Study on operating factors and performance of supercharged compressed natural gas engine via Artificial Neural Network

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DECLARATION

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Abstract

In recent years, the emphasis on the sustainable development has become one of the main criteria and considerations of invention or utilisation of new technologies. Sustainable development is the process of development that meets the needs of the present without compromising the future generation to meet their own needs. The same condition has been occurred inside the automotive area.

There are mainly two types of operating engine in this area, such as spark-ignition (SI) engine that mainly operated by using gasoline and compression ignition (CI) engine which use diesel as its main fuel to operate. However, the decreasing storage of the crude oil worldwide and toxic emissions of these engines has caused the public swift their focus on any alternative fuel. The emissions of some greenhouse gases such as carbon dioxide, nitrogen oxide and some hydrocarbon emission have severe effect on world climate change and the main cause of global warming.

The deterioration effect as stated above has caused some invention of new technologies. Firstly, it includes Homogeneous Charge Compression Ignition (HCCI) which causes hybrid operation in the automotive area. Secondly, change the fuel of operation from originally petrol or diesel to the biogas which contains mainly methane as a result of advancement of biomass field as the renewable alternative energy. Then, the utilisation of compressed natural gas (CNG) in the SI engine or using as dual fuel in CI engine due to several benefits.

In this report, the study on the operating factors and performance of supercharged direct injection compressed natural gas (CNG) engine via response surface methodology or Artificial Neural Network is carried out. The increasing interest in supercharging SI engine is mainly due to its superior knock-resisting properties. By using normal natural gas engine in SI engine, the compression ratio increase and hence increase the thermal efficiency but this tend to increase nitrogen oxide and hydrocarbon emission while reducing carbon dioxide emission due to higher hydrogen-carbon ratio in natural gas. Since natural gas is in gaseous state, the volumetric efficiency will be reduced and hence reduce the power, therefore by supercharging and direct injection, this problem can be eliminated. The effect of boost pressure can help to reduce combustion duration as faster heat release at Top Dead Center (TDC) and hence increase the performance and combustion of CNG in DI engine at operating

speed by comparing it to naturally aspirated engine. For the ignition timing, the performance of longer timing is better when engine operate at high speed to allow complete scavenging occurred. By carrying out research, the effect of the ignition timing with boost pressure can be observed at CNG SI DI engine.

For CI engine, natural gas tend to have higher octane number but lower cetane number, therefore it exist at dual fuel mode where high cetane pilot fuel injected along with natural gas. The thermal efficiency of this kind of engine is almost same with normal diesel fuelled engine but with lower NO_x and CO_2 emissions. These trends are caused by the low charge temperature and increased ignition delay, resulting in low combustion temperatures, insufficient penetration and distribution of the pilot fuel in the charge, resulting in a lack of ignition centers. Exhaust Gas Recirculation (EGR) admission at low and intermediate loads increases combustion temperatures, lowering unburned HC and CO emissions and larger pilot quantities help increasing combustion efficiency.

In conclusion, natural gas can be used in both SI and CI engine, however, some modification need to be carried out to enhance the thermal efficiency and reduce the toxic emissions. Furthermore, some research has been carried out to understand the benefits of compressed natural gas (CNG) as a better fuel compared to biogas and HCCI. Since the investigation of the advancement of the engine is very complex, by using Artificial Neural Network, the work will become easier as the simulation carried out is approximate to the real situations.

Chapter 1 Introduction

1.1 Background

In the recent years, as the steady growth of the world population and advancement of the life quality, the consumption of fossil fuel had grown by 36% over last 15 years [1]. The increased of energy demand cause increasing usage of fossil fuel and hence draining the fossil fuel reserves in the world at the faster rate. According to BP Energy Outlook 2014 report, the global energy demand is expected to increase with 1.5% annually to year 2035 and the dependence on the fossil fuel will be reduced from 86.7% until 75% in year 2035 [36].

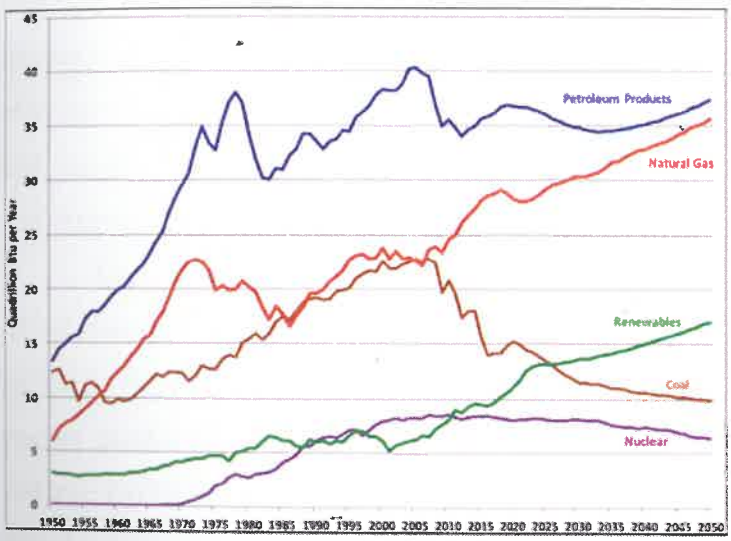

Figure 1: US Energy Consumption by US Energy Information Administration [33].

As the automotive vehicles have increased dramatically, the road transport sector has become one of the major sector that required more secure and sustainable future fuel sources. For example, China already surpassed United States and become the world largest fossil fuel consumers in 2013 and responsible as largest carbon dioxide emission in the world that is 26.4% in 2012 [27]. Besides, in the recent years, the concept of sustainable development has become more prevalent. This situation causes the work to reduce exhaust emissions become more important to prevent green house effect or climate change [2]. For example, the enforcement of Euro 5 emission regulation September 2009 [3, 31] strictly requires reduction of about 30% of nitrogen oxide (NO_x) from gasoline and diesel engine as it is also the major component of greenhouse gases. Besides, International Transportation Forum (ITF) showed that there are 23% carbon dioxide emission is from transportation sector, so, it is necessary to utilise less pollutant emitting fuel and increase fuel conversion efficiency [36]. Therefore,

increased in thermal efficiency, specific power and reduced harmful emissions become the major concern for advancement of technology or power station nowadays [3, 31].

In order to reduce the dependence on the fossil fuel in the transportation sectors, the alternative ways such as electricity, hydrogen and natural gas had been used to improve air quality and reduce carbon dioxide emission [26, 34, 36]. There are several ways to achieve the goals as stated above, such as modern SI engine with three way catalyst that emit low amount of toxic emissions, hybrid systems and high pressure direct fuel injection. Improving fuel economy such as operate SI engine and HCCI with diluted mixture or EGR [4, 39] can cause low combustion temperature, low heat transfer losses and low pumping losses, using fuel with higher hydrogen to carbon ratio and alternative fuel can reduce CO_2 emissions. The utilisation of alternative fuel had been encouraged in South American, for example, Brazil also uses bio-ethanol as an engine fuel extensively to reduce their dependence on crude oil and establish energy security; and this cause relatively constant fuel requirement in Brazil and Argentina in the past decades [3].

Undoubtedly, natural gas is one of the more established alternative fuels that consist of various gas types but methane is its major constituent that occupies more than 90% [5-8]. In 2015, natural gas become the top in energy production and occupy for about 32% of total energy production in US due to advanced in the technology of horizontal drilling and high-volume hydraulic fracturing according to US Energy Information Administration [30] and this lead to natural gas become major alternative fuel in US [50]. Although it is non-renewable, natural gas has large proven reserves compared to crude oil [3, 9-10]. Though the entire process of collecting, purifying and using methane gas emissions from landfill and biomass decomposition, methane can also considered as a renewable source [3, 10]. Besides, natural gas become the interest is mainly due to its safety characteristics that caused by high ignition temperature, non-toxic and will not contaminate groundwater if leakage [50].

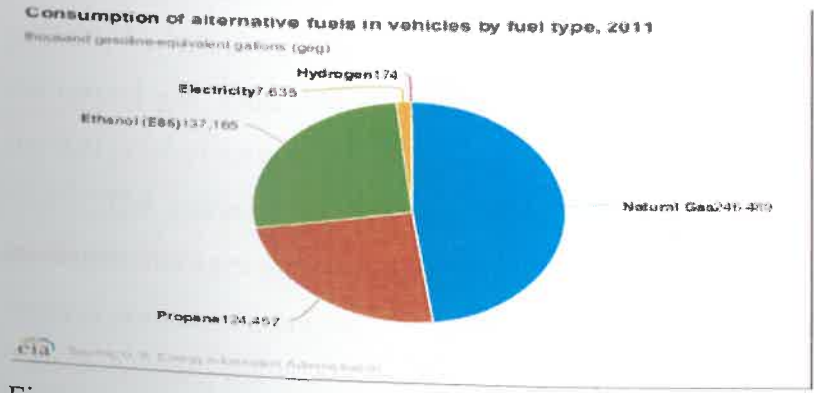

Figure 2: Alternative fuel consumption in US.

When comparing to stoichiometric condition, in ultra lean condition, the wider flammability limit and lower peak temperature causing higher knock-resistance in natural gas [11, 36]. Knock is mainly caused by the autoignition of the end gas before the flame propagation that result in "clanging" sound, increases engine noise and reduce thermal efficiency [42]. Besides, compared to gasoline, natural gas has higher compression ratio, lean burn mixture and high EGR in torque and power [11-12]. This condition cause reduced in emissions of pollutants and [9, 12] an improvement in thermal efficiency [11]. Moreover, natural gas is environmentally clean [12] as it is non-toxic [13] and will not contaminate the ground water. Besides, the combustion efficiency also will increase due to increased compression ratio in SI engine as higher octane number of natural gas. Natural gas is mainly existed in two main forms, such as in compressed form (CNG) and liquid form (LPG) in order to increase its volumetric efficiency [9, 41]. Due to higher hydrogen to carbon ratio [8, 14], the compressed natural gas will has lower CO_2 emissions [5-6]. In additions, natural gas is much cheaper than gasoline and diesel, better engine wear and maintenance characteristics [9].

However, the displacement of air and evaporation loss in liquefied fuel can cause reduced production of power at full throttle and decreased in volumetric efficiency [14]. Mitigation of NO_x emissions occurs as relative low flame speed properties of NG engine when operating at high compression ratio or when engine is supercharged [11]. The cold and hot startability of CNG engine can also be improved due to CNG can prevent wall wetting effect in cylinder [11], its gaseous state [9] and hence help to induce fuel consumption savings. Small percentage of HC emission from oil film adsorption-desorption phenomena also contribute to the reduction of engine out HC emission compared to gasoline engine [15].

Moreover, compared to 1980s, the share of the utilisation of the natural gas is obviously become dominant in the market nowadays. World Energy Outlook (WEO) in the new Policies Scenario had expected that natural gas will have two times increases in about year 2035 when compared to 1980 [25]. In additions, in order to improve the wide usage of the natural gas, some countries such as Japan, Europe and United States decide to decrease the fuel price of natural gas [25].

The composition of about 50% of methane, 50% of CO_2 and trace amount of hydrogen, nitrogen and hydrogen sulphide [3] in biogas make it another alternative fuel in internal combustion engine [3, 46], but it produces less power output than pure natural gas. This is because the contaminant species in the biogas slows the flame speed of methane.

Biogas show reduced emission of NO_x but reduced power and thermal efficiency [3]. Therefore, biogas has to be purified in order to achieve same performance as pure natural gas engine.

In addition, there are several approaches and studies in order to recover power loss when using natural gas in internal combustion engine [10]. These include increasing the compression ratio, modifying combustion chamber shape to enhance the flame propagation, modifying the intake system such as varying timing and valve lift to increase volumetric efficiency [14], accurately mixing the fuel-air at stoichiometric and optimizing the spark timing. However, their uses are quite limits. Research has shown that by direct injection (DI) system for gaseous fuel has significant effect on combustion and lead to better engine performance. By direct injecting the fuel after closure of intake valve, the volumetric efficiency penalty caused by gaseous form of natural gas can be reduced [14]. The performance of port-injected CNG engines can also improve by using DI fuelling as less air was displaced in combustion chamber. Then, the supercharging SI engine operating with natural gas have superior knock resisting properties when compared to traditional liquid fuels [8]. Besides, there are also some research shows that the increasing boost pressure level and vary the injection timing to increase the combustion efficiency in internal combustion engine.

1.2 Problem Statement

Undoubtedly, the human activities especially burning of fossil fuel had generated green house emission and fine particulate matter and transport sector has been considered as one of the main cause of this problem [15]. Besides, the reserves of fossil fuel are finite all over the world and tend to increasing in price due to some world crisis such as war at Iraq and nuclear program in Iran [7]. These situations lead to the ways of finding alternative fuel which emit less pollutant and economically more affordable worldwide [15].

There are some alternative fuels such as hydrogen, electric batteries technologies, CNG, Liquefied Petroleum Gas, Ethanol and Biodiesel for transportation sectors [16]. However, compressed natural gas become one of the main choice of the alternative fuel as it is only cheaper fuel than gasoline and diesel, lower emission of pollutants and it also can be used in conventional gasoline and diesel engine [12, 13, 15, 17]. This shows that CNG not only environmentally friendly, but also economically affordable and also safer than conventional engine which are the main concern now [13].

However, some advancement for NGV vehicles needs to be made in order to remain competitive to conventional petrol and diesel engine. First and foremost, the low density natural gas compared to diesel and gasoline lead to driving range problem in NGV vehicle as low capability for travelling after refuelling [13]. Secondly, it causes loss of cargo space in order to accommodate large natural gas cylinder [13]. Thirdly, NGVs have longer refuelling time than gasoline and diesel engine beside lower amount of natural gas fuel station [13]. Then, lack of rigorous refuelling infrastructure, higher vehicle capital cost and limited engine offerings become major challenges for conversion of CNG in heavy duty vehicles [13]. Last but not least, fuel supply will be disturbed due to accident to natural gas transmission pipeline [13].

In this paper, the operation of the compressed natural gas (CNG) vehicles has been discussed beside the benefit of this kind of alternative fuel. In additions, the main problems and challenges of using CNG has been introduced. The improvement and future advancement of this technology also discussed.