# Performance and Emission Characteristics of Heptane/Toluene Blends at Constant Injection Operation on a CI Engine

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## Abstract

*Hydrocarbons are chemical compounds whose molecules are made of hydrogen and carbon. Heptane is an aliphatic hydrocarbon with good ignition quality and high cetane number, while Toluene is an aromatic hydrocarbon with a very poor ignition quality and very low cetane number. The two different compounds are blended in varying proportion and tested in a single cylinder 2.0L Ford Puma automotive diesel engine to investigate their effect on engine performance and emission. The cylinder pressure, heat release rate, exhaust gas emissions and particulate were measured. The results show that H70T30 blend has the highest specific* $NO_X$ *emission which was due to the high peak temperature and produces slightly more soot than pure heptane (H100T0). H50T50 attained the lowest heat release rate, peak cylinder pressure and temperature. These low values favour the formation of low NOx, high amount of unburned hydrocarbon and high amount of soot particles. Although heptane has a high cetane number, it fails to act as an ignition improver to toluene.*

**Keywords:** *Hydrocarbon, Heptane, Toluene, Blend, Constant Injection, CI Engine*

## 1. Introduction

Hydrocarbons are organic chemical compounds that contain only carbon (C) and hydrogen (H). The hydrocarbon molecule is built upon a skeleton of carbon atoms bonded to each other either in the form of closed rings or in a continuous row-like links in a chain. The carbon atoms chain may be either straight or branched. In all cases, whether it is ring or chain, straight or branched, all the hydrogen atoms are attached to the carbon bonds that have not been used in tying carbon atoms together in the carbon skeleton. The fact that there is apparently no limit to the size and complexity of the carbon skeletons, there is therefore no limit to the number of different hydrocarbons that can exist [1]. Hydrocarbons, on the basis of their sources and properties are classified as either aliphatic or aromatic. Aliphatic is the hydrocarbons derived from the chemical degradation of fats or oils. They are either saturated or unsaturated. The aromatic hydrocarbons are a group of related substances obtained by chemical degradation of certain pleasant-smelling plant extracts [2-5]. They are either alkylated or non-Alkylated. According to Murphy and McCormick (2004), cetane number (CN) of a blend of fuels is a linear combination of the cetane numbers of the components. $[BlendCN = molar\ fraction\ of\ fuel\ A(CN\ of\ fuel\ A) + Molar\ fraction\ of\ fuel\ B(CN\ of\ fuel\ B)]$ [6]. Kwon et al in 2003 determined experimentally the diffusion coefficient for some hydrocarbons and observed that toluene at $24.6^0$C and 1atm with heptane at $24^0$C and 1atm have diffusion coefficient of 0.0859cm$^2$/s and 0.0734cm$^2$/s respectively. These values imply that under the same condition toluene has a greater tendency of diffusing faster by 0.0125cm$^2$/s out of the mixture relatively to heptane [7]. Ciniviz *et al* 2011 carried out an experimental investigation of the effect of methanol blended diesel fuels on engine performance and observed that the brake specific fuel consumption and nitrogen oxide emissions increased while brake thermal efficiency, carbon monoxide and hydrocarbons decreased relative to single diesel fuel operation with increasing amount of methanol in the fuel mixture [8]. Many other researchers reported on the benefit of blending ethanol with diesel fuel [9-19]. In their investigation on the performance and emission characteristics of diesel engine fuelled with ethanol-diesel blend, Lei *et al* (2011) determined experimentally that the equivalent brake-specific fuel consumption (BSFC) of ethanol-diesel blends are better than that of diesel under different atmospheric pressures and that the equivalent BSFC gets great improvement with the rise of atmospheric pressure when the atmospheric pressure is lower than 90 kPa [20]. The investigations on blended hydrocarbons show a positive improvement in engine performance. It is worth noting that most of the experiments conducted were on hydrocarbons with good ignition qualities.

In this paper, heptane (aliphatic hydrocarbons) is blended with toluene (aromatic hydrocarbons) to examine the influence of a better ignition quality fuel (heptane) on a poor ignition quality hydrocarbon (toluene). The basis for the analysis was strictly the percentage concentration of heptane in toluene and its resultant effect as fuel on engine performance and emissions. Heptane is a straight chain aliphatic hydrocarbon of seven carbon atoms and sixteen hydrogen atoms having a molecular formula of $C_7H_{16}$. It is colourless liquid which is soluble in water. Toluene is an aromatic hydrocarbon with one benzene ring and a methyl group. It consists of seven carbon atoms and eight hydrogen atoms. It is clear water- soluble liquid with a typical smell of paint thinner which is quite dangerous for human inhalation and could cause neurological harm.

## 2. Materials and Methods

### 2.1 *Experimental Apparatus*

A single cylinder direct injection common rail research engine with an electronically controlled solenoid injector based on Ricardo Hydra engine was used for the experiment. The engine was a 2.0L Ford Puma$^{TM}$ with an automotive compression ignition engine and a compression ratio of 15:1. The external exhaust has a gas recirculation system with optional cooling in the homogenous charge compression ignition (HCCI). A naturally aspirated air flow was used for the engine. The crank angle was monitored with an optical shaft encoder driven directly by the engine crankshaft at 1800 pulses per revolution. A Kistler$^{TM}$ 6056AU38 piezoelectric pressure transducer and a Kistler$^{TM}$ Type 5011 charge amplifier was used to record the cylinder pressure at a constant interval of 0.2 degree crank angle. The exhaust gas emissions were measured using four different sensors/detectors. The chemi-luminescence detection (CLD) was used to measure the NOx emission, the non-dispersive infrared sensor (NDIR) for CO and $CO_2$ emission, the flame ionization detector (FID) for the unburned hydrocarbon emission and magneto-pneumatic detection (MPD) for the $O_2$ emissions at the exhaust. The Cambustion DMS500$^{TM}$ fast particulate spectrometer can measure particles of the order of 5-2500nm was used to measure the quantity and size of the particulates. The text rig for the experiment is shown in figure1.

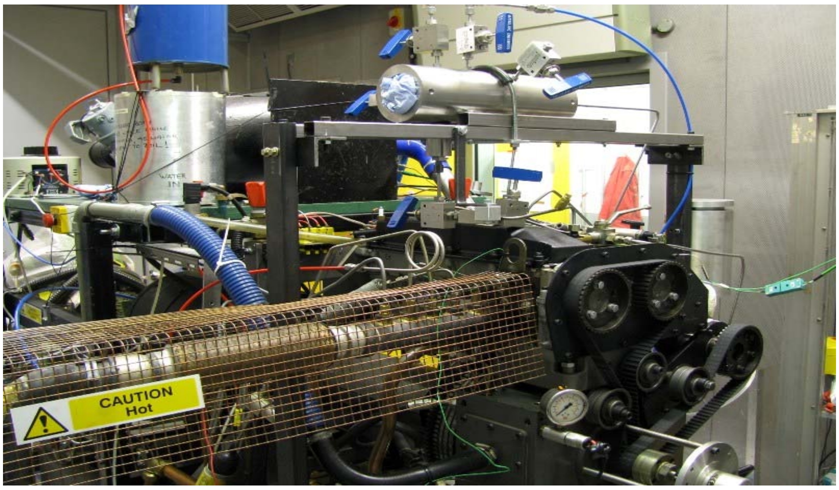


Figure 1. The test rig (The 2.0L Ford Puma Engine)

### 2.2 *Experimental Procedure*

The experiment was conducted at 1200 rpm, with a corresponding to 0.4 MPa IMEP output and an injection pressure of 45 MPa. At the beginning of the experiment, the piston in contact with fuel sample was removed by blowing in a highly pressurized fuel from the compressed air line in the laboratory through one of the port located on the cylinder. In order to avoid contamination, the piston was removed and cleaned. The test samples was fed in through the funnel into the left chamber of the cylinder and bled to displace any amount of air trapped in the cylinder. Also the valve leading from the ultra-low volume cylinder into the injector was opened and all other valves were shut. The fuel system was held at a constant temperature of 353 K ± 2K. The heating system was controlled by an electronically proportional-integral-derivative (PID) installed on the fuel injection system. The engine dynamometer control system was used to motored the engine to the required speed after the pressure connections and valves were secured. The injection timing for the small fuel test sample and the pressure of the common-rail were adjusted electronically via the engine control system [21,22].

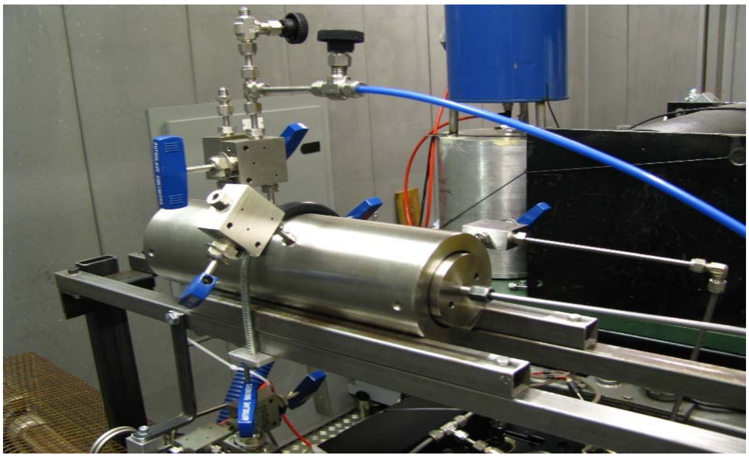
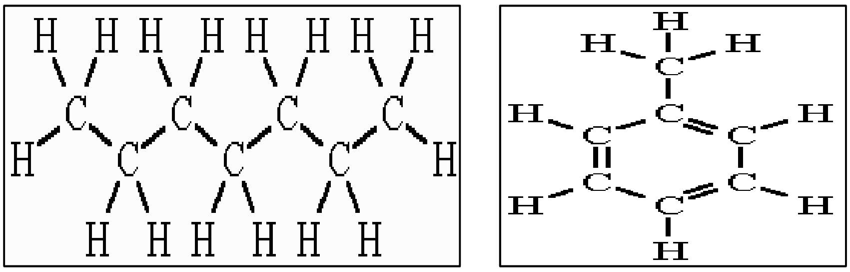


Figure 2. Ultra low volume fuel system

### 2.3 *The Test Fuels Properties*

The test fuel was a mixture of a straight chain aliphatic (heptane) and aromatic (toluene) hydrocarbon in varying proportion. The varying proportion of toluene and heptane was decided in molar ratios while the preparation and mixing of the two hydrocarbons was done gravimetrically. The gravimetric analysis made it possible to determine the mass equivalent of the molar proportion and mix accordingly as shown in table 2. Figure 3 shows the molecular structures of heptane and toluene while table 1 shows the details of the properties of the two hydrocarbons.



(a) (b)

Figure 3. Molecular structure of Heptane (a) and Toluene (b) [23,24]

Table 1. Properties of Test Fuel

| Properties | Heptane | Toluene |
|---|---|---|
| Lower heating value (KJ/Kg) | 44.566 | 40.589 |
| Density (g/mL) | 0.684 | 0.865 |
| Cetane number | 52.5,53,56 | -5,9,18.3 |
| Normal boiling point ($^{0}$C) | 98 | 110-111 |
| Melting point ($^{0}$C) | -91 | -93 |
| Carbon composition by weight (%) | 83.89 | 91.24 |
| Hydrogen composition by weight (%) | 16.12 | 8.76 |
| Molecular weight (g/mol) | 100.20 | 92.14 |
| Flash point ($^{0}$C) | -4 | 4 |
| Autoignition temperature ($^{0}$C) | 215 | 536 |
| Purity level (%) | 99 | 99.8 |