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Studies on exhaust emissions in semi-adiabatic compression ignition engine with alternate fuels

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Alcohols (ethanol and methanol) and a few non-edible vegetable oils are showing a great potential for replacing conventional diesel fuels quite effectively. The low heat rejection semi-adiabatic compression ignition (C.I.) engines are gaining prominence for adopting these alternate fuels. The major pollutants of the exhaust emissions of C.I. engines are oxides of nitrogen (NO_x) and black smoke. When alcohols are used as alternate fuels, the pollutants have to be checked specifically for aldehydes which are carcinogenic in nature. The pollution levels of black smoke, NO_x and aldehydes emitted through exhaust of engine are reported here on both conventional and insulated versions of C.I. engines with different proportions of ethanol-diesel and methanol-diesel mixtures. The non-edible vegetable oils crude, and esterified jatropha and pongamia oils are used for total replacement of diesel fuel on both configurations of the engine. The NO_x and smoke levels have been found to be lower with both ethanol and methanol induction with both conventional and insulated versions of the engine in comparison to pure diesel operation. Also, production of aldehydes in the form of formaldehyde has been found to increase with both ethanol and methanol operations. However, the insulated version of the engine with ethanol operation helps in reducing formaldehyde emissions of the engine. With the non-edible vegetable oils, generation of smoke is drastically increased in comparison to pure diesel operation. However, with preheating of vegetable oil and increased injection pressure, the smoke levels get reduced and NO_x levels increase marginally.

In view of the fossil fuel crisis and vehicle population explosion, the studies on replacement of conventional fuels, especially the diesel fuel, by alternate and renewable fuels is gaining importance. Consequently, there is an urgent need to study and control the pollutants emitted through the exhaust of C.I. engines with the new fuels, as pollution is considered as a slow poison globally[1]. Alcohols (ethanol and methanol)[2] and non-edible vegetable oils like crude and esterified jatropha oil[2] in addition to pongamia oil[3] are expected to be future fuels for C.I. engines. The alcohols are usually obtained by fermentation of cheap materials like starch and bagasse whereas the jatropha and pongamia oils are obtained from the seeds of the respective plants, which can be grown in any type of soil and climatic conditions. These fuels need hot combustion chamber for efficient energy utilisation. The concept of low heat rejection engine[4] is being employed for adopting these alternate fuels. The low heat rejection diesel engine employs insulated piston and insulated liner assembly. The piston is made of two parts: the crown made of low thermal conductivity material, superni alloy is screwed to aluminium body of the piston by providing 3 mm air gap between the two parts. Similarly a superni insert is screwed to the liner in the top portion of liner providing 3 mm air gap between insert and liner[5]. The combination of two low thermal conductivity materials of superni-90 alloy and air act as thermal barrier, achieving low heat rejection version of the engine.

When alcohols are used as alternate fuels in C.I. engines, the major pollutants in the exhaust[6] are oxides of nitrogen (NO_x), black smoke and higher levels of aldehyde (oxygenated hydrocarbon) emissions, which are responsible for the pungent smell of the exhaust and irritation of nasal and respiratory tracks. When non-edible vegetable oils are used as substitute fuels, black smoke and NO_x are expected to be pollutants because of low volatility and high viscosity associated with these vegetable oils. The pollutants like NO_x and black smoke cause health problems[7] like bronchoitis, emphysema and eye irritation. The effects of esterification of vegetable oils, preheating and increase in injection pressure are also required to be studied for the

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reduction of pollutants when non-edible vegetable oils are employed as substitute fuels.

The exhaust emissions of NO_x, black smoke and aldehydes, when ethanol-diesel and methanol-diesel mixtures are employed as alternate fuels on both conventional piston and conventional liner (CPCL) and insulated piston and insulated liner [superni piston and superni liner (SPSL)] versions of the engine are reported here. The pollution levels of NO_x and black smoke emitted through exhaust of both CPCL and SPSL versions of the engine with 100% replacement of diesel fuel by non-edible vegetable oils are also reported.

Experimental Procedure

Alcohol operation

The present investigations have been carried out on a vertical single cylinder medium speed C.I. engine coupled to an electrical dynamometer. The experiments are carried out with conventional piston and conventional liner (CPCL) and also with insulated piston and insulated liner (SPSL) fitted in the engine. The details of SPSL are shown in Fig. 1.

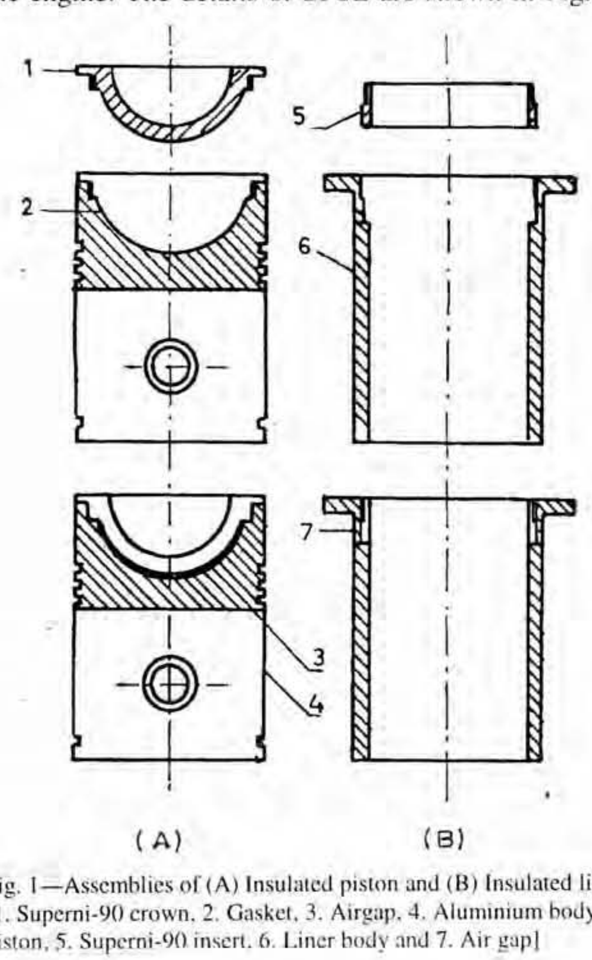

Fig. 1—Assemblies of (A) Insulated piston and (B) Insulated liner [1. Superni-90 crown, 2. Gasket, 3. Airgap, 4. Aluminium body of piston, 5. Superni-90 insert, 6. Liner body and 7. Air gap]

The experimental set-up employed for alcohol-diesel mixtures is shown in Fig. 2. The engine is loaded with the help of rheostat box connected to an electrical dynamometer. The consumption of alcohol (ethanol and methanol) and diesel are measured separately by means of fuel measuring devices fitted to alcohol and diesel tanks. Air consumption is obtained using air box, orifice meter and water tube manometer assembly. Exhaust gas temperature is measured by employing iron and iron Constantine thermocouple fitted to temperature indicator. The oxides of nitrogen (NO_x) are recorded using Netal chromatograph NO_x analyser. Black smoke in Hatrdige smoke units (HSU) is noted using AVL smoke meter. The aldedyde emissions are measured by bubbling the exhaust through three stage 2,4-dinitrophenyl hydrazine solution in hydrochloric acid and extracting the hydrazones formed into chloroform[8]. The extract is analyzed using high performance liquid chromatograph (HPLC). The pollution levels of NO_x and black smoke are recorded for different proportions of ethanol-diesel and methanol-diesel mixtures in addition to pure diesel operation on both CPCL and SPSL versions of engines. Formaldehyde emissions are noted for 35% ethanol and methanol induction in addition to pure diesel operation for peak load operation of the engine

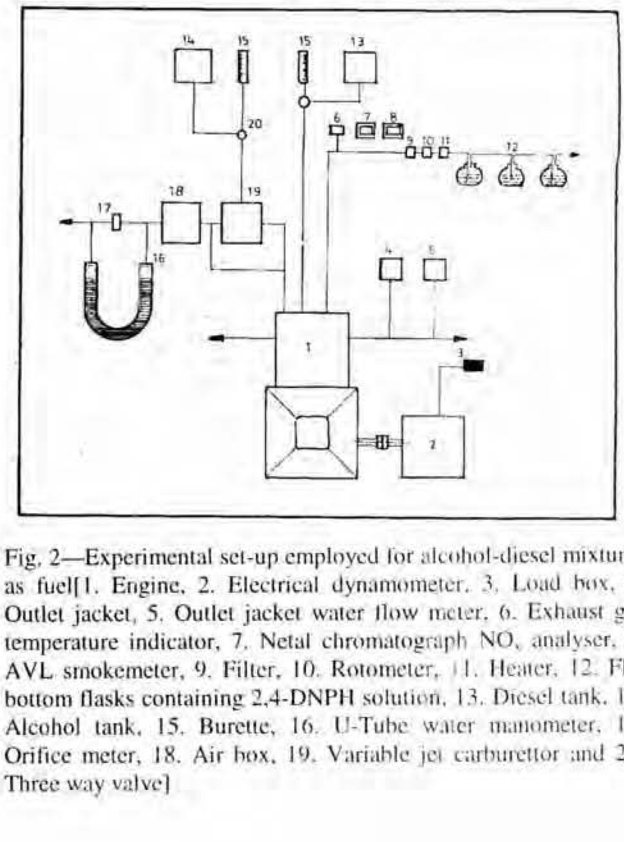

Fig. 2—Experimental set-up employed for alcohol-diesel mixtures as fuel[1. Engine, 2. Electrical dynamometer, 3. Load box, 4. Outlet jacket, 5. Outlet jacket water flow meter, 6. Exhaust gas temperature indicator, 7. Netal chromatograph NO_x analyser, 8. AVL smokemeter, 9. Filter, 10. Rotometer, 11. Heater, 12. Flat bottom flasks containing 2,4-DNPH solution, 13. Diesel tank, 14. Alcohol tank, 15. Burette, 16. U-Tube water manometer, 17. Orifice meter, 18. Air box, 19. Variable jet carburettor and 20. Three way valve]

containing CPCL and SPSL versions.

Non-edible vegetable oil operation

The experimental set-up employed for 100% replacement of diesel fuel by the non-edible vegetable oils is shown in Fig.3. The non-edible vegetable oils are injected into the engine through conventional injection system. Provision is made to pre-heat the vegetable oils to the required levels such that viscosity level is equalised to that of diesel fuel at room temperature. Arrangements are also made to operate the engine at different injection pressures of 190, 230 and 270 bars. Experiments are carried out with different non-edible vegetable oils, viz. crude jatropha (CJ), esterified jatropha (EJ) and pongamia oil (PO) on CPCL and SPSL versions of the engine at room temperature (RT) and preheated temperature (PT) conditions of vegetable oil fuel. The pollutant levels of NO_x and black smoke are recorded in a similar fashion to that of alcohol operation.

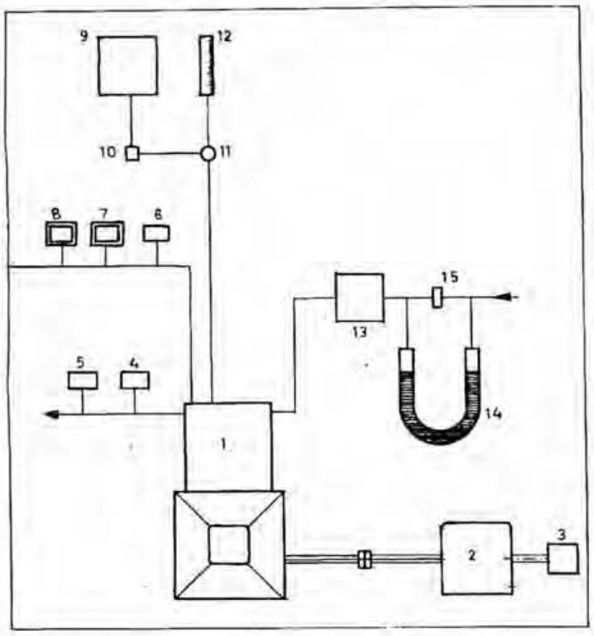

Fig. 3—Experimental set-up employed for non-edible vegetable oils as fuel [1. Engine, 2. Electrical dynamometer, 3. Load box, 4. Outlet jacket water temperature indicator, 5. Outlet jacket water flow meter, 6. EGT indicator, 7. AVL smoke meter, 8. Netal Chromatograph NO_x analyser, 9. Fuel tank, 10. Heater with thermometer arrangement, 11. Three way valve, 12. Burette, 13. Air box, 14. U-Tube water manometer and 15. Orifice meter]

Results and Discussion

Alcohol Operation

The data pertaining to the analysis of emissions of engine using alcohols as fuel are listed in Table 1. The variation of NO_x levels with brake mean effective pressure (BMEP) for 35% ethanol and 35% methanol induction is presented in Fig. 4. It has been found that as the BMEP increases, NO_x levels increase for both ethanol-diesel and methanol-diesel mixtures on both CPCL and SPSL versions of the engine. The histograms (Fig. 5) of NO_x levels in ppm by inducting ethanol and methanol in different proportions for peak load operation of the CPCL and SPSL versions engines show that the reduction in NO_x is more

Table 1—Data of emissions for alcohol operation

Engine version	Alcohol (%) In fuel induction	Smoke (HSU)		NO_x(ppm)		Formaldehyde(%)	
		Ethanol – diesel	Methanol-diesel	Ethanol-diesel	Methanol-diesel	Ethanol-diesel	Methanol-diesel
CPCL	15	45	52	1000	1020	—	—
	25	38	50	900	925	—	—
	35	35	48	875	900	19.71	37.3
SPSL	15	35	45	1622	1650	—	—
	25	30	45	1520	1550	—	—
	35	30	45	1200	1220	4.97	34.8
CPCL	0 (100% diesel)	55		1950		18.08	
SPSL	0 (100% diesel)	48		2100		14.3	

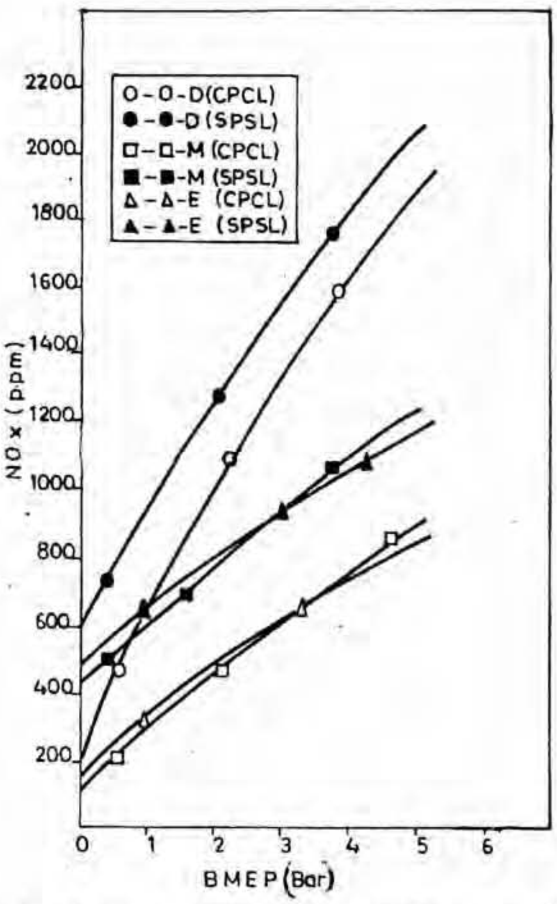

Fig. 4 — Variation of NO_x levels with BMEP for 35% alcohol induction on CPCL and SPSL versions of the engine

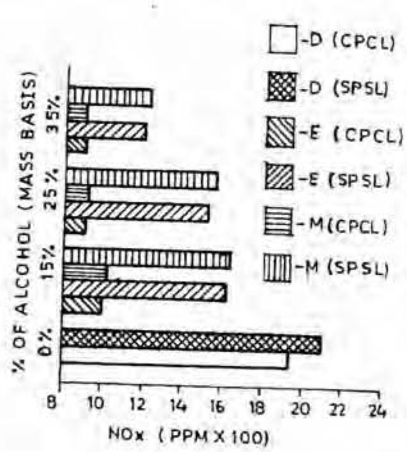

Fig. 5 — Histograms showing the variation of NO_x levels for different percentages of alcohol induction for peak load operation with CPCL and SPSL versions of the engine

predominant with CPCL version of the engine when compared to SPSL version. Further, due to the oxygenated nature of alcoholated fuel, NO_x levels are lowered in comparison to pure diesel operation.

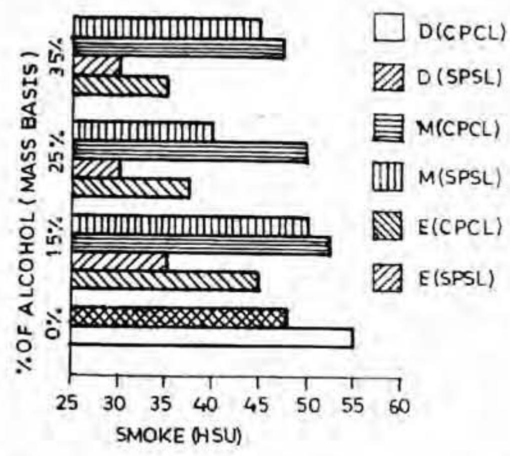

Fig. 6 —Histograms showing the variation of smoke levels on CPCL and SPSL versions of the engine at peak load operation with different percentages of alcohol induction

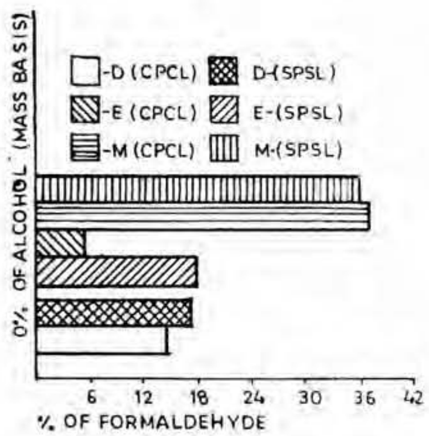

Fig. 7 — Histograms showing the variation of formaldehyde emissions on CPCL and SPSL versions of the engine at peak load operation with pure diesel and 35% alcohol induction

The histograms showing variation of smoke levels in smoke (HSU) on CPCL and SPSL versions of the engine at peak load operation with different percentages of ethanol and methanol induction are shown in Fig. 6. The smoke levels decrease drastically with increase in percentage of alcohol induction in both CPCL and SPSL versions of the engines. Moreover, the greater availability of oxygen coupled with maximum available combustion temperature in SPSL version resulted more decrease in smoke levels than CPCL by providing effective combustion.

Fig. 7 shows the variation in percentage of formaldehyde (in aldehydes) in the exhaust of engine at peak load operation on both CPCL and SPSL versions of the engine with 35% ethanol/methanol

Table 2 — Properties of vegetable oil test fuels

Fuel	Viscosity* (cP)	Specific gravity	Flash point** (°C)	Calorific value (kJ/kg)
Diesel (D)	12.5	0.84	72	41000
Crude jetropha (CJ)	120	0.92	195	36000
Esterified jatropha (EJ)	53.7	0.90	175	36500
Pongamia oil (PO)	25	0.94	230	35800

*At 25°C
**Determined by COC method

Table 3—Data of emissions on non-edible vegetable oil operation

Fuel	Engine version	Injection pressure (Bar)	Smoke (H.S.U.) RT	Smoke (H.S.U.) PT	NO_x (ppm) RT	NO_x (ppm) PT
Crude jatropha(CJ)	CPCL	190	100	100	1000	1120
		230	75	85	1040	1130
		270	85	80	1090	1150
	SPSL	190	100	100	1180	1220
		230	70	70	1225	1240
		270	70	70	1240	1260
Esterifed jatropha (EJ)	CPCL	190	100	100	1100	1200
		230	82	75	1120	1260
		270	82	80	1150	1280
	SPSL	190	100	100	1400	1550
		230	75	75	1440	1580
		270	75	75	1470	1610
Pongamia oil (PO)	CPCL	190	100	100	1200	1300
		230	90	80	1280	1370
		270	80	80	1320	1420
	SPSL	190	90	85	1300	1490
		230	85	80	1350	1495
		270	80	78	1380	1505
Diesel oil (D)	CPCL	190	55	-	1950	—
	SPSL	190	48	-	2100	—

induction in addition to operation with 100% diesel fuel. The figure shows that the formaldehyde emissions increase with both CPCL and SPSL versions of the engines with 35% alcohol operation. Further, it is observed that the SPSL version of the engines helps in reducing formaldehyde emissions to reasonably low levels, indicating that SPSL version of the engines matches well for operation with alcohol in controlling aldehyde emissions.

Non-edible vegetable oil operation

The general properties of vegetable oils crude jatropha (CJ), esterified jatropha (EJ) and pongamia oil (PO) as test fuels[2] along with diesel are listed in Table 2. The data show that these oils can be effectively used as substitute fuels in C.I. engines. The data pertaining to the emissions by engines using non-edible vegetable oils are listed in Table 3. Figs 8 and 9 show the variation of NO_x levels (in ppm) with BMEP pertaining to different non-edible vegetable oils on both CPCL and SPSL versions of the engines at an injection pressure of 190 bar at RT and PT conditions respectively. Figs 8 and 9 also show that NO_x concentration increases with increase in BMEP at different injection pressures on both versions of the engine at RT and PT conditions. The NO_x production is significantly influenced by injection system. Further, the variation in fuel characteristics such as viscosity, Cetane number, etc., also contributes to variation in NO_x levels pertaining to different non-edible vegetable oils. Fig.10 compares the variation in NO_x levels with different non-edible vegetable oils and diesel at RT and PT conditions on both CPCL and SPSL versions of the engine at peak load

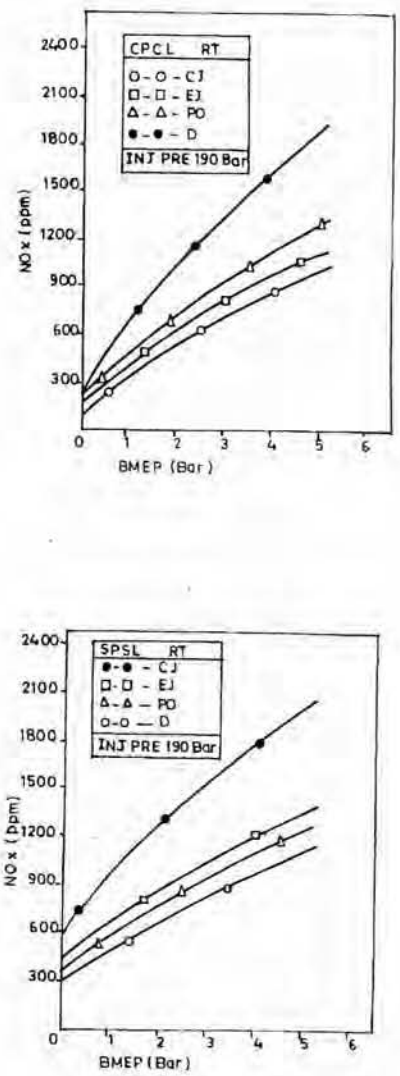

Fig. 8 — Variation of NO_x levels in ppm with BMEP on CPCL and SPSL versions of the engine at injection pressure of 190 bars at RT conditions with different vegetable oils

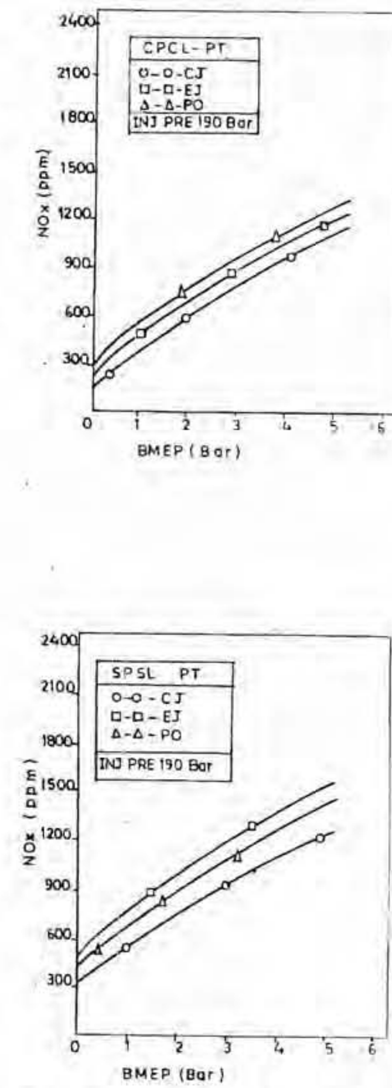

Fig. 9 — Variation of NO_x levels in ppm with BMEP on CPCL and SPSL versions of the engine at injection pressure of 190 bars at PT conditions with different vegetable oils

operation. The NO_x levels decreased with the non-edible vegetable oils in comparison to pure diesel operation. Preheating of the vegetable oils resulted in marginal increase of NO_x levels. The increase in injection pressures also resulted in marginal increase in NO_x levels with non-edible vegetable oil operation.

The histograms in Fig. 11 depict the variation in smoke levels with different non-edible vegetable oils and diesel at RT and PT conditions on both CPCL and SPSL versions of the engine at peak load operation at different injection pressures. The smoke levels are found to increase with non-edible vegetable oil operation as compared to pure diesel operation.This can be due to high viscosity and low volatility of vegetable oils which affect the injection process and the combustion effectiveness. However, preheating of non-edible vegetable oils tends to decrease the viscosity levels and increase the injection pressures improving the effectiveness of combustion leading to small reduction in smoke levels.

Conclusions

Ethanol and methanol induction decrease NO_x and smoke levels and increase formaldehyde emissions as compared to pure diesel operation. SPSL version of the engines helps in decreasing NO_x, smoke and formaldehyde emissions considerably.

Non-edible vegetable oils can be employed for 100% replacement of diesel on both CPCL and SPSL

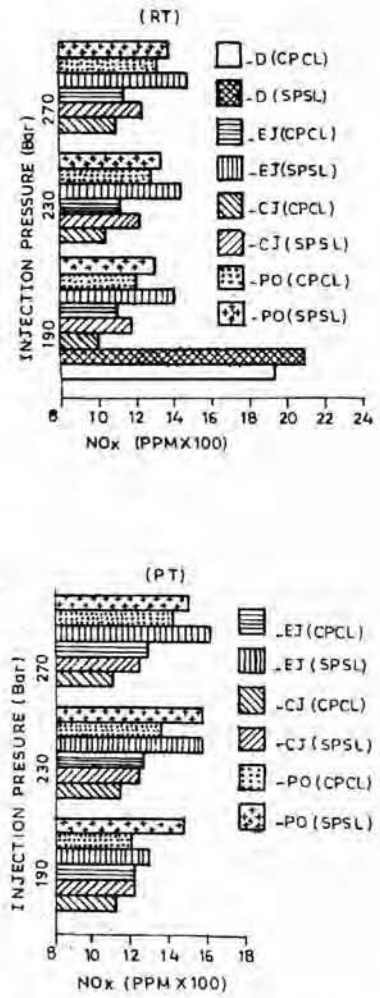

Fig. 10—Histograms showing the variation of NO_x levels in ppm with different vegetable oils at RT and PT conditions on CPCL and SPSL versions of the engine at peak load operation

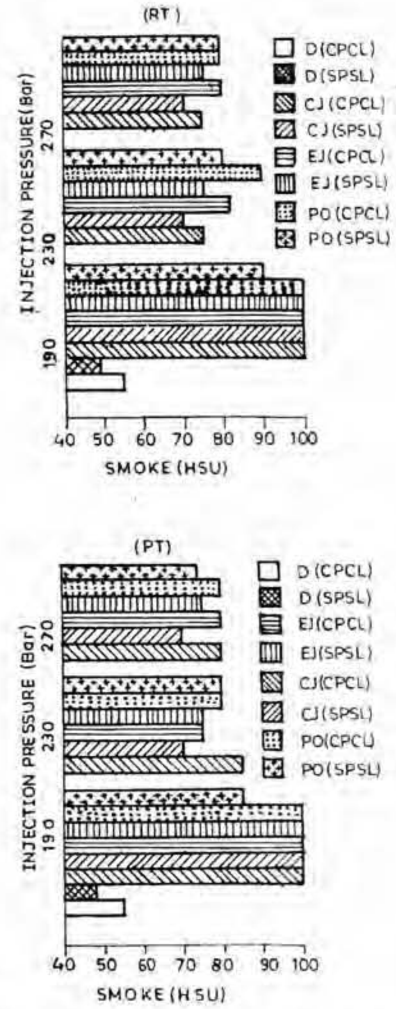

Fig. 11—Histograms showing the variation of smoke in HSU with different vegetable oils on CPCL and SPSL versions of the engine at RT and PT conditions at peak load operation with different injection pressures

versions of the engine. The NO_x levels decrease while smoke levels increase with non-edible vegetable oils in comparison to pure diesel operation. The SPSLversion reduces smoke levels but increases NO_x marginally with all non-edible vegetable oils especially with esterfied jatropha. Preheating of non-edible vegetable oils helps in reducing the smoke levels to a great extent. Increased injection pressures help in decreasing smoke levels marginally.

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