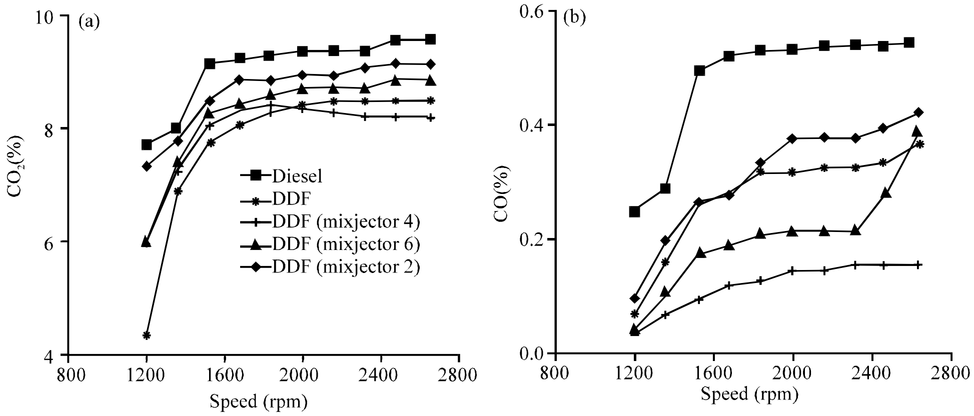


Fig. 21: a, b) Carbon monoxide (CO) and Carbon dioxide (CO_2) concentrations at different engine speeds under full load condition based on Supee, Shafeez

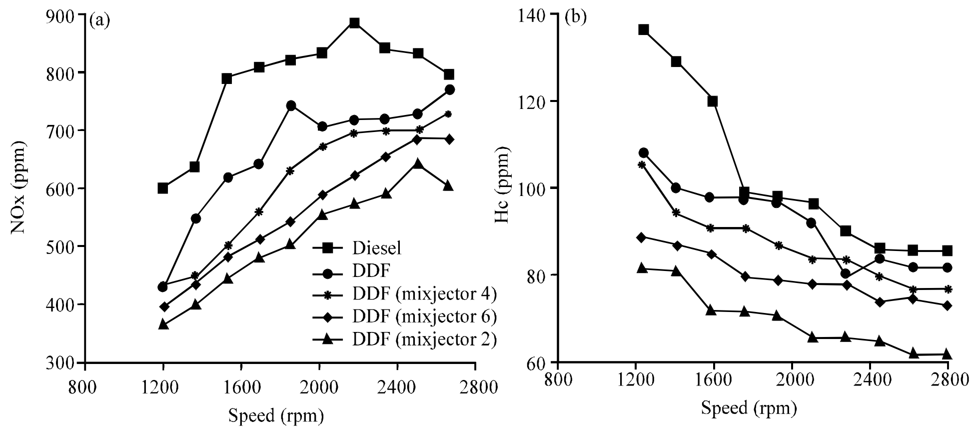


Fig. 22: Nitric Oxides (NOx) and HC concentrations at different engine speeds under full load condition based on Supee, Shafeez

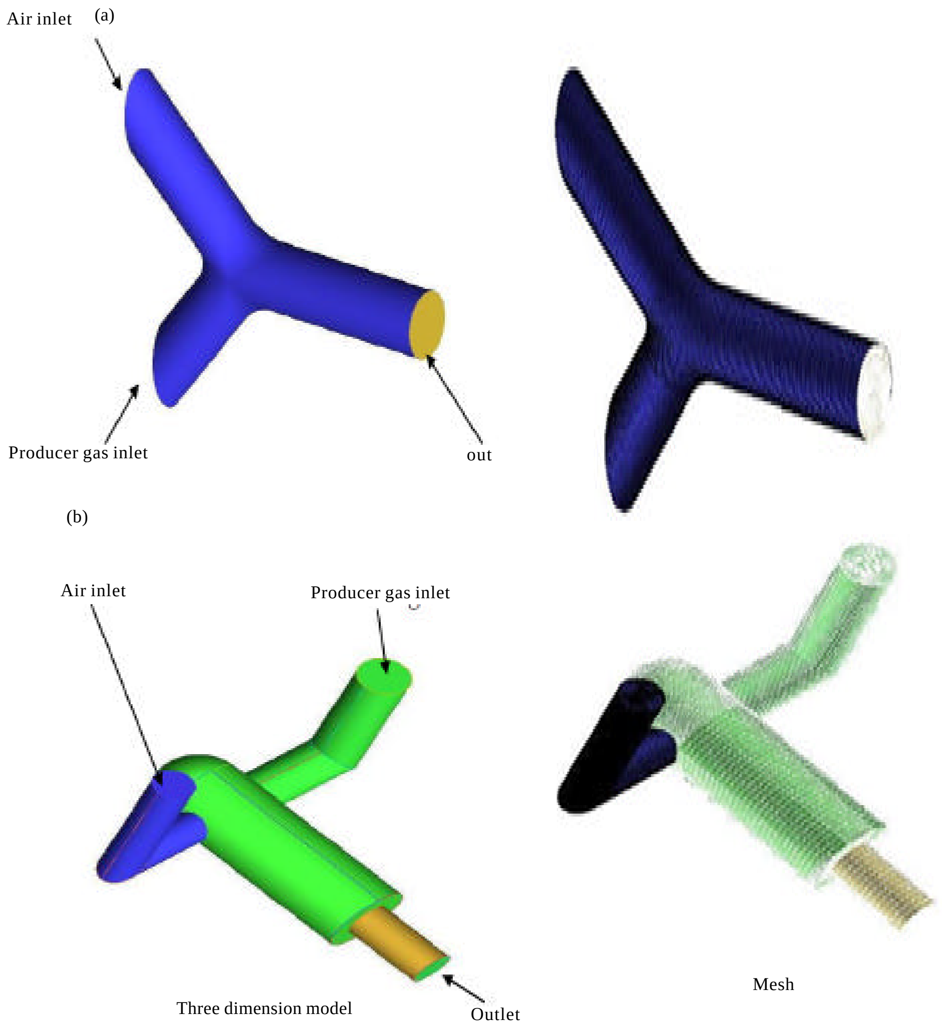


Fig. 23: Details of mixers modeled by Banapurmath: a) Y-shape mixer and b) Parallel flow gas entry mixer

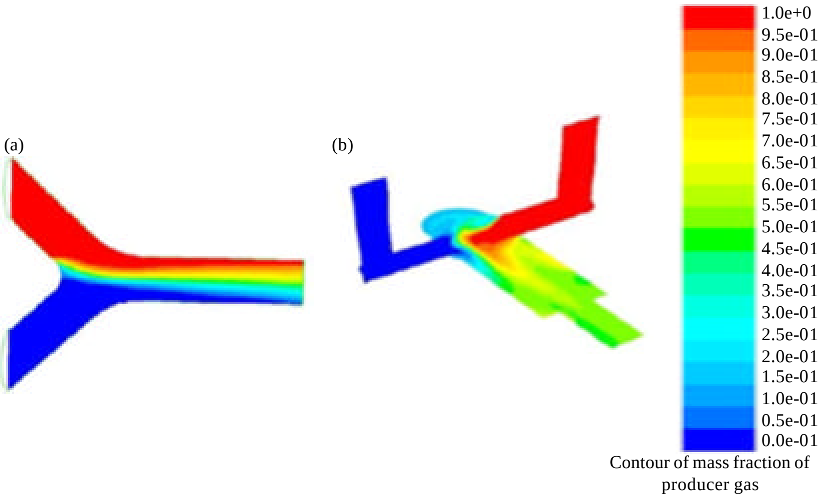


Fig. 24: Distribution of mass fraction inside the mixers designed based on Banapurmath: a) Y-shape mixer and b) Parallel flow gas entry mixer

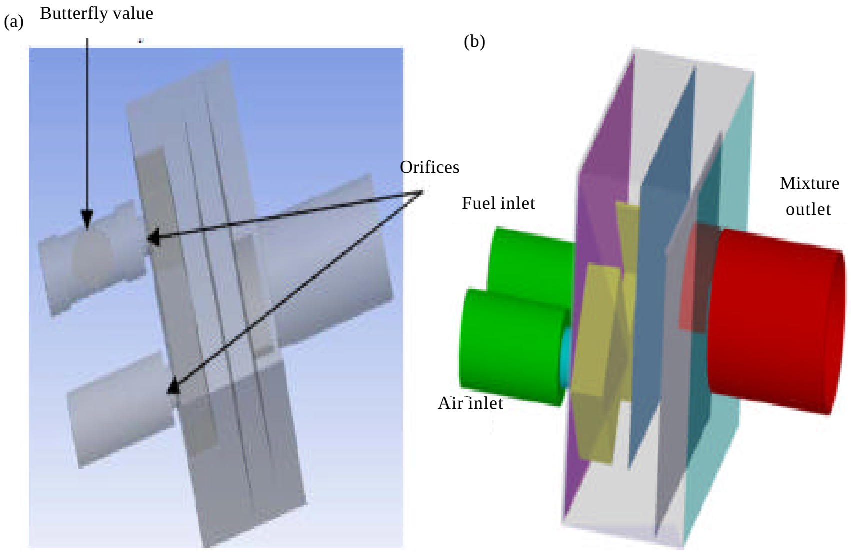


Fig. 25: a, b) Details of the mixer designed by Anil

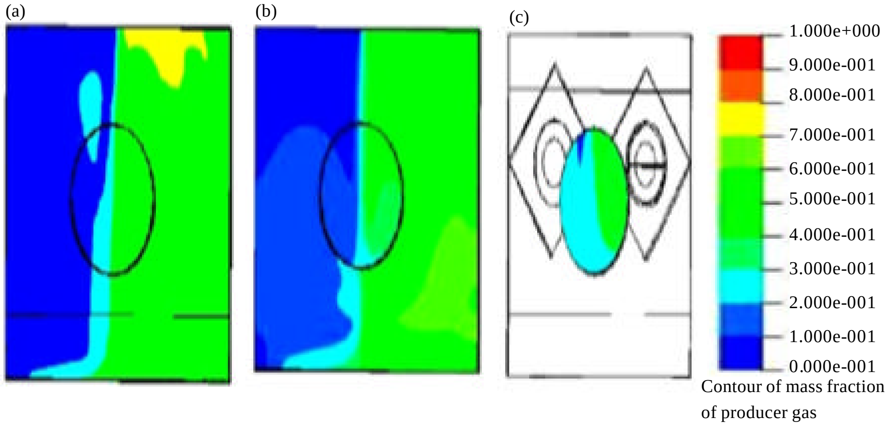


Fig. 26: a-c) Producer gas mass fraction on different planes inside the mixer for 25 iterations for a 90° butterfly valve opening and an outlet condition of 0.025 kg/sec (based on Anil)

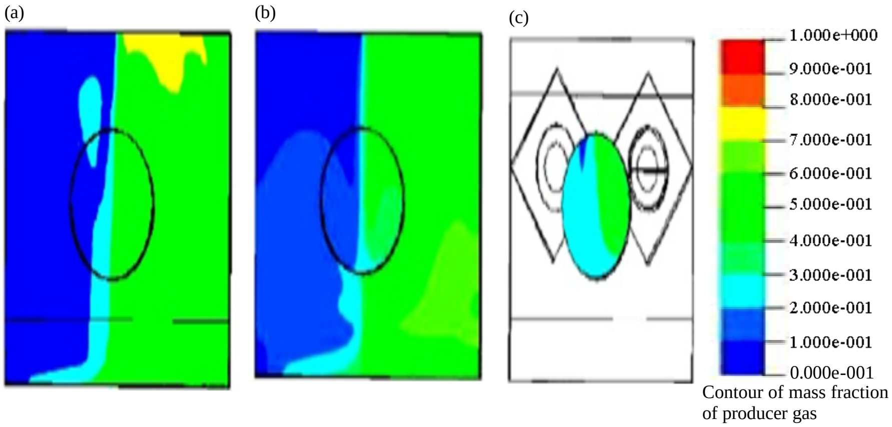


Fig. 27: a-c) Producer gas mass fraction on different planes inside the mixer with for 75 iterations for a 90° butterfly valve opening and an outlet condition of 0.025 kg/sec (based on Anil)

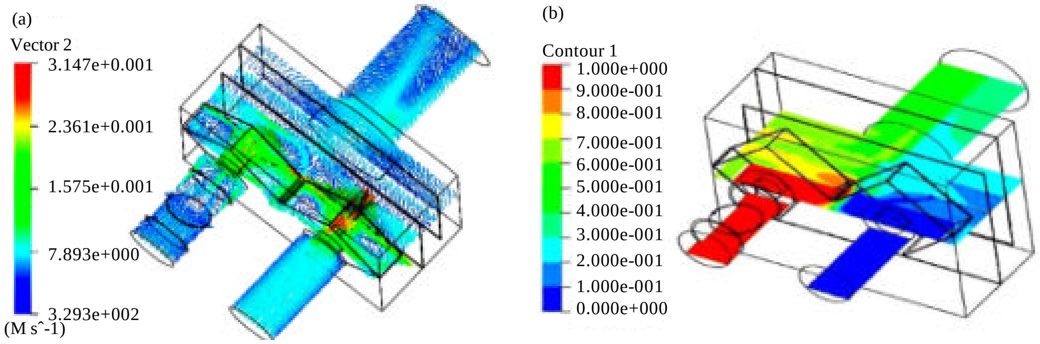


Fig. 28: Distribution the mass fraction and velocity on the planes inside the mixer (based on Anil): a) Volcity and b) Mass fraction

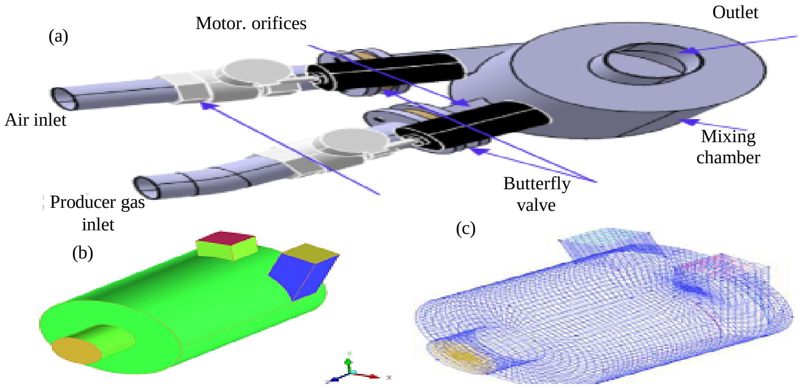


Fig. 29: a-c) Details of the mixer modeled by Reddy

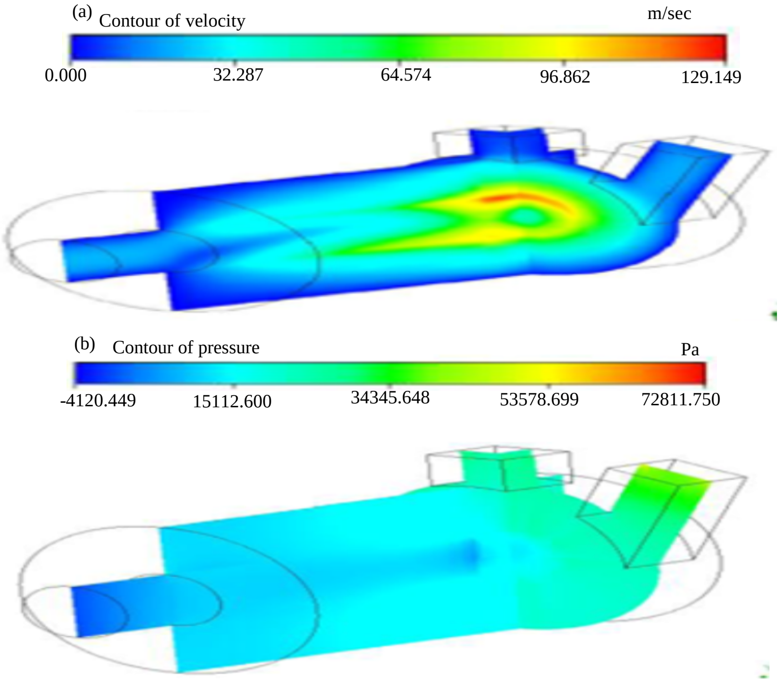


Fig. 30: Continue

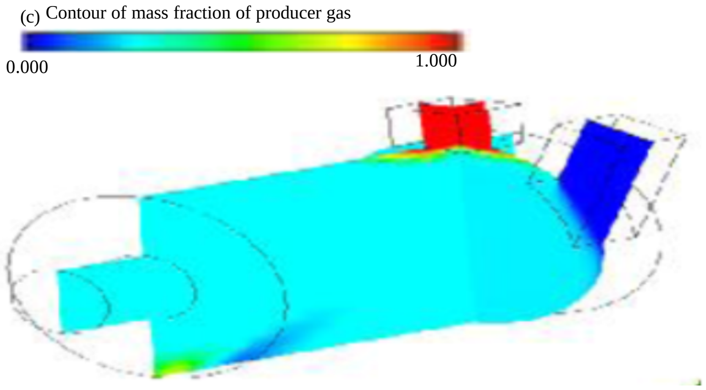


Fig. 30: Distribution of mass fraction, pressure and velocity on planes inside the mixer designed based on Reddy : a) Volcity contour; b) Pressure contour and c) Mass fraction

CONCLUSION

Diesel engines exhaust a larger amount of PM and NO_X pollutant emissions than gasoline engines whereas the HC and CO emissions from the diesel engine are low. The combustion process inside the engine is directly related to the homogeneity of the mixture and the AFR inside the engine, thereby affecting the emissions.

The emission for the diesel engine can be reduced using an exhaust after-treatment systems (DOC, DPF and SCR) However, the methods are based on the use of precious and expensive metals. Using alternative fuel with a diesel engine under dual-fuel mode is a promising solution to reduce the emissions of conventional diesel engines and helps improve the world economy.

An air-fuel mixer is an easy and cheaper method to use to convert a diesel engine to work under dual-fuel mode compared with MPI and direct injection which require further engine modification in and are expensive. The AFR and homogeneity of the mixture are important factors to consider when designing the mixer. Diameters, numbers and positions of the holesinside the mixer affect the homogeneity of the mixture and AFR inside the mixer. nhancing the combustion process and emission reduction inside the engine is directly related to enhancing the homogeneity of the mixture (air-fuel) inside the engine.

The literature review discussed that the homogeneity of the mixture was checked inside the mixers based on the mixture distribution. All researchers did not depend on the real factor to measure the homogeneity of themixture inside the mixers. The literature review mentioned that the maximum and minimum numbers of holes inside the mixer are 1 and 16, respectively. The literature review indicated that no researcher connects the mixer directly with an electronic control unit for cars. Most researchers either depended on the Venturi principles or connected the mixer with an accelerator pedal (diesel) through a butterfly valve or mechanical control.

The literature review was shown that all kinds of current mixers are designed for mixing one type of gaseous fuel and also working with constant mixing ratio and specific engine capacity While requires a change in the design of the mixer to be suitable to work with other types of fuels, different mixing ratios and different engine capacities.

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