Experimental Thermal and Fluid Science 70 (2016) 316–324

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Synthesis and utilization of catalytically cracked cashew nut shell liquid in a diesel engine

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ARTICLE INFO

Article history:
Received 12 April 2015
Received in revised form 21 September 2015
Accepted 21 September 2015
Available online 30 September 2015

Keywords:
CNSL (cashew nut shell liquid)
Catalytic cracking
Fuel injection pressure
CC-CNSL
Combustion
Emission

ABSTRACT

In this study, CNSL (cashew nut shell liquid), an economically viable feedstock among the other contemporary resources, has been considered as an appropriate source of alternate fuel. Herein, CNSL was extracted from cashew nut outer shell, a waste product, through a unique approach of steam treatment process followed by mechanical crushing technique. In contrast to the past studies that have attempted to use unprocessed CNSL directly as substitute for diesel, this study has resorted to use processed CNSL by cracking it using zeolite catalyst. Thus, both the extraction of CNSL from cashew nut outer shell and processing of it through catalytic cracking process to help synthesize CC-CNSL (catalytically cracked CNSL) are different, which underscores the significance of the current work. In wake of adopting such distinct methodologies with fuel characterization, the properties of CC-CNSL such as viscosity and calorific value were figured out to be improved. Subsequently, CC-CNSL20 (20% CC-CNSL and 80% diesel) was tested at different fuel injection pressure such as 200 bar, 235 bar, 270 bar and 300 bar so as to optimize its use in a single cylinder diesel engine. From the engine experimental study, CC-CNSL20 was found to evince better engine performance than diesel and the composite emissions of CO (carbon monoxide), HC (hydrocarbon), NO_X (oxides of nitrogen) and smoke, computed based on ISO 8178 D2 standard test cycle, were found to be better than diesel and incompliance with the legislative norms for genset.

1. Introduction

Over the years, though the emissions of deleterious toxic gases are abated when utilizing biodiesel, the cost of it is reported to be higher than conventional petroleum based fuels [1]. Basically, the exorbitant price of vegetable oil from which biodiesel is produced contributes to around 80% of total biodiesel production cost, increasing the total cost of biodiesel [2]. Therefore, despite the advantage of renewability and biodegradability, commercialization of biodiesel seems far-fetched in certain countries. In such a scenario, researchers have redefined the selection of feedstock for biodiesel production and have resolved to choose inedible oils, as they are cheaper when compared to edible vegetable oils and would not have a negative influence on food chain [3,4]. By the time the production and characterization of biodiesel from inedible oils were prospering, an eminent threat to the availability of land to grow this inedible biomass propped up [5,6]. Therefore, besides exploring an inedible feedstock, focus on utilizing waste products, which are economically viable, as suitable raw material for producing biodiesel has been targeted recently [7]. In all likelihood, biodiesel produced from these inedible as well as waste products would replace a fraction of petroleum based fuels in the near future and generate green energy to help prevent adverse effect on atmosphere.

From the research studies, which tend to report the use of waste products as alternate fuel in a diesel engine, it is construed that waste vegetable and frying oil, animal fats, plastic oil, engine lubricating oil, kapok oil and CNSL (cashew nut shell liquid) were being used as probable substitutes for diesel in a diesel engine [8–13]. Distinctly, CNSL, a waste product from cashew industry, has caught the attention of many researchers because of its much cheaper price [14,15]. Notably, CNSL may be extracted from cashew nut outer shells by different processes viz roasting, hot bath, cold extraction and solvent extraction techniques [16]. In hot bath process, CNSL is extracted by immersing cashew nut outer shells in a hot bath at 185–190 °C and the produced CNSL is characteristically different from the one produced by cold extraction process [17]. On the other hand, general roasting of cashew nut outer shell in a controlled environment produces a dark brown liquid, which is a sort

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http://dx.doi.org/10.1016/j.expthermflusci.2015.09.026
0894-1777/

of different grade of CNSL [18]. Technically, during the extraction of CNSL, the anacordic acid present in it is converted into cardanol, through decarboxylation process. In addition to cardanol, CNSL obtained by these extraction techniques also consists of cardol and other polymeric material [19]. Some studies have reported distillation or pyrolysis of CNSL as additional processing strategies to increase the yield of cardanol and remove other polymeric and contaminated material [20,21]. Of course, the phenolic material, cardanol, forms the major constituent of CNSL and materializes as pertinent fuel candidate for diesel engine application.

It is worthwhile to recount that CNSL processed by different methods does manifest different physical and thermal properties, considering each method are unique in their own right. In this regard, Velmurugan and Loganathan [19] subjected CNSL to pyrolysis process and reported that the calorific value of it is improved. Despite this, operation of CNSL in a diesel engine has been reported to evince poor engine performance and emission on account of its higher viscosity. To avert this limitation, attempts on diluting CNSL with less viscous fuels such as ethanol and camphor oil were up taken [15,22]. As an outcome of dilution, the viscosity was reduced to some extent and the engine characteristics were reported to be improved and brought closer to diesel. In a measure to further reduce the viscosity, Vedharaj et al. [13] subjected CNSL to double stage trans-esterification process, wherein an acid and alkali catalyst were used along with methanol. In event of this, viscosity was reduced to certain extent and the operation of trans-esterified CNSL – diesel blend showed improved performance and emission in a coated diesel engine. Though dilution and trans-esterification appears to have reduced the viscosity, calorific value was found to be dropped. Thus, the above reported processing methods of CNSL has either improved the calorific value or viscosity of the fuel and, therefore, it is imperative to develop an appropriate processing method for CNSL so as to improve its fuel properties on the whole.

Given much improved processing methods of CNSL were not considered before, in this study, we resort to chemically treat CNSL and make its properties more appropriate for diesel engine application. In our previous work, we conventionally trans-esterified CNSL in two stages to produce CNSL biodiesel and experimentally investigated the synthesized biodiesel in a diesel engine [13]. Subsequently, in the current study, as an improvement in fuel characterization, CNSL was cracked using zeolite catalyst to help synthesize CC-CNSL (catalytically cracked CNSL). Catalytic cracking of CNSL has never been done before and therefore, it would be interesting to consider it, given the process itself improves the fuel properties than the traditional trans-esterification process. Distinctly, we have employed a unique strategy of steam treatment process followed by mechanical crushing technique to extract CNSL from cashew nut outer shells. As such, this work is unique in respect of both the extraction of CNSL from cashew nut outer shells and processing of it through catalytic cracking process. In the quantitative analysis, the synthesized CC-CNSL was estimated for its properties as per ASTM standard method and compared with CNSL biodiesel as well as diesel. Subsequently, 20% CC-CNSL was blended with diesel and operated in a diesel engine at various fuel injection pressures of 200 bar, 235 bar, 270 bar and 300 bar so as to optimize its use in a diesel engine. Herein, as a different attempt, the engine was operated in five mode ISO 8178 D2 test cycle and the estimated composite emissions were compared with legislative emission norms.

2. Materials and methods

2.1. Extraction of CNSL from cashew nut outer shells

The cashew nut outer shell is about 0.3 cm thick, having a soft feathery outer skin and a thin hard inner skin. Between these skins is the honeycomb structure containing the phenolic material known as CNSL. In this study, a unique approach to synthesize CNSL from cashew nut outer shells has been employed, as shown in Fig. 1. Large quantities of cashew shells are placed in a huge steel container and from the bottom; steam is fed into the container to initiate steam treatment process. The impingement of hot steam is deemed to soak the shells in a hot environment for some time and help recover some amount of oil. Subsequently, the hot shells are crushed in a mechanical expeller and by which, maximum quantity of CNSL has been extracted. Notably, this process was selected over other contemporary techniques like roasting and hot bath process, as it renders the benefit of bulk extraction of oil in a single trail, which is likely to reduce the production cost. Previously, either thermal or mechanical extraction methods were embraced to extract CNSL from cashew nut outer shells: however, herein, both

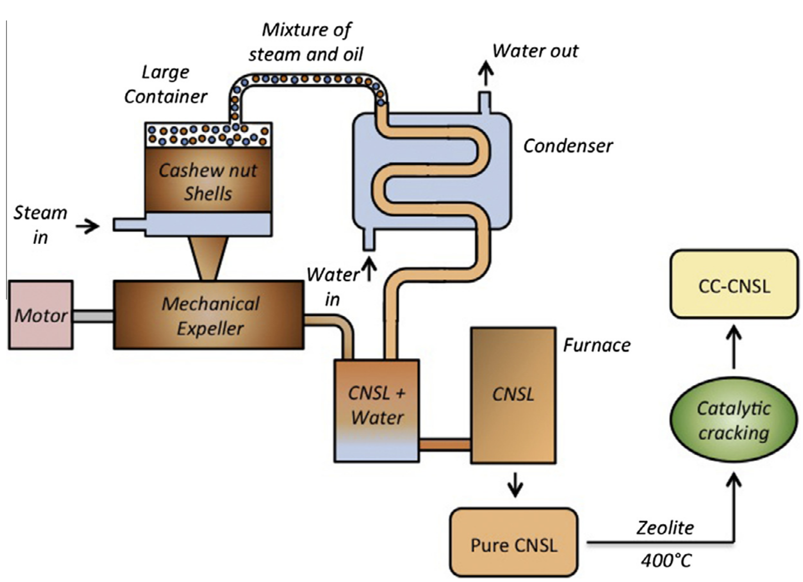

Fig. 1. Extraction and processing of CNSL.