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Gasoline and diesel fuel quality survey for India: Part 1

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Background

India has officially transitioned to Bharat Stage (BS) VI vehicle emission standards. The BS VI regulation, effective as of April 1, 2020, contains new fuel specifications and standards for commercial gasoline and diesel to support the advanced emission control technologies that automakers are incorporating in BS VI vehicles. As in many other regions, Indian fuel quality standards have historically been implemented to complement vehicle emission standards, and the standards have gradually gotten stricter over the last two decades. Indeed, since the introduction of unleaded gasoline in 2001, fuel quality in India has come a long way. When BS IV fuel quality standards went into effect in April 2017, fuel sulfur levels in both gasoline and diesel were limited to 50 parts per million (ppm) nationwide.

The BS VI regulation further reduces the diesel and gasoline sulfur content to 10 ppm; this is to enable optimal functioning of advanced emission control systems like diesel particulate filters, selective catalytic reduction systems, and lean-NO_x traps. In addition to sulfur, BS VI fuel quality standards also improve upon some of the other fuel quality characteristics shown in Table 1 (Bureau of Indian Standards [BIS]–Diesel, 2017; BIS–Gasoline, 2017). While some parameters, like octane number, olefin content, and fuel density in gasoline, and cetane number in diesel, do not directly impact exhaust pollutant emissions, they have an effect on the engine's thermal efficiency. Other parameters, like ethanol content in gasoline and polycyclic aromatic hydrocarbon content in diesel, have a direct effect on exhaust emissions (Dallmann & Bandivadekar, 2016).

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Table 1. BS IV and BS VI fuel standards

Characteristics	Unit	Bharat Stage IV	Bharat Stage VI
Gasoline			
Implementation date		2010 (selected cities); 2017 (nationwide)	2020
Density 15°C	kilograms (kg)/ cubic meter (m^3)	720–775	720–775
Research octane number (RON)	minimum	91/95[a]	91/95[a]
Anti-knock index (AKI) or motor octane number (MON)	minimum	81/85	81/85
Sulfur, max	ppm	50	10
Lead, max	grams (g)/liter (L)	0.005	0.005
Benzene, max	% volume	1.0	1.0
Aromatics, max	% volume	35	35
Olefin, max	% volume	21/18[a]	21/18[a]
Oxygen content, max	% mass	2.7	2.7
Reid vapor pressure (RVP) @ 37.8ºC, max	kilopascal (kPa)	60	60
Diesel			
Implementation date		2010 (selected cities), 2017 (nationwide)	2020(nationwide)
Ash, max	% mass	0.01	0.01
Carbon residue (Ramsbottom) on 10% residue, max [b]	% mass	0.3	0.3
Cetane number (CN), min	—	51	51
Cetane index (CI), min	—	46	46
Distillation 95% vol. recovery at °C, max	°C	360	370
Flash point Abel, min	°C	35	35
Kinematic viscosity @ 40 °C	centistokes (cSt)	2.0–4.5	2–4.5
Density @ 15 °C	kg/m^3	815–845	810–845
Total sulfur, max	milligram (mg)/kg	50	10
Water content, max	mg/kg	200	200
Cold filter plugging point (CFPP) **a) summer, max** **b) winter, max**	 °C °C	 18 6	 18 6
Total contaminations, max	mg/kg	24	24
Oxidation stability, max	g/m^3	25	25
Polycyclic aromatic hydrocarbon (PAH), max	% mass	8	8
Lubricity, corrected wear scar diameter (wsd 1,4) @ 60 °C, max	µm (microns)	460	460
Copper strip corrosion for 3 hours @ 50 °C	Rating	Class I	Class I

[a] Fuel quality specification for regular/premium gasoline
[b] This limit is applicable prior to the addition of any ignition improvers. In case a value exceeding the limit is obtained on finished fuels in the market, ASTM D 4046 / ISO 13759 shall be used to establish the presence of nitrate containing compound. In such case the present limit for carbon residue cannot be applied. However, the use of ignition improver does not exempt the manufacturer from meeting this requirement prior to the addition of additives.

Methodology

In view of the nationwide rollout of BS VI fuel quality and emission standards, we are undertaking a comprehensive survey of motor gasoline and automotive diesel fuel quality across India. The survey consists of two phases. Samples for phase I were collected in December 2019 and January 2020, and collection of samples for phase II is expected to happen in the second half of 2020. Phase I is aimed at understanding the readiness of suppliers to meet BS VI fuel specifications and the average deviation of parameters from the BS IV fuel standards before BS VI standards went into effect. Phase II is aimed at quantifying the compliance of suppliers with BS VI fuel specifications

and the average deviation of parameters from the BS VI fuel standards after the BS VI standards go into effect. In this paper, we present the results of phase I.

Testing program

We contracted SGS Germany GmbH to carry out sampling and analysis for both phases of the study. When choosing sampling station locations, we did our best to avoid possible redundancy, i.e., sampling multiple stations supplied by the same refinery. Samples of gasoline and diesel were drawn from two retail stations each in 15 cities spread across India, for a total of 30 samples each for gasoline and diesel. While many samples for gasoline and diesel were taken from the same retail outlets, in some cases they were not, and this resulted in a total of 45 retail outlets sampled altogether.

Table 2 also lists if the outlet is Dealer Owned Dealer Operated (DODO), Company Owned Company Operated (COCO), or Company Owned Dealer Operated (CODO). All samples collected were regular gasoline and diesel, and retail outlets were certified to supply BS IV standard fuel at the time of sampling except for the retail outlets in Delhi, which were certified to supply BS VI fuel.

Table 2. Sampling IDs and locations

Retail station #	Gasoline sample ID	Diesel sample ID	Outlet type
AMBD1	Ahmedabad1	Ahmedabad1	DODO
AMBD2	Ahmedabad2	Ahmedabad2	DODO
COH1	Cochin1	Cochin1	DODO
COH2	Cochin2	Cochin2	DODO
KAN1	Kanpur1	Kanpur1	DODO
KAN2	Kanpur2	Kanpur2	DODO
MYSR1	Mysuru1		DODO
MYSR2	Mysuru2		DODO
MYSR3		Mysuru3	DODO
MYSR4		Mysuru4	DODO
NGPR1	Nagpur1		DODO
NGPR2	Nagpur2		CODO
NGPR3		Nagpur3	CODO
NGPR4		Nagpur4	DODO
NDHL1	New Dehi1		DODO
NDHL2	New Delhi2		DODO
NDHL3		New Delhi3	DODO
NDHL4		New Delhi4	DODO
PTNA1	Patna1		DODO
PTNA2	Patna2	Patna2	DODO
PTNA3		Patna3	DODO
RNCH1	Ranchi1		DODO
RNCH2	Ranchi2		DODO
RNCH3		Ranchi3	DODO
RNCH4		Ranchi4	DODO
		Ranchi4-retest	
SHML1	Shimla1	Shimla1	DODO
SHML2	Shimla2	Shimla2	DODO
THAN1	Thane1	Thane1	CODO
THAN2	Thane2	Thane2	DODO

Retail station #	Gasoline sample ID	Diesel sample ID	Outlet type
VSKP1	Visakhapatnam1		COCO
VSKP2	Visakhapatnam2		DODO
	Visakhapatnam2-retest		
VSKP3		Visakhapatnam3	DODO
VSKP4		Visakhapatnam4	DODO
VRNS1	Varanasi1	Varanasi1	DODO
VRNS2	Varanasi2	Varanasi2	DODO
MUMB1	Mumbai1	Mumbai1	DODO
MUMB2	Mumbai2	Mumbai2	DODO
BNSW1	Bhubaneswar1		DODO
BNSW2	Bhubaneswar2		DODO
BNSW3		Bhubaneswar3	DODO
BNSW4		Bhubaneswar4	DODO
UDPR1	Udaipur1		DODO
UDPR2	Udaipur2		DODO
UDPR3		Udaipur3	DODO
UDPR4		Udaipur4	DODO

Two-liter samples of regular unleaded gasoline and diesel from each sampling station were drawn directly from a nozzle at the station and taken in Jerrycans; later they were decanted to International Air Transport Association (IATA) proofed cans, as seen in Figure 1. Gasoline samples were allowed to cool prior to decanting and all samples were delivered by air cargo to SGS Germany for lab analyses.

Figure 1. IATA proofed cans used for storing and shipping fuel samples.

Table 3 lists the standard testing protocols as recommended by the Bureau of Indian Standards. The testing standards used to analyze respective compounds in this study are in bold and italics in the table below, which also lists other standards that could be used for analyzing the same compounds.

Table 3. BIS gasoline and diesel specifications/standard reference

Parameter analyzed	BIS recommended standards (the standard used for this analysis in bold and italics)	Remarks
Petrol		
Aromatics	ASTM D 1319 /D 5580/ D 6730 /D 6839 /***ISO 22854***	
Benzene	ASTM D 3606 / D 55809 / D 6277 /D 6730/ D 6839/ ***ISO 22854***	
Olefins	ASTM D 1319 /D 6730/ D 6839/ ***ISO 22854***	
Ethanol	ASTM D 48159/ D 5599	***ISO 22854*** was used as an alternative to ASTM D5599 since it is more precise for ethanol contents above 1%.
Octane (RON)	ASTM D 2699	
Sulfur content	P: 34 / P: 153/ ISO 20847 /ISO 208469/ ISO 130329/ ***ASTM D 2622***/ D 3120/ ***D 5453***/ D 7220	All samples were measured by ASTM D2622. Samples with less than 10mg/l were measured additionally by ASTM D 5453.
RVP	P : 39 / ASTM D 323 (wet methods) / ***D 5191(dry method)*** / D 6378/ EN 13016	
Density	[P:16] / ISO 3675 / ***ASTM D 4052***/ISO 12185/ ASTM D 1298/ IP 160	
Diesel		
Cetane number	ASTM D 613	
Sulfur content	ISO 130329 / ISO 20884/ISO 208469 / ASTM D 5453/ ***ASTM D 2622***/ASTM D 7220/[P : 34] for Bharat Stage IV grade only [P : 153] /ASTM D 4294	All samples were measured by ASTM D2622. Samples with less than 10mg/l were measured additionally by ASTM D 5453.
Density	[P:16]/ ISO 3675 / ***ASTM D 4052***/ISO 12185/ ASTM D 1298 / IP 160	

Results and discussion

Gasoline results

We found that nearly half of the outlets already complied with BS VI sulfur limits and all complied with BS IV sulfur limits. As shown in Figure 2, one of the samples tested from Visakhapatnam retail stations, Visakhapatnam2, showed a sulfur level that was not compliant with either BS VI or BS IV standards; it was resampled and retested. The retest, Visakhapatnam2-retest, showed that the sample complied with BS IV sulfur standards.

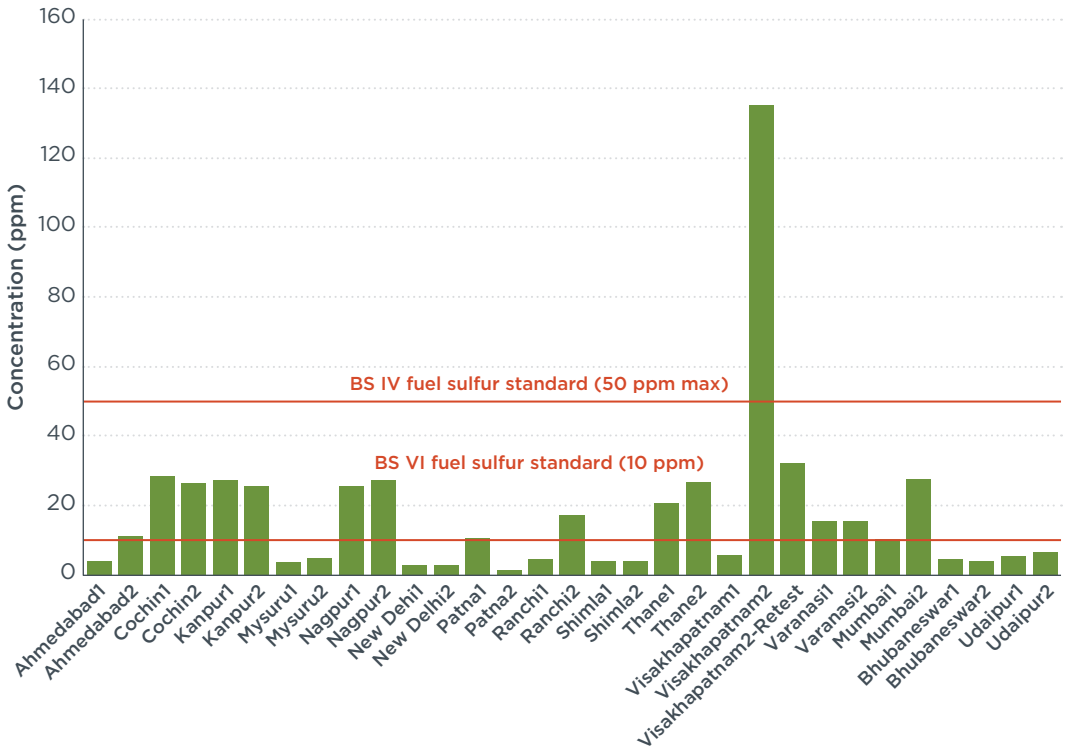

Figure 2. Sulfur content analyzed in all gasoline samples taken

The RVP standards did not change between BS IV and BS VI and remained capped at 60. From the fuel we analyzed from all outlets, three retail outlets were out of compliance, each by about 8%. This does not impact tailpipe emissions.

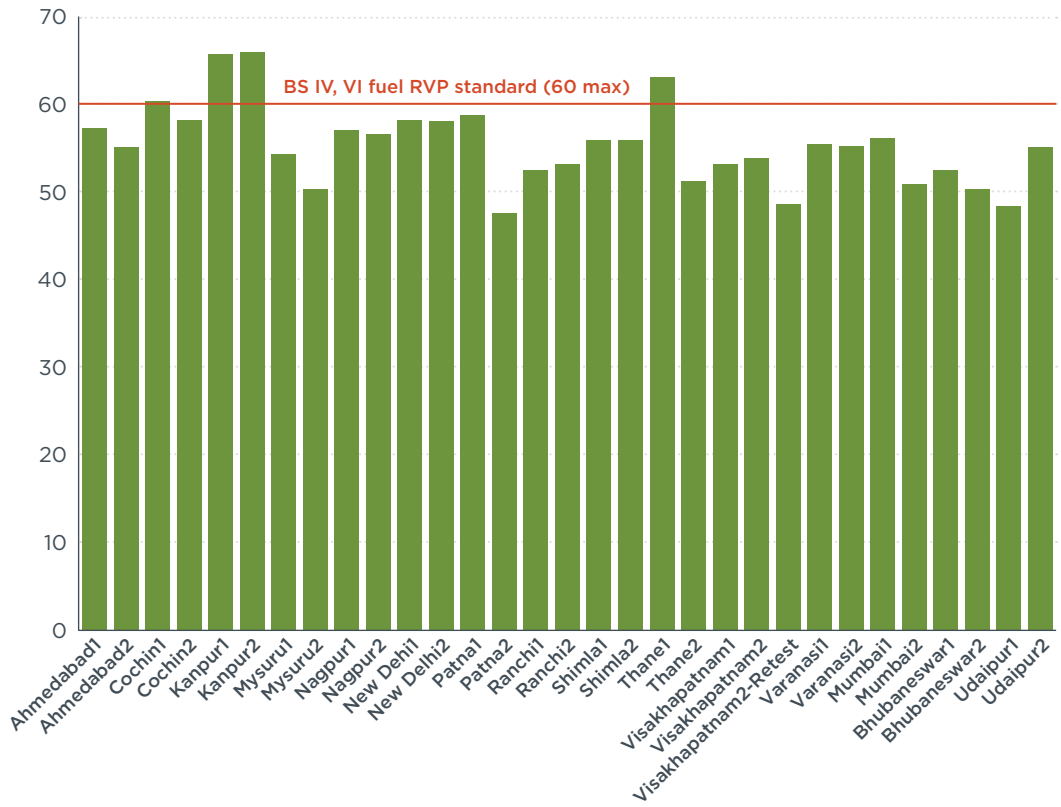

Figure 3. RVP analyzed in all gasoline samples taken

Similar to RVP, the RON standards also did not change between BS IV and BS VI. As illustrated in Figure 4, below, although some samples barely met the minimum requirement, all outlets except for samples collected from one (Visakhapatnam2) complied with the required standards.

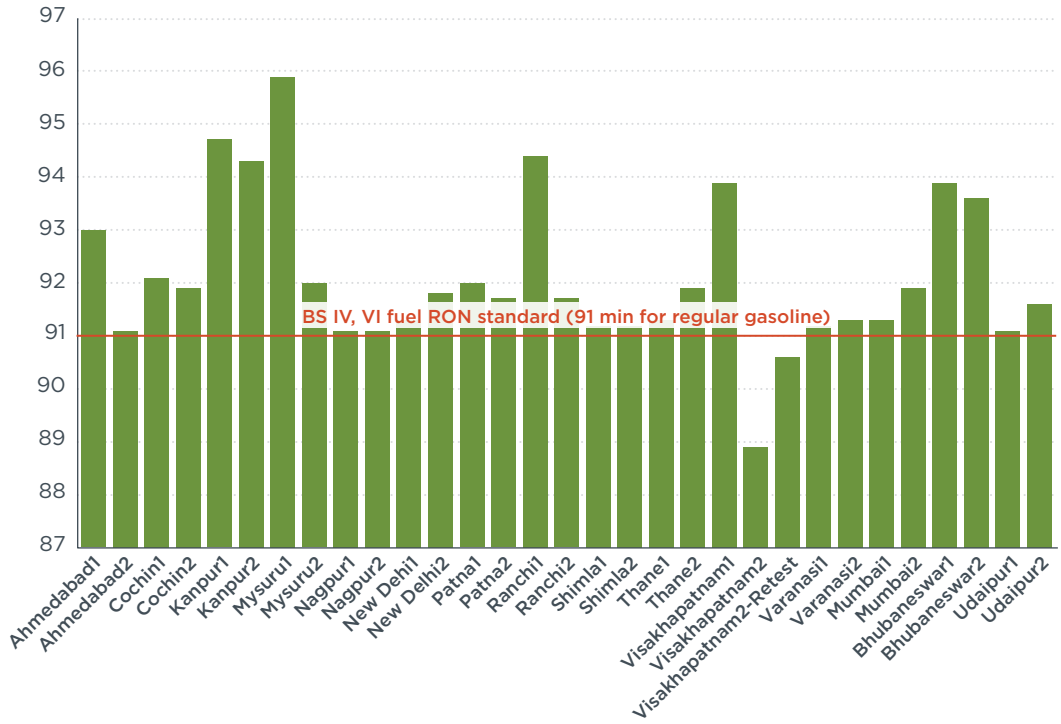

Figure 4. RON analyzed in all gasoline samples taken

The requirements for aromatics also remained the same between BS IV and BS VI. From the data analyzed, two outlets exceed the maximum standard by an average of 1%. Since aromatic compounds are relatively less critical to tailpipe emissions than sulfur or benzene, these fine margins of non-compliance are not treated further.

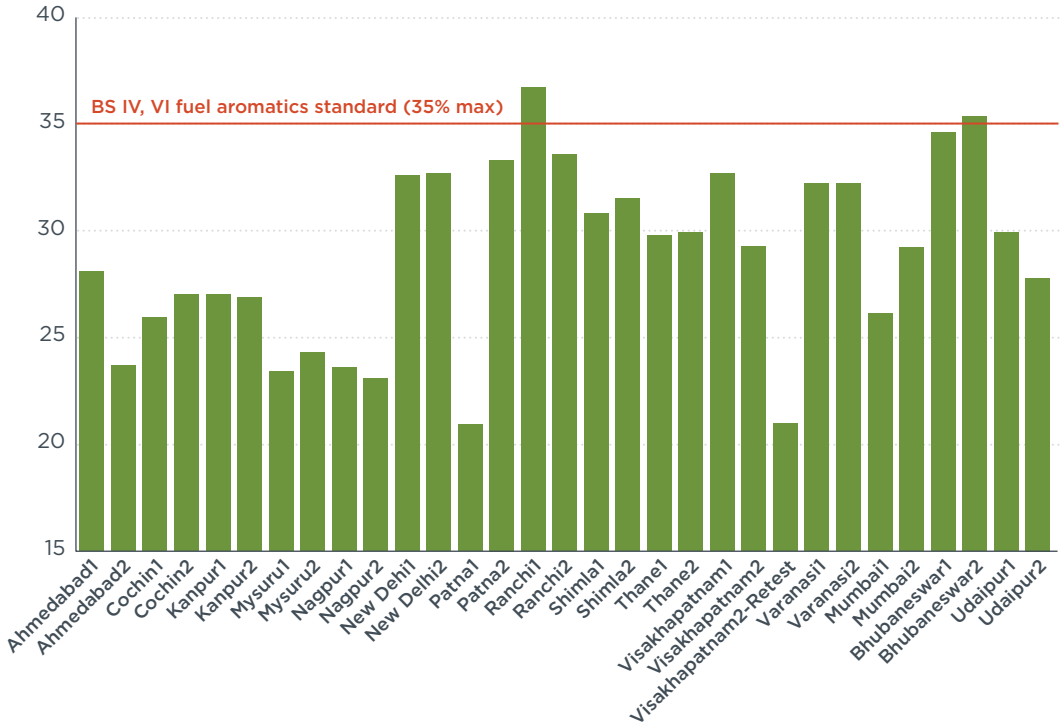

Figure 5. Aromatics content analyzed in all gasoline samples taken

Gasoline density standards, which are in the 720–775 kg/m^3 range, have not changed since BS III. All samples analyzed complied with the requirement.

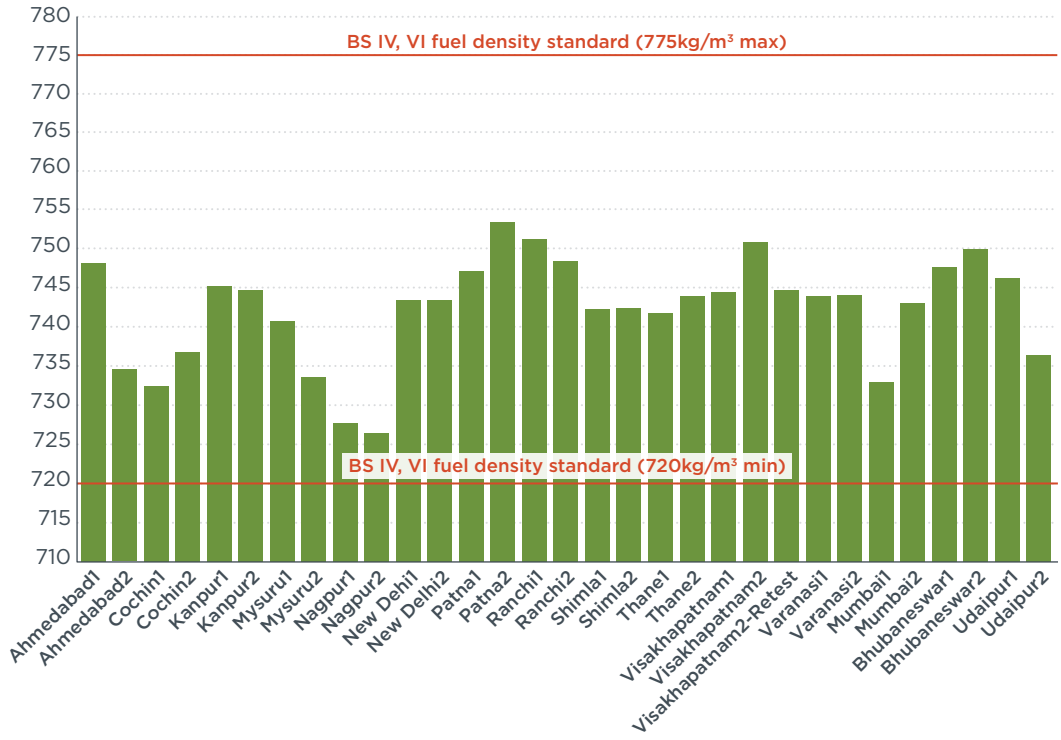

Figure 6. Density analyzed in all gasoline samples taken

The standard for maximum olefin content has also not changed since BS III and remains at 21% for regular grade gasoline in BS VI fuel specifications. All samples analyzed met the standard.

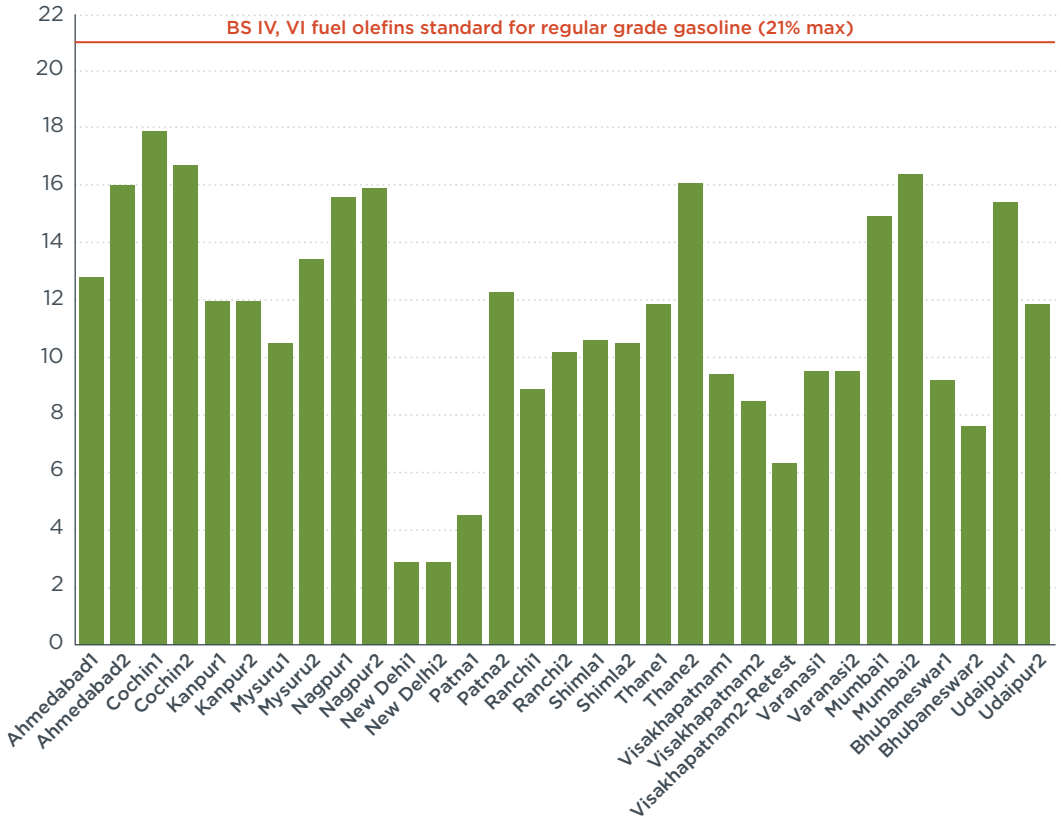

Figure 7. Olefin content analyzed in all gasoline samples taken

One of the critical aspects of India's fuel standards is the benzene limit of 1%. Even though this standard has not changed since BS II, eight samples were not compliant. However, only one sample fell outside the allowed measurement error for this test.[1] The Visakhapatnam2 sample tested at nearly 9 times the standard and when retested (Visakhapatnam2-Retest), it failed by 22%.

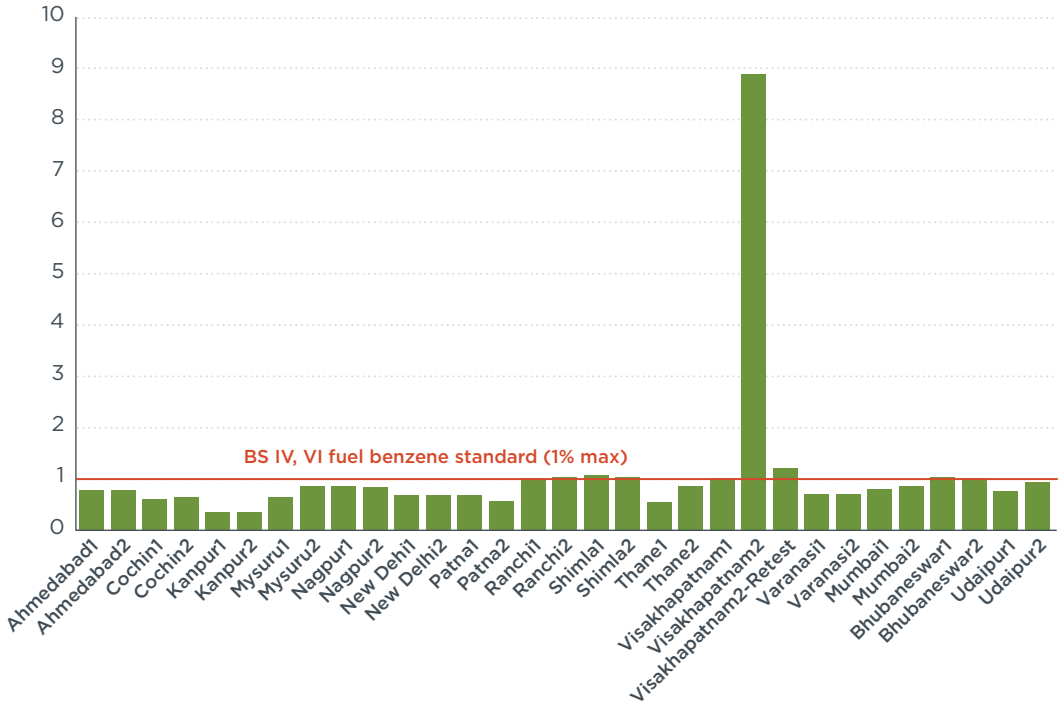

Figure 8. Benzene content analyzed in all gasoline samples taken

No change was made for ethanol content from BS IV to BS VI. The ethanol content allowed in regular gasoline is up to 5% and in the E10 fuel, it is up to 10%. All samples complied with the respective standards for regular and E10 fuel.

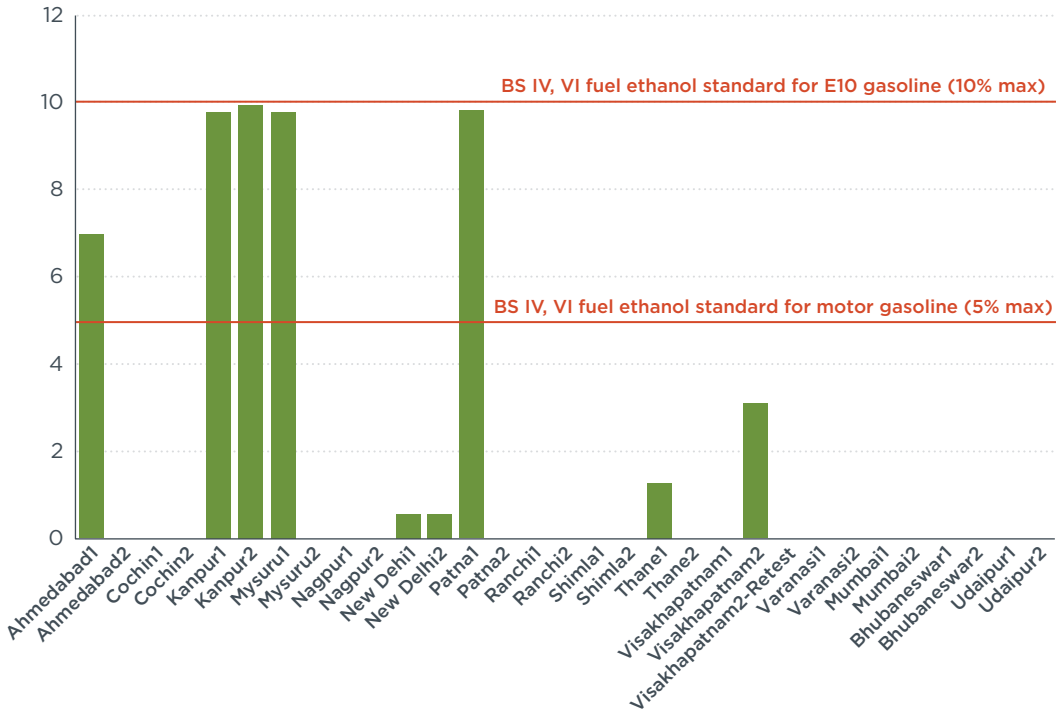

Figure 9. Ethanol content analyzed in all ethanol samples taken

1 The test laboratory (SGS) reported a repeatability of 0.02% and reproducibility of 0.1% for the benzene tests conducted.

Diesel results

The next three figures show the results of analysis of the diesel samples that were also obtained from the same retail outlets as the gasoline samples. Just like in gasoline, one of the major changes seen in diesel standards for BS VI is the sulfur limit of 10 ppm. Similar to the results obtained from the gasoline samples, results show that nearly half the outlets already comply with BS VI limits and all except one (Ranchi4) comply with the BS IV limit. We resampled and retested from the same retail outlet in Ranchi and found it to be better (Ranchi4-retest).

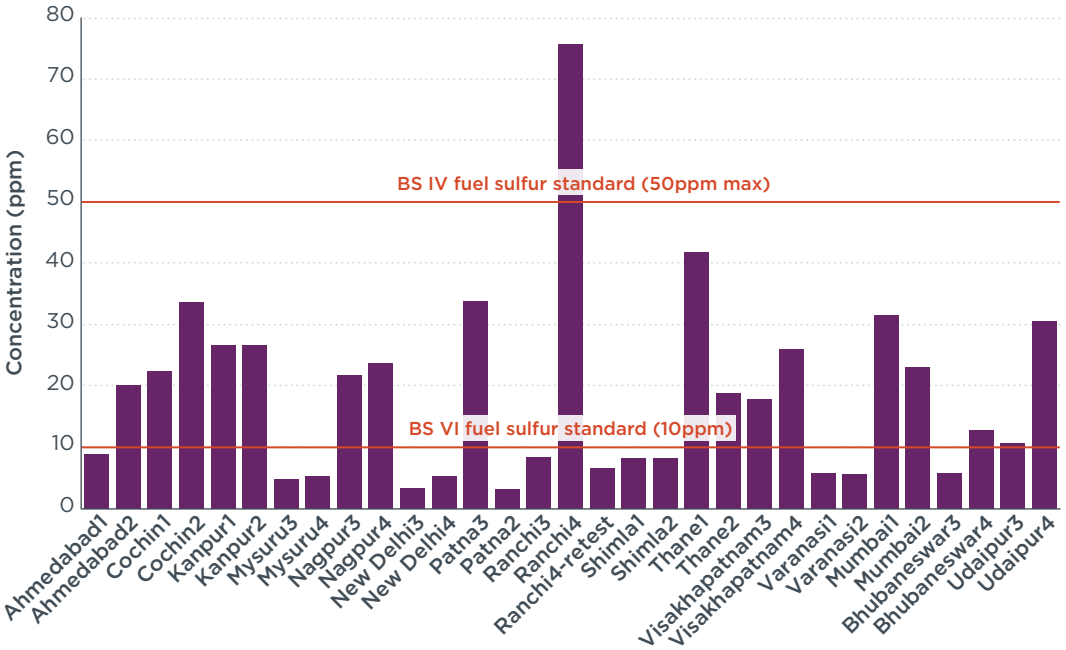

Figure 10. Sulfur content analyzed in all diesel samples taken

The minimum cetane number requirement has not changed from BS IV to BS VI, and it remains at 51. All outlets except three complied with the minimum required standard. Because the out-of-compliance values are under by approximately 1.5%, they do not raise any alarms about impact on tailpipe emissions.

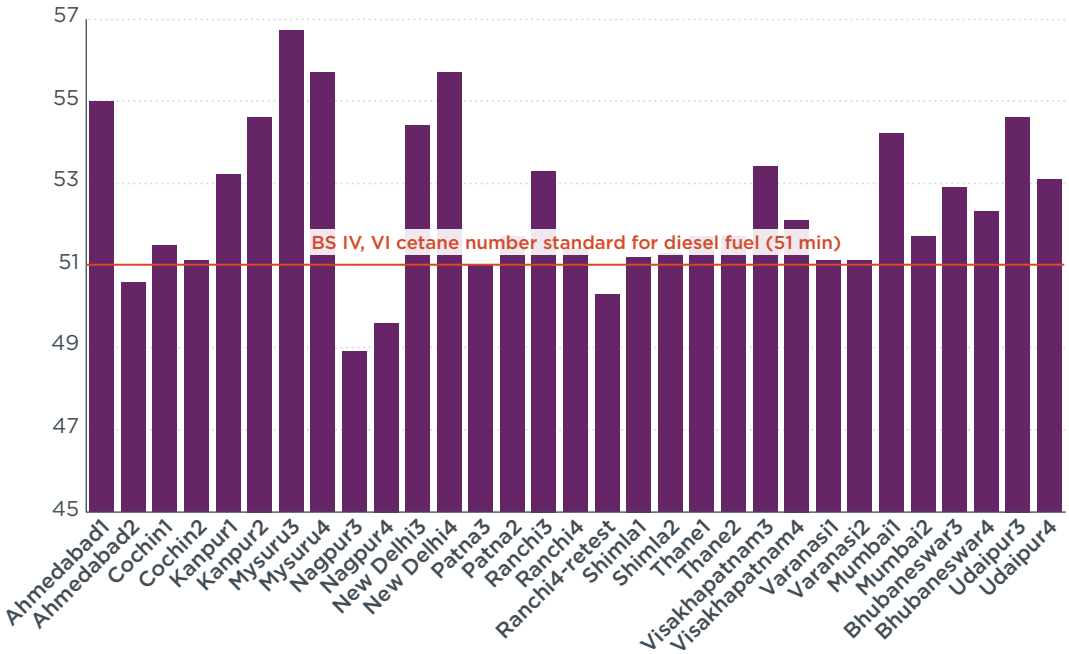

Figure 11. Cetane number analyzed in all diesel samples taken

The density standard range increased to 810–845 kg/m³ in BS VI regulations from the previous range, 815–845 kg/m³ in BS IV. All samples tested complied with both BS IV and BS VI regulations.

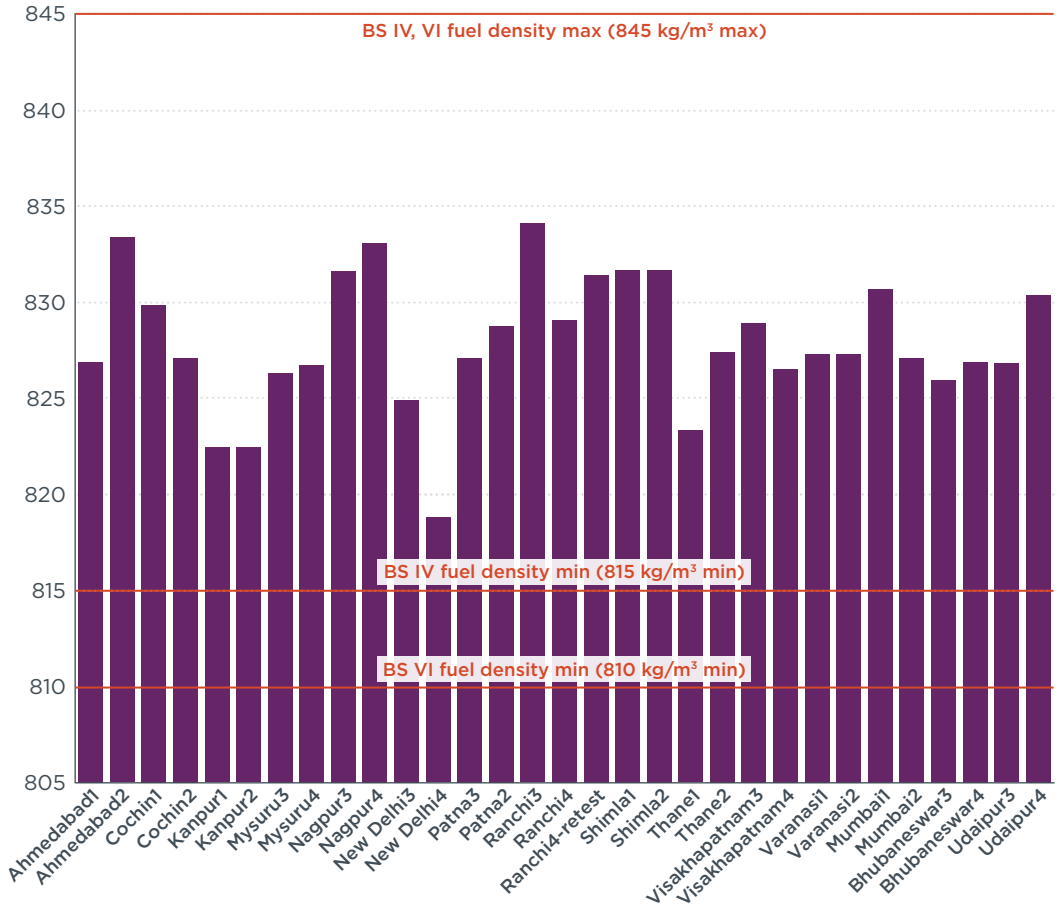

Figure 12. Density analyzed in all diesel samples taken

Conclusion

Results from phase I tests show that while most of the retail outlets complied with BS IV fuel limits, a few did not. Although non-compliant fuel was found to have been sold by a few retailers, it is not clear whether the problem of fuel quality originated with the supplier or the retailer. Therefore, robust fuel quality monitoring is needed both upstream and downstream along the supply chain. Results also show that a number of refineries as of December 2019 had already started supplying BS VI standard fuel to several distributors. While only the retail outlets in Delhi were required to meet the BS VI fuel standard requirements at the time, several other outlets also already complied with BS VI standards. The data analyzed indicates a promising readiness toward full compliance from April 1, 2020 onward. The second phase of this study is expected to begin in the second half of 2020 and samples will be collected from the same cities to examine the transition to BS VI fuel quality.

References

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