'I admit that have read
this report and to my opinion this report
fulfill in terms of scope and quality for the certificate of
Bachelor of Mechanical Engineering (Thermal-Fluid)'

Signature : ..........................................

Name Of Supervisor 1: Puan Ainil Jesita Binti Jalaluddin

Date : 13 May 2008

# CFD SIMULATION OF A DIRECT INJECTION NATURAL GAS INJECTOR NOZZLE

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This report is submitted in partial fulfillment of the requirement for the Bachelor of Mechanical Engineering (Thermal-Fluid)

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MAY 2008

"I hereby declare that this project report is written by me and is my own effort and that no part has been plagiarized without citations"

Signature : .........................................

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Date : 13 May 2008

"Teristimewa buat bonda dan ayahanda tercinta
tidak lupa juga buat abang dan kakak serta keluarga yang tersayang
Jutaan terima kasih buat segala dorongan dan sokongan yang tidak ternilai harganya"

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# ABSTRACT

Computational Fluid Dynamics (CFD) techniques were used to simulate one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. This project is prepared to run CFD simulation using FLUENT 6.1.22 software on existing direct fuel injector using Compress Natural Gas (CNG) and the designed is based on 2D axisymmetric. The medium used during this simulation is considered as methane, $CH_4$ since CNG consist more than 90% mol of the methane gas. The gas penetration result from simulation will be compared with the actual value of experiment. The results for early readings give the validation data but in the middle till final, there are not very accurate. This is due to the setting during simulation which can give some effect to the result obtained.

# ABSTRAK

Pengiraan Dinamik Bendalir (CFD) merupakan satu teknik yang digunakan untuk simulasi cabang mekanik bendalir menggunakan kaedah bernombor dan algarithme untuk menyelesaikan dan mengnalisis masalah yang melibatkan aliran bendalir. Projek ini disediakan untuk menjalankan simulasi Dinamik Bendalir Berkomputer (CFD) menggunakan perisian FLUENT 6.1.22 ke atas aliran keluar muncung paip terus menggunakan Gas Mampat Semulajadi (CNG) dan rekabentuk muncung paip adalah berdasarkan kepada 2D paksi-simetri. Medium yang digunakan untuk simulasi adalah metana kerana Gas Mampat Semulajadi (CNG) mengandungi campuran metana yang melebihi 90% mol. Keputusan penembusan gas daripada simulasi akan dibandingkan dengan nilai sebenar eksperimen. Beberapa bacaan yang diperolehi pada awal simulasi boleh dipakai untuk perbandingan dengan nilai ekperimen tetapi untuk pertengahan hingga akhir bacaan, nilai penembusan gas adalah jauh berbeza. Ini adalah disebab oleh data yang dimasukkan semasa simulasi adalah tidak tepat dan akan memberikan kesan kepada keputusan akhir.

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# CHAPTER I

# INTRODUCTION

## 1.1 Background

From Secondary Energy Infobook, page 28 (2007), the natural gas comes from the plants and animals that was decomposition for a thousand years ago by heating and pressuring under the ground. As it comes out from the ground, it was mixed with various types of liquid and solid matters. These matters can be distillated by using the stage control which is commonly by the oil or petroleum company. One of the products from distillation process is Compress Natural Gas (CNG) which is used commonly used as a transportation fuel to reduce operating cost, emissions, and air pollution. CNG is a substitute for gasoline (petrol) or diesel fuel and is made by compressing the methane ($CH_4$) extracted from natural gas where the general formula for this series is $C_nH_{2n+2}$.

According to (Wakdikar S. 2002), the reasons why CNG is a more beneficial fuel rather than petrol are because it is environmental friendly, cheaper cost, operational advantages, and flexible and ease for use. The use of CNG as a fuel reduces vehicle exhaust emission by 70% to 90% of Carbon Monoxide, 40% to 60% of Hydrocarbon and 10% of Carbon Dioxide compared to petrol. There is not such an impact on the greenhouse effect and also non-toxic or corrosive and will not contaminate ground water. Besides, the cost of CNG is almost a third of the cost of petrol and the basic engine characteristic of a vehicle are retained while converting it to run on CNG. The better carburization of the gas with air allows for the more even filling of the cylinders and there is less engine stress. Furthermore, the method used to store CNG on board the vehicle and the properties of CNG make it the safest fuel for propulsion of vehicle.

Fuel injection means metering fuel into an internal combustion engine. In modern automotive application, fuel metering is one of several function performed by the system of engine management. Fuel injectors perform an important role in the accurate metering and atomize the fuel by forcibly pumping it through a small nozzle under high pressure. The fuel injector is only a nozzle and a valve with power to inject the fuel comes from further back in the fuel supply, from a pump or a pressure container. The benefit usage of using fuel injector is smoother and more dependable engine response during quick throttle transitions, easier and more dependable engine starting, better operation at extremely high or low ambient temperatures, reduced maintenance intervals, and increased fuel efficiency.

Injector Information Packet says that there are many types of fuel injection such as Multi Point Injection (MPI), Single Point Injection (SPI) and also Direct Injection (DI). SPI uses tube with poppet valves from a central injector to spray fuel at each intake port while MPI injects fuel into the intake port just upstream of the cylinder's intake valve. For DI, the injection nozzle is placed inside the combustion chamber and the piston incorporates a depression where initial combustion takes place. Most DI is used on diesel engines which are generally more efficient and cleaner but some recent petrol engines also use direct injection offers another magnitude of emission control by eliminating the "wet" portion of the induction system.

## 1.2 Objective

From this project, the goal is to simulate CNG flow inside an automotive direct injection nozzle using CFD and validate the results with experimental jet penetration data with simulation jet penetration result using Fluent 6.1.22.

## 1.3 Scope

The scopes which must be considered while doing this project are:

1. Run CFD analysis on existing fuel injectors using Fluent 6.1.22 Software.
2. Validation the data obtained with the experimental value before.

## 1.4` Problem Statement

Fuel injection is a system of fuel delivery for mixture with air in an internal combustion engine (IC). It has become the primary system used in automotive engines to replace carburetors. A fuel injection system is designed and calibrated specifically for the types of fuel it will handle such as gasoline (petrol), Autogas (LPG, also known as propane), ethanol, methanol, methane (natural gas), hydrogen or diesel. The majority of fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection (EFI), the diesel and gasoline hardware has become similar. For gasoline engines, carburetors were the predominant method to meter fuel before the widespread use of fuel injection. However, a wide variety of injection systems have existed since the earliest usage of the internal combustion engine.

The primary functional difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on the vacuum created by intake air rushing through it to add the fuel to the airstream.

The common types of injector nozzle used are multiple injectors. Most direct injection is used on diesel engines which are generally more efficient and cleaner. CamPro engine is one of the petrol engines which not used direct injection system. This injector nozzle is design based on Bosh injector nozzle to be applied on CamPro engine. The fuel injector is only a nozzle and a valve which can produce power to inject the fuel comes from farther back in the fuel supply, from a pump or a pressure container.

## 1.5 Limitations

There are some limitations that should be considered when doing this project which are:

1. Considered using one nozzle which had been designed for this project.
2. The flow of CNG during simulation considered as transient non-buoyant turbulent gaseous flow.
3. Used methane ($CH_4$) as the medium during simulation since CNG component contained more than 90% methane.
4. Assume there is no shocked before specified inlet.
5. Assume there is negligible friction or pressure lost between inlet and pressure gauge.

## 1.6 Dissertation Outline

The organization of this report is as follows: Chapter 2 describes the literature review from previous study or researcher that is related with the objective and title of the project. Chapter 3 discusses about the method that is used to achieved the objective and make this project achieve the target. Chapter 4 discuss about the whole data and results obtained through this project and lastly chapter 5 conclude whole of the project result and further recommendation that should be done by further researcher.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Introduction

From the previous study, there is various type of published journal which is related through this project. From the previous study, Gas Versus Spray injector by J. Abraham (2001) presented results of 3-D computations of direct injection of gaseous methane and of liquid tetradecane through a multi hole injector into a Diesel engine. The study focused on the distribution of fuel/air ratio within the resulting gas and spray jets under typical Diesel conditions prior to ignition. Present study on Automatic Optimization of Preswirl Nozzle Design by Ciampoli F. *et. al.* (2007) state that the performance of the nozzle system depends on the design by using computational fluid dynamic, CFD to evaluate nozzle performance. Furthermore, Wakdikar S. (2002) states that compress natural gas give more advantage compared with fuel. Other researcher such as Dr. DenBraven K. R. *et. al.* (2005) had investigated the effects of direct injection nozzle geometry and the spray characterization of the nozzle injection.

## 2.2 Spray Characterization

Particular relevance of engine nozzle designed is to distribute the vapor fuel between lean, flammable and rich mixtures in the combustion chamber. It is useful in engine applications when there is direct injection of liquid fuel and it helped to identify improvements to engine design and isolated controlling physical processes. J. Abraham *et. al.* (2001) state that direct injection of gaseous fuel has become more recently, soured by an increasing interest in the use of natural gas as an alternative fuel. One approach to introduce the natural gas into such engines is by direct injection which results in gas jets. The different between distribution of fuel in the gas jet and spray under Diesel engine operating conditions up to ignition is shown that the mixing of vapor is slower in the gas jet than a spray. He had computed for an eight hole injector with the tip located in the head on the axis of the engine. Figure 2.1 and Figure 2.2 show that the contour plot s that significant amount of fuel are in regions with equivalence ratios greater than stoichiometric. Computations of direct injection of liquid into the engine under the same conditions (same injection rates of mass and momentum i.e same injection velocity) were also made.

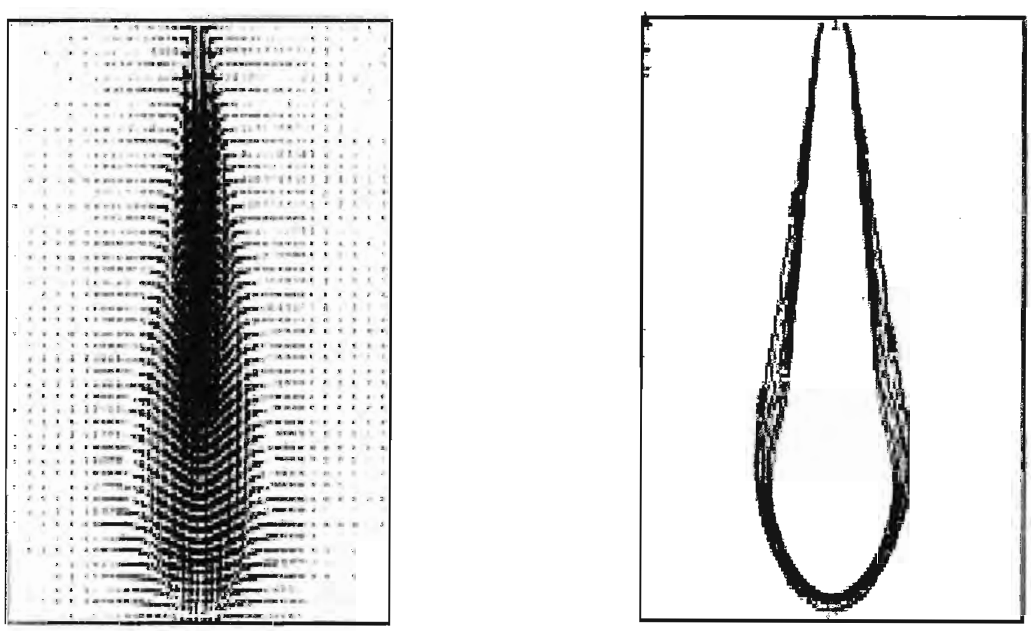

Figure 2.1: Velocity flow field and equivalence ratio contour plots for gas injection. (Source: J. Abraham *et. al.* (2001))

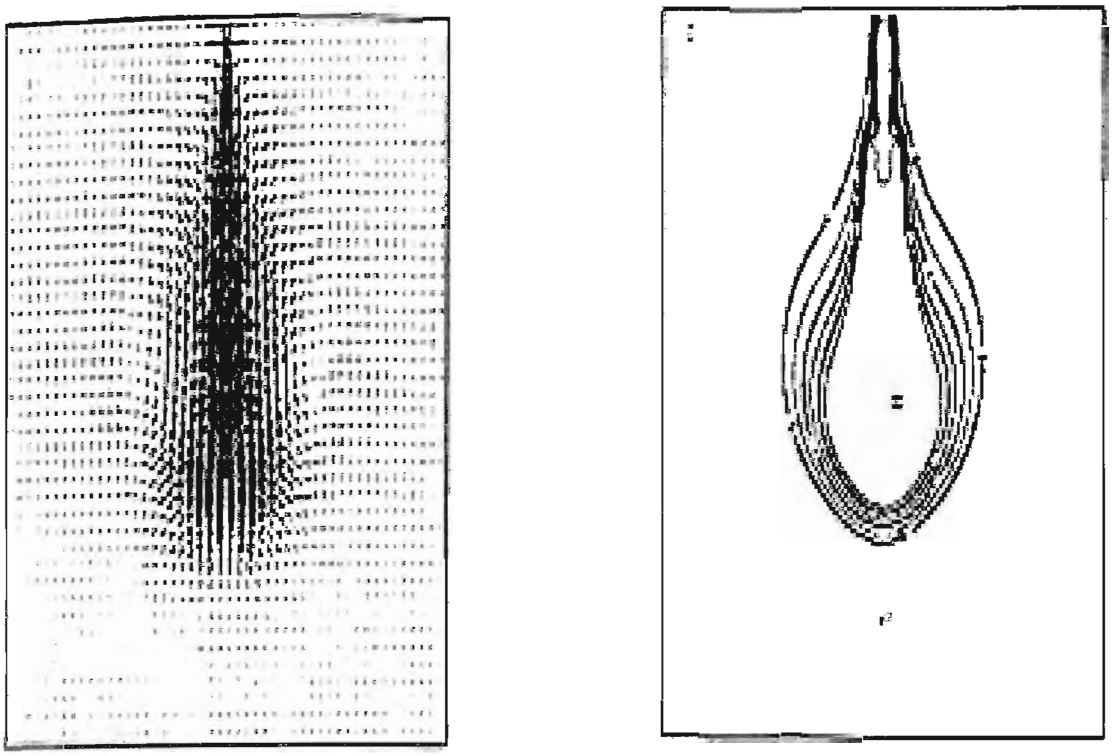

Figure 2.2: Velocity flow field and equivalence ratio contour plots for direct injection. (Source: J. Abraham *et. al.* (2001))

Abraham also found that when the natural gas is injected directly into a Diesel engine, combustion often takes considerably longer and is sootier than when a standard liquid fuel is used. This can be proved by Figure 2.3 which showed the potted graph to determine the amount of flammable mixture available in combustion engine.

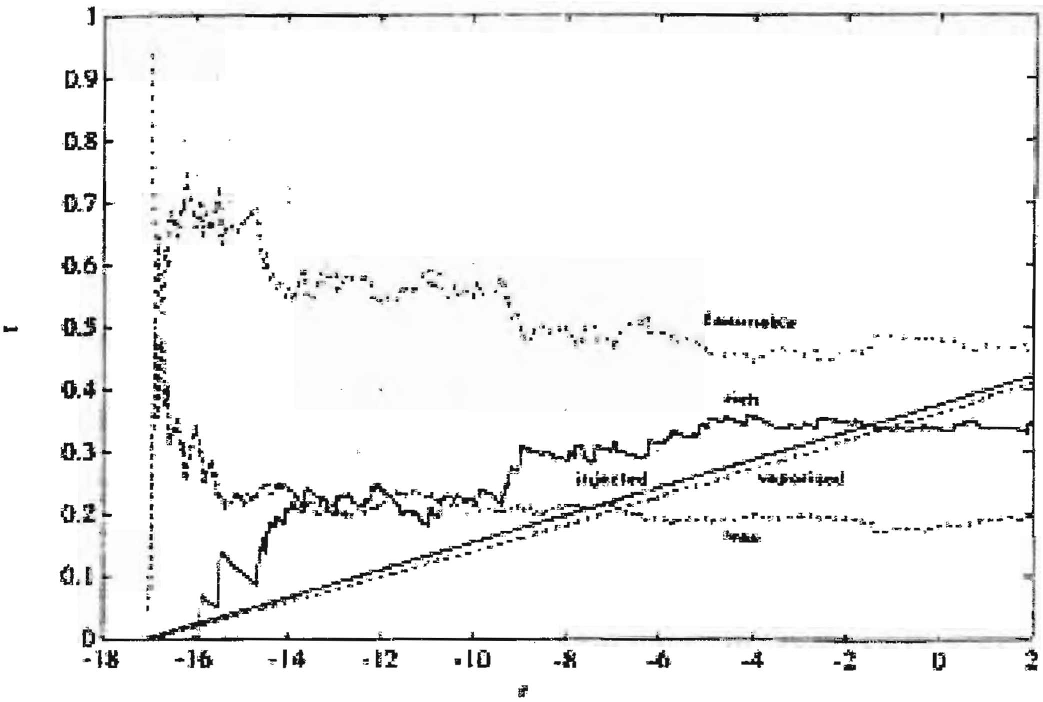


Figure 2.3: "f-θ" plot for the spray.

(Source: J. Abraham *et. al.* (2001))

## 2.3 Meshing Strategy

Ciampoli F. *et. al.* (2007) state that nozzle should operate isentropically ejecting flow uniformly in the tangential direction, thus maximizing use of the available pressure drop. As in every CFD simulation, mesh quality largely determine the quality results obtained. Figure 2.4 shows a section of the computational domain used which includes the nozzle and two hemispherical volumes around the inlet and outlet. It also indicated the mesh strategy to allow the mesh to fit such complex geometry because the size of mesh is very sensitive to the values of design parameter. The use of tetrahedral cells ensures success in generating the mesh for the whole range of variation of the parameter. Hexahedral cells have been used to mesh the boundary layer in the nozzle core and prisms have been used away from the boundary layer. Figure 2.5 shows a close-up view of the mesh at the nozzle inlet for the baseline configuration.

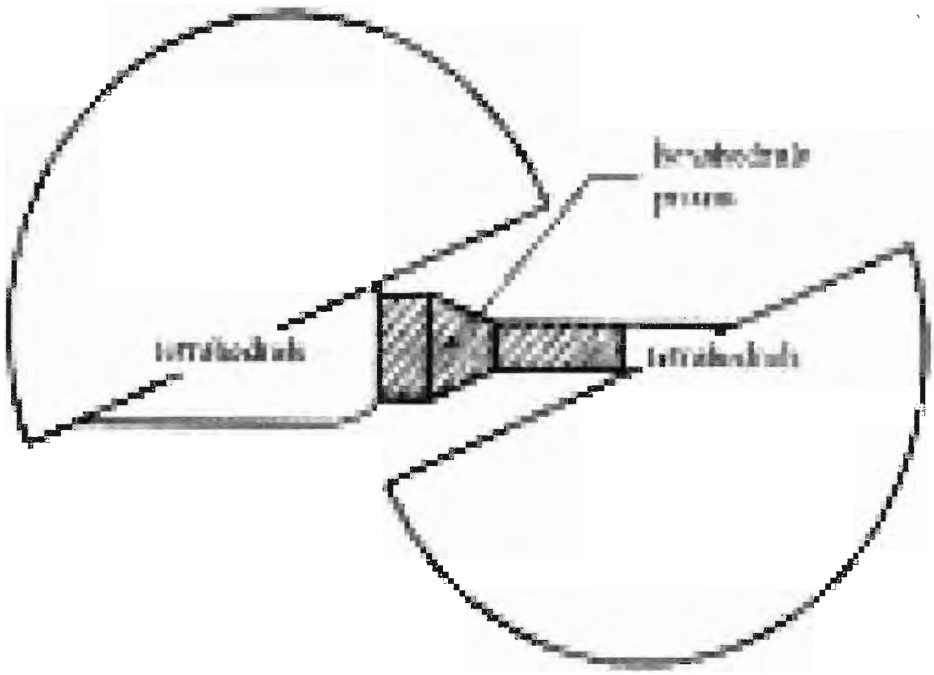

Figure 2.4: CFD domain and meshing strategy.

(Source: Ciampoli F. *et. al.* (2007))

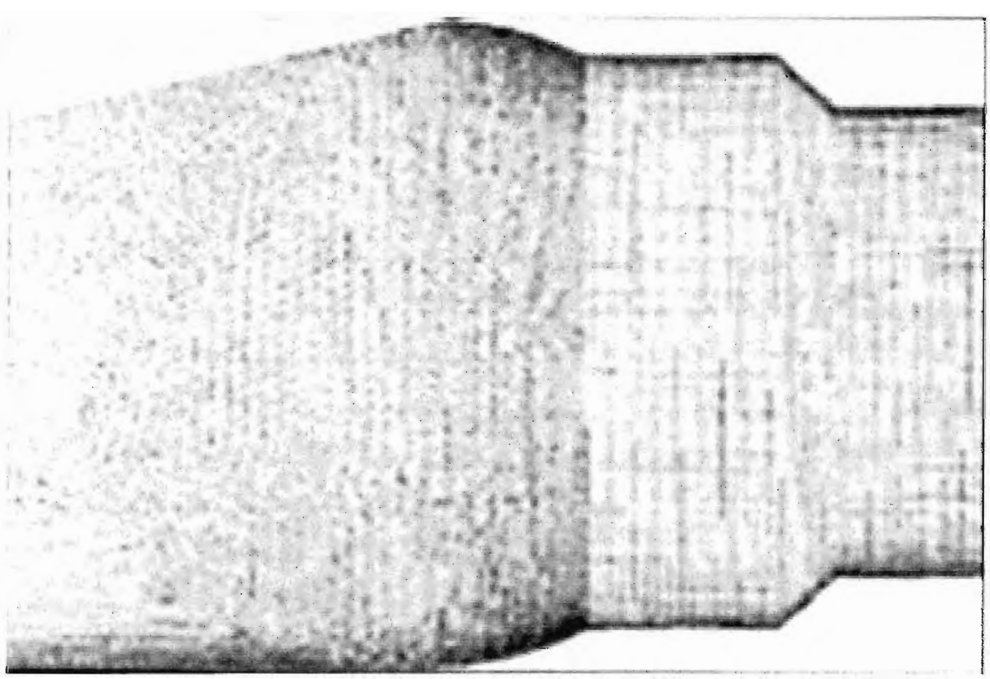

Figure 2.5: View of mesh for baseline geometry.

(Source: Ciampoli F. *et. al.* (2007))

## 2.4 Direct Injection of Gas

Dr. DenBraven K. R. (2005) state that direct injection of gaseous can lessen the effect of charge and exhaust gas mixing and significantly reduce, if not eliminate, short circuiting. In a Gaseous Direct Injection, GDI fuel is injected directly into the cylinder at an optimal time for complete the mixing and combustion.

## 2.5 Compressed Natural Gas

Wakdikar S. (2002) found that Compress Natural Gas, CNG is a safe fuel and being lighter than air because it disperses easily into the atmosphere and does not form a sufficient rich mixture for combustion to take place. CNG is 130 octanes which is considerably higher than 93 octanes for petrol. Consequently, CNG vehicle is more energy efficient because higher octane rating allows higher compression ratios and improved thermal efficiency. Besides it is also an environmental friendly because the usage of CNG can reduce the air pollution and Figure 2.6 below show the population vehicle engine by fuel type.

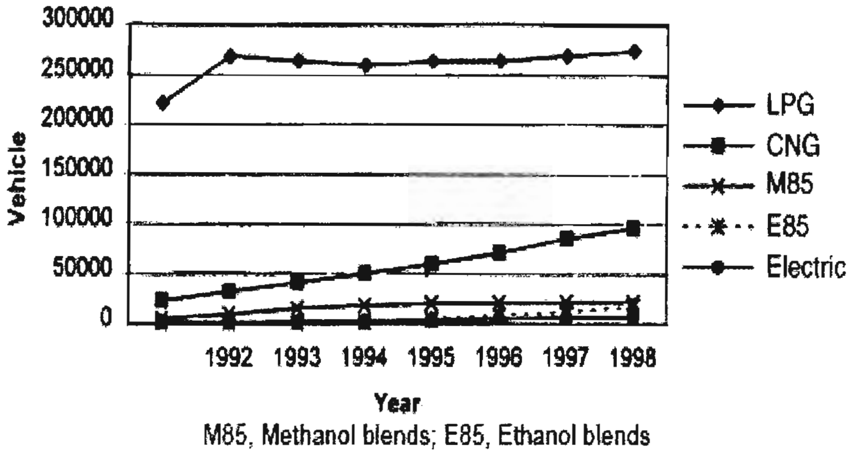


Figure 2.6: AFV populations by fuel type.
(Source: Wakdikar S. (2002))