PETROFED

Ref. No.PF/9
December 17, 2015

Shri Sandeep Poundrik
Joint Secretary (Refineries)
Ministry of Petroleum and Natural Gas
Shastri Bhavan
New Delhi

Subject : Auto Fuel Policy - Specification of BS V Diesel

Dear Sir,

Please refer to our earlier letter of even no. dated September 15, 2015 enclosing a note proposing changes in specifications of four parameters of BS V diesel compared to recommendations of the 'Auto Fuel Policy and Vision 2025' report.

MOP&NG called a meeting of Industry on 7th December 2015 to discuss the issues related to these specifications. During the meeting, Industry members explained the technical justifications in support of their proposition. It was decided that PetroFed will submit a detailed write-up giving technical justification in support of proposed four parameters, specifications followed elsewhere in the world and the benefit to the country in terms of more diesel production.

A note giving technical justifications and the resultant increase in diesel production is enclosed with relevant documents for your considerations.

MORT&H has already issued two notifications for BS V and BSVI emissions norms and draft specifications of commercial gasoline and diesel. While, PetroFed is planning to give suitable representation to MORT&H, you are requested to intervene and advise MORT&H to include specifications once finalised by BIS.

Thanking You

Yours faithfully,

Dr. R. K. Malhotra
Director General

Encl. as above

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17/12/2015

Proposed Specifications of BS V Diesel - Variations in Auto Fuel Policy & Vision 2025 Report w.r.t. Requirements of Indian Refiners.

A. Diesel – An Important Fuel

India is largely a Diesel driven economy. In terms of relative consumption, diesel to gasoline ratio is 4:1 compared to 0.5:1 of USA. For ever growing demand with economic growth in all sectors be it agriculture, industry, captive power generation, transport, infrastructure etc. it has always been the endeavour of Indian Refiners to maximise diesel production. Increase in diesel production is not only add value in the energy basket of India but also reduce import dependence since diesel is single largest volume product from crude oil. ***Formulation of optimum fuel specifications keeping environmental considerations and engine performance in view is key to achieve this objective.***

B. Compliance Schedule for BS IV / BS V / BS VI Norms

In India currently, BS III and BS IV diesels are sold in different regions depending on regional sensitivity to the environment. However, the mass emission standards for BS-IV shall come into force all over the country in respect of four-wheeled vehicles manufactured on or after April 1, 2017. Introduction of BS V and BS VI compliant vehicles and commensurate fuels are in the advance stage of considerations.

Auto Fuels Vision & Policy 2025 document recommends introduction of BS V norms from 1st April 2020 and BS VI norms from 1st April 2024. However, Gazette notifications dated 27th November 2015 of MORTH laying draft rules for all diesel vehicles in M and N categories, compliance dates are set as under :

Table 1

	BS V	BS VI
For New Models	1st April 2019	1st April 2021
For Existing Models	1st April 2020	1st April 2022

C. Proposed Specifications for BS V Diesel

Auto Fuels Vision and Policy 2025 (AFV&P 2025) has recommended BS V diesel specifications. Specifications, however, differ in respect of density, kinematic viscosity, flash point and temperature for 95% recovery (T95) when compared to those suggested by Indian refiners. Specifications recommended by the working group of refiners were agreed during the discussions on AFV&P 2025 policy and included in the last draft report. These, however, were revised in the final report without the consent of working group of refiners. Subsequently, MOP&NG also recommended specifications of refiners to BIS. The difference in these four parameters at various levels of discussions is given in the Table 2 below.

Table 2

Parameter	Recommended by working group and included in last draft report of AFV&P 2025	Recommended in Final report of AFV&P 2025	Proposal of Indian Refiners
Density, kg/Cu.M	Report or 860 max.	820-845	860 max.
Kin. Viscosity , cst	1.8-5.0	2.0-4.5	1.8-4.5
Flash Point , deg. C, minimum	-	42	35
T95 (95% recovery temperature) , deg. C , maximum	370 deg. C max or (90% recovery at 360 deg. C max)	360	370

Except for four parameters mentioned above, Refiners agreed to all other specifications of BS V diesel included in AFV&P 2025 document.

A committee of BIS is discussing these specifications with all stake holders but not able to arrive at a consensus due to some apprehensions largely expressed by Society of Indian Automobiles Manufacturers (SIAM).

Specifications recommended by the Refiners versus incorporated in AFP&V 2025 report and apprehensions of SIAM on engine performance and emissions are discussed below for four subject parameters.

Table 3 below gives a comparative outlook of four specifications under subject discussion.

Table 3

Parameter	BS IV Specifications (IS 1460-2005 amended in March 2010)	Recommended by refiners working group and included in last draft report of AFV&P 2025	Recommended in Final report of AFV&P 2025	Proposal of Indian Refiners
Density, kg/Cu.M	820-845	Report or 860 max.	820-845	860 max.
Kin. Viscosity (KV) , cst	2.0-4.5	1.8-5.0	2.0-4.5	1.8-4.5
Flash Point , deg. C, minimum	35	-	42	35

T95 (95% v/v recovery temperature) , ^{0}C , maximum	360	370 deg. C or (90% recovery at 360 ^{0}C)	360	370

Specifications followed in various countries in respect of above four parameters are given in the enclosure 1 (Source : Auto Fuel Policy and Vision 2025 report).

D. Discussion

Petrofed took the help of experts from IIT , Delhi who prepared a study report based on published literature on extensive research and testing on fuel quality and impact on engine emissions. A copy of the report is enclosed. The outcome of the report is summarised here.

For Heavy Duty Vehicles

Decrease in T 95 recovery temperature from 370 to 325 ^{0}C (40 ^{0}C variation) increases carbon monoxide (CO) and hydrocarbon (HC) emissions (Table 4). There is a marginal impact on oxides of nitrogen (NOx) and **NIL** impact on particulate matter (PM). Conversely , the increase of only 10 ^{0}C (from 360 to 370) sought by the refiners is expected to improve CO and HC emissions with no impact om PM.

Table 4

	CO (g/kWh)	HC(g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Decrease T95 from 370 to 325°C	+0.039 +6.6%	+0.031 +13.4%	-0.120 -1.7%	0.0 0.0% (Statistically not significant)

Research results compiled in the report also clearly indicate that decrease in density (from 855 to 828 kg. cu. M) resulted in substantial increase in unburnt HC but no significant impact on PM (Table 5). Once again , on a reverse path , increase in density parameter from 845 to 860 (max.) sought by the refiners is expected to improve emissions w.r.t. HC and CO with better fuel efficiency with no impact on PM.

Table 5

	CO (g/kWh)	HC(g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Decrease density from 855 to 828 kg/m^3	+0.03 +5.0%	+0.034 +14.3%	-0.245 -3.6%	-0.001 -1.6% (Statistically not significant)

It may be mentioned that PM are most effected by the sulphur contents of the fuel which in BS V will be 10 ppm as per the recommendations of the AFP&V2025 report.

For Light Duty Vehicles

Decrease in T 95 recovery temperature from 370 to 325 ^{0}C (40 ^{0}C variation) decreases carbon monoxide (CO) and hydrocarbon (HC) emissions but the reduction was found insignificant in both the parameters(Table 6). Impact on oxides of nitrogen (NOx) was positive . This change reduces PM by a value of (-) 0.004 g/km . The increase of only 10 ^{0}C (from 360 to 370) sought by the refiners is expected to have negligibly marginal impact (may be to third decimal place) on these parameters.

Table 6

	CO (g/km)	HC(g/km)	NO_x (g/km)	PM (g/km)
Decrease T95 from 370 to 325°C	-0.008 -1.8% (Statistically not significant)	+0.0017 +3.4% (Statistically not significant)	+0.026 +4.6%	-0.004 -6.9%

Kinematic viscosity (KV) , defined as the ratio of dynamic viscosity and density ,is a resultant parameter . If density increases , KV value will reduce. Hence the range sought by the refiners is 1.8-4.5 instead of 2.0 – 4.5

CONCAWE report on engine studies with different automobile engines , diesel fuels and simulated real time drive conditions in Europe conclude that despite of wide range of fuels tested, the engine / vehicle energy efficiency was insensitive to fuel changes and no statistically significant differences between fuels were seen.

As far engine performance , all significant parameters like Cetane Number , Lubricity, RCR, Cold Filter Plug Point etc. will remain as per recommendations of AFP&V 2025 report . Hence , no adverse impact on engine performance is expected if the specifications sought by the refiners are agreed to. Similarly, parameters essential from environment point of view like Sulphur content, Poly Aromatic Hydrocarbons (PAH) also will not be affected due to changes suggested in above mentioned four parameters

Flash Point

Flash point is a safety requirement for storage , handling and transportation of diesel. It does not impact emissions or engine performance. In AFP&V 2025 , flash point has increased from earlier of 35 ^{0}C to 42 ^{0}C .

Flash point of 35 degree C is existing in India for very long safely . This allow blending of 3 – 5% heavy naphtha , a surplus product , in diesel to increase its availability .

Moreover, another significant transport fuel , Gasoline, which has flash point substantially lower than diesel , is already handled in public. With all appropriate safety norms in design , transportation , storage and handling in place for diesel fuels and having experience of handling them in public at 35 degree C flash point , raising flash point of diesel to 42 degree C will result in downgrdation of its components to lower value products.

It may concluded that marginal changes sought by the refiners in four parameters will not have any significant impact on engine emissions and performance.

Impact on Diesel Production

Above changes in four parameters will result in increase diesel production up to 4.0 million MT per annum at national level. The exact quantity may vary from time to time based on refinery configuration and available crude feed stocks. ***As mentioned earlier , India being a diesel driven economy , additional availability of diesel from the same resources with no significant impact on emissions and no impact on engine performance will result in reduction in import dependence on crude to almost 8.0 million MT per annum.***

E. Proposal

In view of the facts stated above , BS V diesel specifications for four parameters i.e. density, viscosity , recovery at 95 degree C and flash point should be as mentioned below. This will improve the diesel production in India without adverse impact on environment and engine performance.

Table 7

Parameter	Proposed Diesel Specifications
Density, kg/Cu.M	860 max.
Kin. Viscosity , cst	1.8-4.5
Flash Point , deg. C, minimum	35
T95 , deg. C , maximum	370

All other specifications as recommended in Auto Fuels Vision and Policy 2025 including special relaxations for gasoline (aromatic contents 40%) and diesel (Cetane number 48) produced by the north east refineries will remain same.

Enclosures:

1 Comparison of diesel fuel specifications in various countries.
2 Report on literature survey of engine studies in respect of impact on emissions with change in diesel fuel quality by IIT, Delhi
3 Extract of CONCAWE report no. 2/05 of 2005

Enclosure 1

Diesel Specifications in Different Countries

(Source : Auto Fuel Policy and Vision 2025)

S. No.	Attribute		India	Europe	USA	Japan	South Korea	China	
			BS IV	EN 590:2009	ASTM D 975-11 No.2	JIS K 2204-2007		Nation wide	Beijing
			April 10	Oct 09	April 11	Jan 07	Jan 09	Jan 10	Jan 08
1.	Density @ 15°C	kg/m3	820-845	820-845	–	860 max	815-835	810-850$	820-845$
2.	Distillation								
	T-50	°C max	–	–	–	–	–	300	300
	T-85	°C max	–	350	–	–	–	–	–
	T-90	°C max	–	–	282-338	360	360	355	355
	T-95	°C max	–	360	–	–	–	365	365
	FBP	°C max	–	–	–	–	–	–	–
	Recovery @ 360°C	% vol. min	95	–	–	–	–	–	–
3.	Sulphur	ppm max	50	10	15	10	10	350	50
4.	Cetane Number	min	51	51	40	50	52	49	51
5.	Cetane Index	min	46	46	40	50	52	46	46
6.	Flash Point	°C min	35	55	52	50	40	55	55
7.	KV @ 40°C	cSt	2.0-4.5	2.0-4.5	1.9-4.1	1.7-2.7	1.9-5.5	3-8$	3-8$
8.	Total Aromatics	% wt max	–	–	35	–	30	–	3-8$
9.	PAH	% wt max	11	11	–	–	5	11	11
10.	Total sediments	mg/100 ml max	–	–	–	–	–	None	None
11.	Total contamination	mg/kg max	24	–	–	–	–	–	–
12.	Oxidation stability	g/m3 max	25	–	–	–	–	–	–
13.	RCR on 10% residue	% wt max	0.3	–	–	–	–	–	–
14.	CCR on 10% residue	% wt max	–	0.3	0.35	0.1	0.15	0.3	0.3
15.	Water content	mg/kg max	200	0.02	–	–	–	Trace	Trace
16.	Water + sediment	% vol. max	–	–	0.05	–	0.02	–	–
17.	Lubricity corrected WSD	Microns max	460	460	520	–	400	460	460
18.	Ash	% wt. max	0.01	0.01	0.01	–	0.02	0.01	0.01
19.	Oxygen	% wt. max	0.6*	–		–	–	–	–
20.	FAME	% vol max	–	7	5	–	5	0.05	–

Note: * Applicable only for diesel with 5% v/v bio-diesel at 20°C
$ At 20°C

Enclosure 2

Impact of Fuel Quality on Emissions – A Summary Paper of Literature Survey

1. Introduction

A report by Asian Development Bank on policy guidelines for reducing vehicle emissions in Asia suggested that diesel fuel properties such as cetane number, density, distillation and polyaromatic content can have positive or negative impacts on emissions and should be carefully evaluated (adb.org).

2. Studies on impact of diesel fuel on emissions

Various studies on the impact of fuel composition on emissions have been performed. An extensive review was conducted for studies done on the impact of fuel composition on emissions from diesel engines (Lee et al., 1998). A review was performed by Hochhauser (2009) for the effect of fuel on emissions with inputs from 128 research articles and 329 abstracts. This mainly consisted of studies which were not covered in the review by Lee et al. (1998). The results of the reviews and the findings from other research articles are discussed next.

2.1 Effect of T95 temperature

A typical distillation curve for diesel fuel is shown in Fig. 8.6. The temperature for 50 percent distillation temperature or mid-boiling point, 90 percent point and the final boiling point are the important distillation parameters.

Lower the boiling point of the fuel, more readily it vaporizes and mixes with air giving more complete combustion. The mid boiling volatility is also correlated to the other physico-chemical properties like, density, viscosity and ignition quality. A higher mid boiling point fuel has higher density and viscosity, and usually a lower CN. Low mid boiling point fuels give faster cold starting and hence lower HC emissions. The fuel components boiling above 350º C may not burn completely, forming high soot concentrations and combustion chamber deposits. Fuels with high T90 and final boiling point are seen to result in an increased injector choking leading to poor combustion and higher smoke emission [8].

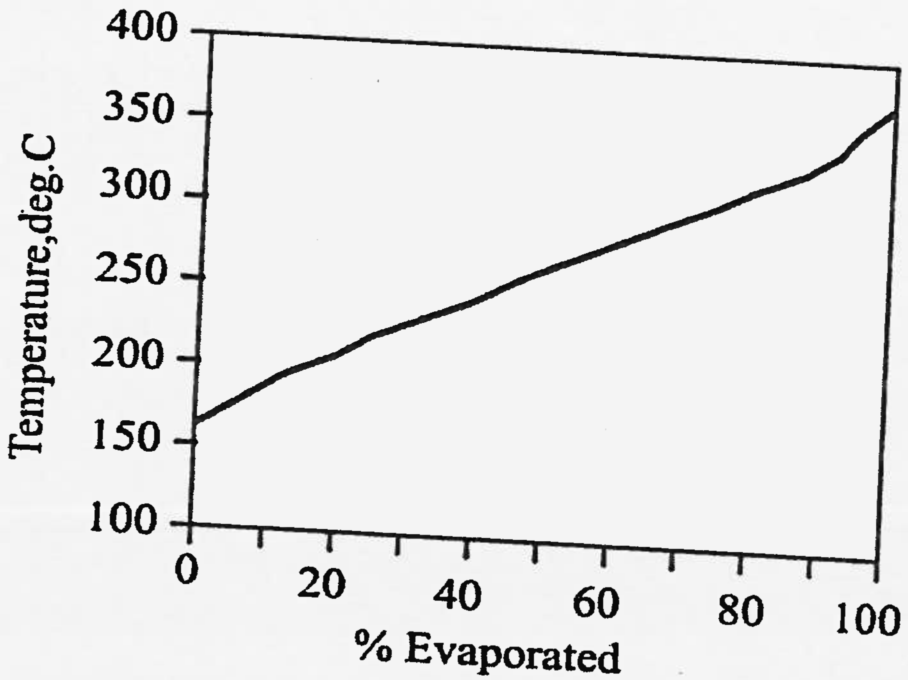

Figure 1. Typical Distillation Characteristics of diesel fuel.

Based on the review of ~450 research articles, Hochhauser (2009) summarized the directional change in proportion of back-end components (having high boiling points) to achieve reduced emissions. The summary is given in Table 1 from where it is observed that the fraction of back-end components should be decreased to achieve low particulate emissions from light duty engines. HC and CO emissions are unaffected whereas the data on NO from various studies does not yield a specific trend due to which no conclusions were made. To achieve low particulate emissions from heavy duty engines, the fraction of back-end components should be decreased which is consistent with the result for a light duty engine. However, the back-end components should be increased to achieve lower CO and HC emissions from a heavy duty engine.

Table 1. Directional change in T95 to obtain reduced emissions (Hochhauser, 2009)

	Light duty	Heavy duty
HC	No effect	Increase
CO	No effect	Increase
NOx	Data exists, but effect is variable for different studies	Data exists, but effect is variable for different studies
PM	Decrease	Decrease

2.1.1 EPEFE study

Next, we discuss some of the key results from a study done as a part of the EU program on emissions, fuel and engine technologies (Hublin et al., 1996; Signer et al., 1996). A comprehensive study of the impact of fuel composition on light and heavy duty diesel engine emissions was performed. The key difference from other similar studies was that a fuel matrix was created to de-correlate two different fuel properties from each other. This was followed by determining the individual effect of each of the properties on the emissions.

Table 2. Effect of change in T95 temperature on emissions from heavy duty vehicles (Signer et al., 1996)

	CO (g/kWh)	HC(g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Decrease T95 from 370 to 325°C	+0.039 +6.6%	+0.031 +13.4%	-0.120 -1.7%	0.0 0.0% (Statistically not significant)

Table 3. Effect of change in T95 temperature on emissions from light duty vehicles (Hublin et al., 1996)

	CO (g/km)	HC(g/km)	NO_x (g/km)	PM (g/km)
Decrease T95 from 370 to 325°C	-0.008 -1.8% (Statistically not significant)	+0.0017 +3.4% (Statistically not significant)	+0.026 +4.6%	-0.004 -6.9%

The quantitative effect of T95 temperature on various pollutants is given in Table 2 for heavy duty vehicles whereas Table 3 shows the results reported by EU study on light duty diesel engines. It is observedthat reducing the T95 temperature from 370 to 325 °Cresulted in a very small decrease in NO_x emissions for a heavy duty engine whereas CO and hydrocarbon emissions increased by 6.6% and 13.4%, respectively. In contrast to the results on heavy duty engines, decreasing T95 from 370°C to 325°Cusing a light duty engine resulted in an increase in NO_x emissions whereas there were no statistically significant variations in CO and HC.It is also observed that the particulate matter (PM) did not display statistically significant variation with change in T95 for heavy duty engines whereas a decrease was observed for light duty engines.

On comparing the results in Tables 1, 2 and3, it is observed that the results in Table 1 for CO and HC are consistent with the EU study for light-duty as well as heavy-duty engines. For PM, the summary results in Table 1 are consistent with the results in Table 3for light duty engines.

The results in Table 2 and 3 are obtained using regression analysis on data obtained from various vehicles and fuels and represent overall trends.These trends were not observed for all the vehicles and engines used in the study. It was observed that the emissions were strongly dependent on factors such as fuel injection system, type of engine and vehicle, turbocharged vs. naturally aspirated engine, etc. For an example, it was observed that for light duty engines, different vehicles showedsignificantly different responses to changes in fuel properties, both in magnitude and direction. The spread in T95 sensitivity is given in Figure 1 where the regression coefficient is defined as the change in emission per unit change in the fuel property (T95 temperature in this case)(Hublin et al., 1996). It is observed that a change in T95 resulted in increase as well as decrease of various emissions.

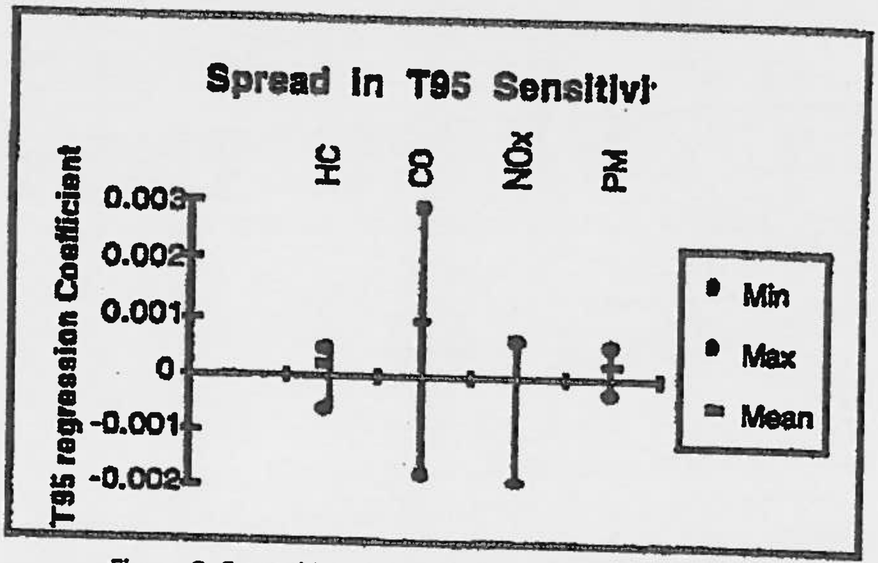

Figure 2. Spread in T95 sensitivity(Hublin et al., 1996)

Similar to light duty engines, it was observed that different heavy duty engines resulted in a different magnitude and direction of change with change in a specific fuel property, e.g., in the case of NOx, two engines showed the largest response to a change in T95 temperature whereas another engine showed no response(Signer et al., 1996). For PM, another set of two engines showed the highest response but in opposite directions. For HC, two engines showed the largest response whereas a third engine showed no response. For CO, three engines showed the highest response whereas one particular engine showed an almost negligible response.

In the EPEFE study for heavy duty engines, it was reported that emission variations due to changing engine models were greater than emission variations due to changing fuel properties with the exception for NOx(Signer et al., 1996).The much larger effect of engines on emissions versus fuel quality was due to the wide range of heavy duty engines investigated, which vary in size, range of rated speed and the various levels and types of technology used to meet the required emission limits. On similar lines, it was reported that changes in vehicle technology and configuration for light duty vehicles had a larger influence on the spread of emissions than changes in fuel properties (Hublin et al., 1996). Also, a comparison of the relative change in emissions due to different fuel properties suggested that density and cetane number had the largest effect in percentage terms on emissions whereas polyaromatics and T95 had smaller effects.

It was also reported that an increase in T95 results in different magnitude of change for direct injection and indirect injection light duty engines(Hublin et al., 1996). The results are shown in Figure 2 where it is observed that the reduction in particulate matter with a decrease in T95 is higher for a direct injection engine.

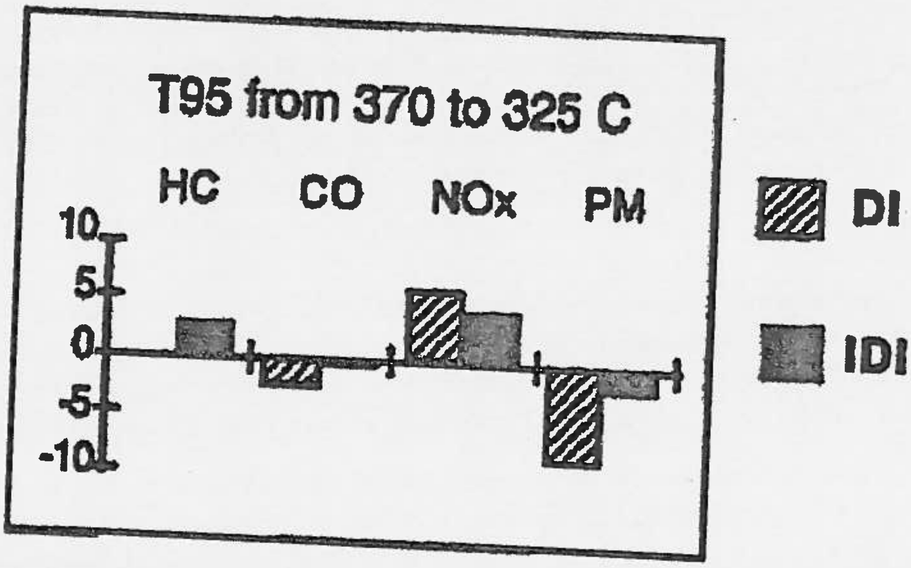

Figure 3. Effect of T95 temperature on direct injection and indirect injection light duty engines(Hublin et al., 1996)

2.1.2 Japan clean air programme study

Studies were carried out as part of the Japan clean air programme (JCAP) examining the effect of back-end volatility on emissions from light duty vehicles. It was observed that lowering T90 reduced PM emissions but did not have a consistent impact on HC, CO or NOx (Hochhauser, 2009). In the JCAP program, tests in eight truck engines representing model years 1990-1999 showed that reducing T90 lowered PM emissions (~0.5 %PM/°C T90)and increased NO_x emissions by a smaller amount (~0.1%NO_x/°C T90) (Hochhauser, 2009).In JCAP testing in engines with aftertreatment, reducing T90 lowered NOx and PM emissions. JCAP also tested an engine with EGR and a Urea-SCR/DPF after treatment system where it was found that reducing T90 increased engine-out emissions of HC and lowered engine-out emissions of PM. For NOx, both engine-out and tailpipe emissions increased when T90 was lowered. The reduced PM with a reduction in T90 for various cases is consistent with the summary results in Table 1.

2.1.3 Other studies

In a book on fuel additives, it is mentioned that the higher boiling fractions between 350 °C and 370 °Ccontain polynuclear aromatics in high concentration and are mainly responsible for particulate emissions (Srivastava). They significantly contribute to the formation of carbonaceous deposits as well. Near the higher end of the boiling range, the concentration of the high molecular weight n-paraffins can be so high that they significantly degrade the cold flow properties. Also, it is reported that decreasing the fraction of the higher boiling point components in the fuels linearly reduces particulate emissions(Sarvi et al., 2008).

In a joint study by Neste Oil and Total, France, 15 different diesel fuels were tested in naturally aspirated engines(onepetro.org). It was observed that an increase in the amount of polyaromatics and especially tri- and higher aromatics in fuel increase the NO, and particulate emissions and smoke. Monoaromatic content had little or no effect on emissions. It was also reported that higher the initial and final distillation points, slightly higher is the content of NO, hydrocarbon and CO-emissions and smoke.

According to Pundir(Pundir, 2013), the low volatility components boiling above 350 °C may not burn completely forming engine deposits and causing high black smoke emissions. The heavy end volatility (T90, T95, and final boiling point) fuel components are more difficult to burn. A poor high end volatility increases injector coking, engine deposits and emissions of smoke and particulate matter. The trend is towards specifying lower limits for T90 or T95 in the fuel specifications. European specifications EN 590:1999 specifies T95 equal to 360 °C maximum in addition to the requirement that a minimum of 85% fuel should evaporate at 350 °C.

2.2 Density

When fuel density changes, thevolume of fuel injected to maintain the same power output also changes, affecting the timing and duration of injection, the onset and duration of combustion, and potentially the fraction of exhaust sent back to the combustion chamber through the EGR system (Hochhauser, 2009). Additionally, it could impact the emissions from the engine.

A summary of the findings given by Hochhauser (2009) for the effect of density on emissions is shown in Table 4. As discussed earlier, this study is based on results from ~450 research articles which have performed studies on the impact of fuel on emissions. It is observed from Table 4 that to obtain reduced CO, HC and PM emissions from a light duty engine, the density should be decreased whereas sufficient data is not available for NOx. For heavy duty engines, density should be decreased to reduce NOx whereas sufficient data was not available for defining the effect on CO, HC and PM.

Table 4. Directional change in density to obtain reduced emissions (Hochhauser, 2009)

	Light duty	Heavy duty
HC	Decrease	Data lacking to define effect
CO	Decrease	Data lacking to define effect
NOx	Data lacking to define effect	Decrease
PM	Decrease	Data lacking to define effect

2.2.1 EPEFE study

The effect of decrease in density from 855 to 820 kg/m³ for light duty vehicles for three different driving cycles is given in Figure 3 (EPEFE light). It is observed that there is a significant impact of density on the emissions except for NOx. These results are consistent with those summarized in Table 4 (Hochhauser, 2009).

The results of the EPEFE study on the effect of density on emissions for heavy duty engines is given in Table 5. It is observed that a decrease in density results in a substantial increase in unburnt hydrocarbons for heavy duty engines. However, there is no significant impact on the particulate matter. On comparing the summarized results in Table 4 and the EPEFE study results in Table 5, it is observed that the two are consistent only for NOx. A possible reason for the inconsistency of the results for PM is the type of vehicle used. In a review by Lee et al. (2), it is reported that the negligible impact of density on particulate matter is only for heavy duty engines which have a low base emission rate. For engines with a high base emission rate, a reduction in density results in a substantial decrease in the particulate matter.

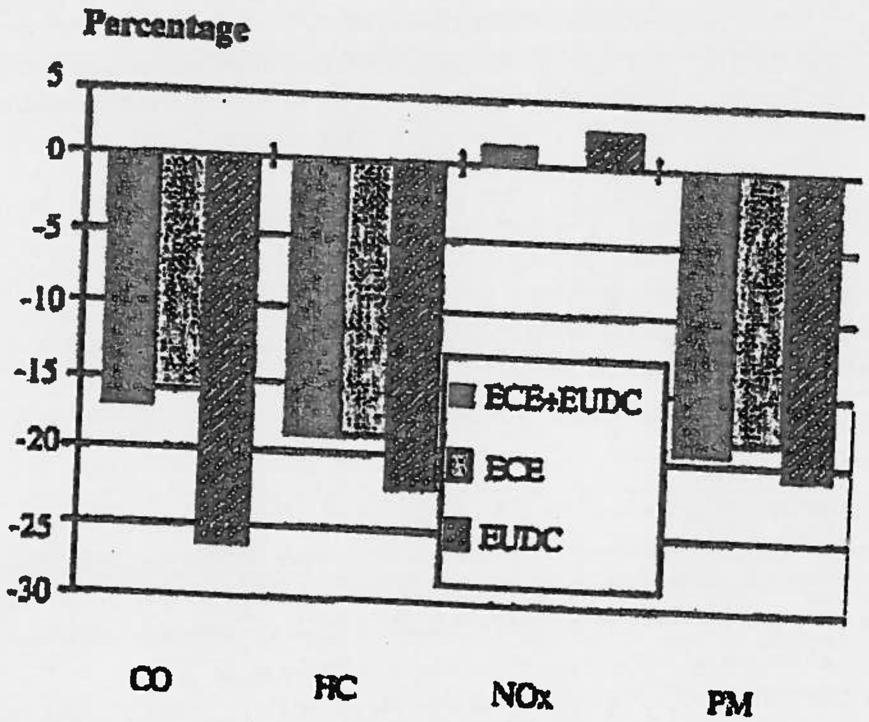

Figure 4. Effect of decrease in fuel density on the emissions from light duty engines (Hublin et al., 1996)

Table 5. Effect of change in density on emissions from heavy duty vehicles (Signer et al., 1996)

	CO (g/kWh)	HC(g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Decrease density from 855 to 828 kg/m^3	+0.03 +5.0%	+0.034 +14.3%	-0.245 -3.6%	-0.001 -1.6% (Statistically not significant)

To study if the observed effect of density on emissions is due to the change in volumetric energy content of fuel, the injection system was adjusted to ensure the same mass of fuel delivered(Signer et al., 1996).Adjustment of the injection system to ensure same mass of fuel for the low and high density fuels eliminated the differences in emissions between the two fuels. It was concluded that the effect of density on engine performance and emissions is caused by a physical interaction with the fuel injection system which is purely hydraulic in nature. There was no evidence of density effects on the combustion process.

2.2.2 Other studies

It was observed in the EPEFE study for heavy duty engines that the fuel density was the most influential property to reduce NOx. Similar observations were made for light duty engines(Hublin et al., 1996). Ouden et al. (1994) also reported that for cars without catalysts, the most important fuel property affecting PM emissions was density followed by polyaromatic hydrocarbons. However, for cars with a catalyst, no single property could be distinguished as the most important.

In a technical review by Chevron on diesel fuel, it was observed that reducing fuel density tends to decrease NO_x emissions in older technology engines that cannot compensate for this change. Emissions from modern engines, with electronic injection and computer control, are not influenced by the density of the fuel(www.chevronwithtechron.ca).

Fuel injection system and emission reduction technology such as EGR rates are set for a given engine load and speed in the engine map of the electronic engine management system (Pundir, 2013). Large variations in fuel density result in variations in EGR rates from the optimum value. However, a number of programs showed that fuel properties affect engine operations and that when compensations are made for these changes, the effects of density, cetane and aromatics are reduced or eliminated (Hochhauser, 2009).

2.3 Viscosity

The viscosity of diesel has a strong influence on fuel atomization, a high viscosity fuel resulting in larger fuel droplets. An increase in viscosity reduces spray cone angle and increases spray penetration. Low viscosity on the other hand, results in an increase in leakage of fuel past the pumping elements and loss of fuel system calibration. High viscosity of fuel is necessary for lubrication and protection of the injection equipment from wear [7].
High viscosity can also lead to the higher frictional losses, and therefore a decrease in output power. This can be overcome using optimum viscosity fuel.
A high viscosity can also lead to higher amount of soot collection in the combustion chamber.

3. Summary

Various studies have been performed to study the effect of fuel properties on the emissions. Some of these studies presented conflicting results. Comparing the results of the individual studies is a challenging task. One of the main reasons is the lack of uniformity in the conditions used for carrying out these studies. It was found that the engine size, engine technology, fuel injection system, after treatment system, detection methods, vehicle size and other such factors contributed to the results. Additionally, statistical analysis was not reported in some of the studies whereas in some studies, the fuel properties were not varied independently. This could result in erroneous data analysis.

A review of various studies on the effect of fuel composition was performed by Hochhauser, the overall results of which are given in Tables 1 and 4 (Hochhauser, 2009). For both light duty and heavy duty vehicles, it was suggested that a decrease in T95 temperature would result in lowering of PM emissions. For heavy duty engines, an increase in T95 would lower HC and CO emissions whereas light duty engines would be unaffected by a change in T95. There have been studies on NOx but the effect of T95 on NOx is highly variable for various studies, due to which a definite trend between T95 and NOx was not established.

It was found that the density had the maximum effect on the emissions as compared to other fuel properties such as cetane number, polyaromatic hydrocarbons and T95. However, it was also mentioned that there was no conclusive evidence of a change in combustion characteristics due to a change in the fuel density. One of the major cause of change in emissions with changing density was the different amount of fuel being added by a volume-based injection system. Based on a review of various studies, Hochhauser (2009) concluded that a decrease in density would result in a decrease in CO, HC and PM emissions for light duty engines whereas no conclusive trend was found for NOx. A decrease in density would result in a decrease in NOx for heavy duty engines. For CO, HC, and PM, it was observed that sufficient data did not exist to establish a trend with the density.

It was further observed that the effect of Flash Pont from the viewpoint of emissions was insignificant.

High viscosity fuel (above the optimum) is seen to reduce the power output due to increased frictional losses. A highly viscous fuel is seen to have higher carbon deposits and hence increased HC emissions.

The various trends relating the effect of a fuel property on emissions are based on a regression analysis on various vehicles and engine types. This does not necessarily mean that for each vehicle and each type of engine, these trends would be observed.

The table below summarizes all the findings above.

	To Reduce Emissions, Make the Directional Changes Shown Below (Light Duty / Heavy Duty)						
	Density	Cetane	Aromatics/PAH	Sulfur	Back-End	FAE	FT
HC	↓/*	↑/↑	↑/↓	0/0	0/↑	↑/↑	↑/↑
CO	↓/*	↑/↑	↑/*	0/0	0/↑	↑/↑	↑/↑
NOx	*/↓	*/*	↓/↓	0/0	##	↓/↓	#/↑
PM	↓/*	↓/#	↓/↓	↓/↓	↓/↓	↑/↑	↑/↑

0 No effect
* Data are lacking to define effect
# Data exist, but effect is variable

*Back-end test corresponds to T90/T95 effect.

4. References

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7. CONCLUSIONS

- Large improvements in exhaust emissions control were demonstrated with advanced engine / after-treatment technologies in combination with low sulphur fuels.
- HC and CO emissions from the advanced diesel engines and vehicles were very low, well below the prescribed emissions limits.
- For the heavy-duty engines, Euro-4 and Euro-5 emissions limits were achieved with the nominal 50ppm sulphur fuel.
- PM emissions were dramatically reduced in engines/vehicles equipped with diesel particulate filters.
  - In such cases, PM emissions were so low that the impact of fuel properties other than sulphur became negligible.
  - Fuel sulphur content influenced PM emissions under high speed/load (high temperature) conditions.
  - In the Euro-3 systems without DPFs, effects of both fuel sulphur and other properties on PM emissions were observed; the size of these effects varied with operating conditions.
- Clear progress in control of NOx emissions was demonstrated with the advanced diesel engine technologies.
  - Fuel sulphur content had no direct effect on NOx emissions in the engine/vehicle technologies tested here, though sulphur reduction should enable a wider range of NOx after-treatment systems to be employed.
  - Other extreme fuel property changes influenced NOx emissions in the heavy-duty engines, and in the light-duty vehicles in the ARTEMIS motorway cycle, but not in the NEDC. Fuel effects on NOx emissions were smaller in light-duty vehicles than in heavy-duty engines.
  - Optimisation of the exhaust after-treatment was also important, with increasing urea rate reducing NOx emissions.
  - Further progress on NOx emissions can be expected as control of engine-out emissions improves and NOx after-treatment technology matures, with the availability of sulphur-free fuels.
- Application of SCR/urea to control NOx in a Euro-5 prototype engine, with the engine tuned for better efficiency, improved fuel efficiency by about 5% versus a Euro-3 base case engine. Conversely, the use of EGR plus CRT to achieve Euro-4 heavy-duty emissions limits resulted in a loss in engine efficiency versus the Euro-3 engine.
- Diesel fuels with higher H:C ratios gave lower engine/vehicle CO2 emissions, though this would need to be considered on a well-to-wheels basis. These fuels also gave higher volumetric fuel consumption and lower maximum power due to their lower density.
- Despite the wide range of fuels tested, the engine/vehicle energy efficiency was insensitive to fuel changes, and no statistically significant differences between fuels were seen.

As India is poised to switch to BS V fuels , diesel and gasoline both , completely in next 4-5 years , Indian refiners are gearing up to produce these fuels as per time table. In this direction, while keeping the objectives of emission management and engine performance compatibility, Indian Refiners are endeavouring to maximise production of diesel which is a high value product and consumed in a large variety of sectors , transport being the major one.

Formulation of appropriate specifications for BS V diesel to achieve these objectives is one of the key approach in this direction. Indian refiners , as a part of working group of the committee on Auto Fuels Vision and Policy 2015 , proposed specifications which were agreed and included in last draft of Auto Fuels and Vision Policy 2025 but later on revised in final report without their consent. The inclusion after discussion with all stakeholders however, indicate that the specifications were meeting the overall national objectives.

A self contained note prepared by the PetroFed on BS V diesel specifications representing the views of Indian Refiners is enclosed for your perusal. PetroFed strongly feels that specifications proposed by the Refiners not only meet the national objectives of emission control through fuel quality and engine performance but also increase diesel production which is economically beneficial to the nation as it would reduce our dependence on import. Because of these benefits, these specifications should be included in the national policy document on BS V and BS VI fuels.