BEHAVIOUR OF DIESEL COMBUSTION AND EXHAUST EMISSION WITH NEAT DIESEL FUEL AND DIESEL-BIODIESEL BLENDS

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ABSTRACT

The diesel combustion and exhaust emissions with neat diesel fuel and diesel-biodiesel blends are investigated. In the investigation, firstly, making of biodiesel is done by esterification and secondly, experiment is conducted with neat diesel fuel and diesel-biodiesel blends in a four stroke naturally aspirated (NA) direct injection (DI) diesel engine. The volumetric blending ratios of biodiesel with conventional diesel fuel are set at 0, 5, 10, 15, and 20.. Compared with neat diesel fuel, diesel-biodiesel blends show lower carbon monoxide (CO), nitrogen oxides (NOx) and smoke emissions due to improved properties after esterification and presence of oxygen in the biodiesel. Engine noise is reduced with all diesel-biodiesel blends.

INTRODUCTION

As world petroleum supplies become constrained attention is directed to crop-based sources of fuels for engines. Among such sources are crops, which produce oil directly. Of these oils, castor is the highest yielding oil producer. Commonly the processing of the castor fruit to extract the oil is done in plants, which use process residue to meet all plant fuel requirements. Because of these energy economics, the fossil fuel consumption to operate the entire castor oil production system has an energy value less than 10 percent of the energy contained in the oil produced. The non-renewable nature and limited resources of petroleum fuels become a matter of great concern. After the 1973 oil embargo, it is very important to study the alternative sources of fuel for diesels because of the concern over the availability and the price of petroleum based fuels. The present source of fuels used in IC engines and diesel will deplete within 40 years if consumed at an increasing rate estimated to be of the order of 3% per annum. All these aspects have drawn the attention to conserve and stretch the oil reserves by way of alternative fuel research. In Bangladesh, diesel is primarily used for transportation, agriculture and electric power generation. Transportation of goods and people in Bangladesh is dominated by road transport, which accounts for 80% of accounted for about 75% of diesel. Despite, Bangladesh rapidly growing industrial, she still has a very low per capita energy consumption of 245 Kg of oil equivalent per year only as compared to 7200 Kg for USA and 670 Kg for China. As energy and economy are closely linked, it is realized that a growing economy should demand a much higher level of energy consumption. There are several possible alternative sources of fuels, namely vegetable oils, alcohols such as methanol and ethanol gases such as compressed natural gas (CNG), liquefied petroleum gas (LPG) and producer gas etc. Among them vegetable oils present a very promising alternative to diesel since they are renewable and are produced easily in rural areas where is an acute need for modern forms of energy. The inventor of diesel engine, Dr. Rudlof Diesel was first to use vegetable oil in one of his engines. The choice of the

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vegetable oil for diesel engine fuel naturally depends upon the local conditions. A number of oils are being considered world wide for use in engines. This includes karanji oil, cottonseed oil, palm oil, castor oil, and Neem oil. Before petroleum fuels were in widespread use in topical countries, there was considerable interest in the use of both vegetable and animal oils as fuel. In general, the investigations cited reported that castor oil served satisfactorily as fuel for engine, although energy output of the engine was greater than for diesel value of castor oil.

Fang (1) used various vegetable oils as fuel in a diesel engine and found incomplete combustion to be a problem when these fuels were used in a cold engine. He recommended starting and stopping the engine on diesel fuel and heating the injectors and fuel lines so that vegetable oils could be better atomized to burn more completely.

Bruwer et al (2) used sunflower oil in engines and concluded that there may be some potential for improving the feasibility of such applications by making methyl or ethyl esters from the vegetable oil so that the viscosity of the fuel material may be more nearly that of the diesel fuel.

Cruz et al (3) reported tests with several vegetable oils in diesel engines. They found that the high viscosity of these oils was associated with reduced atomization of the fuel by the injector, which is some cases caused delayed ignition characteristics and reduced efficiencies of mechanical power production from those found with diesel fuel.

Bona et al (4) found valves; cylinders and pistons are in good condition as regards carbon deposits, while a lacquer-like coating is found to be especially thick on the piston. Rod bearings showed clear but acceptable traces of mechanical damage, probably due to the reduced lubrication characteristics caused by the typical dilution found when using biodiesel fuel. During dismantling, various types of deposit and sludge are noted in several parts of the engine. Reduced engine performance observed during bench tests may be attributed to malfunctioning of the injection system, oil filters, which still functioned in an acceptable manner, has accumulated considerable quantities of sludge.

Kenneth J. Suda (5) observed that diesel engine performance with vegetable oils is similar to that with diesel fuel. The objective of the experimental work performed by Prof. Suda was to eliminate the excessive liner wear in higher rated pre-chamber diesel engines, while burning the lowest reasonable grade vegetable oil fuel.

K.C. Singhal and H.B. Mathur (6) have worked with ethanol diesel dual fuel and investigated the effects of ethanol carburetion on engine performance of a direct injection diesel engine. They carried out the combustion studies to analyze dual fuel engine performance. Their investigations revealed that the engine performance with ethanol carburetion at higher loads is comparable to that with neat diesel fuel and that the engine could develop more power with cleaner exhaust effluents than that obtainable with neat diesel fuel.

In this report diesel combustion and exhaust gas emissions was investigated with neat diesel and diesel-biodiesel blends. The methyl ester of nonedible vegetable oil was made first and then blended with conventional diesel fuel. The volumetric blending ratios of biodiesel to diesel fuel were 5-15%. Finally, the exhaust gas emissions with biodiesel blends were investigated and compared with those of neat diesel fuel.

EXPERIMENTAL SETUP AND PROCEDURE OF EXPERIMENTATION

The engine used in this experiment was a single cylinder water-cooled, DI diesel engine. The specification of the tested engine is shown in Table 1. The experiment was conducted with conventional diesel fuel, esterified Neem oil and their blends. The properties of the diesel fuel and esterified Neem oil are shown in Table 2. The RPM was measured directly from the tachometer attached with the dynamometer. The outlet temperatures of cooling water and exhaust gas temperatures were measured directly from the thermometer attached to the engine. The exhaust gases including smoke, NOx, CO, CO_2 were measured with a portable digital gas analyzer (IMR 1400). The data of exhaust emissions were taken from 0.61m apart from the engine. The reading of filter smoke number is taken as 6, 7, 7.5 etc out of scale 9. The determination of smoke number depends on the technique, which is used. IMR 1400 is featuring the bacharach soot (smoke) number with a scale from 0 to 9. Evaluation of the soot spot is made visually by comparing the soot spot on the filter paper versus the bacharach scale. The Bosch soot number, which is scaled also from 0 to 9, requires a higher resolution. According this technique a soot number is determined 0 to 9, which cannot be determined visually. The Bosch soot number features a densitometer, which can determine the soot number accordingly.

RESULTS AND DISCUSSION

Making of biodiesel from Neem oil

The process used for making laboratory quantities of vegetable oil esters is to first mix the proportion of anhydrous lye catalyst (NaOH) to methyl alcohol (CH_3OH) and to then mix this combination with the moisture-free Neem oil. The materials are maintained at 55-60C and allowed to settle by gravity for 24 hours. After that, the translucent methyl esters of Neem oil are produced, which are termed as biodiesel. In all cases, 0.6% of lye catalyst as a reagent and 20% methyl alcohol are used for making biodiesel.

Fourier transform infrared (FTIR) spectroscopy of esterified Neem oil

Figure 1 shows the ir-spectra of esterified and non-esterified Neem oil, which is almost common to all petroleum products. The ir-spectra of neat esterified and non-esterified Neem oil shows the pronounced functional groups, which indicates the presence of alkanes and lesser extent aromatics and poly-aromatics groups, with a clear absence of phosphorus and sulfur. The ir-spectra of these oils also show that they contain significant amount of esters. The esterified Neem oil contains a little amount of water and this water is removed by heating the oil before using in the engine. The higher percentages of esters, alkanes and absence of phosphorus and sulfur make this esterified non-edible oil the future candidates for alternative environment-friendly fuels. The comparative frequency ranges and their corresponding functional groups and indicated compounds are presented in Table 3.

Table 1 Specification of tested engine

ITEMS	SPECIFICATION
ModelS	195
Type	Single cylinder
Bore stroke	95 115 mm
Rated output	13.2 hp/2000 rpm
Compression ratio	20
Type of cooling	Water evaporative
Injection pressure	13.5 MPa

Table 2 Properties of tested fuel/oil

Fuel/oil	Viscosity (cP)	Density (g/cc)	HHV (MJ/kg)
Diesel fuel	6.8	0.80	44.5
Non-esterified Neem oil	73.0	0.90	39.5
Esterified Neem Oil	8.8	0.82	40.1

Table 3 FTIR functional groups and indicated compounds of esterified and non-esterified neem oil

Frequency Range (cm^{-1})	Non-esterified neem oil: Functional Group	Non-esterified neem oil: Class of Compound	Esterified neem oil: Functional Group	Esterified neem oil: Class of Compound
3700-3100	O-H stretching	Alcohol (Medium),	O-H stretching	Alcohol (Strong)
3000-2650	—	—	C-H stretching	Alkanes, Alkenes
2400-1900	C=C bending	Sulfur, Phosphorus, Silicon, Alkynes & Isocyanides	—	—
1850-1450	—	—	C=O stretching	Acid (Medium), Oxygenated compound, Aldehydes, Ketones
1450-900	—	—	H-CO-O-R	Ester and ether
900-650	—	—	—	Aromatic compound

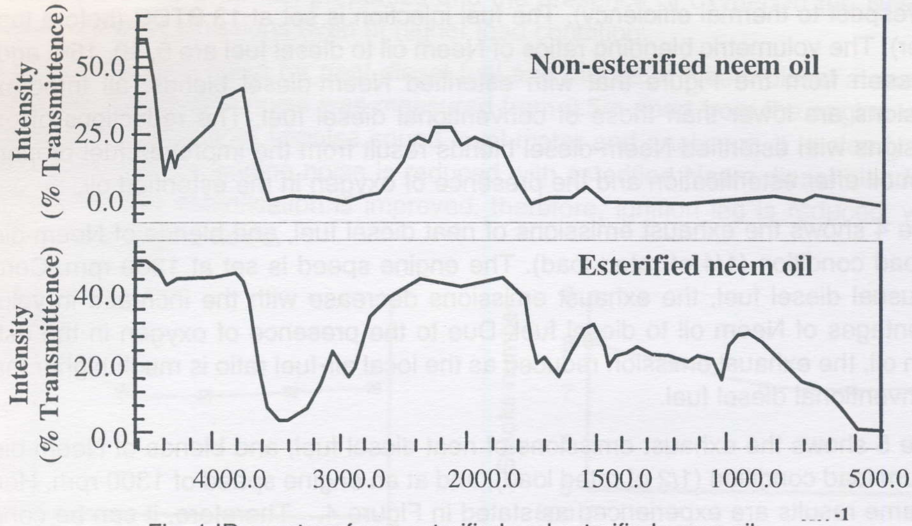

Fig. 1 IR-spectra of non-esterified and esterified neem oil.

Engine speed optimization

Figure 2 shows the brake thermal efficiency with neat diesel fuel at different engine speeds. To optimize the engine speed, thermal efficiency versus engine speed curve is drawn. It is seen from the Figure that with the increase in engine speed, the brake thermal efficiency increases and than decreases. The brake thermal efficiency reaches maximum at 1300 rpm and thus this speed was chosen for all other experiments.

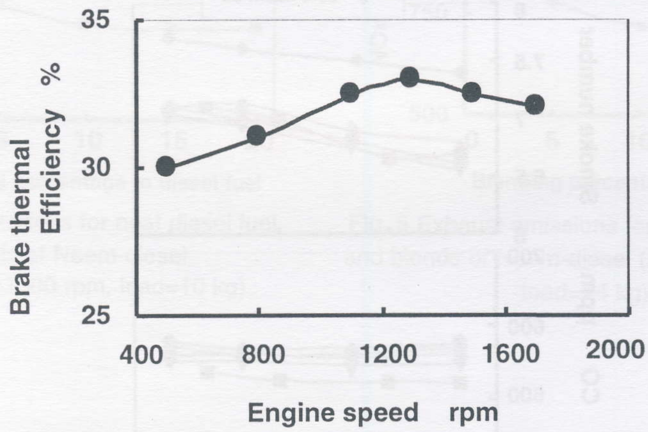

Fig. 2. Brake thermal efficiency at different engine speeds with neat diesel fuel.

Exhaust emissions with neat diesel fuel and esterified Neem-diesel blends

Figure 3 shows the exhaust gas emissions with neat diesel fuel and different blends of esterified Neem-diesel at different loads. The engine speed was set at 1300 rpm (optimum with respect to thermal efficiency). The fuel injection is set at 13 BTDC (before top dead center). The volumetric blending ratios of Neem oil to diesel fuel are 5, 10, 15% and 20%. It is seen from the Figure that with esterified Neem-diesel blends, all three-exhaust emissions are lower than those of conventional diesel fuel. The reductions of exhaust emissions with esterified Neem-diesel blends result from the improved fuel properties of Neem oil after esterification and the presence of oxygen in the esterified oil.

Figure 4 shows the exhaust emissions of neat diesel fuel, and blends of Neem-diesel at low load condition (1/4 of rated load). The engine speed is set at 1300 rpm. Compared with usual diesel fuel, the exhaust emissions decrease with the increase in volumetric percentages of Neem oil to diesel fuel. Due to the presence of oxygen in the esterified Neem oil, the exhaust emission reduced as the local air-fuel ratio is much higher than that of conventional diesel fuel.

Figure 5 shows the exhaust emissions of neat diesel fuel, and blends of Neem-diesel at medium load condition (1/2 of rated load), and at an engine speed of 1300 rpm. Here also the same results are experienced as stated in Figure 4. Therefore, it can be concluded that due to

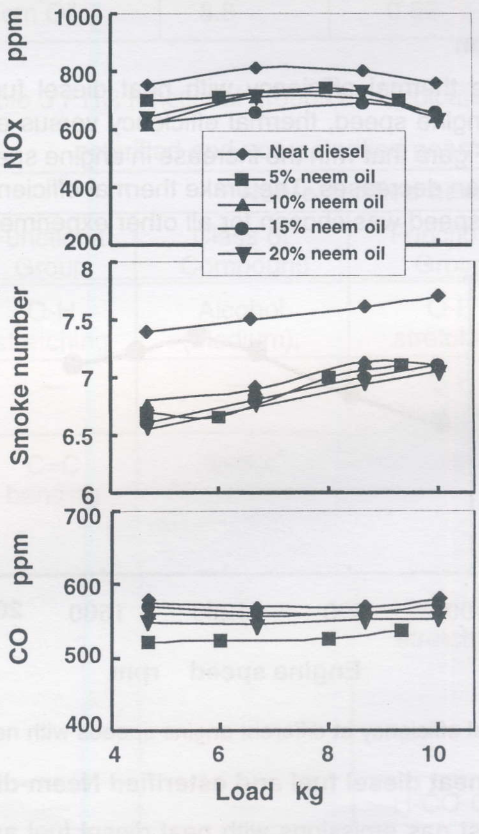

Fig. 3 Exhaust emissions for neat diesel and blends of Neem-diesel at 1300 rpm.

esterification, the improved fuel properties and the presence of oxygen in the Neem oil help reduce exhaust emissions even at higher load condition.

Figure 6 shows engine noise for neat diesel fuel and blends of Neem-diesel at medium load condition. The engine noise was measured from 0.5m apart from the engine with a sound level meter (CEL-228 Impulse sound level meter and analyzer). It is clearly seen from the Figure that the engine noise is reduced with esterified Neem-diesel blends. As cetane number after esterification is improved, therefore, ignition lag is reduced, which results the lower engine noise.

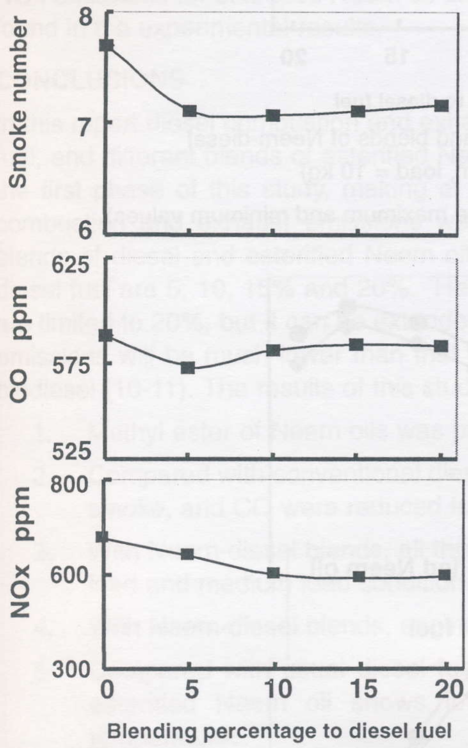

Fig. 4 Exhaust emissions for neat diesel fuel, and blends of Neem-diesel (Engine speed=1300 rpm, load=10 kg).

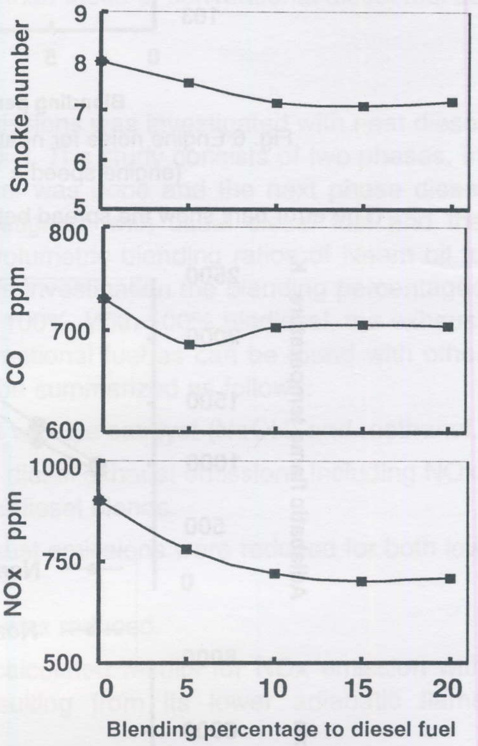

Fig. 5 Exhaust emissions for neat diesel fuel, and blends of Neem-diesel (speed=1300 rpm, load=14 kg).

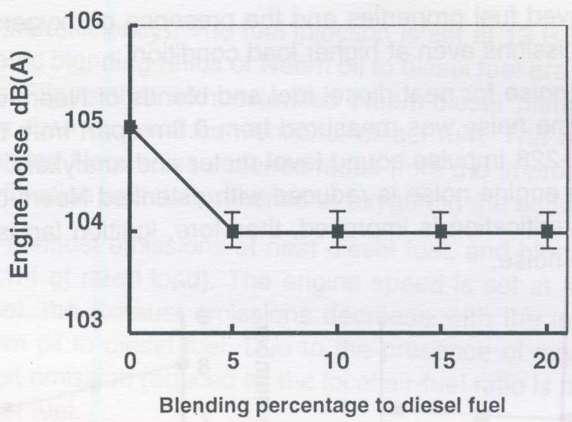

Fig. 6 Engine noise for neat diesel and blends of Neem-diesel
(engine speed = 1300 rpm, load = 10 kg)
(The error bars show the spread between the maximum and minimum values).

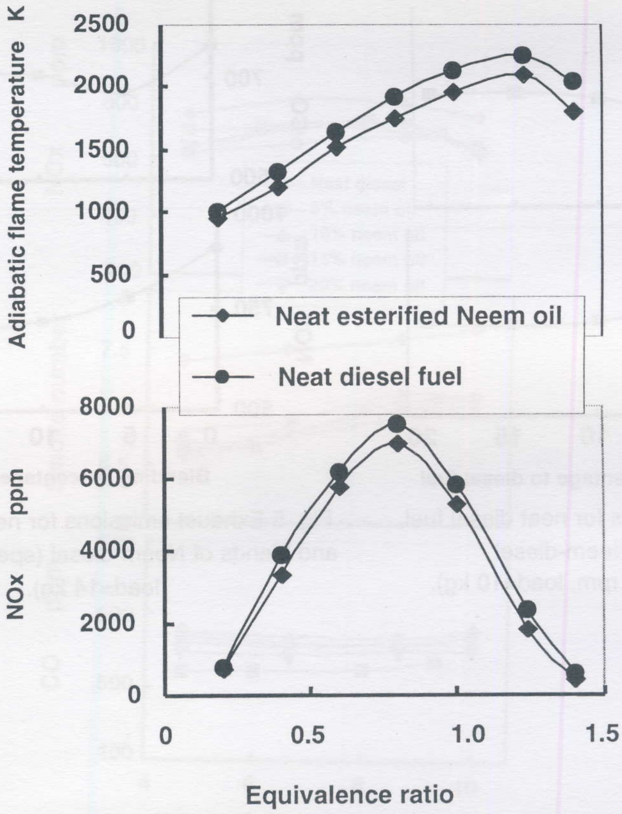

Fig. 7 Effect of equivalence ratios on estimated adiabatic flame temperature and NOx emission for neat diesel fuel and esterified Neem oil.

Figure 7 shows the effect of equivalence ratio on adiabatic flame temperature (AFT) and NOx emissions for neat diesel fuel and neat esterified Neem oil. AFT and NOx emissions are calculated data. Thermodynamic properties of combustion gases in JANAF table and the programs of Mizutani and Ferguson were used for the computations (7-9). (For both diesel fuel and Neem oil, NOx emissions increase with the increase in equivalence ratios up to 0.8 and then decrease and become minimum at equivalence ratios of 0.4. It is interesting to note that the NOx emissions for Neem oil are lower than those of diesel fuel resulting from the lower adiabatic flame temperature of Neem oil. Thus it is proved that NOx emissions for esterified Neem oil are lower than those of conventional diesel fuel as found in the experimental results.

CONCLUSIONS

In this report diesel combustion and exhaust emissions was investigated with neat diesel fuel, and different blends of esterified Neem-diesel. The study consists of two phases. In the first phase of this study, making of biodiesel was done and the next phase diesel combustion and exhaust emissions were investigated with usual diesel fuel and the blends of diesel and esterified Neem oil. The volumetric blending ratios of Neem oil to diesel fuel are 5, 10, 15% and 20%. Here in this investigation the blending percentages are limited to 20%, but it can be extended up to 100%. With 100% biodiesel, the exhaust emissions will be much lower than that of conventional fuel as can be found with other biodiesel (10-11). The results of this study may be summarized as follows:

1. Methyl ester of Neem oils was prepared with lye catalyst (NaOH) and methanol.
2. Compared with conventional diesel fuel, diesel exhaust emissions including NOx, smoke, and CO were reduced for Neem-diesel blends.
3. With Neem-diesel blends, all three-exhaust emissions were reduced for both low load and medium load conditions.
4. With Neem-diesel blends, engine noise was reduced.
5. Compared with usual diesel fuel, the calculated results for NOx emission with esterified Neem oil shows lower resulting from its lower adiabatic flame temperature.
6. Neem oil is nonedible vegetable oil, so if it is used as fuel, food versus fuel conflict will not arise. The methyl esters of this oil can be used as environment-friendly alternative fuel for diesel engine.

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REFERENCES

1. Fang, K. S., "Vegetable Oils as Diesel Fuel for China", MS Thesis, University of Nebraska, Lincoln (1949).

2. Bruwer, J. J., B. Van D. Boshoff, F. J. c. Hugo, J. Fuls, C. Hawkins and A. N. Vander Walt, "Sunflower Seed Oil as Extender for Diesel Fuel in Agricultural Tractors", Department of Agricultural Technical Services, Pretoria, Transvaal, South Africa (1980).
3. Cruz, J. M., Orgunlowo, Chancellor, W.J. and Goss, J.R., "Vegetable Oils as Fuel for Diesel Engines", Resources and Conservation, vol-6, pp. 69-74(1981).
4. Stefano Bona, Giuliano Mosca and Teofilo Vamerali, "Oil crops for biodiesel production in Italy", Proceedings of the International Workshop on "Environmental Aspects of Energy Production", Brasimone (1997).
5. Kenth J. Suda, "Vegetable Oil or Diesel Fuel-A Flexible Option", SAE Paper No. 840004, pp. 1.23-1.31 (1985).
6. Singhal, K.C. and H.B. Mathur, "Performance and Combustion Characteristics of Ethanol Diesel Duel Fuel Direct Injection Engine", National Conference on I.C. Engines & Combustion, India, pp. 336-374 (1989).
7. JANAF, "Thermodynamic Tables", DOW Chemical Company, 1965.
8. Mizutani, Y., " Internal Combustion Engines", Sankaido 11-7, 1972.
9. Ferguson, C.R., "Internal Combustion Engines-Applied Thermo-Sciences", John Wiley and Sons, 1986.

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AERODYNAMIC FORCES AROUND A TAPERED SQUARE CYLINDER

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ABSTRACT

An experimental investigation of the pressure distribution around a tapered square cylinder placed in uniform flow with three Reynolds numbers i.e. 5.49 X 10^4, 6.88 X 10^4 and 1.38 X 10^5 is presented. Mean pressure was measured for 0 and 45 angle of attack at different planes of the tapered square cylinder in an open circuit wind tunnel. The drag co-efficient was calculated by numerical integration. The pressure co-efficient around the cylinder at different planes has been obtained by measuring the static pressure head on the surfaces of the cylinder.

INTRODUCTION

In fluid mechanics the flow around a cylinder is a very important problem from fundamental and applied points of view. The investigation of mean pressure distribution and drag are very important for designing aircraft, windmill, buildings and structure that have to face wind load. While designing square tapered cylindrical type object, towers, buildings, vehicles, missiles and other structures the designer should keep in mind the effect of wind loading. Flow past a cylinder is always associated with the separation of flow from the cylinder incurring large energy losses. Specially in the case of flow past square cylinders the separation of flow occurs at the corner of the frontal face and a complex wake is created behind it. Although studies with both the models and full-scale structures are being carried out now a days, it is easier and simpler to study with a model rather than the full-scale object. So, a wind tunnel study is the only means to investigate the flow phenomena past such cylinders. Till now extensive research works have been carried out on isolated bluff bodies. Even then, very little information is available concerning the flow around tapered square cylinder although this is a problem of considerable practical significance. The knowledge of wind loading on tall buildings and the windmill towers is essential for sound planning and design.

One approach to the problem of predicting the flow around an object or structure is to develop an understanding of the nature of flows on relatively simple arrangement of bluff bodies by wind tunnel experiments. With this end in view, the present investigation of pressure distributions around a tapered square cylinder was carried out. Tapered square cylinder represents the general shape of the windmill towers and sometimes high-rise buildings. Thus the study on the tapered square cylinder would be helpful in the analysis of wind effects on windmill towers or high-rise buildings. The present study is an attempt to give an understanding about the variation of wind load pattern imposed on a square tapered structure at different planes.

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