Fuel 217 (2018) 131–150

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Development of a particle swarm optimisation model for estimating the homogeneity of a mixture inside a newly designed CNG-H_2-AIR mixer for a dual fuel engine: An experimental and theoretic study

Hussein A. Mahmood[a,b,*], Nor Mariah. Adam[a], B.B. Sahari[a], S.U. Masuri[a]

[a] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia
[b] The Engineering Affairs Department, Presidency of the University of Baghdad, Baghdad, Iraq

ARTICLE INFO

Keywords:
Homogeneity of the mixture
AIR-CNG-hydrogen mixer
Internal combustion engines
Computational fluid dynamics
Particle swarm optimisation

ABSTRACT

Many research works have intended to enhance fuel economy and decrease emissions during conversion from a diesel engine to a dual fuel engine. However, the majority of these works do not take into account enhancement of homogeneity of the mixture inside the engine and precise control of the air fuel ratio. This deficiency can cause higher emissions, greater brake-specific fuel consumption, and likely knocking. Conversely, there is limited research pertaining to empirical equations for projecting the mixture's homogeneity. In this study, a new air–fuel mixer was devised, produced and tested. For the air-gaseous fuel mixer, the proposed design was meant to be appropriate for mixing air with hydrogen and CNG. It was also designed in such a way that it would result into extremely homogeneous mixing for the gaseous fuel as it mixes with air and exhibits high uniformity index (UI). Lastly, it is also meant to promote easy connection with an electronic control unit so that the air-gaseous fuel ratio could be accurately controlled for varying engine speeds. To optimise the homogeneity within the new mixer, fifteen varying mixer models having 116 cases were made in order to study how the location, diameter, and number of holes within the mixer affect the mixture's homogeneity and distribution under ACNGR = 34.15 and AHR = 74.76. Afterwards, the distribution, flow behaviour, and homogeneity of the mixture within the new mixer models were checked using computational fluid dynamics analysis software. Based on the simulation results, it was discovered that the best uniformity index (UI) values were achieved for models 7/ case 48. Based on the simulation results, a fairly simple method was then developed to estimate the mixture's homogeneity (UI) from the new models of the mixer. The basis of the proposal model (empirical equation) is from the best values determined for the unknown constant F so that the equation for UI estimation could be formulated. The particle swarm optimisation (PSO) algorithm was used to solve an optimisation problem and achieve this outcome. The outcomes indicated that the built model could precisely project the UI values.

1. Introduction

The utilisation of diesel engines as a dependable and fuel-efficient power source for transporting goods and people and for other essential social needs, such as limited-capacity energy generation, has gradually increased in the past century. However, diesel engines are key contributors of nitric oxides (NOx) emissions and particulate matter (PM). Different ways of decreasing PM and NOx emissions have been employed, such as diesel particulate filter and selective catalytic reduction, respectively. However, these two methods are considerable reliant on the usage of costly precious metals as catalysts. Furthermore, it is difficult to retrofit the devices in vehicles that are already in use. Thus, different compromising approaches have been recommended, such as dual-fuel combustion [1–3].

Use of alternatives such as gaseous fuels in diesel engines as part of the dual-fuel mode (where gaseous fuels are the main fuel and diesel is the pilot fuel) can help in decreasing emissions and enhancing fuel economy. For dual-fuel engines, the induction of the gaseous fuel (alternative fuel) is performed with the intake before it is compressed in a manner that is similar to that of a conventional diesel engine [4]. The air and gaseous fuel (hydrogen and CNG) mixture does not automatically ignite due to its high auto ignition temperature. Thus, to ignite the gaseous mixture, a small quantity of liquid diesel fuel gets injected close to the end of the compression stroke. This causes the diesel fuel to automatically ignite and make ignition sources for the air–-gaseous fuel mixture that surrounds it. The conventional diesel

* Corresponding author at: Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia.
E-mail addresses: hussanadul@yahoo.com, hussanadul@gmail.com (H.A. Mahmood).

https://doi.org/10.1016/j.fuel.2017.12.066
Received 4 October 2017; Received in revised form 24 November 2017; Accepted 17 December 2017
0016-2361/

Nomenclature

A	The cross area where UI is assessed (mm^2)
ACNGR	Air-compressed natural gas ratio
AF mixer	Air–fuel ratio within the mixer
AFR	Air–fuel ratio
ag	The angle of the holes
AHR	Air–hydrogen ratio
Ai	The local area (mm^2)
BSFC	Brake-specific fuel consumption
CNG	Compressed natural gas
CoV	The coefficient of variation
c_1; c_2	Cognitive and social acceleration parameters, respectively; "acceleration coefficients"
D	Dimension of particles
Dh	Diameter of holes (mm)
F_1,F_2,F_3,F_4,F_5,F_6,F_7,F_8,F_9andF_{10}	Unknown coefficients.
gbest	The best global position for all the particles
H	Hydrogen
LHV_D	Lower heating values of diesel (MJ/kg)
$LHV_{gaseousfuel}$	Lower heating values of gaseous fuels (MJ/kg)
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
$\dot{m}_D$	Mass flow rates of diesel (kg/h)
$\dot{m}_{gaseousfuel}$	Mass flow rates of gaseous fuels (kg/h)
N	Number of particles
Nh	Number of holes
NS	The number of data samples used in this study
pbest	The best location for every particle that is studied
PSO	Particle swarm optimization
RMSE	Root Mean Square Error
r_1 and r_2	The random numbers that are unvaryingly distributed from 0 to 1
R^2	Coefficient of determination
T	Maximum number of iterations
t	Number of iterations (generations)
UI	Uniformity index
V_i	The velocity of the particles studied,
w	Inertia weight
Wi	The local mass fraction
w_{mean}	The mean mass fraction
XL_1,XL_2,XL_3 and XL_4	The distances between the mixer centre and the holes (mm)
X_i	The location of the particles studied
x^L	Lower bound of the NS design variables
x^U	Upper bound of the NS design variables
y	Actual value
Ý	Predicted value

injection equipment is used to inject the pilot liquid fuel [5–13].

Compressed natural gas (CNG) and hydrogen (H) are appropriate substitutes to pure fossil fuels, and they have long been the focus of many studies in the area of diesel dual-fuel technology [14]. NG is plentiful, reasonably priced, and eco-friendly. The key constituent of NG is methane (CH4), which is a sustainable and renewable energy source and can be acquired from other sources like biomass [15,16]. The key benefits of dual-fuel NG–diesel engines comprise lower PM and NOx emissions in comparison to diesel engines. However, the emission levels of CO and HC (hydro-carbonic) in compressed NG (CNG)–diesel engines are quite higher compared to those in regular diesel engines [17–19].

Hydrogen is another potentially important alternative fuel for automotive [20,21]. It is a promising renewable fuel as it is naturally available and can be generated from different resources, like biomass. Hydrogen can also be produced through electrolysis of water with solar-generated electricity in terms of CO_2 emission reduction. Certainly, hydrogen is a substitute for hydrocarbon fuels like diesel and gasoline, with many possible applications. Moreover, it is safe to produce and eco-friendly. Combustion of hydrogen generates no greenhouse gases and chemicals that deplete the ozone layer, besides little or no acid rain constituents and contamination. If hydrogen is added to a compressed ignition engine as part of the dual-fuel mode, it can help decrease CO, HC and smoke discharges (PM) [22–24].

Alternative fuels such as hydrogen and natural gas can be infused into a diesel engine cylinder by means of a gas mixer/carburettor injection, direct injection or multi-point injection [25–27]. For converting a diesel engine so that it functions under the dual fuel mode sans any extra alterations to the engine, an air fuel mixer is a simpler and inexpensive method in comparison to MPI as well as direct injection. Combustion efficiency rises with the rise in the homogeneous mixing of fuel and air in the engine. Several research works have shown that the mixing of gaseous fuels with air is more vital compared to liquid fuels because of the lesser penetration of fuel and lower density. Gaseous fuels can mix with air without difficulty because of their high diffusivity; however, they might not have adequate time for mixing when the engine speeds are high, thus causing substandard mixer formation. The injectors in direct injection as well as MPI are set up close to the engine cylinder. As a result, fluids do not mix evenly because of the limited time for mixing. The air-fuel mixer facilitates extra time for mixing as the distance is appropriate for homogeneously mixing fuel and air in the engine [27,28].

The AFR and mixture homogeneity are the most crucial aspects impacting the engine output, combustion efficiency, and emission decline in gases [27]. One issue with gaseous mixers is their inability to formulate a homogeneous mixture of fuel and air at a particular air–fuel ratio (AFR) before entering the engine and in regulating the air–fuel ratio (AFR) for different engine speeds. This causes greater brake-specific fuel consumption (BSFC) and exhaust discharges [29,30]. Many studies have indicated that HC emissions are triggered by the inadequate combustion within the engine. Most PMs are generated by partial combustions of HCs in the lube oil and fuel coupled with their combustion with heterogeneous air–fuel mixtures. The volume of NO and CO emissions can be decreased in internal combustion engines by improving the combustion procedure. Hence, improving the combustion procedure and decreasing emissions is directly associated with improving the mixture's homogeneity (air–fuel) within the engine [27]. Furthermore, the AFR of the produced mix should be within the range ascertained by the engine's operating state. An AFR that is not in the range leads to an uneven gas engine functioning and the generation of exhaust gas discharges, which are not in line with the environmental criterion [31].

Furthermore, several research works have stated that the homogeneity of mixture (air and fuel) and AFR inside the mixer are impacted by many aspects, such as the hole diameter, angle and location; the number of holes; size and shape of the mixer; and control system [32–35]. There is limited work on empirical equations that can assess the homogeneity of the mixture on the basis of different parameters such as the number of holes, location of holes, diameter of holes, and angle of the holes, which control the design of the gaseous mixer (CNG and hydrogen). Hence, using an optimization technique is considerably efficient to address linear and non-linear problems.

The process of optimisation is spontaneous and pervasive; it is an essential segment of our daily life. Optimisation, primarily, is defined as the ability to select the best alternative from a given set of options. Optimisation problems are present in all fields of science and technology, such as in agricultural sciences, engineering design, economics, physical sciences, manufacturing systems, and pattern recognition