WORKING PAPER 2021-17

APRIL 2021

Gasoline and diesel fuel quality survey for India: Part 2

Authors: Bharadwaj Sathiamoorthy and Anup Bandivadekar
Keywords: gasoline, diesel, Bharat Stage VI, vehicle emissions, fuel quality, fuel standards

Background

The ICCT began a two-part survey of motor gasoline and diesel fuel in India in December 2019, and phase I was carried out between December 2019 and January 2020. This was just prior to the implementation of Bharat Stage (BS) VI vehicle emission standards, which also include new fuel specifications. Phase I was meant to assess both the average deviations from the BS IV specifications in place at the time and the overall readiness of suppliers to meet BS VI specifications (Sathiamoorthy & Bandivadekar, 2020). The data analyzed showed that a few retailers sold non-compliant fuel, but overall there was promising readiness toward full compliance with BS VI from April 1, 2020 onward. Results also pointed to the need for robust fuel quality monitoring both upstream and downstream along the fuel supply chain.

Samples for phase II were drawn between July and November 2020. The major difference from BS IV to BS VI is the sulfur content limit, which is reduced to 10 parts per million (ppm) from 50 ppm. The methodology for sample collection and analysis in phase II remained the same as in phase I and was carried out again by SGS Germany GmbH. Some additional parameters for gasoline and diesel were analyzed in phase II: ash, water content, and metal additives. Each of these can negatively affect new aftertreatment systems and increase tailpipe emissions.

We intended to take samples from the same retail outlets as in phase I, but were restricted by the disruptions of the COVID-19 pandemic. Both retail outlets in Cochin and one each in Patna and Ranchi were inaccessible in phase II and thus were replaced by four retail outlets from Chennai. Table 1 shows the BS IV and BS VI fuel specifications, as listed in the Bureau of Indian Standards (BIS, 2017a; BIS, 2017b), and Table 2 shows the retail station identifications (IDs) we applied and the location for each sample. Table 2 also lists if the outlet is Dealer Owned Dealer Operated (DODO), Company Owned Company Operated (COCO), or Company Owned Dealer Operated (CODO).

www.theicct.org

communications@theicct.org

twitter @theicct

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

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
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
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 compounds. In such case, the present limit for carbon residue cannot be applied. However, the use of an ignition improver does not exempt the manufacturer from meeting this requirement prior to the addition of additives.

Table 2. Sampling IDs and locations

Retail station #	Gasoline sample ID	Diesel sample ID	Outlet type
AMBD1	Ahmedabad1	Ahmedabad1	DODO
AMBD2	Ahmedabad2	Ahmedabad2	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	DODO
RNCH2	Ranchi2		DODO
RNCH3		Ranchi3	DODO
SHML1	Shimla1	Shimla1	DODO
SHML2	Shimla2	Shimla2	DODO
THAN1	Thane1	Thane1	CODO
THAN2	Thane2	Thane2	DODO
VSKP1	Visakhapatnam1		COCO
VSKP2	Visakhapatnam2		DODO
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
CHEN1	Chennai1	Chennai1	COCO
CHEN2	Chennai2	Chennai2	COCO
CHEN3	Chennai3	Chennai3	CODO
CHEN4	Chennai4	Chennai4	CODO

Table 3 lists the standard testing protocols as recommended in the BIS. The testing standards we used to analyze respective compounds in this study are listed in bold and italics in the table below, which also contains 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 is in bold)	Remarks
Petrol		
Aromatics	ASTM D 1319 / D 5580/ D 6730 / D 6839 /***ISO 22854***	Oxygen content was also measured using the same test method.
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 D 5599 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 D 2622. 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	
Metallic additives	SGS M 2533: ICP	No specific test method listed in BIS.
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 D 2622. Samples with less than 10 mg/l were measured additionally by ASTM D 5453.
Density	[P:16]/ ISO 3675 / ***ASTM D 4052*** / ISO 12185 / ASTM D 1298 / IP 160	
Ash content	ASTM D 482	
Water content	ISO 12937 ***/ ASTM D 6304***	

Results and discussion

Gasoline results

Samples from almost all retail outlets mostly complied with BS VI specifications. One exception is gasoline oxygen content, and nearly one-third of all samples analyzed exceeded the BS VI limits.

Figure 1, below, shows the sulfur content results, and all the retail outlets were compliant with the BS VI sulfur limit.

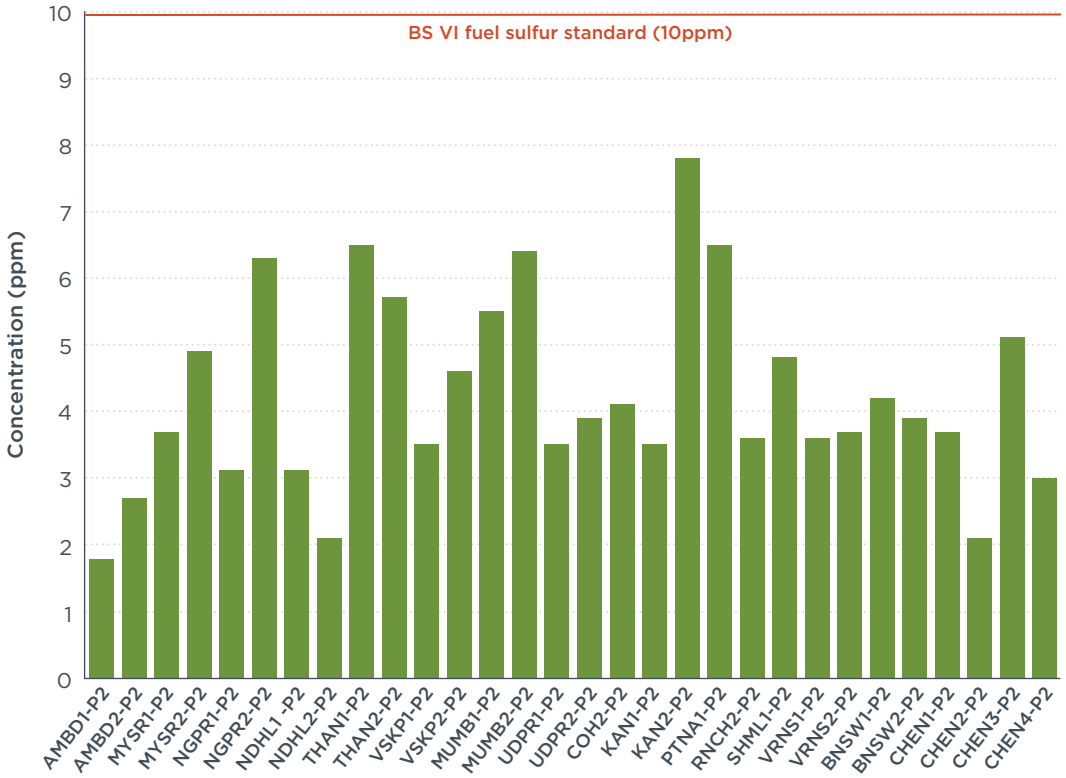

Figure 1. Sulfur content of all gasoline samples.

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, four retail outlets were out of compliance: two marginally out of compliance, one out of compliance by 2.5%, and another out of compliance by 4.5%. This does not significantly impact tailpipe emissions.

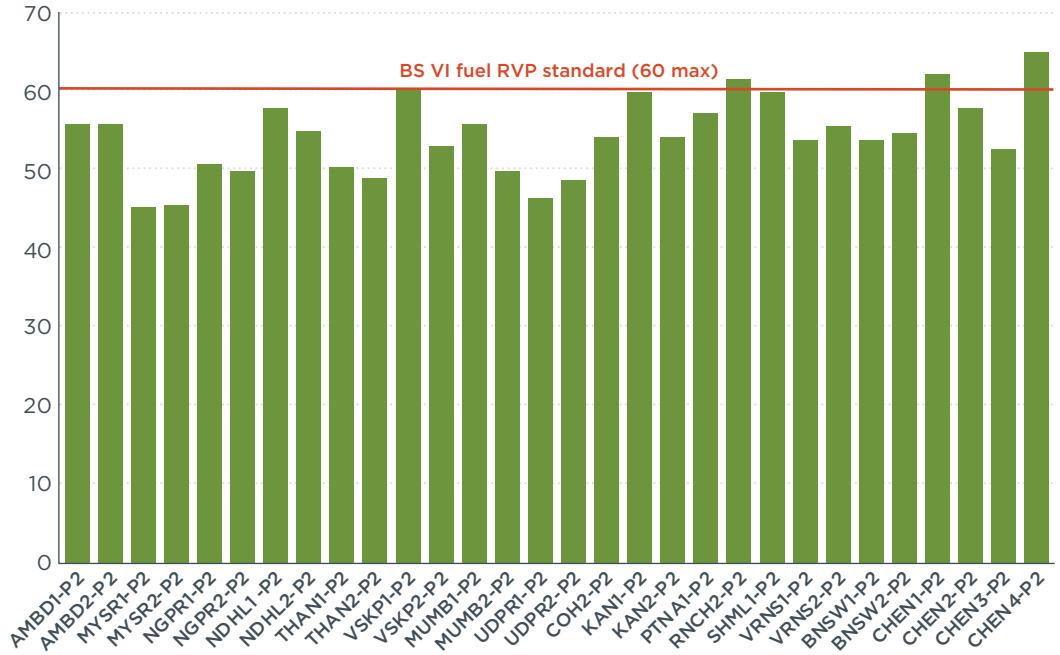

Figure 2. RVP analyzed in all gasoline samples.

Similar to RVP, the RON standards also did not change between BS IV and BS VI. As illustrated in Figure 3, all outlets complied with the standards.

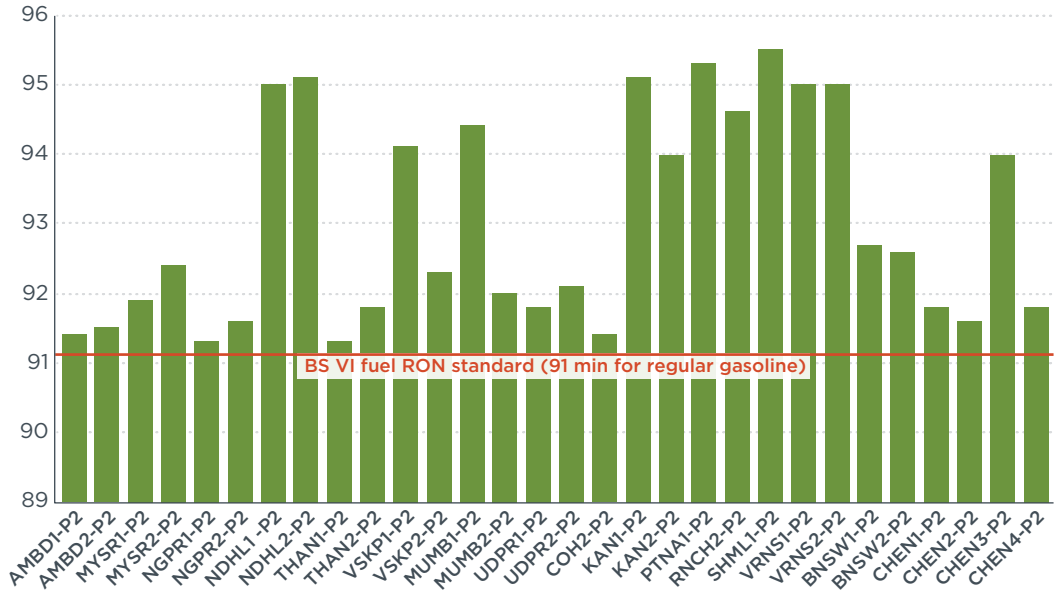

Figure 3. RON analyzed in all gasoline samples.

The requirements for aromatics also remained the same between BS IV and BS VI. All samples complied with the BS VI limit.

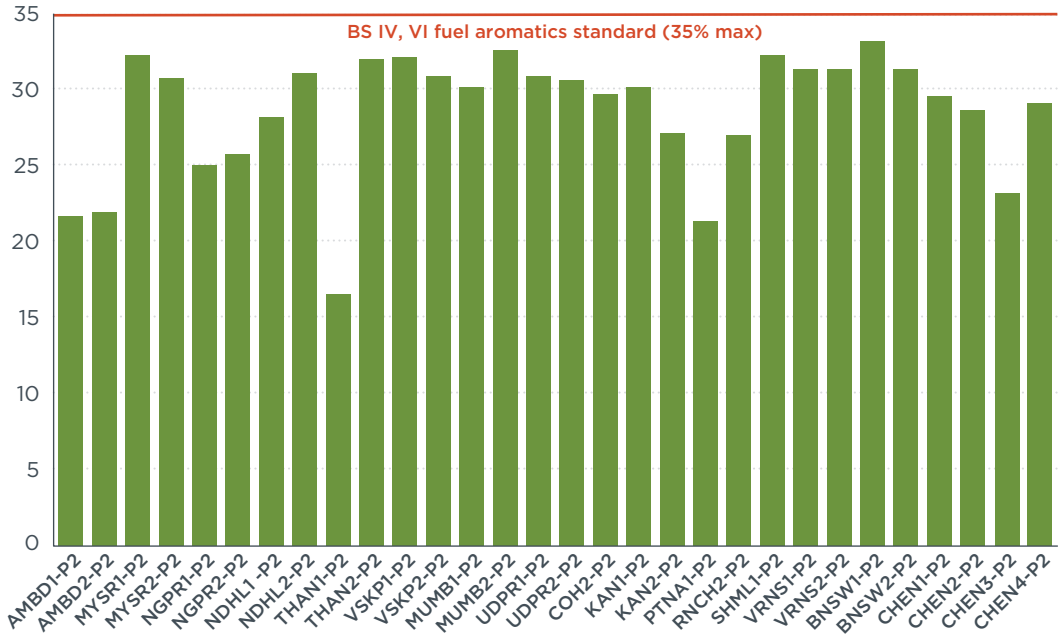

Figure 4. Aromatics content analyzed in all gasoline samples.

Gasoline density standards, which are in the 720–775 kg/m3 range, have not changed since BS III. All samples analyzed complied with the BS VI requirement.

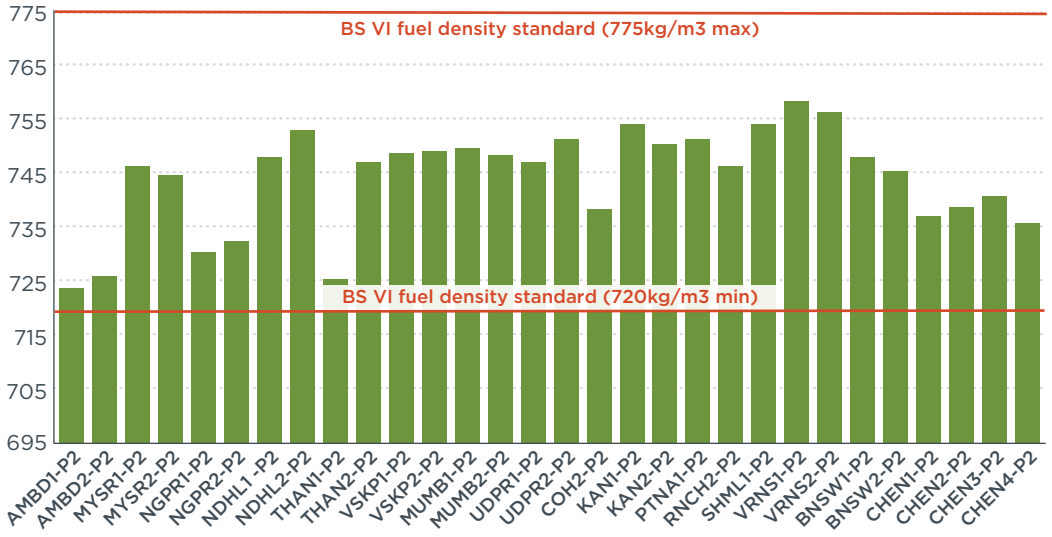

Figure 5. Density analyzed in all gasoline samples.

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. As shown in Figure 6, all samples analyzed met the standard.

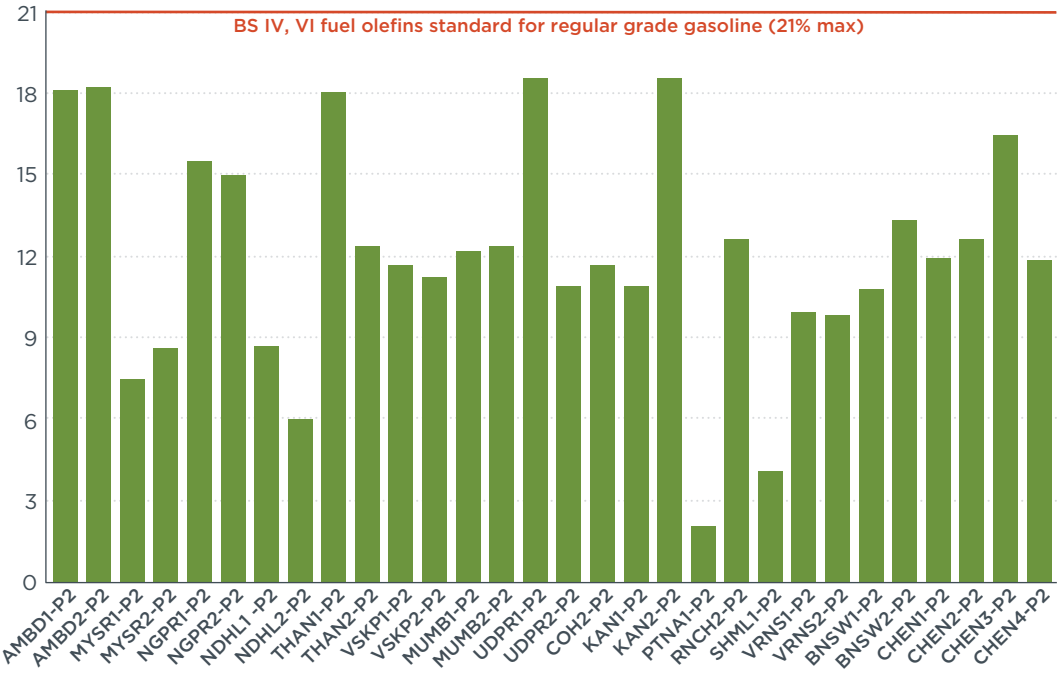

Figure 6. Olefin content analyzed in all gasoline samples.

One of the critical aspects of India's fuel standards is the benzene limit of 1%, which has not changed since BS II. Figure 7 shows that only one sample was non-compliant, and it still fell inside the allowed measurement error for this test.[1]

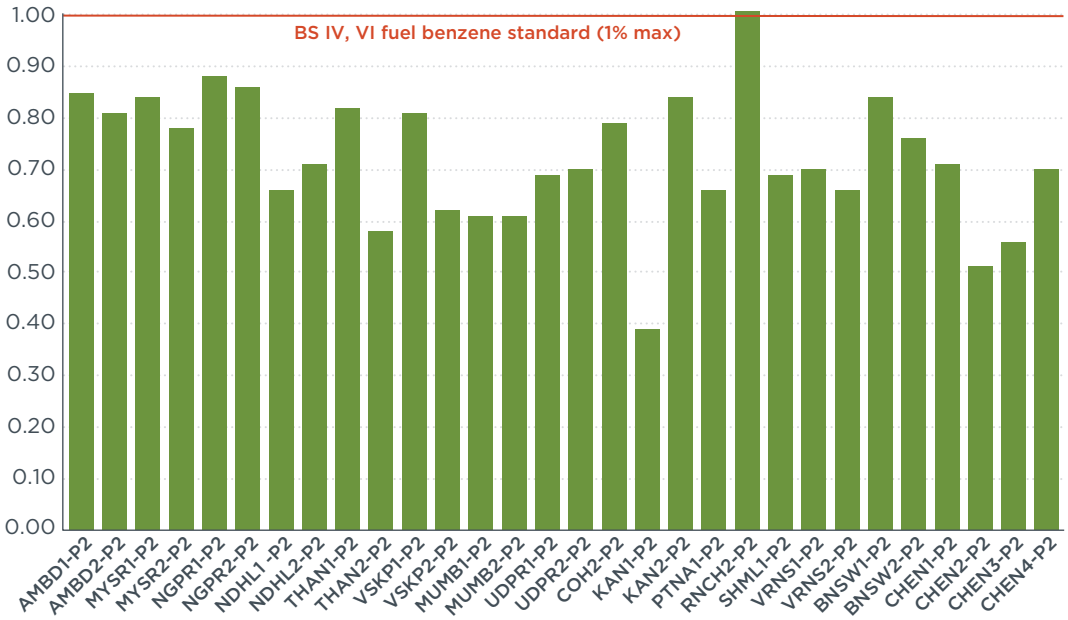

Figure 7. Benzene content analyzed in all gasoline samples.

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 E10 fuel, it is up to 10%. All samples complied with the respective standards for regular and E10 fuel.

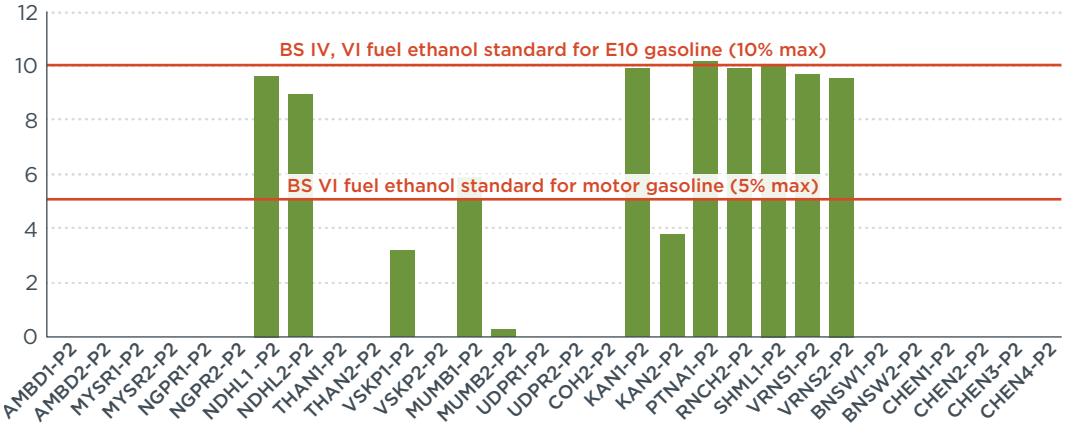

Figure 8. Ethanol content analyzed in all ethanol samples.

The maximum allowable limit for oxygen content in gasoline has not changed since BS IV. Eight samples were found to be out of compliance with the BS VI limit (Figure 9). Note that oxygenated fuels with ethanol content are expected to have higher oxygen content than those without ethanol. Generally oxygen content in gasoline is likely to lead to higher emissions of nitrogen oxides (NO_x) and the standards limit oxygen for this reason. However, it should be noted that these standards were first adopted during a time when most gasoline engines were running "open loop" and some vehicles were even carbureted. While newer engines equipped with closed-loop fuel injection actively monitor air-to-fuel ratio using an oxygen sensor and could mitigate the risk of any excess

1 Test laboratory SGS reported a repeatability of 0.02% and reproducibility of 0.1% for the benzene tests conducted.

tailpipe NO_x that could result from higher fuel oxygen content, engines running open loop or carbureted, like several BS IV and pre-BS IV engines (for two-wheelers, three-wheelers, and even some passenger cars), could be at risk of emitting excess NO_x.

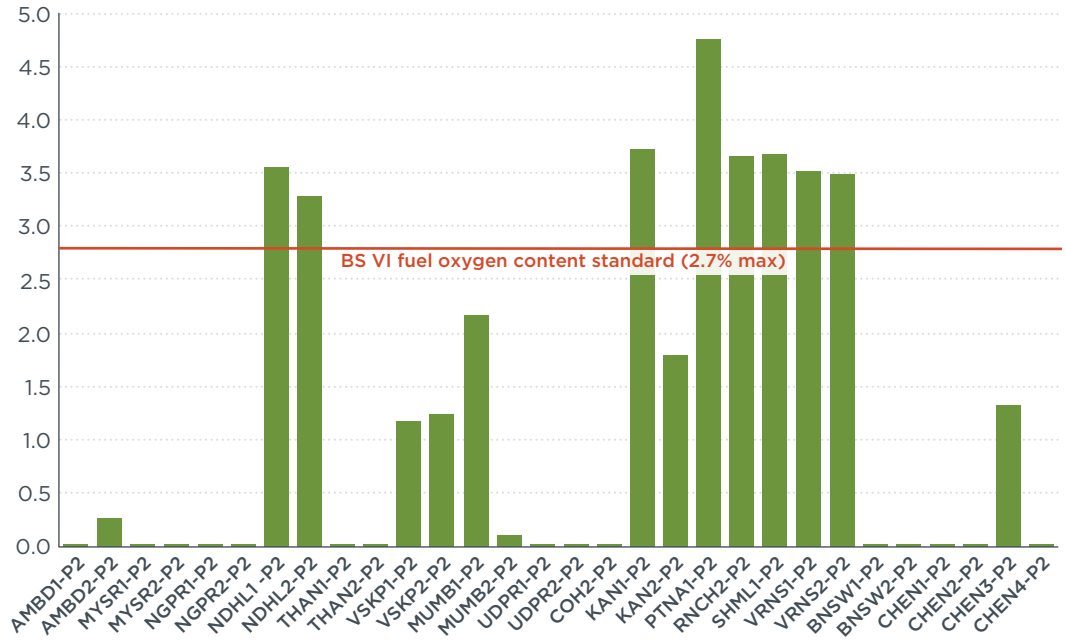

Figure 9. Oxygen content analyzed in all samples.

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 in phase I (except four outlets which were replaced by outlets in Chennai). Just like in gasoline, one of the major changes for BS VI is the sulfur limit at 10 ppm. Figure 10 below shows that all diesel samples complied with the BS VI sulfur limit.

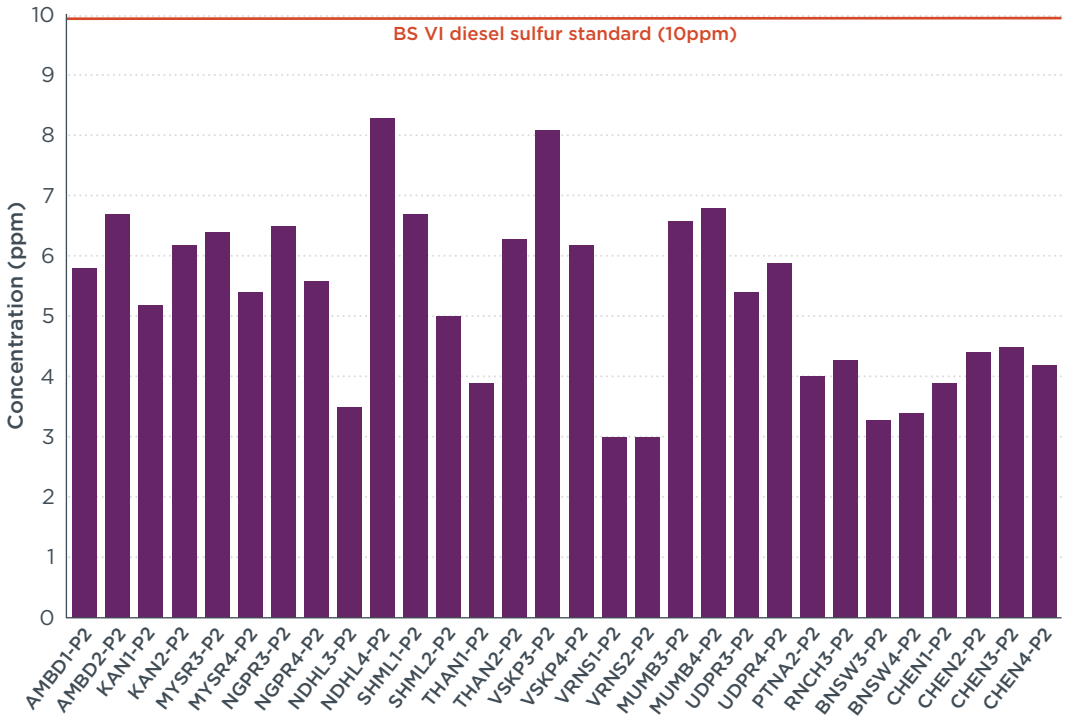

Figure 10. Sulfur content analyzed in all diesel samples.

The minimum cetane number requirement did not change from BS IV to BS VI, and it remains at 51. All outlets complied with the minimum required standard.

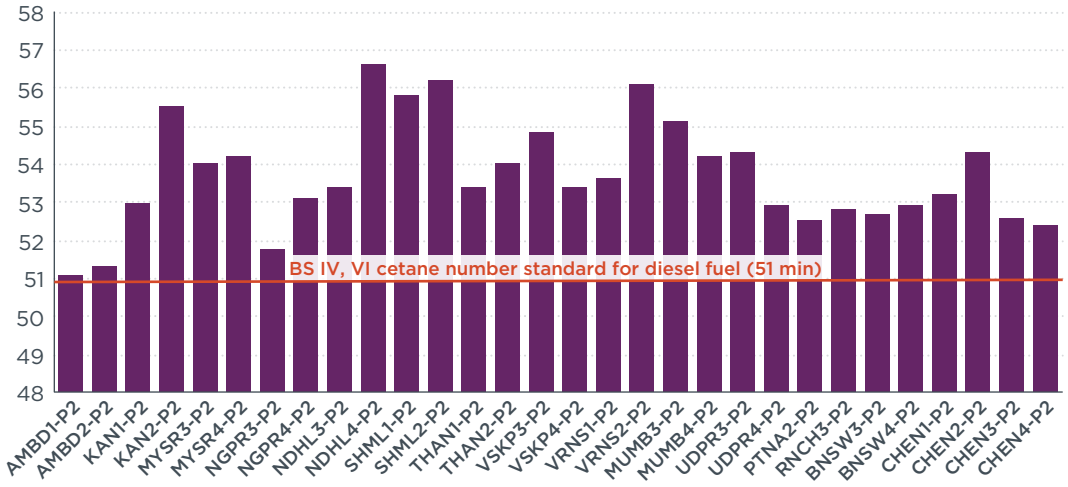

Figure 11. Cetane number analyzed in all diesel samples.

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

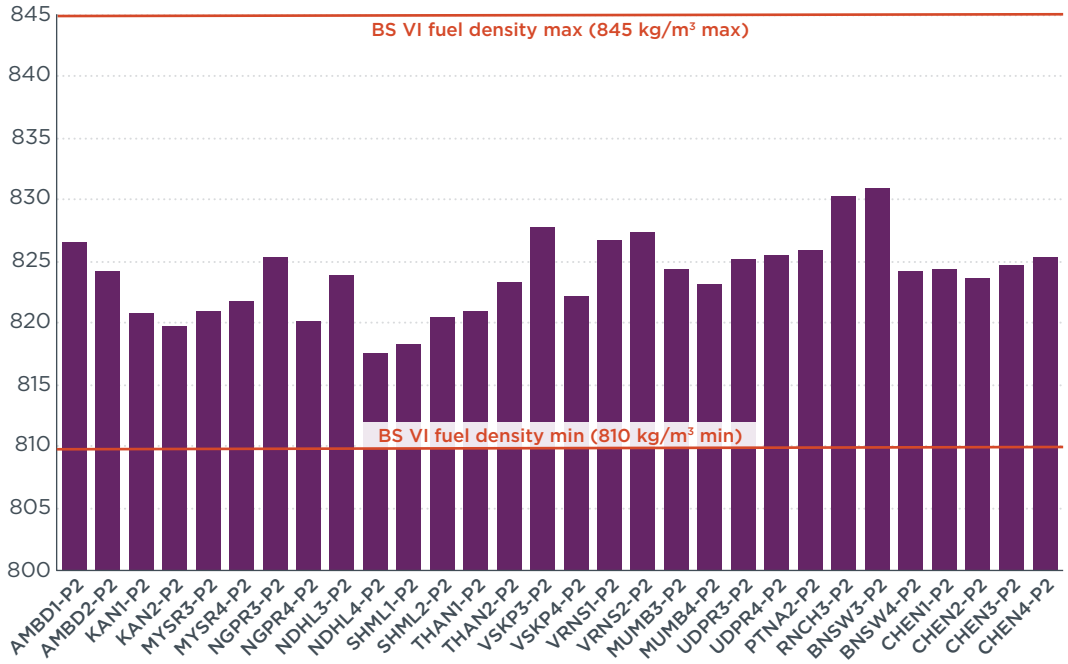

Figure 12. Density analyzed in all diesel samples.

All samples analyzed complied with the BS VI limit for ash content in diesel.

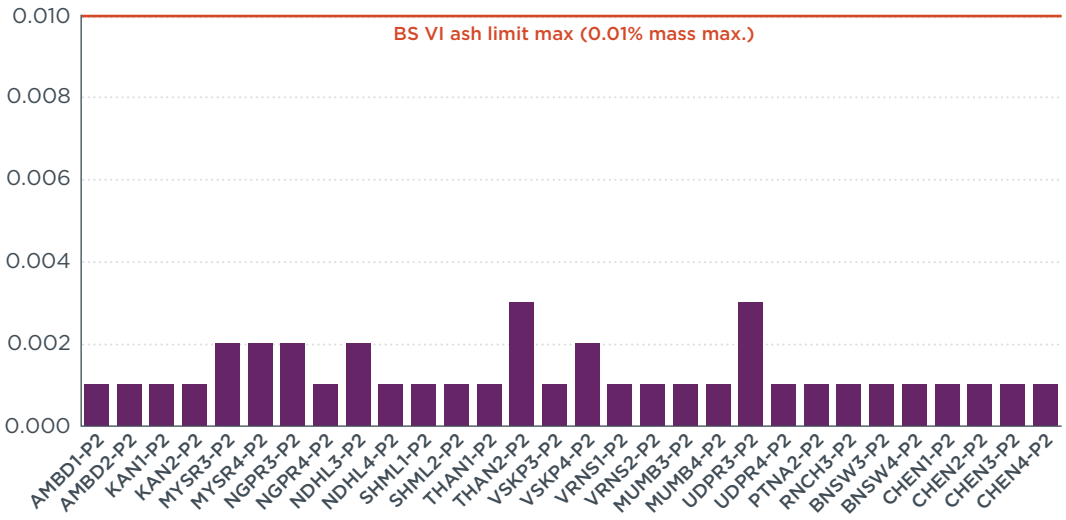

Figure 13. Ash content analyzed in all diesel samples.

Analysis of water content found that all samples complied with the maximum 200 mg/kg BS VI limit, and this is shown in Figure 14 below.

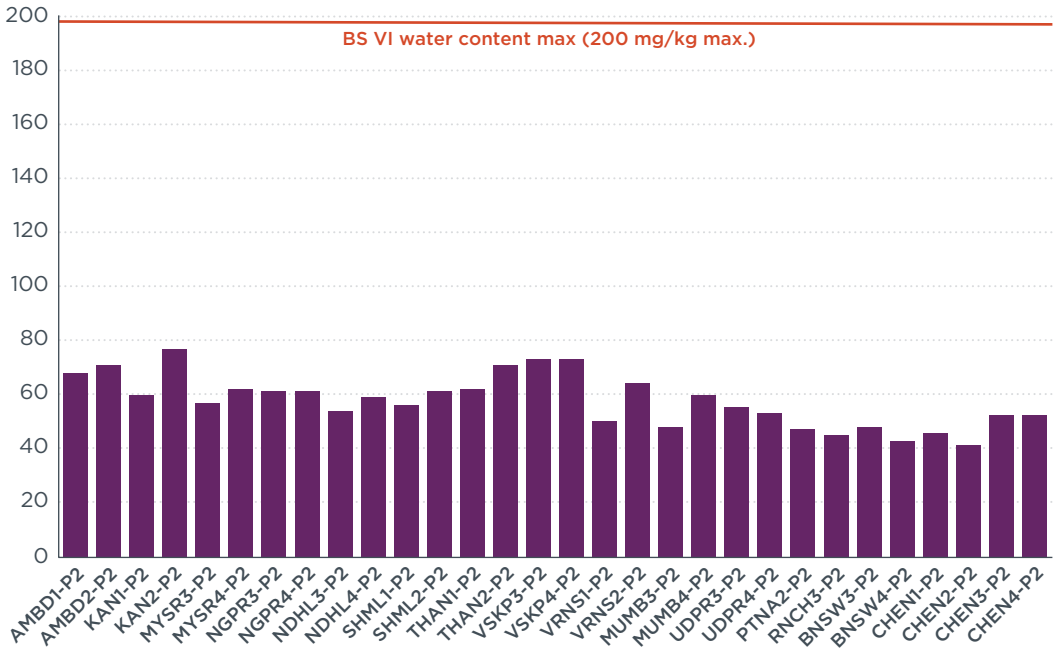

Figure 14. Water content analyzed in all diesel samples.

Comparison of phase I, BS IV, and phase II, BS VI

The figures in this section show how results from phase I compare to results for phase II for the same retail outlets. Since the sampling periods for the two phases were in BS IV and BS VI era, respectively, these figures illustrate how these retail outlets transitioned from BS IV to BS VI.

Gasoline comparison

Figure 15 shows the density comparison between samples analyzed in phase I and phase II. Overall, a slight increase in density is seen across BS VI samples, and they all remain within the required density range.

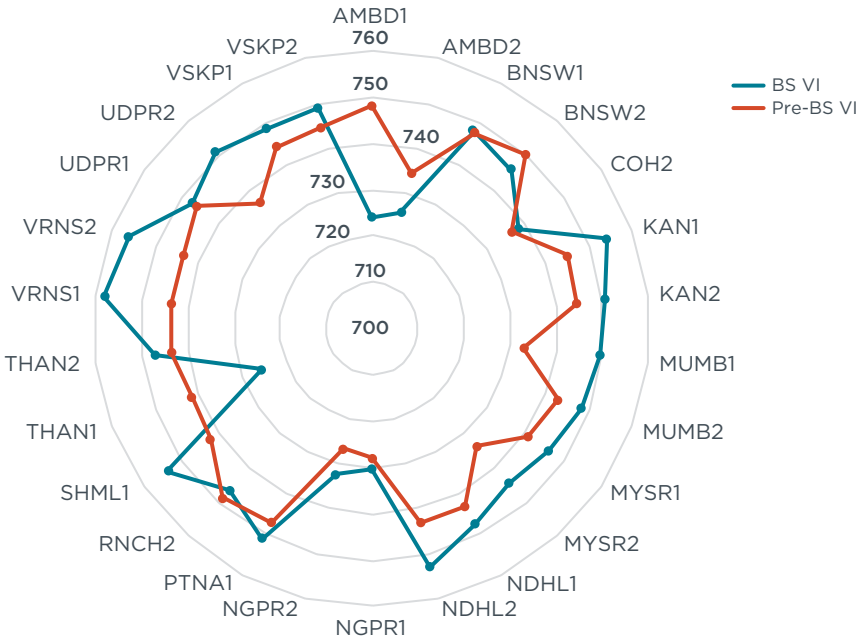

Figure 15. Density comparison between pre-BS VI and post-BS VI samples.

Figure 16 compares the RON of samples analyzed in phase I and phase II. Overall, a slight increase in RON is seen across all BS VI samples.

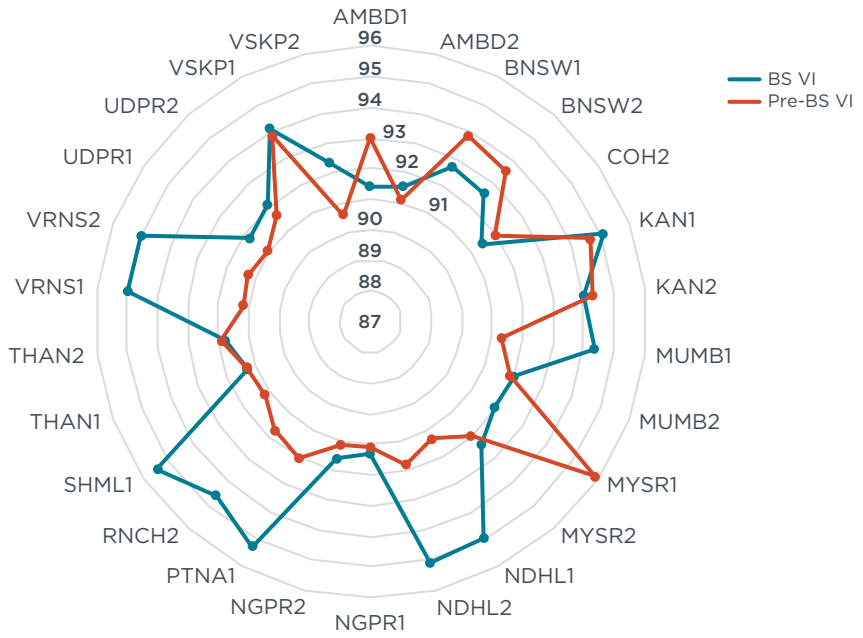

Figure 16. RON comparison between pre-BS VI and post-BS VI samples.

Figure 17 shows the comparison of RVP between samples analyzed in phase I and phase II, and no tangible difference is observed.

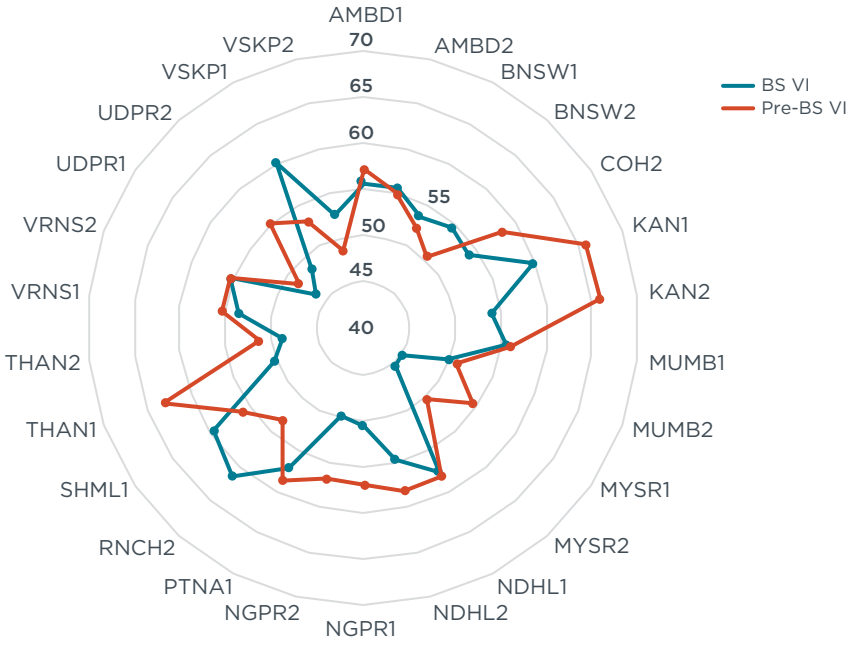

Figure 17. RVP comparison between pre-BS VI and post-BS VI samples.

Figure 18 shows the comparison of aromatics between samples analyzed in phase I and phase II. No significant difference was observed.

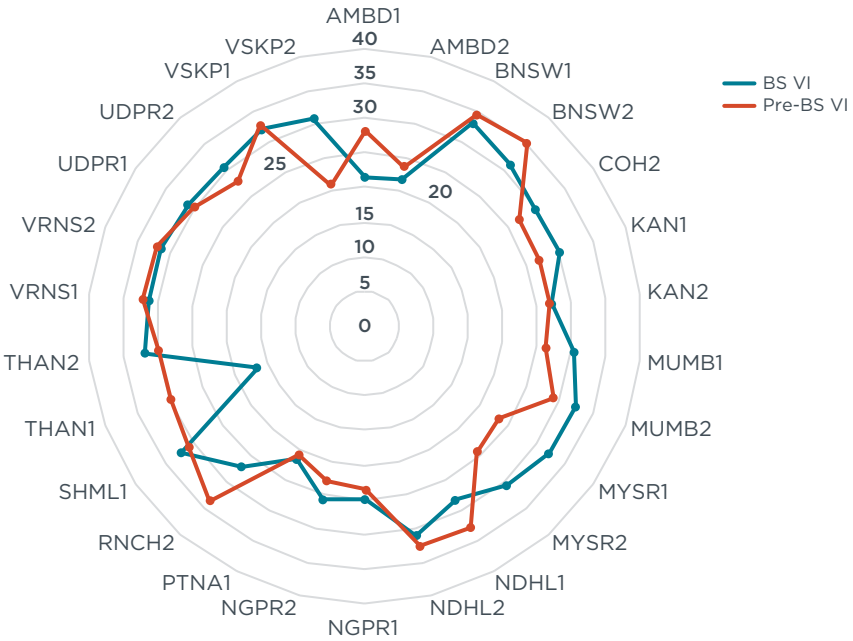

Figure 18. Aromatics comparison between pre-BS VI and post-BS VI samples.

Figure 19 compares olefins between samples in phase I and phase II. Here, too, no significant difference was observed between the samples.

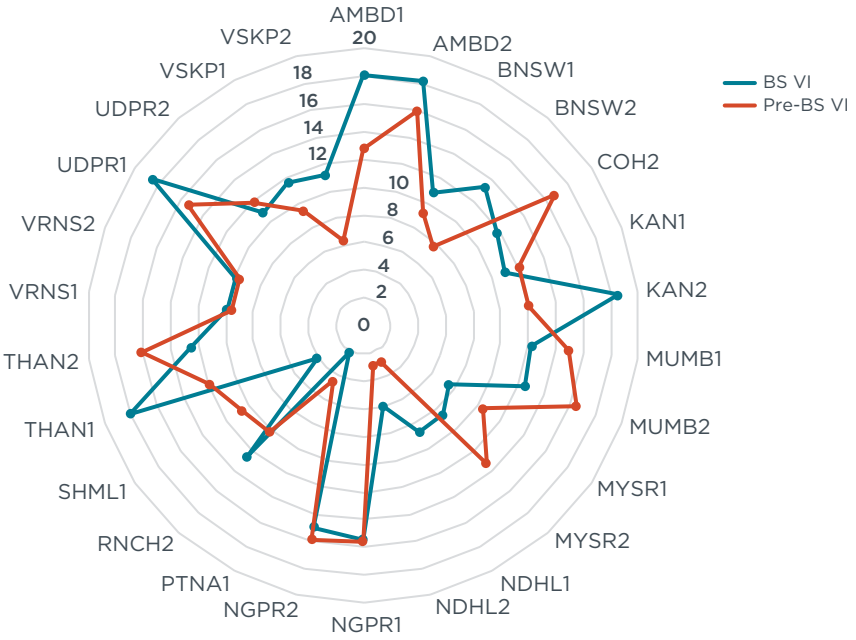

Figure 19. Olefins comparison between pre-BS VI and post-BS VI samples.

Benzene samples analyzed in phase I are compared with those analyzed in phase II in Figure 20. Only one sample was found to be marginally non-compliant among all BS VI samples, as opposed to five non-compliant samples from the phase I testing.

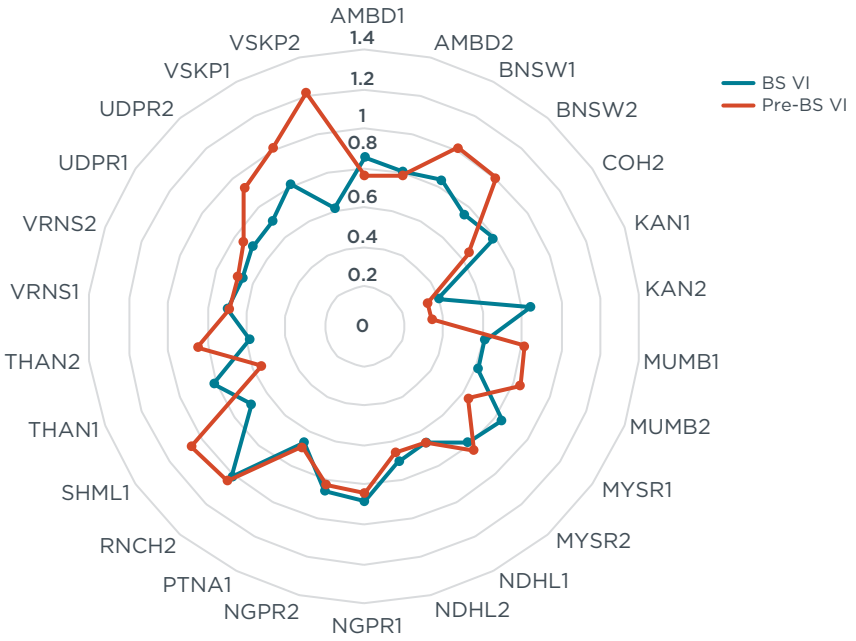

Figure 20. Benzene comparison between pre-BS VI and post-BS VI samples.

Figure 21 compares sulfur content. During phase I, some of the retail outlets were already supplying 10 ppm sulfur fuel. Phase II results show that the other retail outlets which were supplying BS IV fuel with 50 ppm sulfur subsequently transitioned to BS VI fuel.

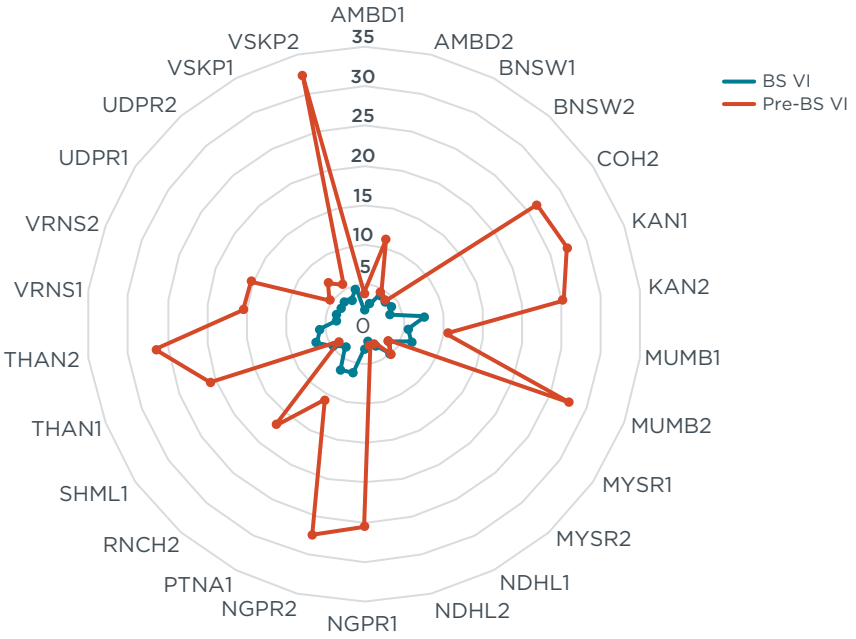

Figure 21. Sulfur comparison between pre-BS VI and post-BS VI gasoline samples.

Figure 22 shows a comparison of ethanol between samples analyzed in phase I and phase II. More retail outlets have transitioned to supplying ethanol blended fuels in phase II.

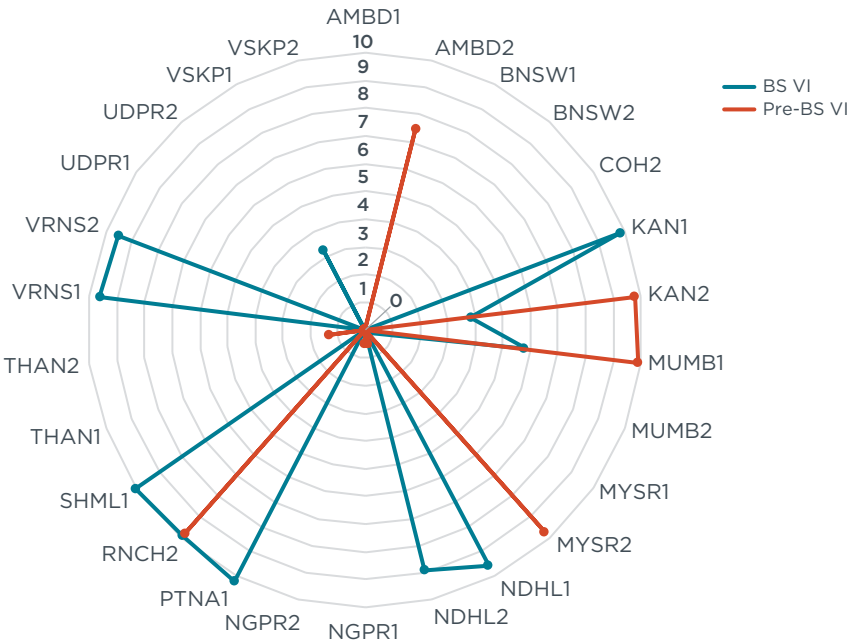

Figure 22. Ethanol content comparison between pre-BS VI and post-BS VI samples.

Oxygen content is compared in Figure 23. More samples failed to comply with the maximum oxygen content specification in phase II than in phase I. This does not, however, raise concerns for tailpipe emissions, as the air-to-fuel ratio in BS VI vehicles is controlled electronically. Nonetheless, an engine running open loop or carbureted, as in several pre-BS IV vehicles, could be at risk of emitting excess NO_x.

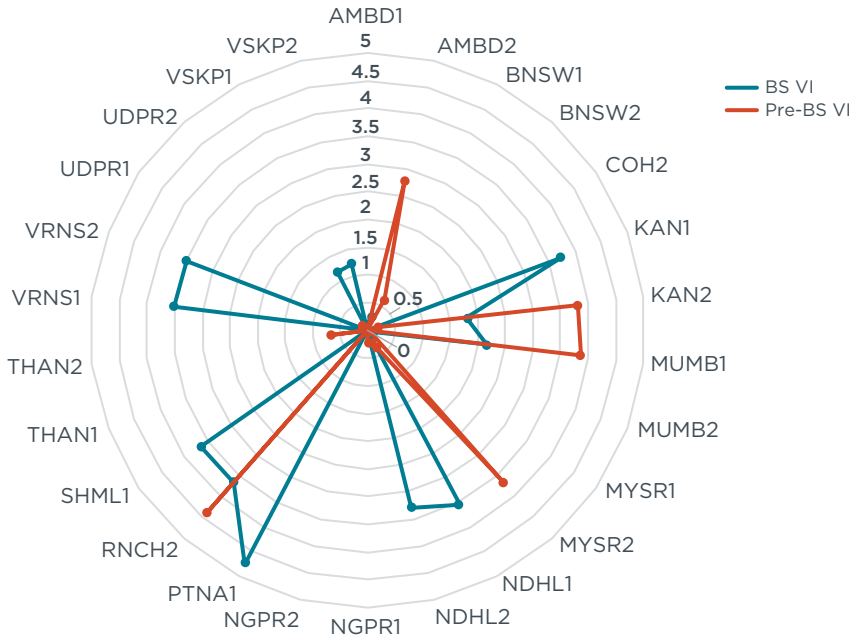

Figure 23. Oxygen content comparison between pre-BS VI and post-BS VI samples.

Diesel comparison

Figure 24 shows the comparison of fuel density. Overall, a slight decrease in fuel density can be seen in phase II samples. With the latest advancements in fuel injection and aftertreatment systems in diesel engines, this decrease is not expected to have any significant effect on tailpipe emissions (Dallmann & Bandivadekar, 2016).

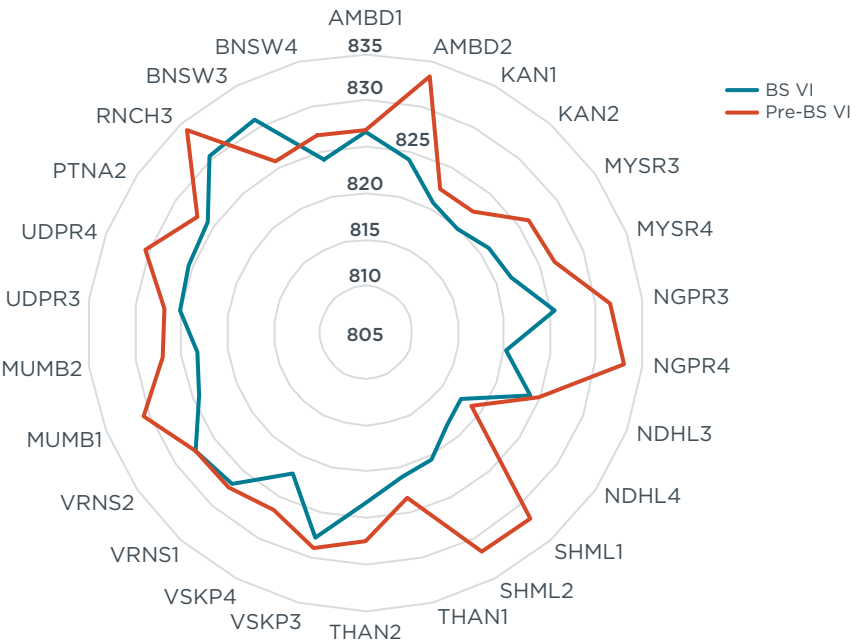

Figure 24. Density comparison between pre-BS VI and post-BS VI samples.

Figure 25 compares cetane numbers between diesel samples analyzed in phase I and phase II. No significant difference between the samples obtained from phase I and II were observed.

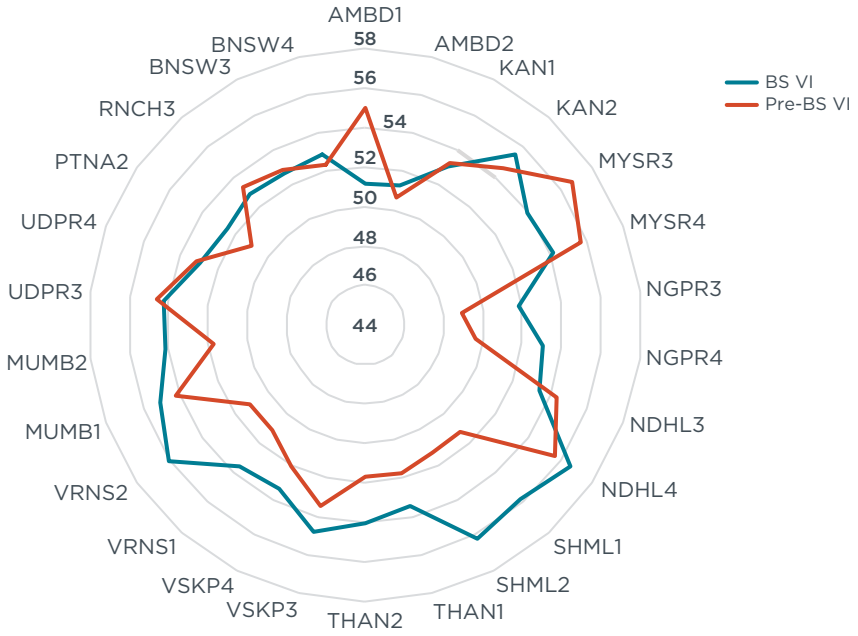

Figure 25. Cetane number comparison between pre-BS VI and post-BS VI samples.

Sulfur content is compared in Figure 26. Similar to the gasoline samples, some of the retail outlets had already been supplying 10 ppm sulfur fuel in phase I, and it can be seen that the other retail outlets have now also transitioned to BS VI fuel in phase II.

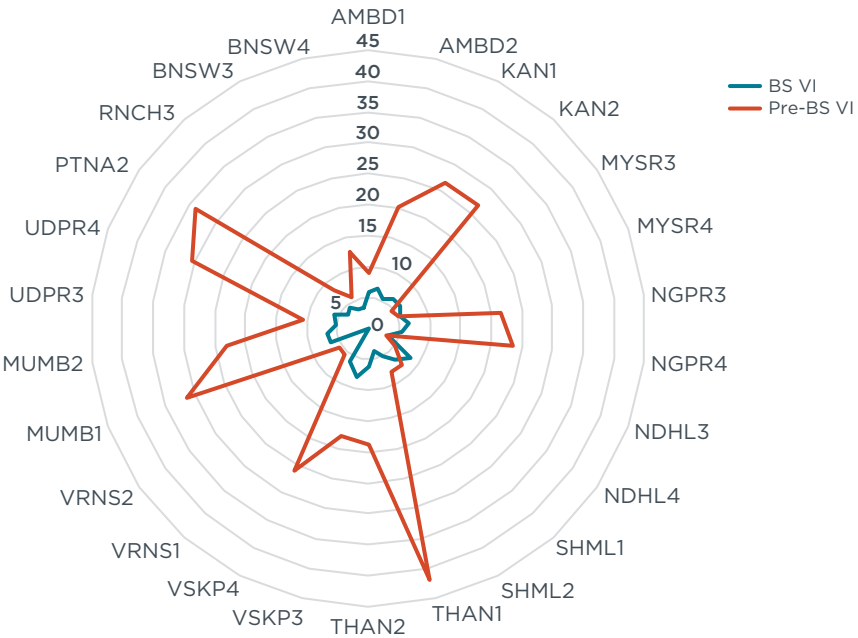

Figure 26. Sulfur comparison between pre-BS VI and post-BS VI diesel samples.

Conclusion

In both gasoline and diesel fuel, sulfur is the compound of most interest in this study, because of its substantial potential to impact tailpipe emissions. All samples that we analyzed from all retail outlets in phase II complied with BS VI sulfur standards. Further, the sulfur reduction across all retail stations to comply with the more stringent 10 ppm standards for BS VI was the most obvious and largest difference seen between samples taken during phase I, when BS IV was still in effect, and during phase II, after BS VI had been implemented.

India's transition to BS VI fuel is remarkable, but a few concerns remain. For one, a couple of gasoline samples were found to be out of compliance for RVP and one was found to be out of compliance for benzene (although it was within the measurement error). Additionally, eight samples did not comply with BS VI limits on oxygen content. It was also seen that more retail outlets transitioned to ethanol blended fuels (E5, E10) in phase II compared to phase I. In India, where most retail outlets have service representatives who fill fuel for the consumers, it is critical to enable the consumer to make a more conscious choice when deciding a fuel type or retail outlet. With this transition to more fuel blend availabilities, there is an increased need for clearer pump labeling requirements and violation enforcements so consumers have sufficient information to make that decision.

While not the specific focus of this study, we note that India's fuel quality monitoring requirements still require significant overhauling. The results from this study certainly show encouraging signs of compliance nationwide, but for compliance to be sustained over the coming years, India must address its fuel quality monitoring requirements. Some areas of shortcomings identified in an earlier ICCT study (Bansal & Bandivadekar, 2013) included a lack of comprehensive government oversight and independent fuel testing laboratories, fuel adulteration, lack of liability from oil companies, and very few resources to ensure fuel quality at retail outlets. Some of the key recommendations made in the study were to develop a centralized authority responsible for fuel quality compliance, making oil companies accountable for fuel quality, and increasing the number of independent fuel quality testing labs. Another recent study (Yang, 2020) on China's compliance and enforcement (C&E) structure discussed the importance of enforcing stringent source control with fuel tracking systems upstream of retail outlets and enforcing presumptive liabilities on parties in possession of any non-conforming fuel, anywhere in the fuel distribution system, with substantial non-compliance and criminal penalties. It would be advantageous for India to adopt C&E programs similar to those in the United States, the European Union, and China.

References

Bansal, G., & Bandivadekar, A. (2013). *Overview of India's vehicle emissions control program: Past successes and future prospects.* Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/ICCT_IndiaRetrospective_2013.pdf

Bureau of Indian Standards: 1460:2017 (2017a). *Automotive diesel fuel specification (sixth revision)*.

Bureau of Indian Standards: 2796:2017 (2017b). *Motor gasoline specification (sixth revision)*.

Dallmann, T., & Bandivadekar, A. (2016). *Technical background on India BS VI fuel specifications*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/technical-background-india-bs-vi-fuel-specifications

Sathiamoorthy, B., & Bandivadekar, A. (2020). *Gasoline and diesel fuel quality survey for India: Part 1.* Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/India-fuel-quality-pt1-jul2020.pdf

Yang, L. (2020). *Motor vehicle diesel fuel quality compliance and enforcement in China: A look at the status quo and international best practices.* Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Motor-diesel-fuel-quality-China.3.4.2020.pdf

Yao, Y., Tsai, J., & Chiang, H. (2009). Effects of ethanol-blended gasoline on air pollutant emissions from motorcycle. *Science of the Total Environment*, *407*(19), 5257–5262. https://doi.org/10.1016/j.scitotenv.2009.06.017