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Aims and Scope

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Contents

Optimization of Solar Assisted Production of Biodiesel From Cotton Seed Oil

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A B S T R A C T

At present, there are many research and developments are taking place in every aspects of human life, but still millions of people are facing the problem of deficient-electricity in India and all around the world. It's true that biodiesel can be an alternative to petroleum-fuels (Gasoline and Diesel), but the production process of biodiesel is still not so cost effective that it can be used commercially in automobiles. To make it cost effective, a small parabolic dish type solar reflector was used for heating required in transesterification process which avoid the use of electrical heating and magnetic stirrer. This paper presents optimization of different process parameters used in solar assisted biodiesel production.

Keywords- Biodiesel; Solar irradiation; Taguchi's method; Transesterification; Yield.

1. Introduction

In recent years, new technologies of biodiesel production are becoming more promising. Solar assisted biodiesel production is one of the new technologies which not only utilize solar energy for heating purpose in place of electrical heater, but also produce biodiesel of better quality. In solar assisted method, a parabolic dish type solar reflector is used which concentrate heat at its focal point. A vessel containing oil, methanol and catalyst in different proportions is placed on the focal point of reflector and transesterification process takes place when it is maintained at around 70˚C for one hour [1]. In transesterification process, there are four process parameters: oil to methanol molar ratio, reaction time,

reaction temperature, catalyst concentration. In some previous work on conventional method biodiesel production, these process parameters were optimized to increase the yield of biodiesel produced. Mishra et al. [2] presented optimization of process parameters on the Neem oil methyl ester production. In this work, they used Taguchi's method of optimization. Sherbiny et al. [3] discussed the production of biodiesel from jatropha oil using microwave irradiation method and then optimization of process parameters was performed to increase the conversion yield. The optimum conditions in this work were methanol to oil molar ratio as 7.5:1 and 1.5% potassium hydroxide as the catalyst. The optimum reaction temperature was 60˚C. The conversion yield was found as 97.4% in just 2 min using the microwave irradiation technique.

In this paper, process parameters are optimized using the Taguchi's method. This method not only optimized the process parameters but also make the better feasibility of solar assisted biodiesel production.

2. Design of Experiments Using Taguchi's method

At first, the design of experiments was done using Taguchi's method. In this work, the experiments were designed using a 3-level and 4-factor database. The process parameters or factors and their level are tabulated as follow:

Table 1. Process parameters and their levels

	Factors			
Level	Molar Ratio	Time (min)	Temperature (℃)	Catalyst Conc. (wt%)
1	4.5:1	50	60	0.50
2	6:1	60	70	0.75
3	7.5:1	70	80	1.00

Taguchi's software generate a L9 type orthogonal array on the basis of 3-level 4-factors. The experiments were performed using these nine iterations of L9 orthogonal array and the yield is calculated by performing experiments. The following table shows the different yield percentage at different conditions of process parameters:

Table 2. L9 orthogonal array with yield (%) calculated

	Levels of design for different Factors				
S. No.	Molar Ratio	Time	Temperature	Catalyst Concentration	**Yield (%)**
1.	1	1	1	1	**90.32**
2.	1	2	2	2	**92.56**
3.	1	3	3	3	**92.86**
4.	2	1	2	3	**94.24**
5.	2	2	3	1	**95.10**
6.	2	3	1	2	**94.56**
7.	3	1	3	2	**93.45**
8.	3	2	1	3	**94.60**
9.	3	3	2	1	**94.23**

With the help of this orthogonal array, Main effect plots for mean values of yield and signal to noise ratios are generated by Taguchi's software.

3. Experimental Method of Solar Assisted Biodiesel Production

A parabolic dish type solar reflector was used in this work. At first, the cotton seed oil was heated up to remove moisture content then it was cooled to 60℃. A mixture of methanol and KOH is prepared in different beaker then it is mixed with the cotton seed oil. Now, this mixture of oil, methanol and KOH is heated by putting it at focal point of reflector. The flux temperature is maintained around 60℃-80℃ for 50 to 70 minutes. In this way, solar assisted transesterification is performed. The different yields of cotton seed oil methyl ester found from different experiments are shown in table 2.

Figure 1. Solar Assisted Transesterification.

4. Determination of Optimal Experimental Condition By The Design of Experiment

The yield of biodiesel produced under nine sets of experimental conditions are estimating by performing experiments under the same experimental conditions. After conducting nine experiments and measuring the percentage yields, there are nine observations in total for each experiment. According to the analysis for the case of 'larger the better', the mean squared deviations (MSD) of each experiment were evaluated using the following equation [2]:

$$MSD = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{y_i}\right)^2$$

Where 'n' is the number of repetitions of each experiment and 'y_i' is the yield of biodiesel.

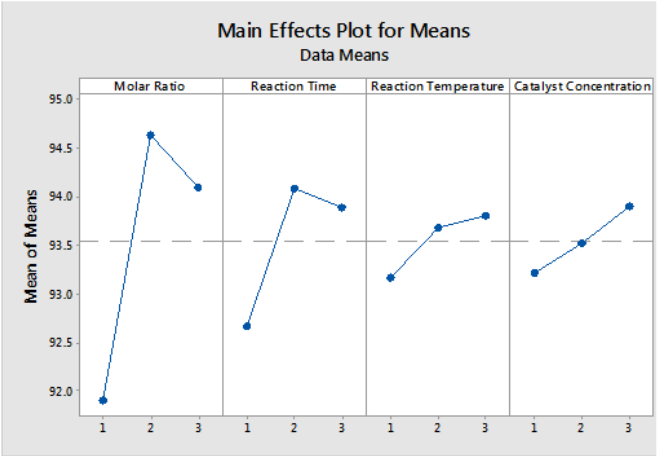

Figure 2. Main effect plot for means. Signal to Noise (S/N) Ratio

In Taguchi optimization Signal to Noise Ratio is a significant parameter which is used to estimate the extent of deviation of quality function from the expected value. Taguchi approach uses three types of S/N Ratios on the basis of objective of the problem.

i. Nominal-the-Best

ii. Smaller-the-Better

iii. Larger-the-Better

In normal-to-best S/N ratio, normalization problems are solved. Smaller-the-better S/N ratio is used for minimization problem and larger-the-better is used for maximization of problem. In the transesterification process, we need to maximize conversion yield of biodiesel, so larger-the-better ratio is used.

The mathematical equation for these three types of S/N ratios are as follow-

$$SNR_i = 10\ log\left(\frac{\bar{y}_i^2}{s_i^2}\right)\ (Nominal\ the\ best)$$

$$SNR_i = -10\ log\left(\sum_{j=1}^{n}\frac{y_j^2}{n}\right)\ (smaller\ the\ better)$$

$$SNR_i = -10\ log\ \frac{1}{n}\left(\sum_{j=1}^{n}\frac{1}{y_j^2}\right)\ (larger\ the\ better)$$

Where

$$\bar{y}_i = \frac{1}{n}\left(\sum_{j=1}^{n} y_{i,j}\right)\ (mean\ value\ of\ response)$$

$$s_i^2 = \frac{1}{n-1}\left(\sum_{j=1}^{n} y_{i,j} - \bar{y}_i\right)\ (variance)$$

Where, i – Experiment number

j – Trial number

n – Number of trials

So the optimum level of design factor will be the level with maximum signal to noise ratio.

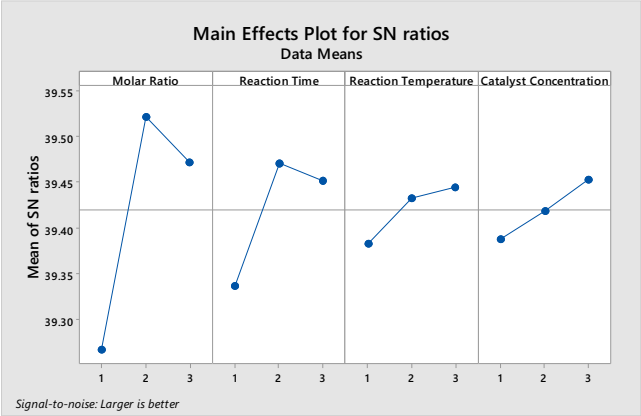

Figure 3. Main effect plots for signal to noise ratios

ANOVA Table

The optimal value of different process parameters can be simply determined by signal to noise ratio analysis. But this S/N ratio analysis can't distinguish the reason for different fluctuation of each factor level. Improper experimental conditions or experimental errors might be the reason for this. Therefore, the experimental error can't be estimated by S/N ratio analysis. Additionally, S/N ratios cannot systematically calculate the differences among the mean values and specify the magnitudes of the factor effects using the same standard.

Due to these drawbacks of S/N ratio analysis, ANOVA analysis is necessary for calculating the magnitudes of the factor affecting the index. The analysis of variance (ANOVA) is conducted for identification of the optimum set of process parameters. Response data is used for ANOVA analysis. The most significant process parameter can be identified by calculating the percentage contribution of each parameter on the conversion yield of biodiesel. The percentage of contribution can be calculated using the following equations-

$$\%\ contribution = \frac{SS_i}{SS_T} \times 100$$

Here SS_i is the sum of the square for i^{th} parameter and SS_T is the total sum of the square of all parameters.

$$SS_i = \sum_{j=1}^{3}[(SNR_L)_{ij} - SNR_T]^2$$

$$SS_T = \sum_{i=1}^{4} SS_i$$

In this work, ANOVA table generated by Taguchi's software is as follow:

Table 3. ANOVA Table

Source	Degree of Freedom	Sum of Squares	Mean of Squares	F-value	P-value
Molar ratio	2	12.4424	6.2212	7.59	0.023
Reaction time	2	3.5205	1.7602	0.76	0.507
Reaction temp	2	0.6969	0.3484	0.13	0.884
Catalyst conc.	2	0.7029	0.3514	0.13	0.883
Error	0	*	*		
Total	7	17.3626			

ANOVA table clearly shows that P-value is minimum for molar ratio, so the contribution of molar ratio is affecting yield will be greatest. Reaction temperature and catalyst concentration have less contribution in affecting yield

Maximum yield prediction

The theoretical maximum yield of biodiesel can be predicted by using the following equation. The process parameters are taken in optimum condition.

$$Y_o = 10^{\left(\frac{SNR_o}{5}\right)}$$

Where, SNR_o – S/N ratio under optimum conditions

Y_o - Theoretical optimum yield

5. Results and Discussions

Taguchi's method used for optimization of process parameters also generate main effect plots of yield with respect to different process parameters individually. The optimum conditions for transesterification can be found by analyzing these main effect plots.

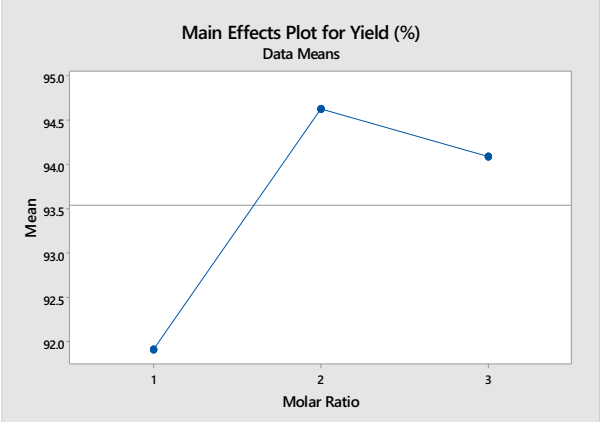

Figure 4. Yield vs Molar ratio

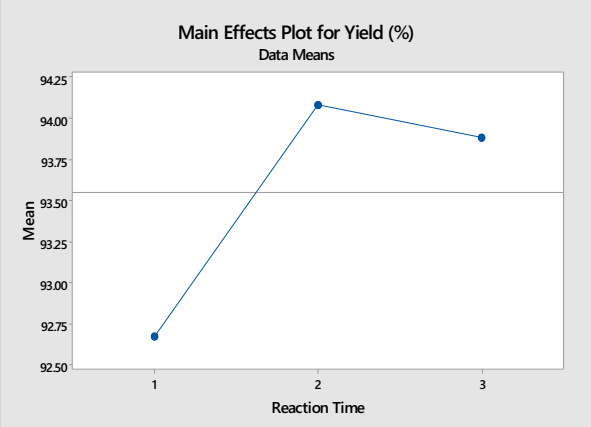

Figure 5. Yield vs reaction time

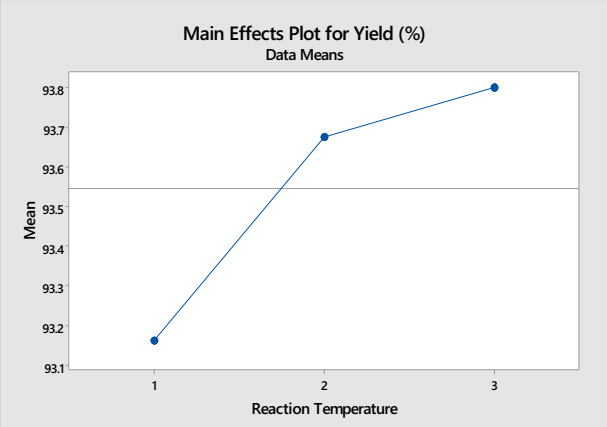

Figure 6. Yield vs reaction temperature

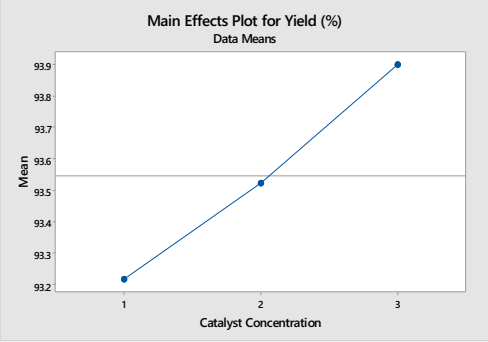

Figure 7. Yield vs Catalyst concentration

Main effects plots for yield with different parameters clearly depict that optimum conditions in this solar assisted biodiesel production are: oil to alcohol molar ratio 6:1, reaction time 60 min, reaction temperature 70℃ and catalyst concentration 1.0 wt%. At these conditions, the conversion yield was found maximum (95.56%). The ANOVA table also depicts the P-values for every process parameters. Lower the P-value, higher is the contribution of parameter in affecting yield. So, Effect of oil to methanol molar ratio on conversion yield is higher than the effects of other parameters.

6. Conclusion

In this work, optimization of process parameters were done using Taguchi's software. Solar assisted biodiesel production is cost effective because there is no use of electrical heater in this process. To make this process more qualitative and commercialized, optimization of parameters is important. The maximum yield was obtained in this case was 95.56% at optimum condition of molar ratio 6:1, reaction time 60 min, reaction temperature 70℃ and catalyst concentration of 1.0 wt%.Thus, it can be said that solar assisted biodiesel production is not only cost effective but also a qualitative method of biodiesel production.

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Overview of Carbon Nano Tubes

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ABSTRACT

In all manufacturing industries, tool cost accounts for about 50-55%. So, greater emphasis is given to cutting tool cost and inventing newer tool coatings which significantly increases Tool life. Carbon is abundant and unique element in periodic table. Not only in nano form it is also used in cutting tool industry as CBN, industrial diamond .CBN is artificial diamond and has very high hardness, next only to natural diamond.Reseach is going on how to use carbon nano coatings. Various synthesis techniques as PVD, CVD, CCVD, Laser Ablation etc. are available to deposit carbon nano coatings on substrate. The challenge is yet to develop a mechanism for large scale production of nano tubes. Further the quality of Nano tube obtained is also important. Single walled Nano Tubes (SWCNT) is far more superior to MWCNT as far as their mechanical properties are concerned. But they are purest form of carbon nano tubes and are difficult to obtain. Carbon nano tubes are coiled grapheme tubes which possess a very high aspect (L/D) ratio. These carbon molecules are tiny tubes with diameters down to 0.4 nm, while their lengths can grow up to a million times their diameter. They are very light in weight and their toughness is very high. The carbon nanotube reinforcement of metallic binders for the improvement of quality and efficiency of diamond cutting wheels is being tested. Advantage of superior mechanical properties of the carbon nanotubes, can be taken by using them as fillers in epoxy resins.

Keywords- Carbon Nano Tube; Aspect Ratio; Diamond;Tool Coating; MWCNT,SWCNT.

1. INTRODUCTION

One of most advanced manufacturing technology which is often labelled as technology of future is Nanotechnology. It is often referred as “Extreme Technology”.It combines miniturisation with precision. Nanotechnology covers the molecules having at least one dimension of about 1–100 nm. [1]

Carbon Nano Tubes are first discovered by Ijima[2] and since then their discovery has contributed a lot in Physics, Chemistry and aterial Sciences.[3]

Carbon Nano tube are rolled up graphene tubes which can be found as either Single walled Carbon Nano

Tubes SWCNT or Multi walled Carbon Nano Tubes MWCNT. Single wall carbon nanotubes (SWNTs) have well defined atomic structure, have high length to diameter ratio,and higher chemical stability.[4]

However synthesis of SWCNT is big challenge because of greater control needed while yielding them . However MWCNT are easier to synthesise but they are far inferior than SWCNT as far their physical properties are concerned.

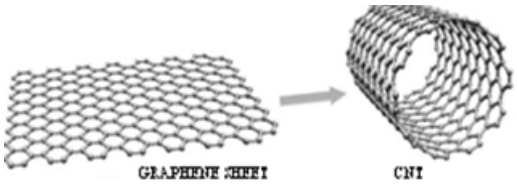

Figure 1. Graphene sheet rolled to form CNT

2. SYNTHESIS OF CNT

There are different techniques to synthesise SWCNT and MWCNT.

Previously very high temperature synthesis techniques as arc discharge method, laser ablation were used for their synthesis, but nowadays low temperature synthesis thechniques as chemical vapour deposition (CVD) techniques (<800) are abundantly used, as the latter process can be controlled better.[5]

Whatever types of CNTs are prepared by any above mentioned process, a number of impurities are present in the CNTs. The extent of impurity will always depend upon the process of synthesis. Impurities present generally are carbonaceous particles such as nanocrystalline graphite, amorphous carbon, fullerenes and different metals (typically Fe, Co, Mo or Ni) that were introduced as catalysts during the synthesis. Therefore one of fundamental challenge is to purify the CNTs.[6]

2.1 PVD TECHNIQUES:

These techniques involves deposition of carbon at very high temperatures.

2.1.1 ARC DISCHARGE

Arc discharge processes use higher temperatures (above 1700 °C) for CNT synthesis, as a result CNTs with fewer structural defects are formed in comparison with other techniques.

Different catalytic precursors are used for the arc discharge deposition of CNTs.[7-8]
Usually the MWNTs are produced when no catalyst is used. On the other hand, the SWNTs are produced

when the transition metal catalyst is used.

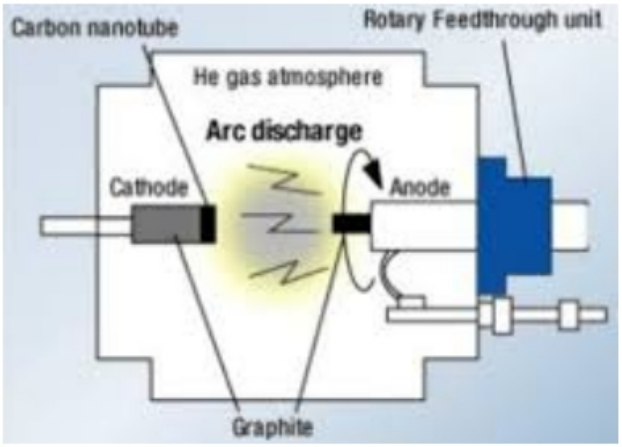

Figure 2.Arc Discharge Method source: www.intechopen.com

2.1.2 PULSE LASER DEPOSITION

Pulse Laser deposition (PLD) is dependant upon the laser properties as energy fluence, peak power, repetition rate and oscillation wavelength, the structural and chemical structure of Target workpiece, the chamber pressure, flow and pressure of the buffer gas, the substrate and ambient temperature and the distance between the target and the substrate.Accelerated electrons are discharged from cathode in short pulses ranging from milli to micro seconds.[9]

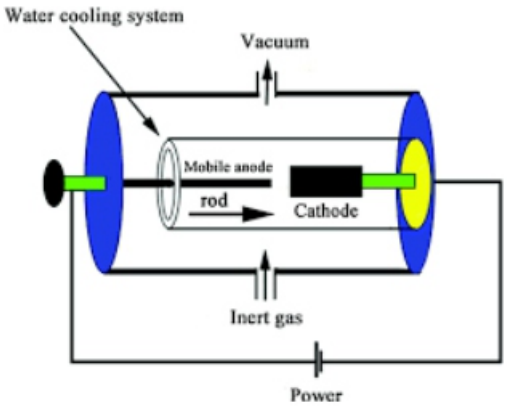

Figure 3: Pulse Laser Method Source:pubs.rsc.org

2.3 CVD TECHNIQUES

In 1996 a CVD method was invented for nanotube synthesis; 50 nm thick film of nanotubes that were highly aligned perpendicular to the surface.[10]

This method is capable of controlling growth direction on a substrate. In this process a mixture

of hydrocarbon gas, acetylene, methane or ethylene and nitrogen is introduced into the reaction chamber. During the reaction, nanotubes are formed on the substrate by the decomposition of the hydrocarbon at temperatures 700–900 ◦C and atmospheric pressure [11]. Here the process is occurring at comparatively low temperatures.

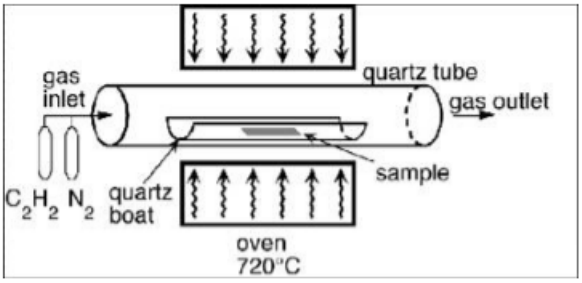

Figure4: CVD Techniques Source:sites.google.com

3. PURIFICATION OF CNTs

Different post-growth treatments have been developed to purify the tubes and also to eliminate the defects in the tubes. An ultrasonic bath method can be used to free many tubes from the particles that are originally stuck together [12].

The smaller the particles the more difficult is the elimination. Impurities in MWNTs can be treated by oxidative treatment by a liquid phase treatment in acidic environment. For SWNTs, methods are more complicated as cross-flow filtration.

4. PROPERTIES OF CNTs

4.1 PHYSICAL PROPERTIES

The thermal vibrations of nanotubes can be used to find The Young's modulus of elasticity ; a very high average value of 1.8 TPa was found by Wong et al. used a scanning force microscope [13-14].
The density of bundled nanotubes is 1.33–1.40 g/cm3, as compared with aluminium, possessing a density of 2.7 g/cm3 [15].

4.2 ELECTRICAL PROPERTIES

Carbon nano tubes are good conductors of electricity.Field emission is another good property of CNTs; they emit electrons from their tips, when they are placed in an electrical field[16]

4.3 THERMAL PROPERTIES

They possess good thermal properties and displays stability in vacuum up to 2800 ◦C, and in air up to 750 ◦C. is 6000W/mK at room temperature which is comparable with nearly pure diamond, which has 3320W/mK [17].

5. APPLICATION OF CNTs

5.1 GENETIC ENGINEERING

The nanotubes conduct water at a rate similar to that of certain channels in the kidneys. These unusual transport properties of carbon nanotubes might be used in biomedical applications, such as highly targeted drug delivery.

A carbon nanotube-tipped atomic force microscope can be used for tracing a strand of DNA and identify chemical markers, used for gene identification.[18]

5.2 AEROSPACE AND AUTOMOTIVE INDUSTRY

CNT have very high (L/D) or aspect ratio and has high strength combined with the low density which can be used for the developing of a space elevator. Although this sounds a fancy but scientists are researching on this.[19-20]

5.3 ELECTRONICS AND CHIP MANUFACTURING

Essential devices like field-effect transistors (FET) have been developed using CNTs which have been termed as carbon nanotube FET (CNT-FET).

The carbon nanotube-based devices operated at very low temperatures, with electrical characteristics remarkably similar to silicon devices. [21]

6. CONCLUSIONS AND FUTURE SCOPE

CNTs are very promising materials of future engineering.They can be produced by high temperature processes as PVD or low temperature processes as CVD.

Their mechanical properties are very promising strength comparable to diamond. Some researchers

are using them in Biomedicine and genetics. Also because of good semiconducting properties they are used for developing microchips.

Their future usage includes developing Bullet-proof vests, Space elevators, Gene identifiers etc. Ijima et al. has discovered revolutionary material as CNTs, for which he rightly got Nobel Prize in Physics in 1991.

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Production, Utilization and Performance of Diesel-Biodiesel-Ethanol Blends in IC Engines

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ABSTRACT

Biodiesel is considered as a promising alternating fuel for CI engines. In the present work, production (using hydrodynamic cavitation), utilization and performance characteristics of biodiesel blends produced from waste cooking were compared. In the first session of research, the production of biodiesel from waste cooking oil and various fuel properties were measured. In the second session, performance of single cylinder Kirloskar diesel engine has been studied at a constant engine speed of 1500rpm. During engine performance tests, the biodiesel blends showed similar brake power and while marginally higher BSFC and BSEC than the diesel fuel at higher loads were noticed. Engine emissions showed higher nitrogen oxide emissions, but decreased amount of carbon monoxide and hydrocarbon for biodiesel blends compared to the neat diesel fuel. From the results, it is clear that the waste cooking oil-based biodiesel blends can be used in a CI engine without any modifications.

Keywords- Biodiesel; Waste Cooking Oil; Hydrodynamic Cavitation; IC Engine.

1. INTRODUCTION

Ever increasing demand of energy for development, transportation, luxurious lifestyle and technology boost is having a negative effect on the sustainability of the existing fossil fuels (oil) reservoirs. The world's total oil reserves is estimated to be 1697.6 thousand million barrels (at the end of 2015) which is consumed at the rate of 95008 thousand barrels per day whereas India shares only 5.7 thousand million barrels and consumption rate is 876 thousand barrels per day [1, 2]. To compensate the decreasing reserves and increasing demand of crude oil we need to find an alternative to fulfil our energy requirements and thus biodiesel can be used as a good substitute for diesel. It is difficult for the currently

running CI engines to use pure biodiesel as fuel due to the huge cost required for replacements and modifications [3]. Thus, diesel-biodiesel-ethanol blends can be used with little or no modifications in existing CI engines to avoid the expense upto an extent. Various oil seeds (like sunflower, peanut, soybean, rapeseed, palm, olive, cottonseed, linseed, jatropha, coconut, pongamia, rubberseed, jojoba etc.) can be used to extract oil and then processed to biodiesel, again extraction is a money consuming processes [4]. Thus, an attempt can be done to produce biodiesel from waste cooking oils from restaurants, hotels and canteens which can reduce a little of the production cost. But due to presence of fatty acids in waste cooking oil, it cannot be directly used for blending and thus need filtration and transesterification [5, 6].

The basic reaction carried out in the biodiesel production is transesterification. In this reaction, different catalysts can be used to enhance the transesterification reaction which is namely alkali catalyst, acid catalyst and lipase catalyst [7]. Different technique has been developed so far for biodiesel production like mechanical stirring, hydrodynamic cavitation, ultrasonic cavitation [8] and supercritical methanol [9]. Among all, hydrodynamic cavitation is a potential method for biodiesel production at industrial scale due to its easy scale-up property.

The cavitating conditions identical to acoustic cavitation could be generated in hydrodynamic cavitation, which even had a better effect on mixing immiscible liquids [10]. Furthermore, scale-up of hydrodynamic cavitation to meet industrial-scale operations had better opportunities than the ultrasonic reactor by reason of its easier generating and less sensitivity to the geometric details of the reactor. Hydrodynamic cavitation is a cheaper alternative and requires approximately a half of the energy that is consumed by the conventional mechanical stirring method. In hydrodynamic cavitation method, mixing of two phases of reaction is carried out by cavitation conditions. The cavitation condition is produced by pressure variation, which in turn obtained by using the geometry of system to create velocity variation. Cavitation is generated by the flow of liquid under controlled conditions through simple geometries such as venturi tubes and orifice plates. When the pressure at the throat falls below the vapour pressure of liquid, the liquid flashes, generating a large number of cavities which subsequently oscillate. This phenomenon gives rise to pressure and temperature pulses. These pulses cause the better mixing of immiscible liquids and enhanced transesterification process [11].

The oxygen content in the fuel facilitates a complete combustion of the fuel even in fuel rich zones during combustion in engine cylinder and thus reducing carbon monoxide (CO) and hydrocarbon (HC) emissions. The higher cetane number of biodiesel reduces the combustion delays and thus the probability of fuel rich zone formation. This led to reduction in HC and CO emissions [12–15].

Biodiesel molecule oxygen content, generates lower stoichiometric requirement of air in case of biodiesel combustion [16, 17], which reduces the probability of fuel rich regions and the absence of aromatics in biodiesel fuel, those being considered soot precursors [18], results in reduction of particulate matter (PM) emissions. Nitrogen Oxides (NO_x) formation in engine exhaust is a direct function of combustion temperature. Lower temperature exists in combustion chamber with biodiesel due to overall leaner combustion and its lower LHV. However the higher NO_x values, with respect to petroleum diesel fuel case, suggest that local oxygen availability has dominant effect [18]. Carbon deposits on cylinder head, piston top and injector tip for biodiesel fuelled engines were 40% less compared to diesel fuelled engines. Carbonization of biodiesel injector after 512 h of operation was far less than the diesel injector after 200 h of engine operation [19].

It is evident from above literature survey that majority of work has been done on edible oils and non-edible oils whereas only limited work has been done on waste cooking oil. The present work deals with the production and performance of biodiesel from the waste cooking oil which is available in abundance.

2. ABBREVIATIONS USED

D70B20E10	blend of 70% diesel, 20% biodiesel and 10% ethanol
D75B15E10	blend of 75% diesel, 15% biodiesel and 10% ethanol
D85B10E5	blend of 85% diesel, 10% biodiesel and 5% ethanol
D90B5E5	blend of 90% diesel, 5% biodiesel and 5% ethanol
CO	carbon monoxide
HC	hydrocarbon
NO_x	nitrogen oxides
% vol.	percentage by volume
ppm	parts per million
BP	brake power
BSEC	brake specific energy consumption
BSFC	brake specific fuel consumption
MJ/kWh	Mega-Joule per kilo-Watt-hour
rpm	rotations per minute

3. MATERIALS AND METHODS

3.1 Materials

The waste cooking oil was collected from canteen of Delhi Technological University. The oil was properly filtered to separate any kind of suspended impurities present in it. Anhydrous methanol (99.8% min.) and potassium hydroxide (85% min.) were purchased from chemical store.

3.2 Biodiesel Production Method

For this production process, a 3kg sample of filtered waste cooking oil was taken in a beaker and heated to about 120C in order to remove any water content present in it to avoid soap formation. Then, 500g of anhydrous methanol (CH_3OH) at a molar ratio of 1:6 (1 Methanol and 6 Oil) was mixed in the filtered waste cooking oil sample. 30g of Potassium Hydroxide (KOH) was then added to the mixture of waste cooking oil and methanol using Magnetic stirring process. The mixture was stirred until all of the KOH get dissolved into the mixture.

The orifice plate (diameter 2.2cm) with single hole (diameter 0.6mm) at its centre was fixed to the Hydrodynamic Cavitation reactor as shown in the fig. 1 and the mixture was then poured into the reactor through the inlet. After intervals of 30, 40, 50 and 60mins samples of 100g were taken in beaker. Similar process was repeated for the other two plates having 3 and 5 holes respectively.

The samples collected were then allowed for gravity settlement for about 24 hrs so that the heavier Glycerine gets settled down at the bottom of the beakers. This layer of Glycerine was then removed with the help of separating funnels. The remaining solution was then washed with warm water by mixing the two and then leaving the mixture for settlement for about 3-4 hrs. The separated water was then removed using separating funnel and the remaining solution was tested for the yield of Biodiesel.

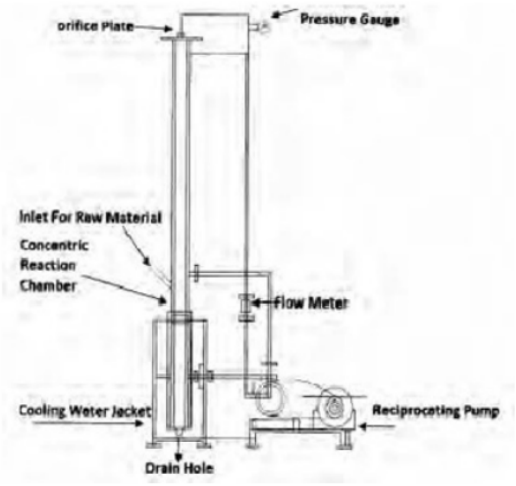


Figure 1: Hydrodynamic cavitation reactor

Table 1: Fuel Blends Properties

Blend	Density (g/cm^3)	Specific gravity	Kinematic viscosity (mm^2/s)	Calorific Value (MJ/kg)
Neat Bio-diesel	0.9047	0.9056	10.9919	38.28
D70 B20 E10	0.8509	0.8516	4.8643	42.33
D75 B15 E10	0.8479	0.8487	4.6004	43.23
D85 B10 E5	0.8434	0.8442	4.3741	43.52
D90 B5 E5	0.8395	0.8403	4.0819	44.11

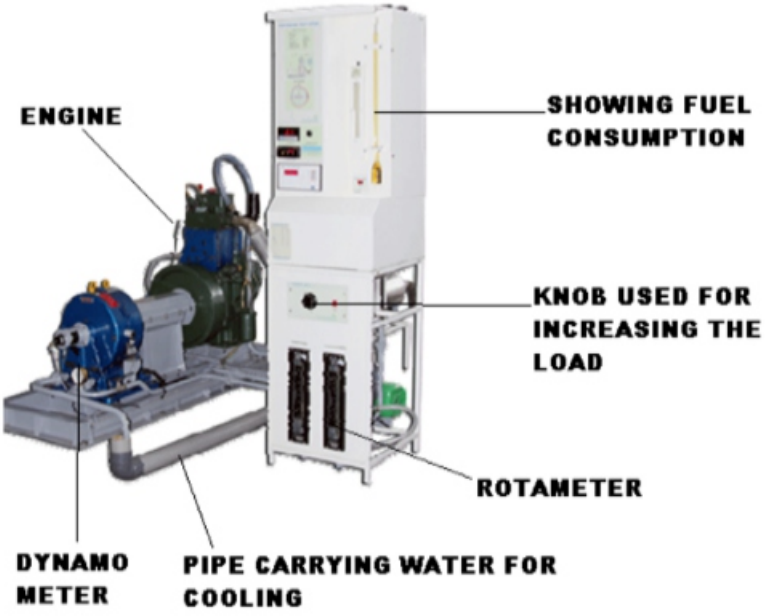


Figure 2: IC engine test setup

3.3 Blend Preparation

Blends of biodiesel and methanol with diesel fuel are prepared in the International Combustion Engines Laboratory of Delhi Technological University, (formerly Delhi College of engineering). Blends are prepared on the volume percentage base of biodiesel, ethanol and diesel. Blends prepared are as- D70B20E10, D75B15E10, D85B10E5 and D90B5E5 respectively. E represents the volume percentage of ethanol, B represents the volume percentage of biodiesel and D represents the volume percentage of diesel. Fuel properties for different blends are shown in the Table 1.

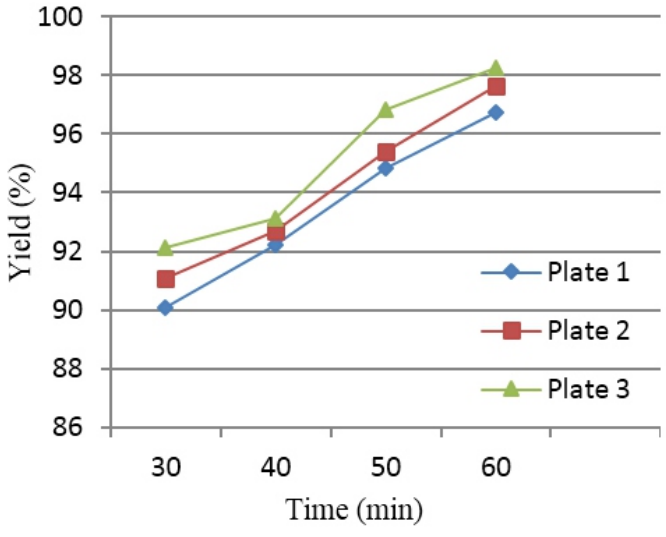
3.4 Experimental setup

The setup consists of a Kirloskar, single cylinder, four stroke, 3.5 kW, 1500 rpm with stroke 110mm and bore 87.5 diesel engine connected to eddy current type dynamometer for loading as shown in the fig. 2. The Compression ratio is adjusted at 17.5 for whole experiment. A set of reading was obtained first by running the engine with neat diesel and varying the load from idle to rated load of 3.5 kW. The engine performance characteristics were recorded by using the software Engine Soft and instrumentation provided by the National Instruments. The emissions were recorded for each load by using Gas Analyzer AVL DiGas 444 and the opacity was recorded by smoke opacity meter (AVL 437c). Then, the engine was run on blends of ethanol-biodiesel-diesel and the parameters were recorded as above. The calorific value and density values of the fuels were entered accordingly in the Engine Soft. Similar sets of readings were recorded for different blends with varying the load.

4. RESULTS AND DISCUSSION

4.1 Percentage yield with time

For a plate, the percentage yield of biodiesel from waste cooking oil-methanol mixture increases with time. The percentage yield for the plate with more holes is higher than the plate with lesser holes. For a molar ratio of 1:6 (1 Methanol and 6 Oil), the highest percentage yield obtained is about 98.27% (for plate 3) as shown in fig. 3.



KOH %age = 1% of Oil
Molar ratio (Alcohol/Oil) = 1:6

Figure 3: Percentage yield v/s time

4.2 Carbon monoxide emissions

The CO emissions v/s Load for the engine is shown in the fig. 4. The CO emissions decreased with increase in blending ratio whereas the emissions increased with increasing load. It was noted that CO emissions of diesel fuel are higher than ethanol-biodiesel blends. This was due to ethanol-biodiesel blends containing more oxygen element, which gave better combustion..

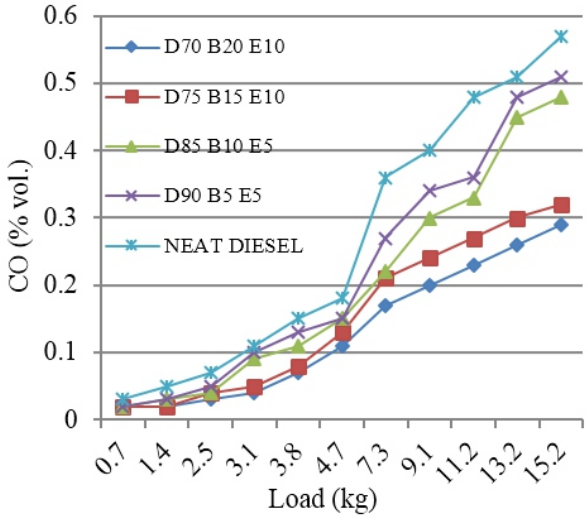


Figure 4: CO (% vol.) VS Load (kg)

4.3 Hydrocarbon emissions

The variation of HC emissions v/s Load for the engine is shown in the fig. 5. The HC emissions decreased with increase in blending ratio whereas the emissions increased with increasing load. It was noted that CO emissions of diesel fuel are higher than ethanol-biodiesel blends. This reduction in the emissions of HC with increasing the blends and load in the test fuel could be due to the combined effects of higher in-cylinder temperature, higher cetane rating and reduced ignition delay (Selvam and Vadivel, 2012).

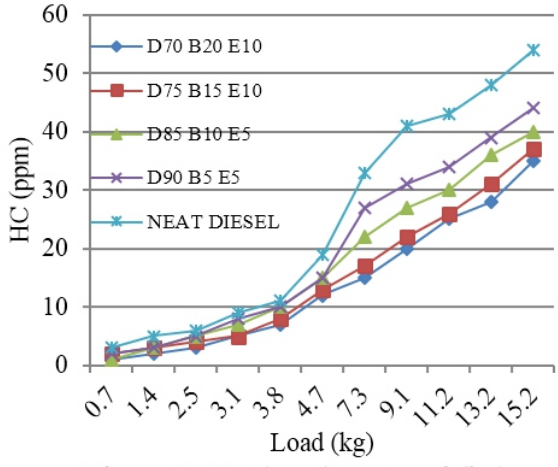


Figure 5: HC (ppm) Vs Load (kg)

4.4 Nitrogen oxide emissions

A comparison of NO_x emissions between ethanol-biodiesel blends and neat diesel v/s Load for the engine is shown in the fig. 6. It was found that NO_x emissions increased with the increased blending and load. The NO_x emissions of ethanol-biodiesel blends are higher than neat diesel. The trend is due to the higher oxygen content in ethanol-biodiesel blends is responsible for NO_x formation because it increases the local temperature which results in oxidization of excess hydrocarbon.

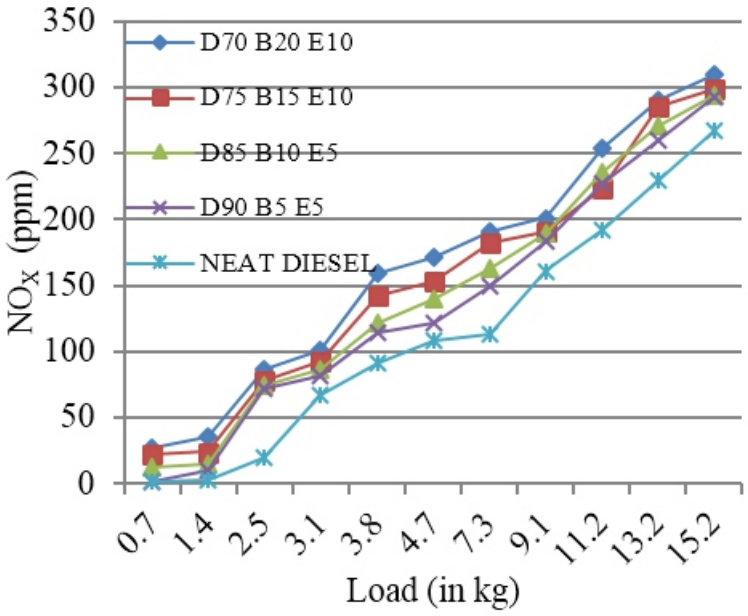


Figure 6: NO_x (ppm) Vs Load (kg)

4.5 Smoke Opacity V/S Load

The variation of opacity vs. Load for the engine is shown in Figure 7. The opacity value for neat diesel is slightly higher as compared to all type of blends for lower loads but as the load raised beyond 3.5kg, the opacity value for ethanol-biodiesel blends become higher than neat diesel.

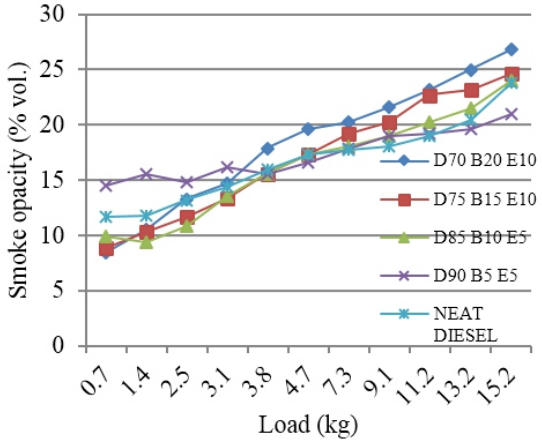


Figure 7: Smoke opacity (% vol.) Vs Load (kg)

4.6 Brake power

Figure 8 shows the variation of brake power v/s load for the engine. The power output increases with increasing load. There is nearly no variation observed in the power output of ethanol-biodiesel blends and neat diesel with engine load. Only D90B5E5 shows a slight decrease after a load value of 5.5kg. The highest brake power is obtained for D75B15E10 at 15.18kg load.

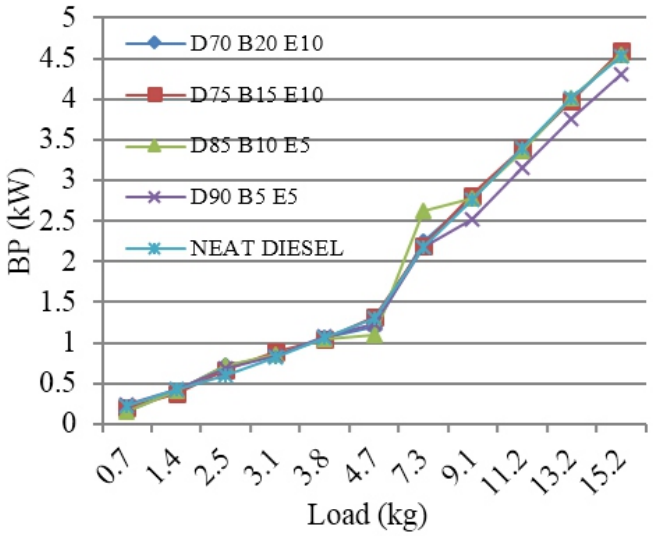


Figure 8: Brake power (kW) Vs Load (kg)

4.7 Brake specific energy consumption

The variation of brake specific energy consumption v/s load is shown in Figure 9. As shown in the figure, the BSEC initially has high value but it decreases with an increase in the load value. The BSEC for ethanol-biodiesel blends is higher than neat diesel for all load values.

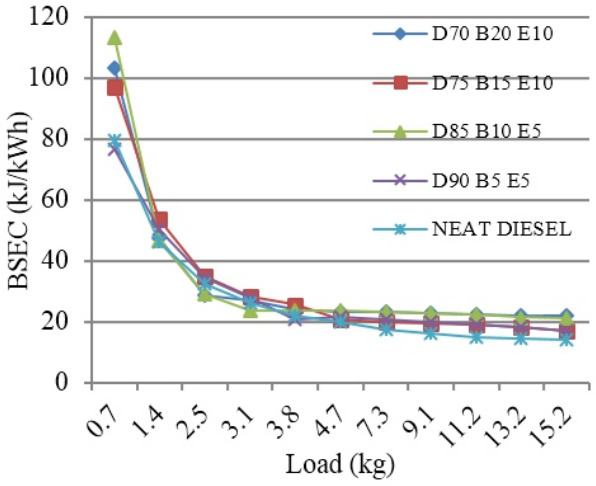


Figure 9: BSEC (kJ/kWh) Vs Load (kg)

4.8 Brake specific fuel consumption

Figure 10 shows the test results of the brake specific fuel consumptions (BSFCs) with load for the engine, when the engine fulled by different ethanol-biodiesel blends and neat diesel. From the results, it can be seen that the fuel consumption decreases with increase in the load. The more ethanol blends have more fuel consumption compared with neat diesel.

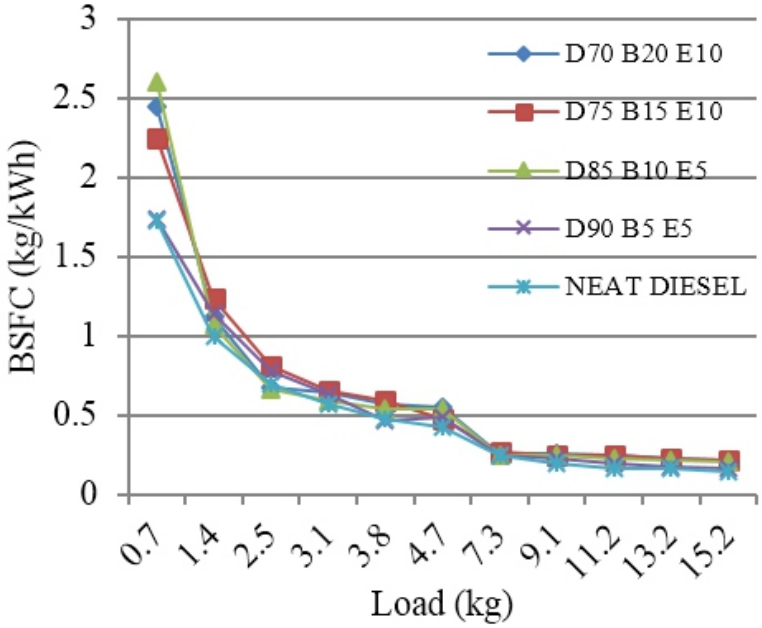


Figure 10: BSFC (kg/kWh) Vs Load (kg)

5. CONCLUSIONS

In the present research work, biodiesel is produced from waste cooking oil using Hydrodynamic cavitation and magnetic stirring. It was found that as we increase the amount of biodiesel in the blends, the density, specific gravity and kinematic viscosity of the blends increases and calorific value decreases. Hence, Hydrodynamic cavitation is found to be very feasible process for biodiesel production. For all the blends, there is almost linear increase in the BP with load. BSEC is least for D85B10E5, which is 0.65kJ/kWh at lower loads of 2.5kg and for neat diesel, BSEC is 0.15kJ/kWh at higher loads of 15.25kg. Among all the blends, D75B15E10 shows minimum emissions of carbon monoxide (0.08 %vol.) and hydrocarbon (8ppm) whereas a little higher emissions of NO_x (142ppm) at lower load of 3.8kg. Hence, from the results it is implied that ethanol-biodiesel-diesel blends show lesser emissions and better fuel characteristics than the neat diesel and therefore, they can be a good substitute for the neat diesel fuel.

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Review On Morphology And Microstructure Analysis Of Mgo Reinforced Al Composites For Rame 2016

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A B S T R A C T

The never-ending demands of advanced materials in the various fields of engineering and manufacturing has significantly increased the development of composite materials. Nowadays a shift is observed from the monolithic materials towards the composite materials. Numbers of ceramic materials are being used to reinforce various grades of aluminium alloy matrices. Metal matrix composites are exhibiting high potential characteristics as aerospace, automobile, defence, and research industries' materials. The properties of aluminium based composites can be easily tailored to achieve the desired strength, hardness, etc. This paper reviews the morphological and microstructural properties of aluminium reinforced with a refractory material i.e. MgO at Nano and micro levels. The input parameters governing the morphology and microstructure were weight and volume fraction of reinforcement and the sintering temperature along with the fabrication technique. The study of morphology included the porous nature of composite and the density measurements with hardness (Brinell Hardness Tester). A detailed review revealed the MgO as reinforcement in a various grades of aluminium is a promising material with a little consideration of its agglomeration and rigid nature during the fabrication process. It can be easily overruled by controlling the sintering temperature at the time of fabrication. Therefore, it can effectively and efficiently be used as a reinforcement with all heat treatable and non- heat treatable aluminium alloys.

Keywords: Aluminum Metal Matrix Composite, Magnesium Oxide, Morphology, Density, Hardness, Microstructure, Sintering, Powder Metallurgy

1. INTRODUCTION

Growing technologies demand smart materials and composites on nanoscale possessing all the desired properties. The various components of the composite retains their structure and characteristic, but the composite display better properties such as low density, elastic modulus, stiffness, high specific strength, strength-to-weight ratio, and enhanced wear and creep resistances [1]. The shift from monolithic alloys to particle and fibre reinforced composites revolutionised the aerospace and automotive world. The base metal used extensively is aluminium (Al) because of its properties and easy availability. Aluminium is ductile, light and strong material whose mechanical and electrical properties can be tailored. The aluminium based composites exhibits excellent properties such as excellent thermal conductivity, high shear strength, excellent abrasion resistance, high temperature operation, non-flammability, etc. allowing it to be used in various kinds of environment. The various kinds of reinforcements used are SiC, Al2O3, ZrO2, B4C, MgO, industrial wastes and agricultural wastes [2]. These materials possess properties such as refractoriness, high hardness, and high compressive strength, wear resistance, etc. enhancing their suitability as reinforcement in matrix of composites.

This paper reviews the research carried out previously on magnesium oxide reinforced aluminium based composite. Magnesium oxide (MgO) is a refractory material possessing properties such as the good thermal shock resistance, high melting point, low thermal conductivity and excellent thermodynamic stability [2]. MgO has high modulus and high strength refractoriness which when added to low ductile matrix produces composite with properties lying in between matrix and reinforcement. The controlling factors for the composite properties are the processing conditions, distribution of reinforcement and relative amount. Manufacturing of aluminium metal matrix composites can be done by liquid state process (squeeze casting, ultrasonic assisted casting, compo casting and stir casting) and solid state process (friction stir process, vapour deposition technique, powder blending followed by consolidation (PM processing) and diffusion bonding).

2. DENSITY MEASUREMENT

M.A. Baghchesaraetal. [2] investigated the variables that affect the density of the fabricated composite having elemental parts as Aluminium powder alloy (A356.1 with D50 = 1 μm) and nano-sized MgO (with D50 = 70 nm). The significant variables were the sintering temperature and volume per cent of Nano MgO. The highest density value were recorded in samples containing 1.5 and 2.5 volume per cent of nanoMgO at three temperatures (575°C, 600°C and 625°C). Increasing volume fraction of MgO particles in aluminium, increases the density of samples adhering to the fact that MgO has higher density. But the increased volume fraction affects the sintering and wettability of MgO in molten Al alloy

resulting in particles agglomeration and eventually in reduction of density. The melting point and sintering point temperatures are inter-related and due to this sample compaction is prevented. Hence, increasing the sintering temperature increases particles wettability which helps to reduce the porosities rate thereby increasing the density of samples.

Table 1: Reinforcement with SiC, Al2O3, MgO with particle size 0.220 µm for porosity and density after extrusion[4]

x	SiC		Al_2O_3		MgO	
	Density (gm/cm^3)	Porosity	Density (gm/cm^3)	Porosity	Density (gm/cm^3)	Porosity
0	2380	2.01	2380	2.01	2380	2.01
0.05	2421	3.0	2521	3.13	2501	4.0
0.06	2424	2.99	2499	3.12	2522	4.2
0.07	2451	3.2	2525	3.09	2493	4.1
0.08	2462	3.1	2509	3.09	2499	3.79
0.09	2466	3.15	2530	3.11	2507	4.06
0.10	2460	3.4	2533	3.13	2511	4.08

H. Abdizadeh et al. [3] conducted comparative study of density of composite fabricated by stir casting and powder metallurgy process possessing various content of MgO particles by volume. The results exhibited the casted composites were denser than the sintered samples. This occurs due to the high porosity which is encountered in the sintering process. It was clearly discovered that the porosity during the fabrication process significantly affect the density of the sample. As the volume of MgO is increased from 1.5 to 2.5 volume %, the density increases but above 5% the porous nature resurfaces and the density value goes down. Whereas in sintered samples the increased MgO content decrease the density because of the formation of rigid MgO network in composite.

NripJit et al. [4] analysed the porosity and density for SiC, Al2O3 and MgO as reinforcements maintaining the particle size constant at 0.220 in A384.1. A characteristic change was observed in these factors of the Al alloy and MMCs from as-cast to extrusion as a function of reinforcement from x=0 to x=0.10. The porous nature was found to increase with increasing content of reinforcement. The table below shows the high values of porosity are obtained in case of MgO as reinforcement while high values of density are obtained in case of alumina as reinforcement. MgO being a refractory material forms a rigid network in composites resulting in decreased wettability in molten matrix. The decreased value leads to porous nature of composite sample which directly reduces the density.

3. MICROSTRUCTURALANALYSIS

M.A. Baghchesaraetal. [2] conducted the research on the microstructures of fabricated composites with variable MgO content. The figures below shows the microstructures with the content of 2.5 and 5.0 vol % MgO, sintered at 625 °C. With 5.0 vol% MgO, agglomeration of particles has been initiated which becomes prominent as the sintering temperature is slightly decreased from 625 °C to 575 °C. It is clearly visible from the figures that MgO nanoparticles are well embedded in the aluminium matrix at low MgO content. Similar experiments were conducted to study the effect of reinforcement content through the microstructure analysis at various sintering temperatures. MgO agglomeration displayed the porous behaviour in the composite which is visible in the figures 1.

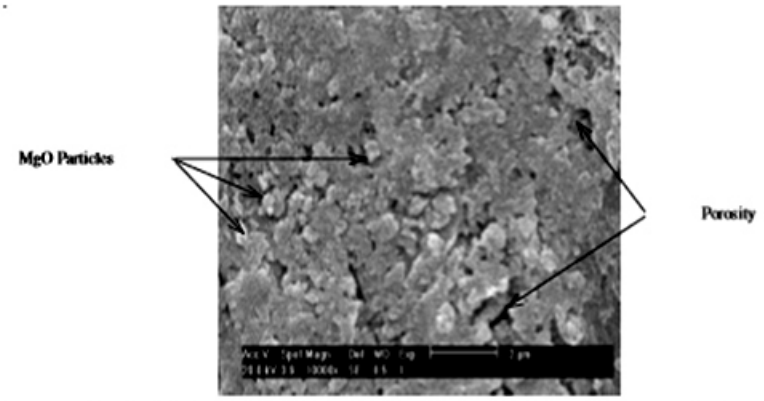

Figure 1 (a): SEM image of composite containing 2.5 vol % MgO sintered at 625 °C[2]

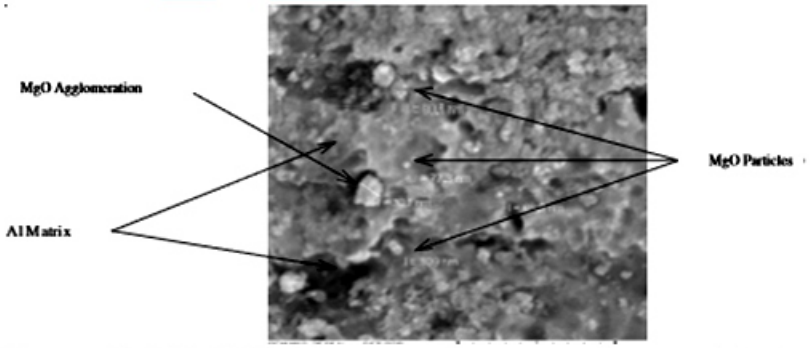

Figure 1 (b): SEM image of composite containing 5 vol % MgO sintered at 625 °C[2]

E. Manikandan et al. [5] studied the microstructural images of MgO reinforced aluminium composite with weight fraction of 2.0 wt.% and 2.5 wt.%. The homogeneity of the composite was excellent at low weight fraction of reinforcement but it was disturbed as the weight fraction was increased. This disturbance occurs due to the rigid behaviour of MgO and low thermal conductivity developing a porous structure.

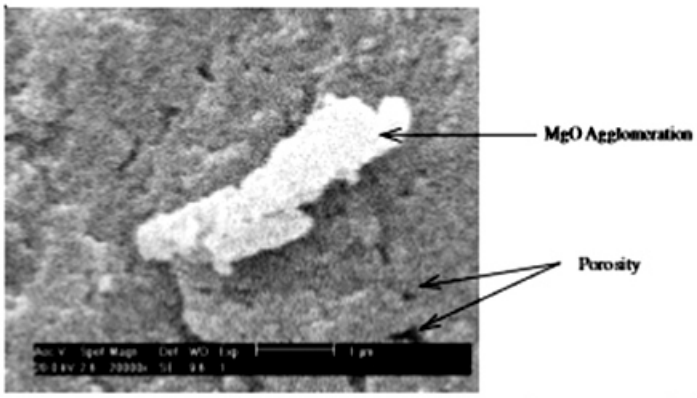

Figure 1 (c): SEM image of composite containing 5 vol % MgO sintered at 625 °C[2]

P. Balaji et al. [6] conducted a comparative research on the microstructure of Al 6061 alloy with Al 6061 – Magnesium Oxide (MgO) composite using SEM. The figures below display the microstructure of aluminium alloy and aluminium composite at 2.0 wt.% of MgO as reinforcement. It was observed that the porosity starts dominantly as the reinforcement content is increased beyond 2.5 wt. %. This can be controlled by increasing the sintering temperature which is directly controlling the wettability property of the reinforcement.

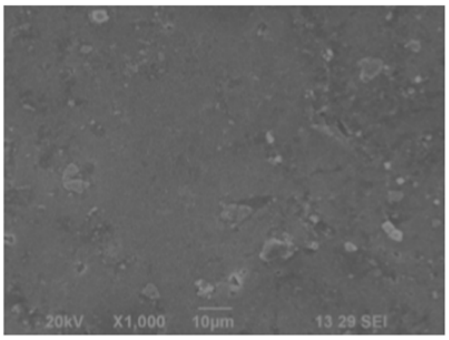

Figure 2 (a): SEM image of aluminium alloy[6]

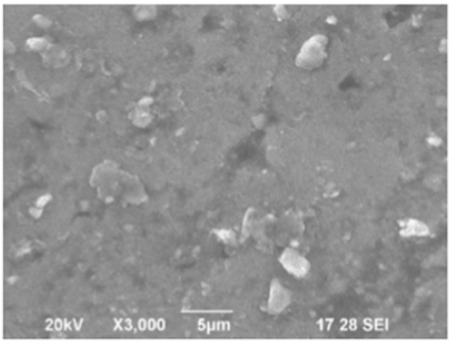

Figure 2 (b): SEM image of Al-MgO composite of 2.0 Wt. %[6]

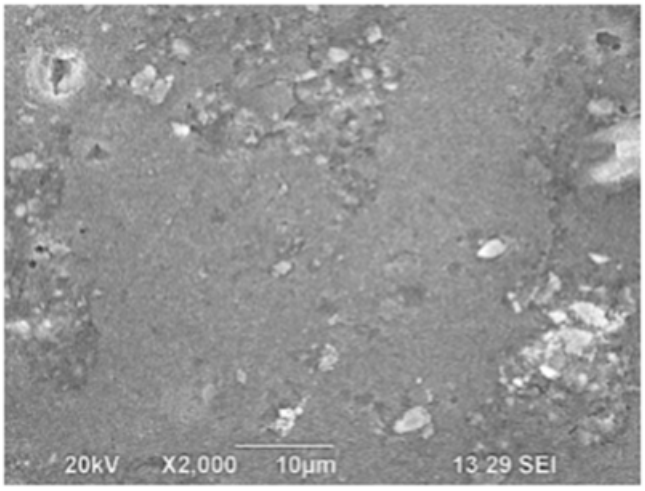

Figure 2 (c): Presence of pores in the Al-MgO composite of 2.5 wt. %[6]

A.R.I. Kheder et al. [7] discussed about the strengthening effect of various reinforcement through the microstructure analysis. Optical microscope was used to analyse the particulate volume fractions, their distribution in the casting and the grain size of the Al matrix at a magnification of X50 [8]. The results displayed that the particulate volume fractions were uniformly present across the casting, horizontally and vertically. Though a slight difference exist between the volume fractions values in horizontal and vertical direction. The variation in horizontal direction is less than that in vertical direction. These results confirmed that the composite preparation was successfully done with relatively uniform distribution of the particulates within the matrix. It was also observed that the addition of the particulates decreased the grain size which was 897 µm for pure Al in as-cast condition. The largest decrease was viewed at initial additions of the particulates, namely at 5 wt% in all cases, then the decrease diminished and at 20 wt% particulate additions it became almost constant. The composite grain sizes are finer than the base matrix as these particulates act as nuclei for the grain formation during solidification and also inhibit the processes of the grain growth [9].

Harsh Bhadiar et al. [10] worked on the morphology of the fabricated aluminium based composite by varying reinforcement weight percentages. The MgO was studied as reinforcement using the Secondary electron imaging mode of Scanning electron microscopy. SEM image of initial silicon carbide particles are mostly angular at 5% weightage of reinforcement which was destroyed to attain flake shaped particles at 15% of weightage reinforcement of MgO and SiC. This destruction of shape was followed to lead to sub-angular particles generating a rough surface morphology. The X-Ray Diffraction and SEM study shows that the addition of MgO particles in different amount of sizes and varying percentage of particle sizes in the casting strengthens composites particularly, at 10% of MgO as shown in the figure(s) 3.

4. HARDNESS

Praveen G et al. [11] investigated the hardness of A356.1 Aluminium Alloy Matrix composite reinforced with MgO particles. The Brinell Hardness Tester with a load of 187.5 Kgf and with a Ball Indenter Diameter of 2.5mm was used to test the composite at various Wt. % reinforcements (0.5, 1.0, 1.5, 2.0) for varying temperature and T6 condition of heat treatment. The Hardness Number (BHN) for As cast A356.1 Aluminium alloy at room temperature (280 °C) is 73.61, which gradually increases to 89.97 at 540 °C for As cast material, after heat treatment.

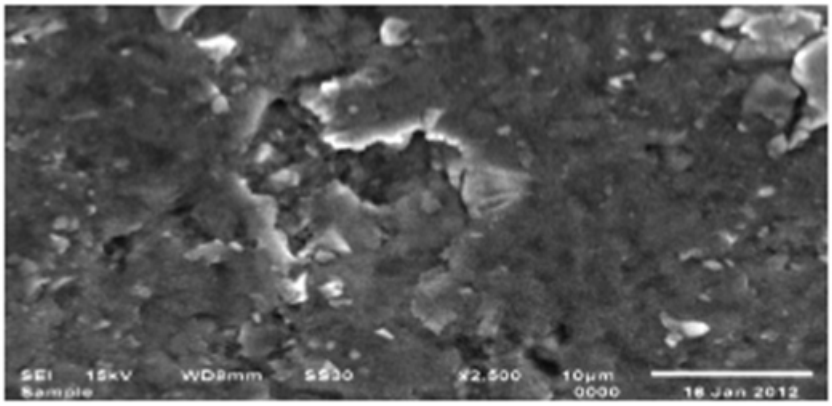

Figure 3 (a):At 5 % (wt.) of MgO-AMMCs[10]

Similarly the Hardness Number for 2 Wt.% reinforced A356.1 Aluminium alloy at room temperature (280 °C) is 79.53 while after heat treatment it increases to 98.41 at 540 °C.

Girisha K.B et al. [12] researched the mechanical properties of Al356.1 aluminium alloy matrix composites reinforced with MgO nanoparticles. The base matrix was reinforced with MgO reinforcement with content % as 0.5, 1.0, 1.5 and 2.0. The hardness increases as the reinforcement content increases but shows a dip due to its rigid nature and agglomeration in the composite. This agglomeration enhances the porosity which decrease the strength and hardness of the composite. This is clearly depicted in the graph shown below.

A.R.I. Kheder et al. [7] discussed about the strengthening effect of various reinforcement along with the hardness and impact tests. The graph below displays the result as enhancement in the value of hardness on increasing wt% of the particulates used in this work. These increases can be related to the interaction of the dislocations with the particulates and grain refinement with increasing wt% of the particulates.

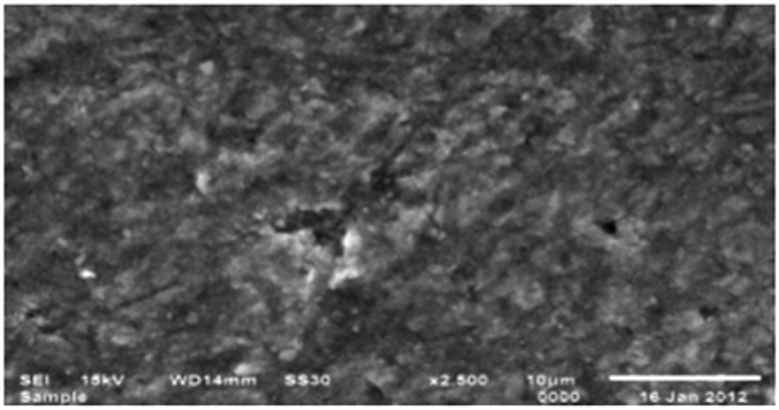

Figure 3 (b):At 10 % (wt.) of MgO-AMMCs [10]

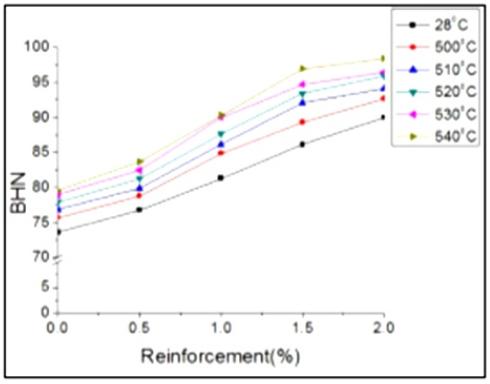

Figure 4 (a): BHN Vs Wt. % Reinforcements at varying temperatures by Praveen G et al. [11]

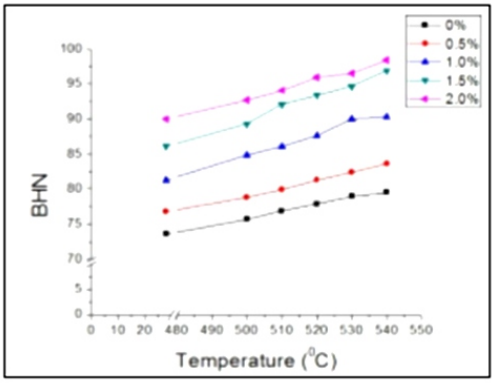

Figure 4 (b): BHN Vs Temperature for Different Wt. % Reinforcements by Praveen G et al. [11]

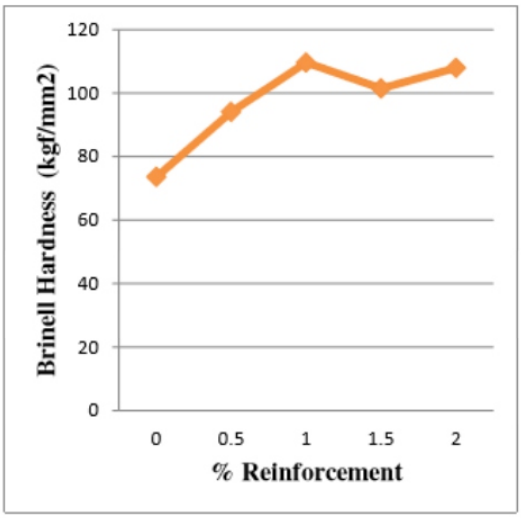

Figure 5 (a):Hardness Vs Reinforcement by Girisha K.B et al. [12]

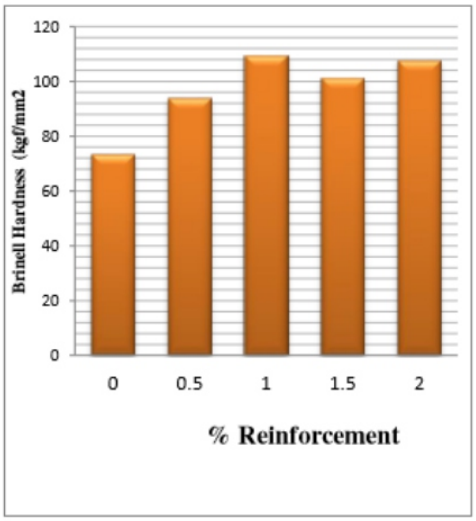

Figure 5 (b): Bar Chart of Hardness Vs %of Reinforcement by Girisha K.B et al. [12]

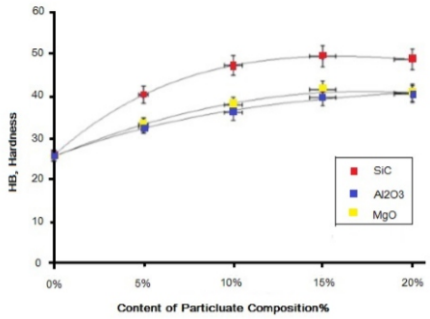

Figure 6: Brinell hardness vs. particulate weight percentage by A.R.I. Kheder et al. [7]

5. CONCLUSION

A review of the research work on Aluminium Matrix Composites has been presented in this paper. The various grades of aluminium have been studied with various reinforcements and they have been tested for their morphology and mechanical properties for a long time. This paper presents the effect of content of magnesium oxide in various grades of aluminium. Three characteristics have been thoroughly focussed on i.e. density, microstructure and hardness.

It can be concluded from the review that on increasing the MgO content beyond a certain value significantly affect the density and hardness of the composite. The density and hardness shows a dip on increase in content of reinforcement due to the refractoriness behaviour of MgO particles which form a rigid network during the process of fabrication. This creates pores and voids which decrease the strength and density eventually affecting the hardness of the composite. In order to prevent the porous structure of the composite, the sintering temperature is increased which enhance the wettability of the MgO particles in the molten aluminium. Hence, the interpretation of the review explains MgO as a good reinforcement material because of the high hardness, stiffness and strength it imparts to the composite considering a little care of its rigid network formation and the agglomeration process.

MgO nanoparticles when added to base matrix alter the mechanical properties such as hardness, density, surface finish etc. The properties strictly vary on the basis of amount being added in the matrix. It has been observed that composites containing 2.5 and 5 vol. % MgO fabricated at 625˚C showed maximum compressive strength and hardness respectively when compared to other volume %. Among these two variants, 2.5 vol % reflects high reliability as it has maximum density. As the content of MgO is increased composites exhibit a decrease in the mechanical properties [13]. MgO nanoparticles also possess an impressive quality of adsorbing and retaining for a long time (in the order of months) the significant amounts of halogens such as chlorine and bromine due to the extensive porous structure with considerable pore volume. They have the potential properties which enable them to act as a potent disinfectant. These particles have a stronger and faster effect on the killing action of both bacteria and spores [14]. Moreover the antibacterial activity of the MgO nanoparticles is size and concentration dependent [15].

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Split and Recombination Micromixer with Offset Inlets

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A B S T R A C T

E Present study proposes a novel design of passive micromixer based on the concept of offset inlets, and split and recombination. The proposed micromixer is designed with non-aligned inlet channels and spatially repeating 3D mixing units with mixing chambers & sub-channel having alternate bends to stir the flow. A variance based mixing index was used to compute the degree of mixing of fluids. A characterization methodology was employed to study the effect of various design parameters. A comparison of mixing performance was performed between proposed micromixer and 3D serpentine micromixer. The proposed micromixer gives excellent performance over a wide range of Reynolds number covered in the study.

Keywords- Passive micromixer; offset inlets; Split and Recombination; Numerical Analysis; Mixing index.

1. INTRODUCTION

Many biological processes require efficient mixing of reactants e.g. enzyme reactions, DNA sequencing, protein folding, etc. Nowadays focus is on developing methods to manipulate the flow in microchannels to enhance fluid mixing. Large surface to volume ratio of microfluidic devices facilitates in mixing that helps to control the output in chemical reactions. Micromixers can be broadly classified into two categories, i.e., active and passive. Passive micromixers do not require any external source, they have specially designed geometries to alter the flow pathuid flow and achieve better mixing.

Stroock et al. [1] investigated a T-channel having periodic herringbone grooves and observed the formation of transverse flow that caused chaotic advection thus enhanced the mixing in the channel. The split and recombination concept has also been considerably used to improve mixing performance in microchannels. Ansari et al.[2] showed that at higher Reynolds numbers (Re > 40) split and recombination based on unbalanced collision was more effective in enhancing the mixing performance. Later Afzal & Kim[3] performed numerical analysis of a micromixer having convergent divergent walls with split and recombination and observed that symmetric pair of Dean vortices formed at the throat of the divergent portion that effectively increased the mixing of fluids. Interfacial area of fluid streams gets increased by Dean vortices, thereby facilitating faster diffusion and increases mixing performance. Hossain & Kim [4] performed numerical simulations on 3D serpentine SAR micromixer and compared its mixing performance with 3D serpentine micromixer. It was noticed that performance of 3D serpentine SAR micromixer was better than the 3D serpentine micromixer and the reason was presence of two mixing mechanisms, split and recombination and chaotic advection.

Viktorov et al.[5] proposed two novel micromixer designs (Y-Y mixer & H-C mixer) based on the concept of split and recombination and carried out comparative analysis with tear drop micromixer. The mixing performance was better for the two designs in comparison to that of tear drop micromixer, also the pressure drop values were lower. Ansari et al.[6] observed that by making the inlet channel non-aligned, mixing performance of micromixers can be significantly increased. With this motivation, a novel design of passive micromixer based on the concept of offset inlets, and split and recombination is proposed in the present study. The micromixer is having non-aligned inlet channels, spatially repeating 3D mixing units of mixing chambers and sub-channels with alternate bends to stir the flow. A variance based mixing index was used to compute the degree of mixing of fluids. A characterization methodology is employed to study the effect of various design parameters and performance analysis has been done through three-dimensional numerical analysis.

2. NUMERICAL METHODOLOGY

The schematic of the proposed passive, three-dimensional, split and recombine micromixer with offset inlets is shown in Fig.1. The height (H)and pitch (p) was fixed at 600 µm and 700 µm, respectively. The mixing channel depth (d) and total depth (D) were fixed at 80 µm and 160 µm, respectively. The main channel splits into two sub-channels of equal width (w) and then recombines at the mixing chamber (length = lc and height = h) with offset arrangements. The inlet and exit channel lengths were fixed at 1.5 mm. Five repeating mixing units were taken for study. Three non-dimensional parameters, viz., lc/p, h/H and w/d, were formed and varied from 0.36 to 0.42, 0.25 to 0.5 and from 0.625 to 1.375, respectively. Water and ethanol were taken as working fluids for micromixer as shown in Fig. 1.

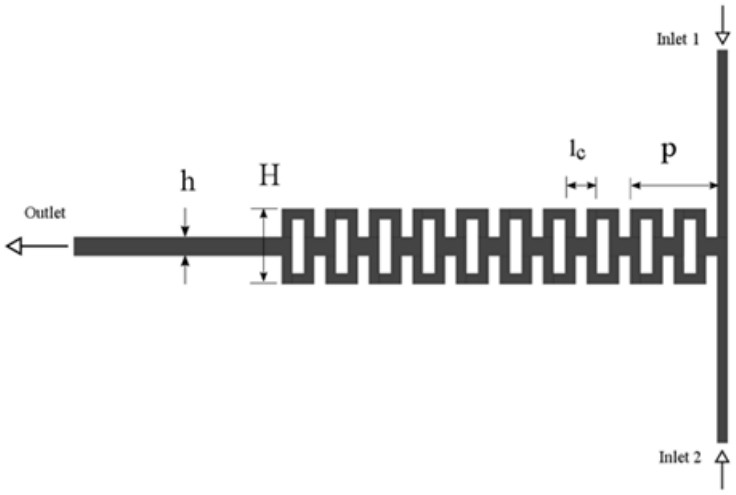


Figure 1. Schematic of the proposed micromixer.

A commercial code was used for performing numerical simulations by solving advection-diffusion equation for steady, incompressible laminar flow. The domain was discretized using structured high quality hexahedral grid. The advection-diffusion type equations solved for the concentration field by combining concentration field with mass conservation equation for each fluid as shown below:

$$\vec{\nabla}.\vec{\nabla}C_i = \alpha\nabla^2 C_i \qquad (1)$$

Here, Ci is the concentration gradient and α is the diffusion constant. Eq. (1) was used to calculate the mass fraction of each of the mixing components. Pure ethanol enters from Inlet-1 and pure water enters form Inlet-2. At outlet condition of zero static pressure was applied. A no-slip condition was used over the channel walls. The properties of both fluids (water and ethanol) have been taken at 20ºC. Reynolds number was computed based on the properties of water. To determine degree of mixing performance of the micromixer variance (of mass fraction) based mixing index has been used. The numerical analyses were performed for various Reynolds numbers ranging from 0.1-50.

3. RESULTS AND DISCUSSION

Fig. 2 shows the velocity vectors and fraction distribution at the mid of different mixing chambers. There is no formation of vortices at low Reynolds numbers (Re = 5) whereas at high Reynolds numbers (Re = 50), a large vortex is formed in the mixing chamber which contributes to mixing enhancements. The presence of secondary flows in mixing chambers & in sub-channels stretches the fluid interfaces resulting in increase in mixing performance.

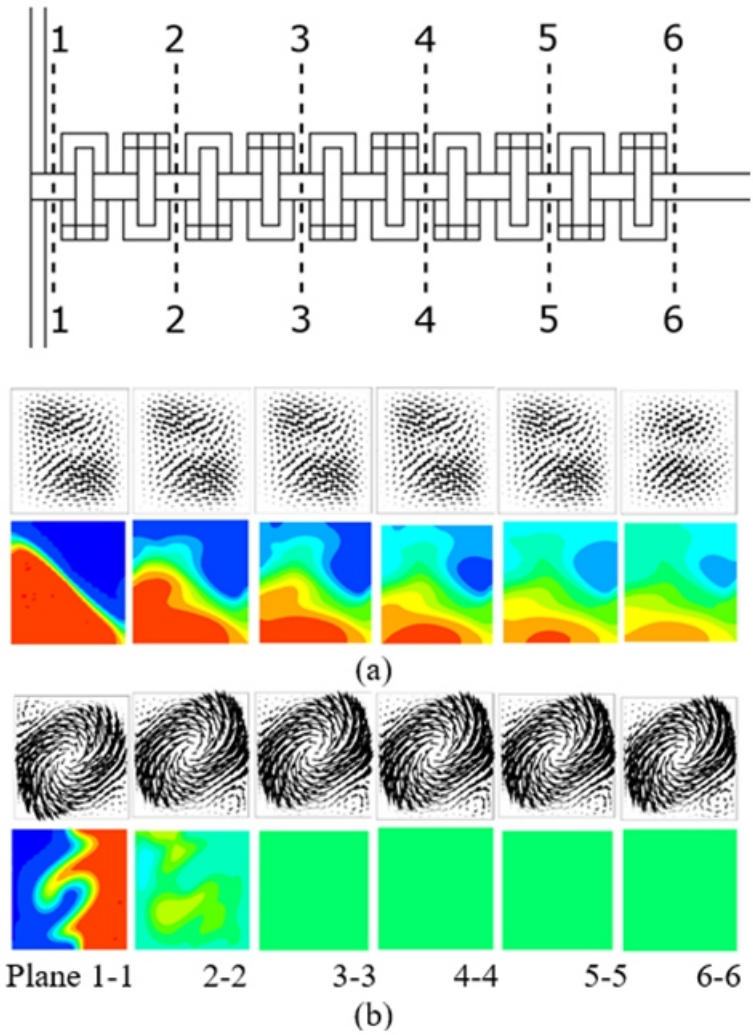
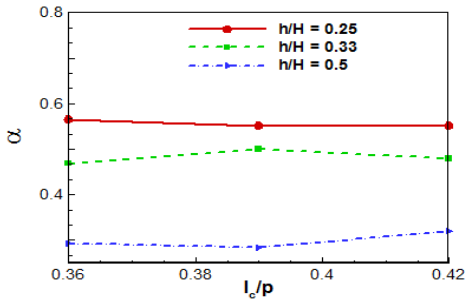


Figure 2. Velocity vectors and Ethanol mass-fraction distribution on yz plane at the middle of mixing chambers for (a) Re = 5 and (b) Re = 50.

It is observed that similar mixing performance is obtained at low and high Reynolds number values for different values of parameters, however their effect becomes significant at intermediate Reynolds numbers. Fig. 3 shows the effect of different parameters on mixing performance at Re = 5. There is insignificant change in mixing index with change in lc/p values. It was also observed that change in h/H values has more pronounced effect on mixing than change in w/d values. Higher mixing performance is observed for lower h/H values (h/H = 0.25).



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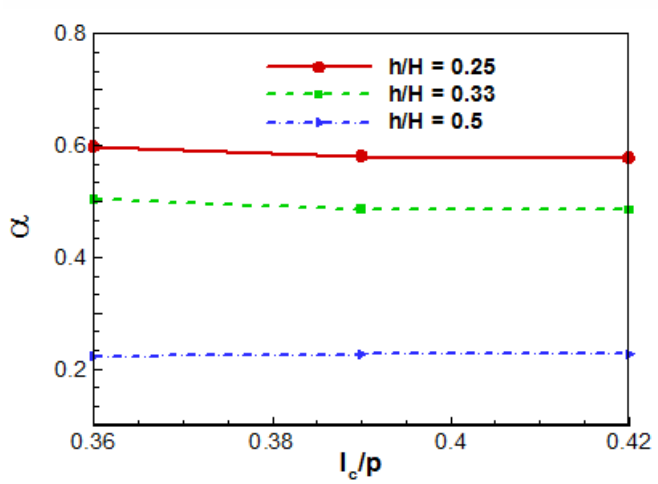

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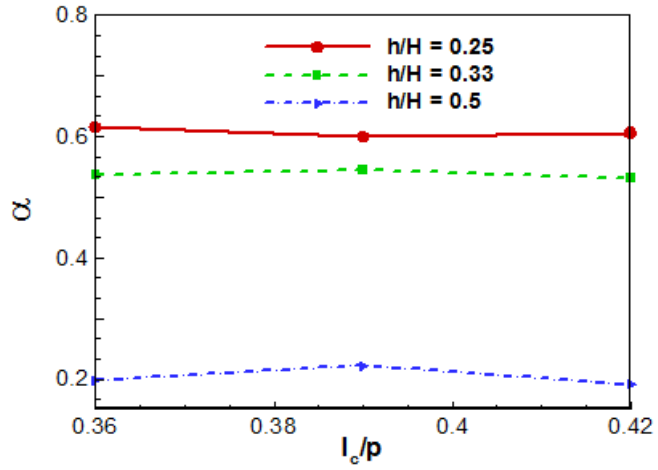
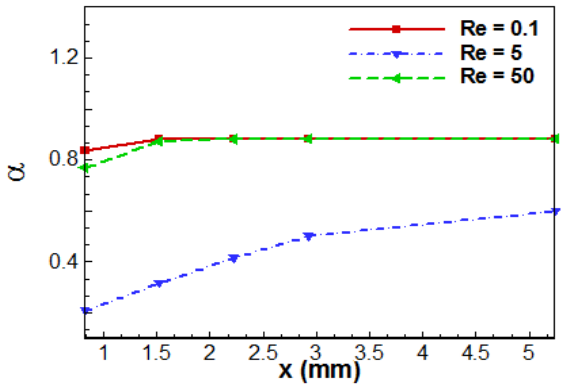


(c)

Figure 3. Variation of mixing index with lc/p for different h/H values at fixed w/d values at Re = 5. (a) w/d = 0.625 (b) w/d = 1 (c) w/d = 1.375.

The mixing performance was found to be the highest for lc/p = 0.36, h/H = 0.25 & w/d = 1 at all Reynolds numbers. It is observed that maximum mixing is achieved within three mixing units, except for Re = 5 (see Fig. 4) and later mixing units contribute marginally. It means we can use lesser number of mixing units to have same mixing performance and it will result in relatively smaller pressure drops.



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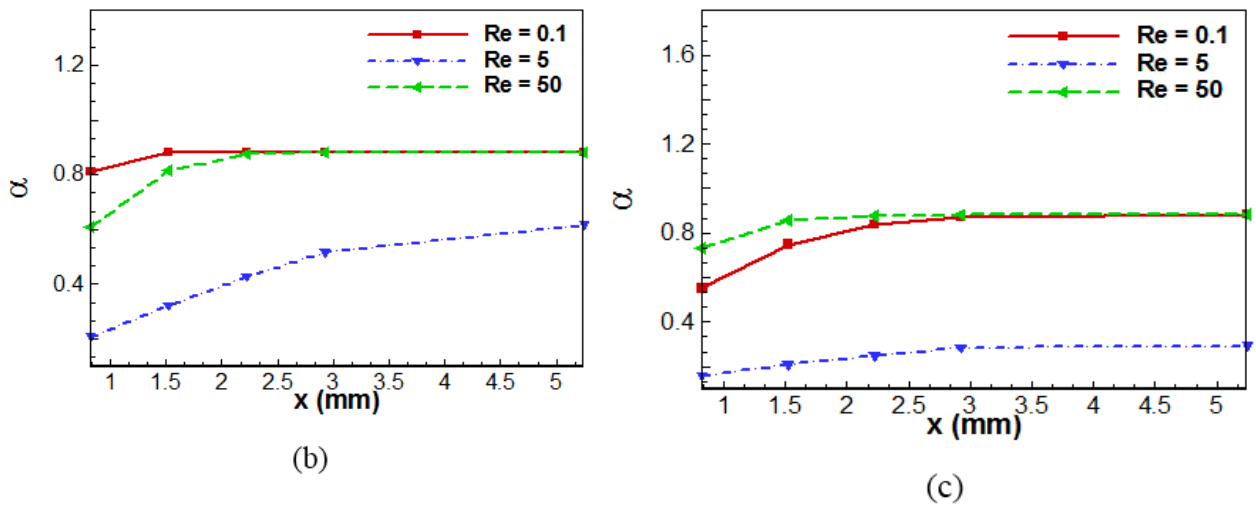

Figure 4. Mixing index variation along the micromixer length for Re = 0.1, 5 and 50 and lc/p = 0.36, h/H = 0.25 & w/d = 1 (b) h/H = 0.25 & w/d = 1.375 and (c) h/H = 0.5 & w/d = 0.625.

A comparison for mixing performance at various Reynold number values has been done between the proposed micromixer and 3D serpentine micromixer as shown in Fig. 5. The mixing performance at Re = 0.1 was found to be 88% higher and at it was 84% higher Re = 1 than the mixing obtained by previously reported 3D serpentine proposed by Ansari et al.[7]. The proposed micromixer performs better than the previously proposed micromixer at all Reynolds numbers covered in this study.

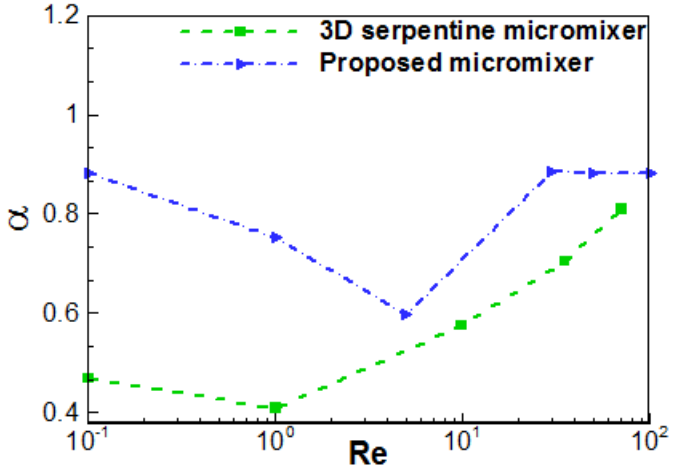

Fig. 5 Comparison of mixing performance of proposed micromixer with 3D serpentine micromixer [7] .

4. CONCLUSION

The variation of lc/p did not show any significant effect on mixing index. The mixing values were higher for smaller values of h/H mixing index. Effect on mixing with change in h/H values, is more significant than change in w/d values. The effects of change of parameters are more prominent for medium Reynolds numbers than low and high Re numbers. Lesser number of mixing units can be used for low and medium Re values as the maximum mixing is achieved within first three mixing units. The mixing index at exit for lc/p = 0.36, h/H = 0.25 and w/d = 1 is the highest, at all Re values covered in this study in comparison to other parameter values. Over entire range of Reynolds number covered in the study, the proposed micromixer gives excellent performance. The mixing performance at Re = 0.1 was found to be 88% higher and at Re = 1 was found to be 84% higher than the mixing obtained by previously reported 3D serpentine micromixer.

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