Production, Performance, Combustion, Emission Characteristics of Biodiesel Synthesized from Mutton Suet

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***Abstract*— Biodiesel is considered as one of the most suitable alternative biofuel because of its self-sustaining nature and renewability, thereby making it an eco-friendly fuel. This nontoxic biofuel has replaced the existing fuel for combustion ignition engines with or without slight modifications. This combustion based applications makes the experts to study the fuel's engine performance, combustion and emission characteristics which varies accordingly for various biodiesel produced from different feedstocks. This paper deals with production of biodiesel from the mutton suet and study related to its physiochemical properties and engine based combustion characteristics. Maximum fat content available in mutton suet was 96% out of which maximum achievable was 92% using autoclave heat extraction with FFA content of 0.5% .Most optimized parameters for transesterification reaction was 1:3 molar ratio, 2% catalyst concentration, reaction temperature of 60^{o}C for 120 minutes which yielded 93%. The physicochemical properties showed better results than conventional diesel and were lying in the range prescribed by standard norms. The performance emission and combustion characteristics were studied and reported.**

***Index* Terms—**Mutton Suet, Transesterification reaction, Specific Fuel Consumption, Thermal efficiencies, NOx Emission

I. INTRODUCTION

The rapid progressive growth of human population survived by technology enhancement solely depends on energy for its operations dominantly using petro fuels, rarely renewable fuels. The concern over the depletion of fossil fuels has sparked innovative ideas to use acceptable renewable energy resources like biofuels to fuel the energy demand. In addition, the production of fossil fuels, followed by excess usage of it and improper disposal is causing serious environmental troubles which have been replaced by these biofuels. The most attracted biofuel renowned worldwide is biodiesel ,known for its renewability, self-sustainability with low sulphur & zero aromatic content having a greater emission profile [1]. The economics involved in biodiesel is an economical concern and the cost of feedstock itself, sums up to 80-95% of biodiesel price [2]-[5]. This can be sorted out by identifying a suitable feedstock which has least market value, zero edibility, neutral in food vs. fuel conflict and greater availability. These feedstocks ranges from non-edible seed oils to disposed waste fats from animals like bovine, pork and mutton. One such resourceful feedstock is mutton suet which is rich in stearic and Palmitic acid and has greater availability in market because of suet based business. The factors influencing the suitability of fat for an ideal transesterification are acid value along with FFA content, Iodine value, and Saponification value.

This fat is converted into biodiesel through the means of catalyzed transesterification reaction, where the fat is treated with an organic solvent which disintegrates complex triglyceride molecule into fatty acids in form of ethyl ester. Most commonly used organic solvent consists of lower carbon chain alcohols like Methanol, Ethanol, Propanol, Butanol and Pentanol whereas the catalyst ranges from Sulphuric Acid to Hydroxides of Sodium (Na) and Potassium (K) [6] and in recent times heterogeneous catalysts [7] have been used. Some of the key physicochemical parameters include Density, Flash point & Fire point, Viscosity and Calorific Value. Density explains the unit mass of the certain fluid for its corresponding volume whereas Fire and Flash point decides the ignition temperature of the fuel. Viscosity decides the consumability of the fuel during engine combustion. The performance combustion and emission characteristics decide the overall performance of biodiesel in engine. [8].

This paper deals with production of biodiesel from the mutton suet through base catalyzed transesterification, validation of its physicochemical parameters and evaluation its performance, combustion and emission characteristics.

II. MATERIALS AND METHODOLOGY

A. Sample Collection

Discarded fatty mutton wastes were collected from nearby slaughterhouses and were refrigerated for preservation to avoid bacterial contamination.

B. Fat Extraction

Mutton suet was extracted by autoclaving it at a temperature of 120^{o}C and pressure of 15Bar. The separated fat was heat treated to remove any excess moisture content and was degummed to remove phospholipids, known for inhibiting catalyst activity.

C. Optimization of Transesterification Reaction

The mutton suet was transesterified using potassium methoxide as catalyzed solvent. Molar concentrations were varied from 1:1 to 1:6, for catalyst concentration from 1-3.5% for reaction time from 50-75oC for a time duration of 30 to 120 mins.

D. Determination of Physicochemical Parameters

The quality of the biodiesel was decided based upon the physical and chemical properties tested using standard testing procedure. Viscosity of the biodiesel was measured using redwood viscometer, whereas flash point and fire point was determined using Pensky-Martens closed tester. The calorific value of the fuel was determined by the bomb calorimeter. The acid value, Free Fatty Acid content was estimated using titration method with respect to corresponding burette and pipette solution.

E. Evaluation of Performance, Combustion and Emission Characteristics

The performance combustion and emission characteristics decide the overall performance of biodiesel in engine**.** To understand the effectiveness of the biodiesel, it was blended with ordinary diesel as B10, B20 and B30 in the ratio of 10%, 20% and 30% respectively.

III. RESULTS AND DISCUSSIONS

The collected mutton waste sample primarily consist of subcutaneous and intramuscular fat wastes whose overall lipid content was found to be 96% using Soxhlet's apparatus by refluxing the waste with hexane for 6 hours.

The fat were extracted in large scale quantity using autoclave operating at 120^{o}C and 15 Bar for 20-30 mins depending upon the quantity of the waste being subjected for extraction.Net output efficiency achieved in extracting those fat using this method was found to be 92% however the maximum amount of transesterifiable fat available in form of triglycerides in those fats were found to be 98%.

The extracted fat is degummed using Orthophosporic Acid in a concentration of 1% with respect to the oil quantity. The mixture was heated along with stirring for first 10 minutes later on with heating alone for another 10 minutes. This was done to remove the phospholipids carried along with the triglycerides, which are known for inhibiting the activities of catalysts used for transesterification reaction.

The refined suet is titrated along with isopropyl alcohol against 0.1N NaOH to determine its acid value, which is indicated by the appearance of pale pink colour, considered as the end point of the reaction. This acid value decides the free fatty acid content based upon the equation given below.

$$\text{Free Fatty Acid} = \frac{\text{Acid Value}}{2} \% \qquad (1)$$

The acid value was found to be 1 and its corresponding FFA% was found to be 0.5%. This FFA % is enough for carrying out the transesterification reaction directly without any pretreatment.

The most optimized parameters for transesterifying the mutton suet using base catalyzed transesterification are as follows: oil to alcohol molar ratio of 1:3, 2% catalyst concentration, and reaction temperature of 60^{o}C for 120 minutes. Fig.1 depicts the surface plot representing the optimized transesterification reaction using XLSTAT.

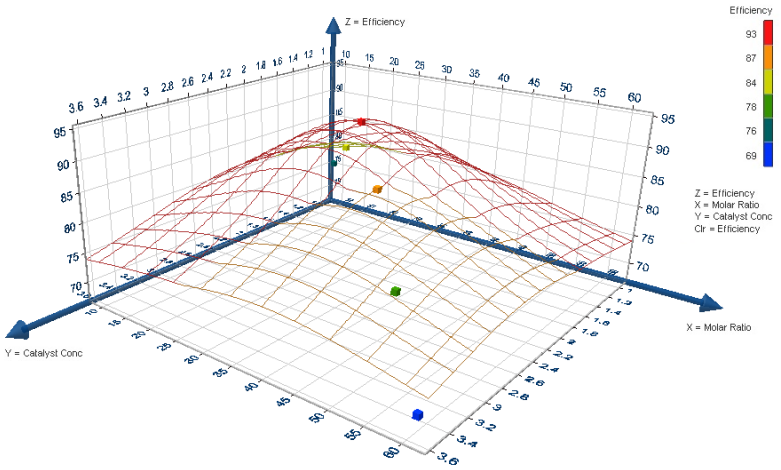

Fig.1:- surface plot representing the optimized transesterification reaction using XLSTAT

Methanol was used as the solvent for the transesterification reaction, where the oil to methanol molar ratio was effective for 1:3 ratio. Similarly, potassium hydroxide was used as the base catalyst and was added in a concentration of 2% with respect to amount of oil taken for the reaction. Thus, for every 100ml of mutton suet; 35ml of methanol and 2g of potassium hydroxide were added and on heating up to 60^{o}C with continuous stirring at 350rpm for 120 minutes, yielded 93ml of biodiesel.

The density of the produced biodiesel was found to be 870 kg/m^3, which was found to be in the applicable range of 882.2 to 0.889.0 kg/m^3. Kinematic viscosity of the produced fuel was found to be in between the standard range from 3.86-5.5 mm^2/s. Flash and fire point was determined as 160^{o}C and 170^{o}C respectively similar to that of the biodiesel [9]. The calorific value of the biodiesel was found to 37500kJ/kg. The acid value was found to be 1 whereas the FFA % was found to be 0.5%. The comparison of tested results with Indian standard has been tabulated in Table 1 along with their testing procedure.

TABLE 1 Physicochemical Properties of Mutton Suet Based Biodiesel

Properties	Units	Indian Standard	M. S. Biodiesel	Test Procedure
Density	Kg/m^3	860-900	870	ASTM D4052-91
Specific Gravity	-	-	0.87	-
Kinematic Viscosity	mm^2/s	2.5-6.0	5.2	ASTM D445
Flash Point	^{o}C	120	160	ASTM D93
Fire Point	^{o}C	130	170	ASTM D93
Calorific Value	KJ/Kg	38500	37500	ASTM D5865-13
Acid Value	mg/KOH	0.50 max	0.1	-

Fig. 2 shows the variation in cumulative heat release for various blends at various crank angle ,it can be clearly concluded that at higher conditions, the heat rate reaches maximum and decreases, for blends at higher ratio because of its long time variation in between diffusion combustion phase and premixed combustion phase [10].the net cumulative energy release was experienced more in biodiesel-diesel blends than ordinary diesel for all load conditions with B20 showing higher heat release than others at higher BMEP conditions.Also,B30 fuel burns faster than other blends (i.e. having shorter combustion duration) showing biodiesel blends burns faster than ordinary diesel.

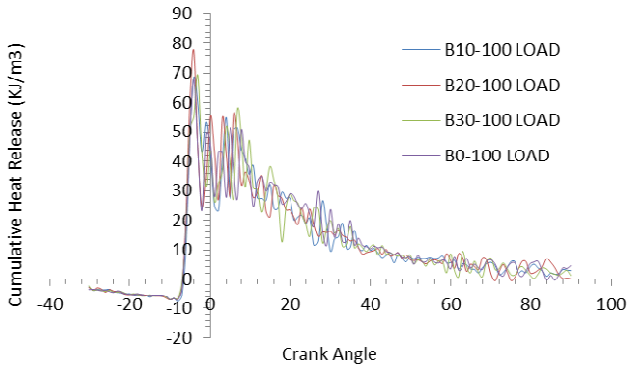

Fig. 2:- Cumulative Heat Release for Various Crank Angle

Fig. 3 shows the Specific Fuel Consumption for various blends at different load conditions. It relates the mass flow with density and effective power. SFC increases with increase in blend ratio and decreases with increase in engine speed and load condition as there is an increase in air flow and cylinder temperature. The mean Specific fuel consumption is greater for biodiesel blends than compared to ordinary diesel because of its higher density which causes more consumption of fuel for any injection pressure and increased fuel flow rate for all displacement of plunger in fuel injection pump [11]. Also the increase in SFC is because of lower heating value of biodiesel than that of diesel.

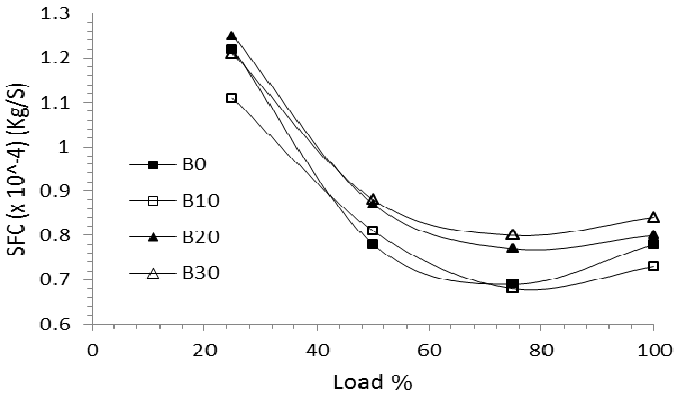

Fig. 3:-Specific Fuel Consumption for Varying Load

Fig 4&5 shows the thermal efficiency (Brake & Inductive) for varying loads for different blends. Thermal Efficiency is the net power obtained for corresponding amount of energy given through fuel injection, where the energy is a product of lower heating value and injected fuel mass flow rate [12]. The thermal efficiency decreased with the increase in the blending ratio, where the thermal efficiency of B10 is higher than that of other blends (B20, B30) as blends with higher viscosities leads to reduced atomization, fuel vaporization and combustion, thereby reducing the thermal efficiency [13]. As the fuel consumption increases, the thermal efficiency decreases.it is to be noted that the thermal efficiency of the blend is considered to be higher than that of pure biodiesel. The mean effective engine power of B10, B20 and B30 was lower than that of diesel fuel because of their lower heating value. The effective engine power was found to be higher for biodiesel at low engine speed; this is because of the availability of more time for combustion.

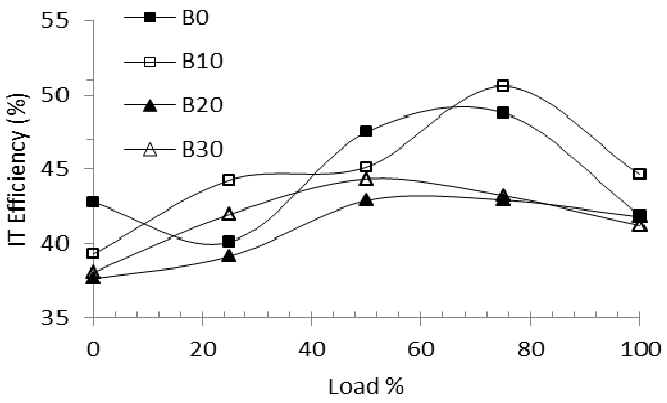

Fig. 4 :- Inductive Thermal Efficiency for Varying Load

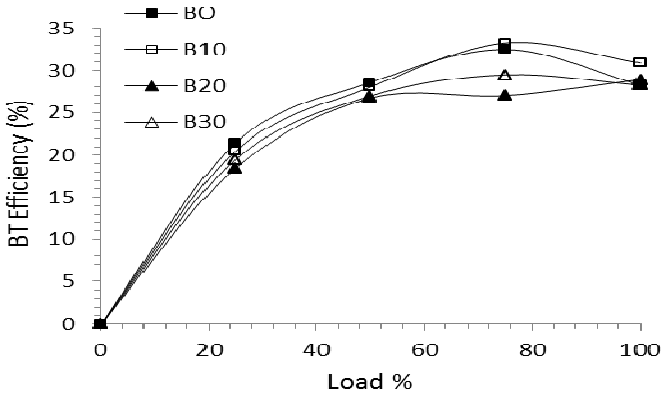

Fig. 5 :- Brake Thermal Efficiency for Varying Load

The least CO emission has been found to be observed in B30 blend than compared to other blends and diesel fuel as blended diesels have lower CO emissions [14, 15]. This is because of the oxygen content present in the biodiesel and also the C/H ratio which is less for diesel fuel.it is also noted that the reduction in the co is not linear [15]. The co formation is affected by the in cylinder temperature and this is reflected because of the lower temperature of the exhaust gas for B30 at 75% load condition than compared to other conditions. Fig. 6 shows the concentration of CO for different blends at varying load conditions.

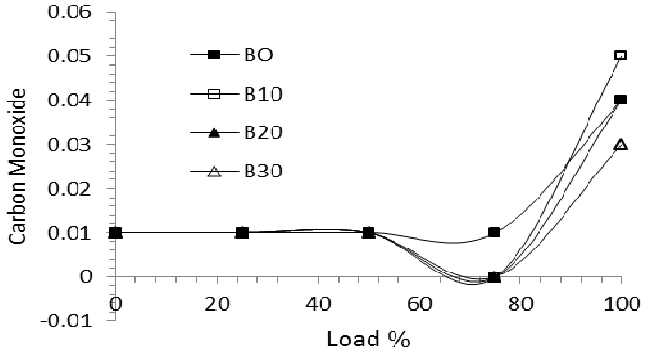

Fig. 6:- CO Concentrations for Varying Load

Biodiesel has higher cetane number with lower flash point than compared to petrodiesel thereby reducing the time for premixed combustion due to reduced ignition delay. This reduced ignition delay lowers the NOx emission in addition to the slow rise in combustion pressure. High cetane number lands up in shortened ignition delay period thus providing small time gap for air/fuel mixing before premixed burning phase thereby forming a weaker mixture that would be burnt during premixed phase resulting in relatively reduced NOx emissions [16]. The presence of any unsaturation in fatty acids causes increase in NOx emission and also for increase in NOx

emission, there is a decrease in cetane number. The consolidation of above statements is represented in Fig. 7, where the NOx emission for varying loads is represented.

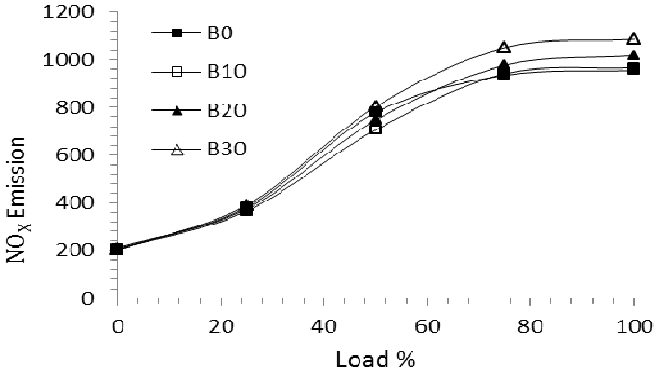

Fig. 7:- NOx concentrations for varying Load

On combusting biodiesel, it produces less amount of smoke because of high oxygen content in the fuel [12]. But the lower C/H ratio and the presence of aromatics sometimes cause the smoke formation. Similarly if a molecule contains more carbon in its molecule, it tends to produce more amount of soot. In addition, aromatics produce more amount of soot, but are present only in fuel with higher C/H ratio [17].

IV. CONCLUSION

Biodiesel, considered as prominent renewable energy resource, was produced from the discarded mutton waste. Suet was extracted from these wastes through the means of autoclaving and was refined using degumming. The refined fat was transesterified using methanol as solvent and potassium hydroxide as base catalyst. The biodiesel produced was tested for physicochemical properties which satisfied the standard norms for an ideal biodiesel. Testing of performance, combustion and emission characteristics revealed that B20 was most effective blend in all aspects and proved that suet based biodiesel was an effective substitute for the existing diesel.

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