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Review on production, characterisation and utilisation of solid fuels in diesel engines

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ABSTRACT

Energy and environment play important role in sustainable development of the world. A continuous research is going on to harness energy from various sources of energy and also reduce the greenhouse gases (GHG) that cause global warning. Despite there is a more focus on utilisation of liquid and gaseous fuels for internal combustion (IC) engine applications, there has also been a continuous interest on utilisation of solid fuels for the same. This paper presents the review of research works pertaining to characterisation and utilisation of different solid fuels such as coal, charcoal, carbon nanotube blended with biofuel, nanoadditive blended fuels, carbon black based fuels and biomass based solid fuels used in compression ignition (CI) engine applications.

Contents

1. Introduction

Before introduction of liquid and gaseous fuels widely, coal was used as a main source of energy for the production of electricity and/or heat, and was also used for industrial purposes, such as refining metals apart from biomass for several years, because of its abundant availability. Due to the decomposition of dead plant matter over several years under the earth, it forms as peat and then is converted into lignite, sub-bituminous coal, bituminous coal, and lastly anthracite in stages. Since industrial revolution began in the 18th Century, the use of coal was gradually reduced to a considerable percentage of consumption as a result of increase in air pollution. Later liquid and gaseous fuels from crude oil have been used in most of the heat and power applications and now

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Nomenclature

CWS	coal water slurry
CWF	coal water fuel
CT	coal tar
CBWD	carbon black water diesel slurry
CNT	carbon nanotube
SMD	sauter mean diameter
IC	internal combustion
CI	compression ignition
°CA	degree crank angle
BTDC	before top dead centre
bsfc	brake specific fuel consumption

still in use. However, towards the end of the 1950s, the Soviet Union started the development of new ways to utilise coal sludge for power generation. Two major problems of sludge transportation and sludge combustion were solved during the series of experiments and research. Pulverised coal was mixed with water to produce coal–water slurry (CWS). It was suggested that CWS could be used in place of oil and gas in heat and power applications. During the last 30 years the US Department of Energy (DOE) has been researching the use of coal/water fuels in boilers, gas turbines and diesel engines. It was reported that when coal based slurry or fuel was used as a fuel in a low speed diesel engine, it provided a thermal efficiency as equal as the efficiency obtained in a combined cycle gas turbines that run on natural gas as a primary fuel. It has been suggested that modified diesel engines run electric power plants fuelled with coal water fuel (CWF) would be economically competitive with natural gas fired electric plants in the range of 10 MWe to100 MWe. The huge crude oil consumption and decrease in the availability of oil reserves, increase fuel price and increase in the air pollution led the researchers to put efforts to reduce the fuel consumption and reduce the emissions from combustion devices and also to find better alternative sources. Some of them are trying to use coal effectively in various combustion devices as it is largely available than the crude oil reserves. This paper presents a collection of review of research works pertaining to the fuel preparation, characterisation and utilisation of solid fuels (i.e) coal water fuel or slurry, char coal water slurry, and some of the fuels other than coal/charcoal fuels which were investigated for their use as alternative fuels for IC engines particularly compression ignition (CI) engines.

2. Scope and current trend of solid fuels

Solid fuels have been used by humanity for many years to create fire. Solid fuel refers to various types of organic material that is originated from variety of sources such as decomposed hydrocarbons in solid from, industrial, municipal and agriculture sectors and used as a fuel to produce energy and provide heat, usually released through combustion. Coal one of the solid fuels was the fuel source which enabled the industrial revolution, from being fired furnaces, to run steam engines and is a major component of electricity generation today. According to the International Energy Agency (IEA) 41% of the world's electricity is generated by firing coal. In addition to continuous improvement in clean coal technology, possibilities of producing solid alternative fuels from different organic wastes are explored.

Generally, energy from the solid organic materials can be recovered from direct combustion. The direct combustion of fuel pellets is harmful to the environment. However, when solid fuels are processed or recycled to replace the existing fossil fuels, GHG emissions can be reduced.

Apart from direct combustion, energy can be recovered from organic materials by pyrolysis and gasification, anaerobic digestion and fermentation. Pyrolysis is a thermochemical decomposition of organic material with a small amount or absence of oxygen, to convert solid materials directly into a gas. Gasification emits some ash particles during the process. Through the anaerobic digestion process organic materials in absence of oxygen converted into the gases and liquid fuel. The process is used for industrial or domestic purposes to manage waste and/or to produce fuels. Similarly, in fermentation process solid biomass materials converted into the useful liquid form. Some researchers have made attempts to directly use solid fuels in the form of slurry or emulsion in IC engines.

3. Preparation of slurries from solid fuels and characterisation

Preparation of fuel and its characterisation is very important, because combustion occurs in a combustion device based on the fuel, its properties and atomisation when it is used as a fuel. In this section, the preparation and characterisation of fuels obtained from coal, charcoal, carbon nanotube and other biomass raw materials are reviewed and discussed.

3.1. Coal based slurries

Chen et al. [1]. prepared different slurries from biomass char, a low rank coal char and sub-bituminous coals. The slurries were prepared by mixing them with water after milling and a range of additives, polyacrylic acid, charged copolymers D101 and D102, and sucrose were included. The effect of the solid type, particle size distribution, and the additives on the preparation of highly loaded slurries with the desired rheological behaviour was systematically examined, in terms of the apparent viscosity and yield stress. It was reported that, for low rank coals such as lignite, thermal and densification treatment would be essential to achieve the solid loading of slurry fuel.

Dincer et al. [2]. investigated the effects of different chemicals that were used as dispersing agents and stabilisers on the stability and viscosity of coal water slurries. In the investigation, they used Anionic type of chemicals-polyisoprene sulphonic acid soda (Dynaflow-K), a derivative of carboxylic acid (AC 1320) and naphthalene sulfonate formaldehyde condensate (NSF) as dispersing agents. In the same study, they used the sodium salt of carboxymethyl cellulose (CMC-Na) as a stabiliser. They used bituminous coal (thermal code no. 434) of Turkish origin, with a medium volatile matter as a sample. They reported that the polymeric anionic dispersing agent such as Dynaflow, showed a greater effect on the viscosity and stability of coal water slurry.

Tian-ye et al.[3], reported that when the proportion of coal was more than 30% in the coal water slurry (CWS), all its properties had improved, and it met the requirements for use as a fuel. Coalification, porosity, surface oxygenic functional groups, zeta potential and grindability showed a great effect on the performance of blended coal CWS. They also reported that this led to some differences in the performance between the slurry made from a single coal and slurry made from blended coal. They affirmed that, coal blending might effectively reduce the concentration of the oxygen functional groups and enhance the absorbing