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A STUDY ON DIESEL ENGINE PERFORMANCE USING BIODIESEL FROM WASTE COOKING OIL (WCO)

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ABSTRACT

The energy consumption, especially in the transport sector, has increased tremendously over decades. The extensive usage has led to an increased demand for petroleum, such as gasoline and diesel fuel, hence causing the depletion of fuel stocks. As concerns mount for long-term energy conservation, it becomes necessary to develop alternative fuels that have properties comparable with diesel fuel. Biodiesel from waste cooking oil (WCO) should be highlighted as a potentially economical alternative fuel. Therefore, the objective of this research is to investigate the engine performance as well as exhaust emission of biodiesel blends produced from WCO by using a single cylinder diesel engine (YANMAR TF120). There were three types of biodiesel blends used throughout this study, namely the B5 WCO, which is 5% WCO biodiesel with 95% diesel, the B20 WCO with 20% WCO biodiesel with 80% diesel and the B100 WCO, with 100% WCO biodiesel without any diesel added. The results produced by biodiesel blends were compared with that of the diesel fuel. The parameters that were measured during the engine testing included in-cylinder pressure, power, torque, and exhaust emissions. From the in-cylinder pressure, calculations were made to obtain the rate of heat release. Results showed that among all the fuels tested, B5 WCO showed the closest trend to diesel. All fuels gave the highest peak pressure at 1500 rpm and B100 WCO marked the highest point compared to other fuels tested. Moreover, for power and torque performance, all test fuels presented the same trend, with diesel dominated the highest value for both results. In terms of rate of heat release, all biodiesel blends also showed similar trends as diesel. For gas emissions, biodiesel blends, especially the B100 WCO showed some improvement in the reduction of NO_x, NO, CO, CO_2 and PM. Finally, it can be concluded that the engine performance and exhaust emissions of all biodiesel blends were compatible and can be operated using diesel engine at certain speeds. The results obviously showed that engine performance using B5 WCO was slightly similar to diesel fuel. Therefore, B5 WCO can be used as a diesel substitute.

ABSTRAK

Penggunaan tenaga termasuklah dari sektor pengangkutan telah digunakan secara meluas sejak berdekad yang lalu. Hal ini telah membawa kepada permintaan tinggi terhadap penggunaan petroleum seperti bahan api gasolin dan diesel, lantas menyebabkan berlakunya kekurangan stok bahan api tersebut dalam jangka masa yang panjang. Menyedari hal ini, pembangunan terhadap bahan api alternatif yang mempunyai ciri-ciri yang setara dengan bahan api diesel amatlah diperlukan. Biodiesel yang dihasilkan daripada sisa minyak masak dilihat dapat menjadi salah satu potensi sebagai bahan api alternatif yang lebih menjimatkan. Oleh itu, tujuan kajian ini dijalankan adalah untuk mengkaji prestasi enjin dan pembebasan gas oleh campuran biodiesel daripada sisa minyak masak (WCO) menggunakan enjin diesel satu silinder (jenama YANMAR TF120). Sepanjang kajian ini, terdapat tiga jenis campuran biodiesel digunakan iaitu 5% biodiesel WCO dengan tambahan 95% diesel, dinamakan B5 WCO, 20% biodiesel WCO dengan tambahan 80% diesel, dinamakan B20 WCO dan 100% biodiesel WCO tanpa sebarang tambahan diesel, dinamakan B100 WCO. Keputusan kajian yang dihasilkan oleh kesemua campuran biodiesel telah dibandingkan dengan diesel. Antara parameter yang telah diukur semasa ujikaji enjin dijalankan termasuklah tekanan dalam silinder, kuasa yang dihasilkan, daya kilasan dan pembebasan gas. Melalui bacaan tekanan dalam silinder, kadar pembebasan haba dapat dikira. Hasil kajian menunjukkan bahawa B5 WCO menghasilkan keputusan yang lebih menghampiri diesel berbanding bahan api lain. Semua bahan api juga menghasilkan tekanan puncak tertinggi pada kelajuan enjin 1500 rpm dengan B100 WCO menandakan aras paling tinggi berbanding bahan api lain. Selain itu, bagi prestasi kuasa dan daya kilasan, kesemua bahan bakar uji menunjukkan hasil yang sama, dengan diesel mendominasi nilai tertinggi bagi kedua-dua keputusan. Dari segi kadar pembebasan haba, semua campuran biodiesel menunjukkan hasil yang setara dengan diesel. Bagi pembebasan gas, campuran biodiesel terutamanya B100 WCO menujukkan keputusan yang baik dengan pengurangan NOx, NO, CO, CO_2 dan PM. Di akhir kajian, keputusan menunjukkan bahawa prestasi enjin yang dihasilkan oleh kesemua campuran biodiesel adalah bersesuaian dan boleh digunakan ke atas enjin diesel pada sesetengah kelajuan. Keputusan sangat jelas menunjukkan bahawa prestasi enjin menggunakan B5 WCO hampir sama dengan diesel. Oleh itu, B5 WCO boleh digunakan sebagai pengganti diesel.

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LIST OF SYMBOLS

A	Cylinder area, m^2
L	Stroke length, m
$\dot{m}_f$	Mass flow per unit time, g/hr
N	Angular engine speed, rpm
ρ	Density, kg/m^3
P_b	Brake power, kW
P_f	Friction power, kW
P_i	Indicated power, kW
p	In-cylinder pressure, bar
T	Brake torque, Nm
t	Time, s
V_d	Displaced volume, dm^3

LIST OF ABBREVIATIONS

ASI	After Start of Injection
ASTM	American Society of Testing Materials
ATDC	After Top Dead Center
BDC	Bottom Dead Center
BMEP	Brake Mean Effective Pressure
BSFC	Brake-Specific Fuel Consumption
BTDC	Bottom Dead Center
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DAQ	Data Acquisition
DI	Direct Injection
DPF	Diesel Particulate Filter
ECU	Engine Control Unit
EGR	Exhaust Gas Recirculation
EOC	End of Combustion
EPA	U.S Environmental Protection Agency
EU	European Union
FFA	Free Fatty Acid
HC	Hydrocarbon
IDI	Indirect Injection

IMEP	Indicated Mean Effective Pressure
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
O_2	Oxygen
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
ROHR	Rate of Heat Release
rpm	Radius per Minute
SO_2	Sulfur Dioxide
SOI	Start of Injection
SOC	Start of Combustion
TDC	Top Dead Center
WCO	Waste Cooking Oil

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nowadays, the world energy usage has increased significantly due to the effect of industrialization. This includes the usage of petroleum products, natural gas, electricity as well as coal and coke. The Malaysian Energy Commission has reported that in 2009, Malaysia was one of the leading energy exporters with 13.7% of its export earnings derived from crude oil, liquefied natural gas (LNG) and petroleum products. At the same time, its energy consumption comprised approximately 42.6% from the coal and coke sector, 36.5% from the transportation sector and the balance of 13.8% was from the residential and commercial sector (Energy Commission, Malaysia). Focusing on a transportation sector, it is among the largest consumers of petroleum products, predominantly gasoline and diesel.

Diesel engines are generally preferred compared to gasoline engines due to their undoubted benefits of fuel economy and torque output. In addition, carbon monoxide, carbon dioxide and hydrocarbon produced in diesel engines are much lower compared to gasoline engines (Brijesh and Sreedhara, 2013). At the beginning, diesel engines were known to be noisy, large and slow features. Nowadays, diesel engines hold a commanding position, not only for light and heavy-duty vehicles, but also for other applications such as marine, construction, military as well as agricultural areas. This can be proven by the increased sales of diesel engine cars. For example, in 2006, Europe had a 51% growth of diesel-powered cars compared to gasoline-powered cars (Adam et al., 2010).

However, the extensive usage of diesel engines has led to an increase in demand for diesel fuel, thus causing the decrease of petroleum fuel stocks. Due to concerns of long-term energy sustainability, it has become paramount to develop alternative fuels from natural sources that have properties comparable to petroleum-based fuels. Furthermore, the ordinary diesel fuels are available only in certain regions of the world and the source has reached its maximum production (Obed and Mamat, 2013). In view of this, considerable attention has been given to the production of biodiesel as a diesel substitute.

In addition, biodiesel is a more attractive substitute because it is a non-polluting fuel and produced from renewable biomass sources. The fuel properties of biodiesel are also comparable to diesel fuel since it promotes lubricating properties besides producing low exhaust emissions. In Malaysia for example, the government had already mandate the use of B5 nationwide starting on July 1st, 2014. Nevertheless, the biodiesel feedstock from vegetable oil is quite limited since the price is higher. Waste cooking oil becomes an effective way of reducing biodiesel production since it reduces feedstock cost by 70-95% (Chhetri et al., 2008), while at the same time it complies with international standard ASTM D6751 (Kumaran et al., 2011). The production of biodiesel from WCO basically does not vary much from standard biodiesel production as it also undergoes the transesterification process with alkaline, acidic and enzyme as catalyst (Enweremadu and Mbarawa, 2009).

Many researchers have proved that biodiesel from WCO can improve exhaust emissions by reducing smoke, hydrocarbon, carbon monoxide and sulphur oxide (Lin et al., 2011; Muralidharan and Vasudevan, 2011 and Abu-Jrai et al., 2011). However, the high viscosity of WCO, similar to other biodiesel, is a major problem because high viscosity could cause numerous engine problems such as poor atomization, carbon deposition and inaccurate operation of fuel injectors (Adam et al., 2011 and Mamat et al., 2012). Due to these problems, most researchers have used a small percentage (5%) of WCO to be blended and tested for engine compatibility.

1.2 PROBLEM STATEMENT

With the rapid increase in prices and the uncertainties abound concerning fuel availability nowadays, the revival of diesel engine related research has been gaining momentum. At this point, attention has been given towards the production of biodiesel as an alternative fuel. This is because the characteristics of biodiesel are similar to conventional diesel and it is much oxygenated, which leads to a more complete combustion. Moreover, the feedstock for biodiesel such as by-products of plants and animals as well as edible and non-edible oils are renewable. However, the use of edible oils such as palm, corn, soybean and sunflower for biodiesel has become an environmental issue since it causes unnecessary clearing of forests for plantation. The European Union has criticised biodiesel production using edible oil at the expense of the millions of people facing hunger and starvation around the world (Gimbun et al., 2013).

In developed countries, there are large productions of municipal and industrial wastes. These wastes comprise of activated sludge, food and organic waste (Hosseini Koupaie et al., 2014) as well as cooking oil waste. The management of these waste products pose a significant challenge because of the problems in disposing them. The uncontrolled disposal of these wastes will cause problems such as contamination of water and land resources. Moreover, there are irresponsible parties who choose to dump these wastes into rivers and landfills, thus causing environmental pollution. In the case of waste cooking oil, which can also be used for soap production, the major part of it is still discharged into the environment.

Therefore, researchers have found that waste cooking oil has a good potential to be biodiesel feedstock. It is a decent approach since it is easy to obtain and can reduce the uncontrolled waste disposal problem. At the same time, the use of waste cooking oil can also decrease the cost of biodiesel production since the cost of waste cooking oil is 2 to 3 times cheaper than edible oils (Phan and Phan, 2008). Furthermore, the waste cooking oil used as biodiesel feedstock can significantly reduce the amount of farmland needed for biodiesel producing crops.

1.3 OBJECTIVES

i. To investigate the engine performance of biodiesel blends from waste cooking oil using a single cylinder diesel engine.
ii. To investigate the exhaust emission characteristics produced by biodiesel blends from waste cooking oil.

1.4 SCOPE

The research presented in this thesis deals with the:

i. Literature review on the application of diesel and biodiesel in engine testing.
ii. Determine the chemical properties of testing fuel, which includes diesel, biodiesel blends from waste cooking oil that are B5 WCO, B20 WCO and B100 WCO.
iii. Conducting engine testing at limited engine speeds of 1200 rpm, 1500 rpm, 1800 rpm, 2100 rpm and 2400 rpm with 20Nm constant loads.
iv. Estimating the engine performance characteristics and exhaust emission characteristics fuelled with four different testing fuels.

This thesis is organized as follows. After the introduction, the experimental rig and conditions are described, followed by the experimental results and discussions. Finally, the major findings of the study are presented and conclusions drawn.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The intention of this chapter is to present a review of previous research efforts related to biodiesel fuels and internal combustion engines. The organized review of other applied research studies is provided so that research can be customized appropriately. This review starts with the diesel engine operation and combustion analysis, overview of the biodiesel production, followed by the potential of waste cooking oil and then the brief explanation on exhaust emission from diesel engines. Finally, at the end of the chapter, is the engine testing analysis.

2.2 DIESEL ENGINES

At present, diesel engines play an important role in the economy and in energy efficiency. Diesel engines are widely used in passenger cars, heavy-duty vehicles, locomotives, agricultural and in industrial applications. However, diesel engines face significant challenges with respect to not only fuel economy and performance but also the type and amount of pollutants emitted.

2.2.1 Diesel Engines Operation

Theoretically, diesel engines are commonly known as compression ignition engines and do not differ much from gasoline engines, which are both designed to convert chemical energy from fuel into a series of combustions. In a gasoline engine, fuel is pre-mixed with air in the carburettor, followed by compression by the pistons and ignition from spark plugs. Compared to gasoline engines, the air in the diesel engine is compressed before the fuel is injected. The pressure in the cylinder increases and so does the temperature. Therefore, the air heats-up when the cylinder is compressed, which then ignites the fuel. Figure 2.1 shows the four-stroke engine cylinder cycle that includes intake stroke, compression stroke, power stroke and lastly, exhaust stroke.

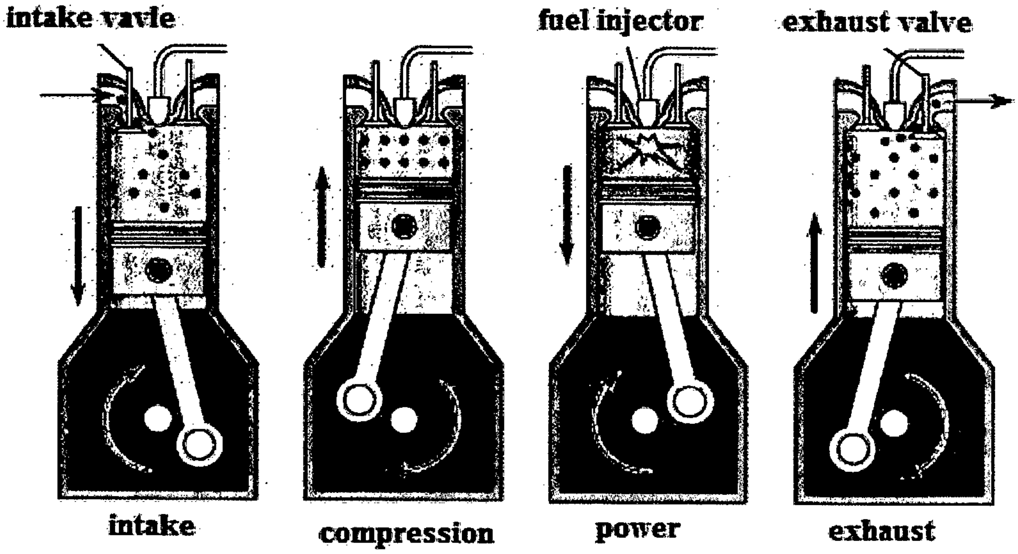

Figure 2.1: Sequence of cycle in four stroke diesel engine

Source: Encyclopedia Britannica (2007)

The stroke of the piston in the intake stroke begins at top-dead centre (TDC). Then, the intake valve opens up, letting in air and moving the piston to the bottom-dead cylinder (BDC), thus increasing the volume of the cylinder. At the compression stroke, both intake and exhaust valves are closed. The piston moves to the top of the cylinder while compressing the air into the cylinder head. During the compression stroke, the compression ratio can be much higher as more power is generated. Conversely, in gasoline engines, the higher compression ratio of air-fuel that exceeds the limit will cause knocking. Next, during the power stroke, as the piston reaches the top, fuel is injected and ignited under high pressure, which then forces the piston down. Lastly, during the exhaust stroke, the piston moves back to the TDC while the exhaust valve is open and pushes out the exhaust created during combustion (Robert, 2005).

2.2.2 Diesel Fuel Injection

The injector on diesel engines is a complex component and has been the subject of a great deal of experimentation. Diesel engines can be categorized into two different types of injection systems called direct injection (DI) system and indirect injection (IDI) system. Figure 2.2 illustrates the comparison between DI and IDI systems in diesel engines.

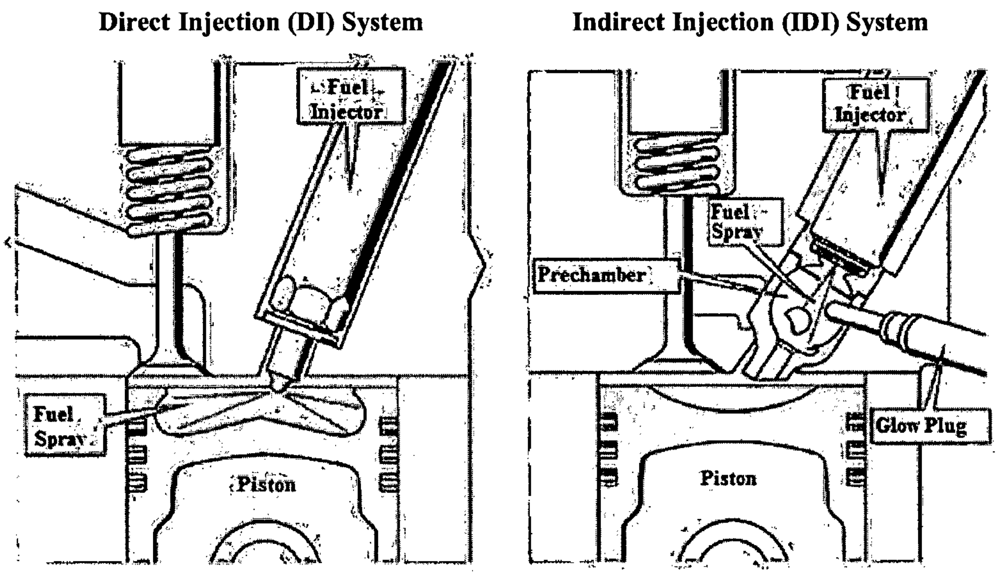

Figure 2.2: Comparison between DI and IDI diesel engine

Source: Romain (2013)

In the DI system, fuel is injected as small droplets and reacts with the hot air inside the cylinder during the compression stroke. The combustion chamber consists of a bowl formed at the top of the piston and the fuel is injected into this volume. Normally, the injector tip has four to eight holes to form multiple spray cones (David and Elsayed, 2011). In this system, the momentum and energy of the injected fuel jets are adequate to achieve sufficient fuel distribution and rate of mixture with the air. A detailed explanation on combustion from DI system will be explained in the combustion subsection.

On the other hand, the IDI system fuel is injected into the pre-chamber, which is located above the piston crown of the engine block and is connected to the main combustion chamber by a nozzle. The pre-chamber promotes rapid mixing of air and fuel and shortens the ignition delay period. The IDI system contains of a glow plug, which functions by heating the combustion chambers and raising the air temperature when the engine is cold so that the engine can be started. The IDI system is usually used in the smallest of engine sizes and the strong charge motion required during fuel injection is generated at the compression stroke (Heywood, 1988). However, this system can cause remarkable efficiency losses or thermal losses.

2.3 DIESEL COMBUSTION ANALYSIS

2.3.1 Diesel Combustion Process

Inside the diesel engine, fuel is injected into a highly compressed gas volume and ignition occurs due to the collision between molecules of air mixture and vaporized fuel. Since thermo chemical reactions during ignition do not occur immediately, some residence time called ignition delay is required as fuel mixes with air during this period. For that reason, the initial phase of the combustion process is premixed and then continues with fuel being burnt in mixed and controlled diffusion flames. As mentioned by Hiroyasu and Arai (1990), the main issue that controls the diesel combustion is the mixture formation that is controlled by the spray characteristics, features of the injection system and also the nature of air swirl and turbulence in the cylinder. This can be explained from the block diagram of diesel combustion, as shown in Figure 2.3.

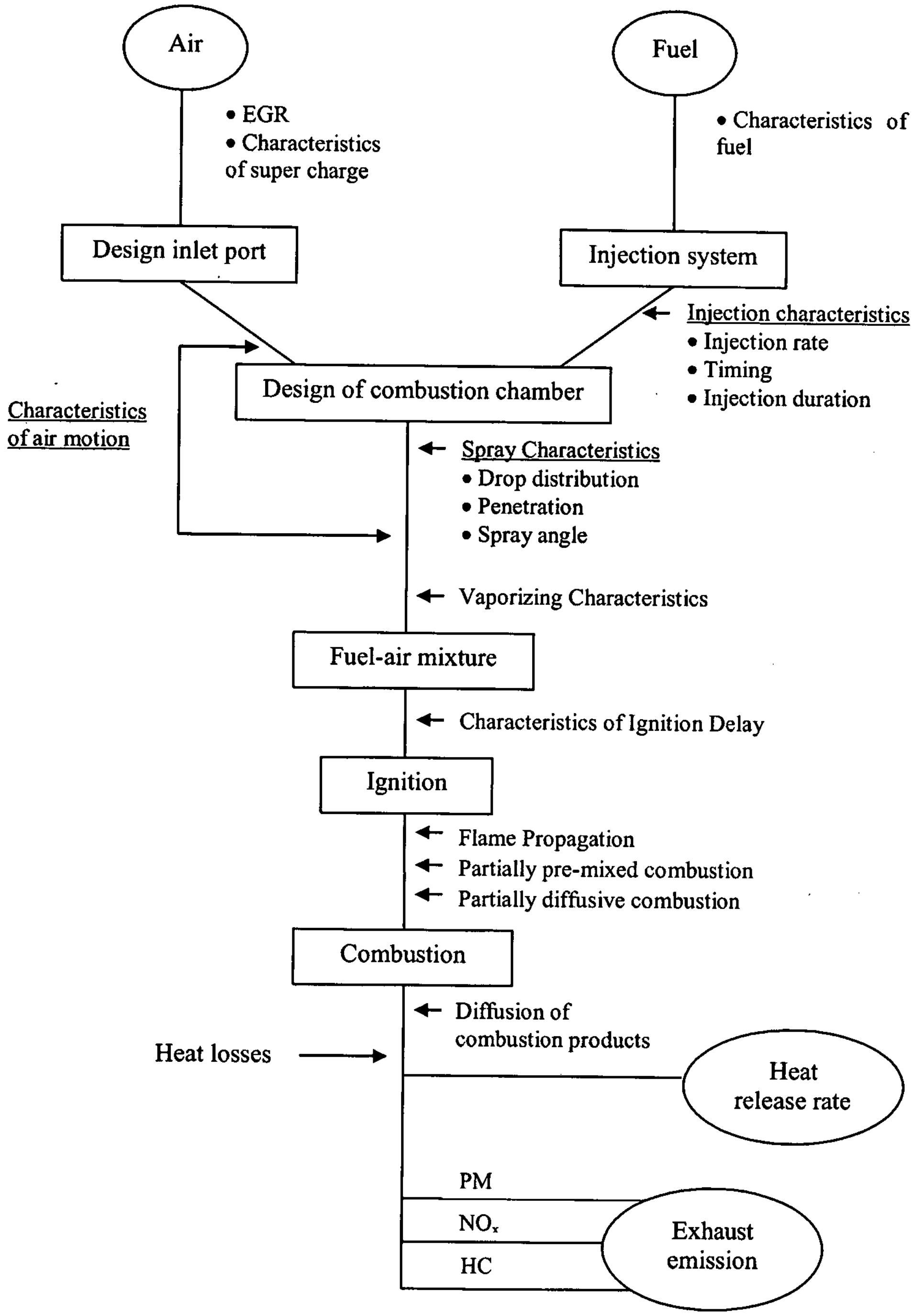

Figure 2.3: Block diagram of diesel combustion

Adapted from: Hiroyasu and Arai (1990)

In general, there are four main phases in the combustion process of diesel engines that have to be taken into account. The four phases are ignition delay period, premixed combustion phase, mixing-controlled combustion phase and late combustion phase as illustrated in Figure 2.4. The ignition delay period is an important parameter as it affects the engine's performance and exhaust emissions, especially the formation of NO_x. During this period, the phase is counted from the start of injection (a - b) where the fuel is injected directly into the cylinder towards the compression stroke. The fuel then atomizes into small droplets and penetrates into the combustion chamber. Fuel vaporizes and mixes in the midst of air with very high pressure and temperature. The rate of heat released is controlled in this phase by the speed of the chemical reactions and the amount of air-fuel mixture formed (Günter et al., 2011).

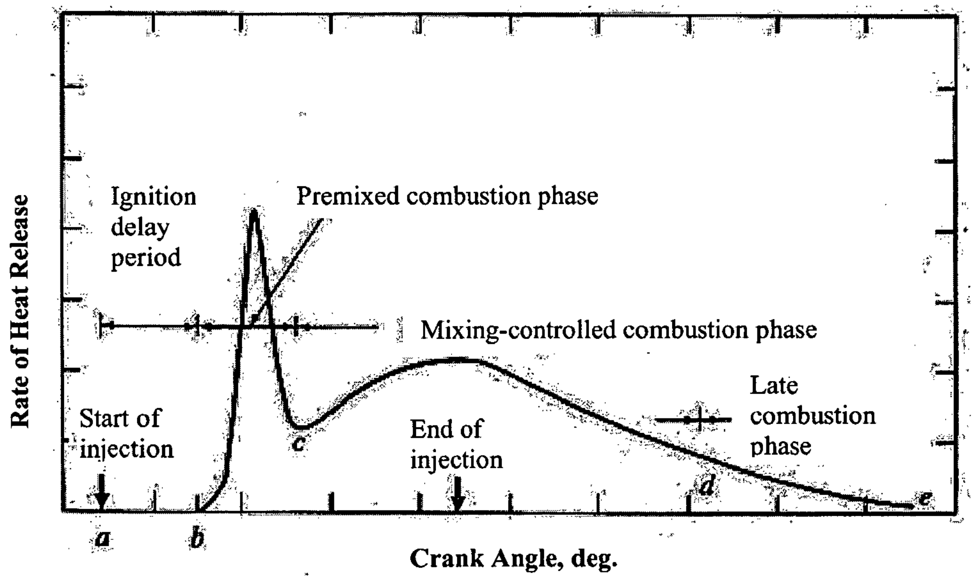

Figure 2.4: Phases of combustion in diesel engines

Source: Heywood (1988)

The premixed combustion phase (b – c) is the initial phase of air-fuel mixture becoming unstable and causes the rapid rise of the in-cylinder pressure. A high rate of rising pressure indicates a sudden application of load to the engine structure, which results in fatigue damage to the parts and also produces knocking (Musculus et al.,