Conversion of Diesel Engine to Port Injection CNG Engine Using Gaseous Injector Nozzle Multi Holes Geometries Improvement: A Review

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Abstract

This paper is the representation of the computational and experimental methods of a new injector nozzle for a sequential port injection CNG engine. The objective of this study was to review the previous research in the development of gaseous fuel injector for port injection CNG engine converted from diesel engine. Next, a simulation of the fuel flow of the new injector nozzle was made using FLUENT. The final objective was to investigate the performance characteristics of the CNG engine using the new injector nozzle. The investigation focused on engine performance based on variations in location of injector, number of holes in injectors and pressure. The results showed that the conversion of the diesel engine to a CNG engine reduced engine performance. The simulation of the fuel flow of the new injector nozzle increased the spray distribution, fuel-air mixing and fuel flow velocity. The fuel nozzle injector multi holes geometries development was to produce optimum fuel air mixing and increasing the volumetric efficiency of the engine that will promote a comparable engine performance and efficiency.

Keywords: *CNG, conversion of diesel CNG, CFD, FLUIENT, Port Injection..*

Introduction

In 1893, Rudolf Diesel constructed an experimental compression-ignition engine and patented the relevant cycle in 1892 with Patent DRP N0, 67207, year 1892. Four years later, a working version of the engine had an efficiency of 26% at a power output of approximately 14.7 kW or 20 hp. This although the engine was not originally applied for driving a vehicle, was the second fundamental invention in the history of the automobile.

In 1976, the total output by the West European countries only was 5,200,000 compression-ignition engines. Although the gas turbine was invented by John Barber in 1791, it was not until 1939 that is became a fully efficient driving engine. Its subsequent rapid development was due to its being applied in air-craft engineering [1]. The regular development of ICE changes direction in answer to changing requirement. In the 1970, the two most important problems determining the development trends of engines technology and in particular, their combustion systems. They were environmental protection against emission and noise and shortage of hydrocarbon fuels. The brief comparison of a variety of engine undertaken in what follows principally concerns specific fuel consumption, emissions and other technical and economic parameters [1].In the direct injection diesel engines or direct injection compression ignition engines, where fuel is injected by the fuel injection system into the engine cylinder toward the end of the compression stroke, just before the desired start of combustion. The liquid fuel, usually injected at high velocity as one or more jets through small orifices or nozzles in injector tip, atomizes into small drops and penetrates into the combustion chamber. The fuel vaporizes and mixes with high temperature and high pressure cylinder air. The air is supplied from intake port of engine. Since the air temperature and pressure are above the fuel’s ignition point, spontaneous ignition of portions of the already-mixed fuel and after air a delay period of a few crank angle degrees. The cylinder pressure increases as combustion of the fuel-air mixture occurs. The major problem in compression ignition engine combustion chamber design is achieving sufficiently rapid mixing between the injected fuel and the air from intake port in the cylinder to complete combustion in the appropriate crank angle interval close to top centre. Horsepower output of an engine can be dramatically improved through good intake port design and manufacture.

Compressed Natural Gas:

Natural gas is produced from gas wells or tied in with crude oil production. Natural Gas (NG) is made up primarily of methane (CH) but frequently contains trace amounts of ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulphide and water vapour. Methane is the principal component of natural gas. Normally more than 90% of natural gas is methane4 [1,3-5,15]. The detail of natural gas compositions is shown in Table 1 by Shelby. But, according to Srinivasan [16], that in the natural gas composition more than 98% is methane.[15]
Natural gas can be compressed, so it can be stored and used as Compressed Natural Gas (CNG). CNG requires a much larger volume to store the same mass of natural gas and the use of very high pressure on about 200 bar or 2,900[17]. Natural gas is safer than gasoline in many respects and ignition temperature for natural gas is higher than gasoline and diesel fuel. Additionally, natural gas is lighter than air and will dissipate upward rapidly if a rupture occurs. Gasoline and diesel will pool on the ground, increasing the danger of fire. Compressed natural gas is non-toxic and will not contaminate groundwater if spilled. Advanced compressed natural gas engines guarantee considerable advantages over conventional gasoline and diesel engines. Compressed natural gas is a largely available form of fossil energy and therefore non-renewable.

CNG Advantages:

However, CNG has some advantages compared to gasoline and diesel from an environmental perspective. It is a cleaner fuel than either gasoline or diesel as far as emissions are concerned. Compressed natural gas is considered to be an environmentally clean alternative to those fuels. According to Ganesan[3],some advantages of compressed natural gas as a fuel are octane number is very good for SI engine fuel, octane number is a fast flame speed, so engines can be operate with a high compression ratio, less engine emissions, less aldehydes than methanol and the fuel is fairly abundant[18,19] worldwide.

Disadvantages:

The disadvantages of compressed natural gas as an engine fuel are low energy density resulting in low engine performance, low engine volumetric efficiency because it is a gaseous fuel, need for large pressurized fuel storage, so there is some safety concern with a pressurized fuel tank, inconsistent fuel properties and refuelling of the compressed natural gas is a slow process. Natural gas can be used as a fuel essentially in the form in which it is extracted. Some processing is carried out prior to the gas being distributed. Methane can also be produced from coal and from biomass or biogas and a whole variety of biomass wastes such as from landfill sites and sewage treatment plants.

CNG as an Alternative Fuel For Internal Combustion Engines:

Compressed Natural Gas (CNG) has long been used in stationary engines, but the application of CNG as a transport engines fuel has been considerably advanced over the last decade by the development of light weight high-pressure storage cylinders.[3] Some researchers[15,16,20-22] have been researched about the compressed natural gas as alternative fuel motivated by the economic, emissions and strategic advantages of alternative fuels.

Several alternative fuels have been recognized as having a significant potential for producing lower overall pollutant emissions compared to gasoline and diesel fuel. Natural gas, which is composed predominately by has been identified as a leading candidate for transportation applications among these fuels for several reasons[15,17]. Shasby[15] has identified three reason, the first reason is availability, the second attraction reason of natural gas is its environmental compatibility and the third attraction reason of natural gas is that it can be used in conventional diesel and gasoline engines. According to Shasby[15], operating costs are another reasons, where natural gas powered vehicles theoretically have a significant advantage over petroleum-powered vehicles, the basis for this argument is the lower cost per energy unit of natural gas as compared to petroleum. Compressed natural gas vehicles exhibit significant potential for the reduction of gas emissions and particulates. There are problems for compressed natural gas applications such as on board storage due to low energy volume ratio, knock at high loads and high emission of methane and carbon monoxide at light loads[17]. According to Sera[23] , the CNG as fuel properties are shown in Table 2.

TABLE: 1 Chemical Composition Of Compressed Natural Gas.

Sr.No.	Composition	Chemical Formulae	Volume Fraction(%)
1.	Methane	CH_4	91.82
2.	Ethane	C_2H_5	2.91
3.	Nitrogen	N	4.46
4.	Carbon Dioxide	CO_2	0.81
			Total : 100

TABLE:2 Chemical Properties of Compressed Natural Gas

Sr no.	Properties	Values
1.	Density (kg/m3)	0.72
2.	Flammability limits (volume % in air)	4.3-15
3.	Flammability limits (Ø)	0.4-1.6
4.	Autoignition temperature in air (C)	723
5.	Minimum ignition energy (mJ)b	0.28
6.	Flame velocity (ms-1)b	0.38
7.	Adiabatic flame temperature (K)b	2214
8.	Quenching distance (mm)b	2.1
9.	Stoichiometric fuel/air mass ratio	0.069
10.	Stoichiometric volume fraction %	9.48
11.	Lower heating value (MJ/kg)	45.8
12.	Heat of combustion (MJ/kgair)b	2.9

TABLE 3: Characteristics of Compressed Natural Gas

Sr No.	CNG Characteristics	Value
1.	Vapour Density	0.68
2.	Auto Ignition	7000C
3.	Octane Rating	130
4.	Boiling Point (Atm.Pressure)	-1620C
5.	Air Fuel Ratio (Weight)	17.24
6.	Chemical Reaction with rubber	No
7.	Storage Pressure	20.6 MPa
8.	Fuel air mix quality	Good
9.	Pollution CO-HC-NOX	Very Low
10.	Flame speed m/sec	0.63
11.	Combust ability with air	4-14%

However, these can be overcome by the proper design, fuel management and exhaust treatment techniques. Most existing compressed natural gas vehicles use petrol engines, modified by after-market retrofit conversions and retain bi-fuel capability. Bi-fuelled vehicle conversions generally suffer from a power loss and can encounter driveability problems due to the design and/or installation of the retrofit packages Shasby[15] . In bi-fuel for diesel engine, natural gas as a fuel for diesel engines offers the advantage of reduced emissions of nitrogen oxides, particulate matter and carbon dioxide while retaining the high efficiency of the conventional diesel engine [22]. Single-fuel vehicles optimized for compressed natural gas are likely to be considerably more attractive in terms of performance and somewhat more attractive in terms of cost.

According to Poulton [17] that a natural gas powered, single-fuel vehicle should be capable of similar power, similar or higher efficiency and mostly lower emissions than an equivalent petrol-fuelled vehicle. Such a vehicle would have a much shorter driving range unless the fuel tanks are made very large ,which would then entail a further penalty in weight, space, performance and cost. The safety aspects of converting vehicles to run on CNG are of concern to many people. However, the low density of methane coupled with a high auto-ignition temperature, CNG is 540°C compared with 227-500°Cfor petrol and 257°C for diesel fuel and higher flammability limits gives the gas a high dispersal rate and makes the likelihood of ignition in the event of a gas leak much less than for petrol or diesel. Additionally, natural gas is neither the toxic, carcinogenic nor caustic. According to Poulton The legal maximum operating pressure for a vehicle storage cylinder will usually be in the range 20-25 MPa commonly 20 MPa. Cylinders are tested before installation to a pressure of 30 MPa (300 bar or4,350 psi) or to a level to meet local requirements. Safety regulations specify a periodic re-inspection, typically at five-year intervals, including a pressure test and internal inspection for corrosion. The usage of natural gas as an alternative fuel has the advantage of a comprehensive supply and distribution system already in place, there by substantially reducing the cost of adopting it as an alternative fuel. A gas supply network has been inexistence, distribution and transmission mains However; the refuelling infrastructure would need to be established.

Cng As Alternative Fuel Characteristic:

The octane rating of natural gas is about 130, meaning that engines could operate at compression ratio of up to 16:1without knock or detonation [17]. In the CNG application policy, many of the automotive makers already built transportation with a natural gas fuelling system and consumer does not have to pay for the cost of conversion kits and required accessories. Most importantly, natural gas significantly reduces CO emissions by 20-25% compare to gasoline because simple chemical structures of natural gas (primarily methane-CH) contain one Carbon compare to diesel($C_{15}H_{324}$) and gasoline (C_8H_{18})[16,17]. CNG as alternative fuel characteristics are shown in Table 3.

Like methane and hydrogen is a lighter than air type of gas and can be blended to reduce vehicle emission by an extra

50%. Natural gas composition varies considerably over time and from location to location[17]. Methane content is typically 70-90% with the reminder primarily ethane, propane and carbon dioxide[15,24]. At atmospheric pressure and temperature, natural gas exists as a gas and has low density. Since the volumetric energy density is so low, natural gas is often stored in a compressed state at high pressure stored in pressure vessels. According to Poulton[17] that natural gas has a high octane rating, for pure methane the RON = 130 and enabling a dedicated engine to use a higher compression ratio to improve thermal efficiency by about 10% above that for a petrol engine, although it has been suggested that optimized CNG engine should be up to 20% more efficient, although this has yet to be demonstrated. Compressed natural gas therefore can be easily employed in spark-ignited internal combustion engines.

It has also a wider flammability range than gasoline and diesel oil[19]. Optimum efficiency from natural gas is obtained when burnt in a lean mixture in the range A = 1.3-1.5, although this leads to a loss in power, which is maximized slightly rich of the stoichiometric air/gas mixture. Additionally, the use of natural gas improves engine warm-up efficiency and together with improved engine thermal efficiency more than compensate for the fuel penalty caused by heavier storage tanks. Natural gas must be in a concentration of 5-15% in order to ignite, making ignition in the open environment unlikely. The last and most often cited advantages have to do with pollution. The percentages vary depending upon the source, but vehicles burning natural gas emit substantially lesser amounts of pollutants than petroleum powered vehicles. Non methane hydrocarbons are reduced by approximately 50%, NOx by 50-87, CO_2 by 20-30, CO by 70-95% and the combustion of natural gas produces almost no

Particulate matter [17]. Natural gas powered vehicles emit no benzene and 1,3-butadiene which are toxins emitted by diesel powered vehicles. The use of natural gas as a vehicle fuel is claimed to provide several benefits to engine components and effectively reduce maintenance requirements. It does not mix with or dilute the lubricating oil and will not cause deposits in combustion chambers and on spark plugs to the extent that the use of petrol does, thereby generally extending the piston ring and spark plug life. In diesel dual-fuel operation evidence of reduced engine wear is reported, leading to expected longer engine life [5]. The use of natural gas in a diesel Spark-Ignition (SI) conversion is expected to allow engine life at least as good as that of the original diesel engine. Because of its very low energy density at atmospheric pressure and room temperature, natural gas must be compressed and stored on the vehicle at high pressure-typically 20 MPa, 200 bar or 2,900 psi. The alternative storage method is in liquid form at a temperature of-162°C. Because of the limited capacity of most on-board CNG storage systems a typical gas-fuelled vehicle will need refuelling two to three times as often as a similar petrol or diesel fuelled vehicle-a typical CNG-fuelled car engine will provide a range of 150-200 km and a truck or bus some 300-400 km. It is possible that the space required and weight of CNG fuel storage systems will fall in the future as a result of improved engine efficiencies as with dedicated designs and lightweight storage tanks. When a vehicle is operating on CNG about 10% of the induced airflow is replaced by gas which causes a corresponding fall in engine power output. In performance terms the converted bi-fuel engine will generally have a 15-20% maximum power reduction than that for the petrol version. When a diesel engine conversion is fuelled on gas more engine power can be obtained due to the excess air available which, due to smoke limitations, is not fully consumed. Because natural gas has a low cetane rating, a spark ignition conversion for diesel engines is required, adding to the conversion cost[17]. Even though more power may be available, experience has shown that SI diesel engine conversions are usually down-rated to prevent excessive combustion temperatures leading to component durability problems. A diesel/gas dual-fuel conversion may experience a loss of efficiency, relative to diesel-fuelling alone. A 15-20% loss in thermal efficiency was reported in a dual-fuel heavy-duty truck demonstration in Canada, where natural gas provided 60% of the total fuel requirement during dual-fuel operation. A further disadvantage of methane is that it is a greenhouse gas with a warming forcing factor many times that of the principal greenhouse gas, CO , Gas leakage or vehicular emission, therefore and the size of release, will have an impact on the overall greenhouse gas (GHG) emissions performance relative to the petrol or diesel fuel it substitutes[15,16,20-22].

Cng Fuel Emissions:

The last and most often cited advantages have to do with pollution. The percentages vary depending upon the source, but vehicles burning natural gas emit substantially lesser amounts of pollutants than petroleum powered vehicles. Non methane hydrocarbons are reduced by approximately50, NOx by 50-87, CO by 20-30, CO by 70-95% and the combustion of natural gas produces almost no particulate matter[17], Natural gas powered vehicles emit no benzene and 1,3-butadiene which are toxins emitted by diesel powered vehicles. The natural gas is a much simpler hydrocarbon than those in petrol and diesel and mixes un-uniformly with air, combustion is likely to be more complete in the time available fluids to inherently lower CO and non-methane HC emissions. Because a gas-fuelled does not require cold-start enrichment, emissions from "cold" engine operation are higher than with liquid fuels and because gas systems are designed to be air-tight, so relative emissions should be negligible. Generally low sulphur content of natural gas is 5-10 ppm, mainly from the odorant[5]. One of the important sources of catalyst poisoning and, for example, should allow placement of platinum by the much more abundant palladium. Palladium also has advantage of being very effective for methane oxidation. The magnitude and character of emissions from CNG engine vehicles, like emissions from alcohol and other vehicles, will vary depending on the tradeoffs made between performance, fuel economy, emissions and other factors. However, the simple physical composition of natural gas (predominantly methane-CH with no carbon-to-carbon bonds) tends to use it a basically lower emission fuel, since the combustion process is less complex than liquid hydrocarbon fuels and there is less of the other hydrocarbons.

Diesel Engine Converted To Port Injection Dedicated Cng Engine:

In the diesel engines converted or designed to run on natural gas, there are two main options discussed. The first is dual-fuel engines. These refer to diesel engines operating on a mixture of natural gas and diesel fuel. Natural gas has a low cetane rating and is not therefore suited to compression ignition, but if a pilot injection of diesel occurs within the gas/air mixture, normal ignition can be initiated. Between 50 and 75% of usual diesel consumption can be replaced by gas when operating in this mode. The engine can also revert to 100% diesel operation.

The second is dedicated natural gas engines. Dedicated natural gas engines are optimized for the natural gas fuel. They can be derived from petrol engines or may be designed for the purpose. Until manufacturer Original Equipment (OE) engines are more readily available, however, the practice of converting diesel engines to spark ignition will continue, which involves the replacement of diesel fuelling equipment by a gas carburettor and the addition of an ignition system and spark plugs [17]. Buses and trucks larger and greater numbers of cylinders are used than for light-duty engines. For compression ignition engines conversions to spark ignition, the pistons must be modified to reduce the original compression ratio and a high-energy ignition system must be fitted. The system is suitable for CNG and is ideally suited to timed (sequential) port injection system but can also be used for single point and low pressure in-cylinder injection. Gas production provides greater precision to the timing and quantity of fuel provided and to be further developed and become increasingly used to provide better fuel emissions. The port-inducted or port injection CNG produces negligible levels of CO, CO_2 and NO. In order to greatly reduce exhaust gas emissions, a port injection system was chosen by Czerwinski and Kawabata[28][25,26][17], Hollnagel and the injector and pressure regulator have been newly developed. At the same time, precise Air-Fuel (A/F) ratio control and special catalysts CNG exhaust gas have been utilized. The resulting CNG engines output power has been restored to near that of the gasoline base engine. With the port injection (sequential) or trans-intake valve-injection system, a high-speed gas jet is pulsed from the intake port through the open intake valve into the combustion chamber, where it causes effects of turbulence and charge stratification particularly at engine part load operations. The system is able to diminish the cyclic variations and to expand the limit of lean operation of the engine. The flexibility of gas pulse timing offers the potential advantage of lower emissions and fuel consumption. With three types of port injectors available on the market, Czerwinski were compared for stationary and transient engine operation. There are several advantages of port injection, e.g., better possibility to equalize the air-fuel ratio of the cylinders, optimization of the gas injection timing and of the gas pressure for different operating conditions. The port injection has an injector for each cylinder, so the injectors can be placed in close proximity to the cylinder's intake port. It also enables fuel to be delivered precisely as required to each individual cylinder (called sequential) and enables more sophisticated technologies such as skip-firing to be used. Skip-firing is when only some of the cylinders are operating (the other cylinders are being skipped). This enables even more efficient use of the fuel at low loads, further lowering fuel consumption and unburned hydrocarbon [26].

Gaseous Fuel Injection Improvement:

Improvement of CNG injector nozzle holes geometries and understand of the processes in the engine combustion is a challenge because the compression-ignition combustion process is unsteady, heterogeneous, turbulent and three dimensional, very complex and the nozzle fuel injector hole is can be variation with any hole geometry. In port injection CNG engines, natural gas fuel is injected by fuel nozzle injector via intake port into combustion chamber and mixing with air must occur before ignition of the gas fuel. To improve the perfect of mixing process of CNG fuel and air in combustion chamber is arranging of nozzle holes geometry, nozzle spray pressure, modified of piston head, arranging of piston top clearance, letting the air intake in the form of turbulent and changing the CNG fuel angle of spray. The CNG fuel spraying nozzle is the level of earning variation so that can be done by research experiment and computational of engine power, cylinder pressure, specific fuel consumption and exhaust gas emissions which also the variation of them. Czerwinski have been researched the sequential injection of CNG offers several advantages to increase the CNG engine performance. The fuel nozzle injector multi holes geometries development is to produce optimum fuel air mixing and increasing the volumetric efficiency of the engine that will promote a comparable engine performance. According to Czerwinski [26], the CNG port injection system has advantages to develop for the more efficiency.

Gaseous Fuel Injection Spray Structure:

Gaseous fuel injection implications and its behavior on combustion chamber design has received considerable attention in recent years. Most present day direct injection engines have been optimized for use with liquid fuels. The optimal configuration may be different than what is required for gaseous fuels. Experiments by Abraham examined the relative effects of combustion on liquid and gaseous fuel direct injection jets. Results showed that fuel-air mixing and burning rates were initially slower for gas injection jets than for liquid sprays. However, burning and mixing rates of the gaseous direct injection in the subsequent stages of combustion increased in comparison with liquid fuel sprays. Initially, the liquid jet was more effective at entraining air and hence was better at producing flammable mixture regions within the combustion chamber. In the end, however, the liquid spray did not burn as completely as the gas jet. Beyond the initial stage, the gas direct injection jet exhibited a higher combustion rate than that of the liquid fuel[24]. The relative decrease in burning rate for the liquid spray results from vaporization of the remainder of the liquid fuel in the mixture. This causes an increase in the richness of mixture behind the flame, leading to a smaller energy release than exhibited by the gas jet. According to Brombacher [24], the significant contributions to the understanding of transient gaseous jet behavior have been reviewed, made and researched. The research a jet model, based on experimental results, consisting of four main regions. Figure 1 shows a transient gas jet showing the four main regions; the potential core region, the main jet region, the mixing flow region and the dilution region[32,33]. The gaseous jet plume is characterized by a high velocity, low temperature core of rich unmixed fuel confined to the jet axis[34] .This core region is referred to as the main jet region and contains the bulk of the unmixed fuel. Turbulent vortices are generated on the periphery of the jet core as a result of shear forces exerted by the ambient air in the chamber[32,34]. In the region close to the nozzle exit, however, very little turbulence is generated. This region, the potential core region, is very stable and is characterized by very low mixing rates. It extends from the nozzle exit to a distance corresponding to a z/d (penetration distance/nozzle orifice diameter) ratio of approximately 12.5[33,35,36] Beyond this region, large scale vortices are generated by shear forces as air is entrained into the jet, resulting in vigorous mixing along the jet periphery. This region of enhanced mixing surrounds the main jet and is referred to as the mixing flow region. As the fuel loses its momentum, it is pushed aside by fuel flowing from upstream. The tip of the jet expands radially, forming the dilution region of the jet. This region corresponds to the jet tip and is characterized by low velocities and high fuel concentration. The experimental study by Tanabe[37] were shown that the flammable region exists only within the thin layer around the periphery of the jet. In the vicinity of the nozzle, the temperature is low and the jet velocity is high; thus resulting in poor mixing conditions. Such conditions do not provide a favorable environment for chemical reactions to take place. Downstream of the nozzle, in the mixing flow region, the temperature in the periphery of the jet is relatively high and the mixture is roughly stoichiometric. The flow has stabilized in this area as result of momentum change between the jet and the entrained air, which provides sufficient residence time for a chemical reaction to occur. In summary, the most likely location for ignition to take place and correspondingly the ideal place to install a glow plug in the periphery of the jet downstream of the potential core region[38]. Results from Aesoy [38] further support the finding. The core of the jet is fuel rich and very cold. The temperature of the core is, in fact, lower than the fuel temperature before injection. This is due to rapid expansion of the jet at the nozzle exit and the high velocity of the jet[24]. The outer edge of the jet is higher in temperature because of heat transfer that occurs as the hot air is entrained into the jet[24] . It would be very difficult to achieve ignition if an ignition assist device were to be placed the core of the jet because a great deal of thermal energy input would be required to elevate the core to the autoignition temperature. Furthermore, the high temperature gradient between the glow plug and the jet core would result in short plug service life. These conclusions provide some explanation for the experimental findings of Aesoy and Thring[39][38].

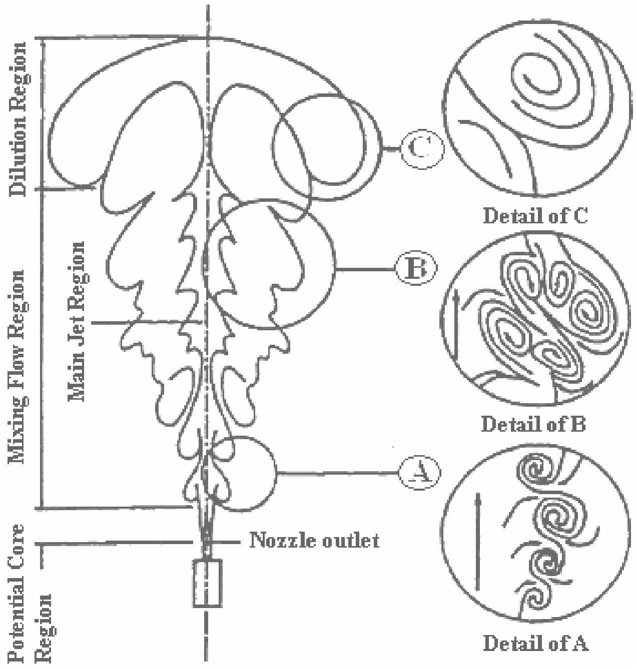

Fig1. Transient gaseous jet structure[33]

Injector Nozzle Geometries Improvement Effect On Fuel-Air Mixing:

Numerous studies have suggested that decreasing the injector nozzle orifice diameter is an effective method of increasing fuel air mixing during injection [24]. The smaller nozzle holes were found to be the most efficient at fuel-air mixing primarily because the fuel rich core of the jet is smaller [34]. In addition, decreasing the nozzle orifice diameter dl would reduce the length of the potential core region (defined as z/d = 12-51 and hence increase the size of the mixing flow region[33].Unfortunately, decreasing nozzle holes size causes a reduction in the turbulent energy generated by the jet. Since fuel-air mixing is controlled by turbulence generated at the jet boundary layer, this will offset the benefits of the reduced jet core size. Furthermore, jets emerging from smaller nozzle orifices were shown not to penetrate as far as those emerging from larger orifices. This decrease in penetration means that the fuel will not be exposed to al1 of the available air in the chamber. For excessively small nozzle size, the improvements in mixing related to decreased plume size may be negated by a reduction in radial penetration[34]. Another significant feature of the injection flow that requires attention is the tendency of the fuel plume to attach to the cylinder head. This behaviour is undesirable because it restricts penetration to the chamber extremities where a large portion of the air m as resides. Furthermore, it hampers air entrainment from the head side of the plume because the exposed surface area of the plume is reduced. The phenomenon responsible for the jet deflection is known as the Coanda effect [24]. The effect arises as a consequence of the velocity and pressure fields surrounding the jet. Low pressure areas are formed above and below the jet, due to the entrainment of air mass into the jet from the local surrounding volume. Below the jet, there is significant air mass in the volume between the piston and the injector. Above the jet, space is limited and the air must be entrained from progressively farther downstream. As the jet develops, the air must eventually be entrained from the air into which the jet would penetrate. The entrainment flow is strong enough to deflect the fuel jet upwards, causing in the attach to the cylinder head. This phenomenon must be carefully avoided in the design of a natural gas engine combustion chamber. The mixing was maximized when the nozzle tip was placed equidistant from the piston and cylinder head [34].

The nozzle containing many small holes would provide better mixing than a nozzle consisting of a single large hole [34]. This hypothesis has been tested by studying injectors with varying numbers of nozzle holes. The diameters of the holes were adjusted such that each nozzle delivered the same overall fuel mass flow. Computational analysis examining eight hole four hole, two hole and one holes nozzles, revealed that the mixing rate improved with the number of nozzle holes[24]. Jennings [34] carried out similar analysis for 8, 12 and 16 holes nozzles. Contrary to the trend, the 16 holes injector performed poorly due to plume merging. Plume merging has an adverse effect on mixing because the total plume surface area available for mixing is decreased [24].

Injector Nozzle Coefficient Of Discharge:

The Coefficient of discharge (Cd) for micro-nozzles for compressible gas flow has measured by Snyder . The coefficient of discharge was defined as per geometry, where A was calculated from the standard isentropic compressible mass flow relation. There is a possibility of further increase in Cd values with a further increase in the Reynold number. The small orifice diameter and large l/d ratio had strong effect on Cd values for compressible gas flow.

The following Eq. 1,2, 3 were proposed for Cd

$$2<l/d<10;\ 10<Re<20000 \qquad (1)$$

$$Cdmax = 0.827-0.0085*1/d \qquad (2)$$

$$l/Cd = l/Cdmax + 20/Re\{l+2.25*l/d\} \qquad (3)$$

Where:
d = Orifice diameter
l = Orifice length
Cd = Coefficient of discharge
Cdmax= Maximum coefficient of discharge
Re = Reynold number

In a later research by Siebers[41], the similar Cd values were obtained again for different diameter orifices as shown in Table 4 and 5.

Injector Nozzle Spray Cone Angle:

A major difficulty in the definition and measurement of the spray cone angle is that the spray has curved boundaries due to the effect of air interaction with the spray [35]. Most of the proposed relations are empirical in nature and cannot predict spray cone angles exactly for different injection systems. The applied dimensional analysis to the data and derived the following equation has used by Arai [42]. The spray cone angle increases as the orifice diameter increases. If θ is the cone angle in measured spray, ρ is ambient air density, ΔP is pressure difference across the orifice length, D is particle diameter and μ is ambient air viscosity. The Eq. 4 is used for calculate the spray cone angle of nozzle injector:

$$2\theta = 0.05\ (\rho a \Delta P D2\ /\ \mu a2)0.25 \qquad (4)$$

The other Eq. 5 by Siebers[41], the constant c was optimized to provide the best fit the data. The effect of the nozzle geometry on spray cone angles is not provided directly in the equation. The value of c is different for different nozzles and its value is on the order of 0.26[35]:

$$\tan(\theta/2) = c[\ (\rho a/\rho f)0.19 - 0.0043\ (\rho a/\rho f)0.5] \qquad (5)$$

Where
θ = The cone angle in measured spray

ρa = Ambient air density

ρf = Fuel air density

Injector Nozzle Orifice Shapes:

The effect of different orifice shapes on the spray characteristics over a range of injection pressures from 21-103 MPa has investigated by Dodge[43]. The concluded that different orifice shapes have little effect on spray quality and fuel air mixing rate[35]. A mathematical model was presented by Schlesinger[44] and re-explored by Baik[35] which described the fluid jets escaping triangular cross sectional micro-channel. The application of the model to the defined geometrical shape of an orifice led to deflection of the liquid jet from the axis of the channel in order to minimize the surface area of the volume element. Actual deflection depended on angle of triangle.

TABLE 4: Coefficient of Discharge [40]

Orifice diameter (mm) Di/Do	Length to diameter ratio	Discharge Coefficient
0.185/0.198	5.1	0.56
0.241/0.257	3.9	0.62
0.330/0.340	2.9	0.62

TABLE 5: Coefficient of Discharge[41]

Orifice Diameter (μm)	Length to diameter ratio	Discharge Coefficient
100	4.0	0.80
180	.2	0.77
251	2.2	0.79
246	4.2	0.78
267	8.0	0.77
363	4.1	0.81
498	4.3	0.84

Conclusion:

Diesel fuel will become scarce and most costly. CNG as an alternative fuel is becoming increasingly important. CNG has some advantages compared to gasoline and diesel from an environmental perspective and the disadvantages is has lower performance compared to gasoline and diesel engines. Hence, systematic studies have been carried out to improve techniques and redesign components in producing optimum CNG engines. To increase the power and decrease the exhaust gas emissions, the CNG engine is need some improvements. The converting of diesel engine to port injection CNG engine spark ignition and improve the gaseous fuel injector nozzle holes geometries which operated in variation injection pressure and injection timing will be give better performance and exhaust gas emissions.

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