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Economy of a utility boiler power plant fueled with vegetable oil, biodiesel, petrodiesel and their prevalent blends

Bahamin Bazooyar[a,b], *Ahmad Shariati*[a,*,1], *Seyed Hassan Hashemabadi*[b,*,2]

[a] *Ahvaz Faculty of Petroleum Engineering, Petroleum University of Technology (PUT), Ahvaz, P.O. Box 6198144471, Iran*
[b] *School of Chemical Engineering, Iran University of Science and Technology (IUST), 16846-13114 Tehran, Iran*

ABSTRACT

The economy of a boiler (operating costs) which was fueled with petrodiesel and its prevalent alternatives (soybean oil (SBO), soybean oil methyl ester (SOME), and two blends 5% (B5) and 20% (B20) by volume of SOME in petrodiesel) is studied by a cost-based function over the years 2000 to 2015. The price of fuels, regulated (CO, CO_2, NO_X, and SO_2), non-regulated emissions (PM) and their contribution to the boiler total expenditure are studied at the optimum equivalence ratios of the combustion. Among all kinds of fuels, B5 and B20 can make good economical substitutes for petrodiesel in the selected boiler since the use of these fuels in the boiler leads to annual cost savings of about 1155 and 752 US$ even when these fuels are considered non-renewable, i.e., the price of CO_2 is considered in boiler external costs. The operation of the boiler with SOME is not economical even when it is considered renewable. The use of SBO fuel leads to annual saving of 2712 US$ in the boiler when it is considered renewable and when it is not considered renewable the operation of the boiler is not economical.

Keywords: Economy; External cost; Internal cost; Cost saving; Biodiesel; Vegetable oil

1. Introduction

The operation of boilers with renewable fuels (vegetable oils, biodiesels, and dimethyl ether) has been studied by many researchers (Barnes et al., 2010; Daho et al., 2009; González-González et al., 2014; Jiru et al., 2010; Lee et al., 2004; Macor and Pavanello, 2009; Ng and Gan, 2010; Pereira et al., 2014; San José et al., 2015; Tashtoush et al., 2003). As the yearly prices of such alternatives in the global/domestic markets are quite competitive with those for petrodiesel, most of them assumed that their usage is economically feasible and therefore, neglected the boiler operating costs. Although, under certain circumstances, the utilization of triglyceride based fuels (vegetable oils and biodiesels) in boilers produces satisfactory engineering results (Bazooyar et al., 2011; Daho et al., 2014), this usage should be performed without any economical uncertainties. Thus, serious consideration must be taken to ensure that the operation of the boiler with the alternative fuels is reliable and lucrative. Due to high similarity of methyl esters and petrodiesel in physical characteristics, burners need no modification to efficiently burn biodiesel (Ghorbani and Bazooyar, 2012). Hence, neither fixed nor equipment

* *Corresponding authors.*
E-mail addresses: Shariati@put.ac.ir (A. Shariati), Hashemabadi@iust.ac.ir (S.H. Hashemabadi).
[1] Tel.: +98 9163013199; fax: +98 61 35551754.
[2] Tel.: +98 21 77240376; fax: +98 21 77240495.
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costs are influenced by the use methyl esters in boilers. The expenses of depreciation and maintenance, however, are worthy of scrutiny when boilers fuel with biodiesel instead of petrodiesel, since some researchers have shown that biodiesel usage in the boiler is problematic, e.g., coking and polymerization are more probable during biodiesel combustion (Barnes et al., 2010; Daho et al., 2009).

Operating costs in boilers consist of price of fuels and that of damage they incur to the environment. In order to quantify the operating costs of a power plant, a multi-objective function consisting of "*internal*" costs (fuel) and "*external*" costs (environment) can be exploited. Investigation of cost function enables the boiler operators to control and monitor any changes in the operating conditions upon the unit economy. Kaewboonsong and Kouprianov (2003) optimized the combustion of fuel oil in a 350 MW pressurized tangentially-fired boiler using the cost-based function and identified compromise excess air in which substantial saving in boiler total costs and minimum soot formation are observed. Ghorbani and Bazooyar (2012) took the advantage of cost-based function to optimize of the combustion of SOME and its prevalent blends with petrodiesel in semi-industrial boiler. They revealed that at a specific excess air, significant costs saving in the operation of the boiler is achieved. Kuprianov et al. (2008) exploited the cost-based function for optimization of load dispatch of a load-variable co-fired power plant. They showed that total costs of the boiler unit are quasi-linear of the unit load. Kouprianov and Kaewboonsong (2004) analyzed the fuel and environmental costs of a 310 MW fuel oil fired burner. They pointed out the influence of excess air and boiler load is noticeable on minor costs. This function is also the most comprehensible strategy to determine the operational feasibility and reliability of thermal power plants.

In this work, this function is applied to study boiler expenditures with various alternative fuels such as SOME, SBO, two prevalent blends of SOME (B5 and B20) and petrodiesel. The annual boiler total costs were estimated from the years 2000 to 2015 to investigate the feasibility and reliability of using the prevalent petrodiesel alternatives in the boiler. Afterward, the contribution of fuel and environmental costs in boiler total expenses is investigated.

2. Material and method

2.1. *Tested fuel*

SOME was produced through an alkali base transesterification of soybean oil as triglyceride base with methanol in the presence of KOH pellets as the catalyst. This vegetable oil has a great contribution in the total biodiesel production. It is believed that vegetable oil is the second best potential for biodiesel production (Gui et al., 2008). Petrodiesel No. 2 was selected to prepare the blends as it has a major contribution to "*residential application*" such as heating purposes and electricity production. Detailed transesterification conditions can be found elsewhere (Bazooyar et al., 2015). The fatty acid composition by weight of the SOME is mainly linoleic (C18:2) 51%, oleic (C18:1) 23%, linolenic (C18:3) 13%, palmitic (C16:0) 9%, and stearic (C18:0) 4%. Two prevalent blends in the global market, B5 and B20, were prepared by complete mixing the produced SOME and petrodiesel. The physical properties of the fuels can be found in Table 1.

2.2. *Test facility*

The experimental investigation was carried out on a semi industrial boiler in "*Heat Transfer Laboratory*" at Ahvaz Faculty of Petroleum Engineering. The boiler is able to supply up to 100 kW of hot water. It is made up of a stainless steel chamber and an oil pressure jet burner, with a 60° hollow cone spray nozzle rated at 4–10 kg/h. The fuel pump pressure was set in a way that adjusts the same energy input of 70 kW for all the fuels. Economical analogy of the fuels in this condition seems to be more reasonable for the boiler. The burner operating conditions were set for the SOME and SBO and were left unaltered for subsequent runs with blends. A schematic of the test facility and the major measurement instrumentations are shown in Fig. 1. More detailed description of the burner technical principles can be found elsewhere (Bazooyar et al., 2014).

2.3. *Test plans*

This article aims at ascertaining whether the use of vegetable oil, biodiesel or its prevalent blend with petrodiesel instead of conventional petrodiesel of the market is economical. It should be noted that SOME, its prevalent blends with petrodiesel, and SBO have lower heating values than that of petrodiesel (Table 1), while SOME, SBO, and its blends with petrodiesel have higher densities than that of petrodiesel. The energy densities of the burner with SOME, SBO, B5, B20, and petrodiesel (lower heating value (LHV) $\times$ Fuel density) are 34, 33.7, 35.9, 35.4 and 36 MJ/L, respectively. At the same combustion pressure, the increase of sprayed mass, due to a higher SOME in a blend, cannot completely compensate for the energy deficit resulting from LHV decrease. Hence, to provide the same boiler duty, biodiesel, blends, and vegetable oil must be sprayed with higher flow rates. Bazooyar et al. (2011) after six disparate experiments demonstrated that the optimum pressure for SOME and petrodiesel combustion corresponds to 160 psi (11.032 bars), i.e., higher than 50% load of the boiler. Initial testing with SBO demonstrated that at pressure 210 psi (7.5 L/h fuel volume rate), and obviously higher, flame of the vegetable oil had an appropriate light intensity and was able to sustain a stable combustion. This fuel pressure is equal to the burner duty of 70 kW, relevant to 70% load. Hence, the efficient operation of the boiler with SOME and SBO as a fuel is limited to high loads 50 kW and 70 kW, respectively. To combat these restrictions, we can either adapt burners to use pure vegetable oil or use blends of vegetable oils with petrodiesel. As far as economical study is concerned in this work, we preferred to set the combustion condition to be the same (same burner with duty of 70 kW) and no modification was made to the burner to burn the SBO. To adjust burner duty 70 kW, petrodiesel, B5, B20 and SOME were sprayed into the chamber at 180, 180 (7.02 L/h), 185 (7.12 L/h) and 195 psi (7.41 L/h), respectively.

Another key element in the design and operation of the boiler is the amount of air and fuel for combustion. This operating condition can be presented by several quantities such as air to fuel ratio, equivalence ratio, and excess air. In this study, firstly, the amount of fuel flow rate was set to provide the 70 kW burner duty. Secondly, only the amount of air was changed in order to change the air to fuel proportion. There are two burner adjustments to change the amount of air: (a) the air damper of the burner, which varied between 1 and 17 mm, and (b) the position of the deflector, which is adopted