Chapter 4
Prospects of Methanol-Fuelled Carburetted Two Wheelers in Developing Countries

Hardikk Valera, Akhilendra Pratap Singh and Avinash Kumar Agarwal

Abstract Most developed countries use indigenous fuels for powering their transport sector, however developing countries have to import transport fuels/petroleum to produce transport fuels and they struggle for fuel production from domestic resources. India is focusing on reduction of fuel import by introducing indigenous transport fuels such as variety of biofuels. High ash content coal is available in India, which cannot be used for electricity generation, however this can be used for methanol production using gasification route that can be used to power the Indian transport sector. Although methanol production is already done in India and the current production capacity cannot fulfil the huge demand of the transport sector currently. However methanol economy initiative is gaining momentum due to active intervention of Government of India (GoI) and the technology is being developed for methanol production from high ash coal, municipal solid waste (MSW) and low value agricultural resides. Methanol has great potential to be utilized in spark ignition (SI) engines. This chapter is explores methanol utilization in small carburetor assisted two-wheelers. Two-wheelers population in Indian road transport sector is more than 70% in terms of number of vehicles registered. Carburetor is used to induct the fuel in these small capacity (100–150 cc) SI engines. Existing engines are designed to operate on gasoline therefore slight modifications become essential for adaptation of methanol in these existing two-wheelers. Currently, India is preparing a road map for large scale adaptation of M15 (15% v/v methanol and 85% v/v gasoline) in the existing SI engines, which has several challenges. This chapter summarises challenges and possible solutions for adaptation of M15 in carburetor assisted two-wheelers.

Keywords SI engine · Methanol · Carburetor · M15

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4.1 Transport Fuel Scenario in Developing Countries

Transport fuels are one of the most important factors affecting the economy of any country. Price of crude oil is increasing and cyclic in nature due to rapid depletion and limited reserves. Increasing crude oil prices lead to increase in price of transport fuels such as gasoline, diesel and natural gas. Statistical data of reserves-to-product ratio of coal, oil and natural gas of 2016 shows that these global reserves will exhaust in next 114 years, 50.7 years, and 52.8 years respectively (BP Statistical Review of World Energy 2016). Increasing fuel prices affect the economy from micro level to macro level. Micro level affects because of the price increase of commodities, used in daily life because transportation cost of these items is dependent on vehicles powered by fossil-fuels. Macro level affects because increased fuel prices increase inflation by increasing the price of manufacturing. Developing countries like India are affected to a greater degree by increasing crude oil prices because their net fuel imports are significantly higher compared to several developed countries. India has to explore more options for alternative fuel production and utilization in transport sector. Crude oil import of India in last five years is shown in Table 4.1 (Indian Petroleum and Natural Gas Statistics 2017).

India is aiming to reduce fuel imports by introducing indigenous transport fuels. Therefore India is looking for a sustainable alternative fuel, which can be utilized in all sectors of the economy. For transport sector, fuel properties become more important because the quality of fuel affects engine performance as well as exhaust emissions (Bharj et al. 2019). Among different options, methanol has shown significant potential to be utilized in transport sector due to triple P factors namely production, pollutants, and price. Methanol can be produced from coal, natural gas, biomass, and atmospheric CO_2. It is a clean burning fuel because it has ~50% inherent fuel oxygen, which helps reduce emissions such as CO, HC, etc. (Valera and Agarwal 2019). Methanol price is approximately one third that of conventional fuels however methanol has ~50% lower energy density. This leads to double the amount

Table 4.1 Crude oil imports (Indian Petroleum and Natural Gas Statistics 2017)

Year	Import crude oil (MMT)	% Growth in import of crude oil	Average crude oil prices (US$/bbl)	% Growth in average crude oil prices
2011–12	171.73	4.97	111.89	31.50
2012–13	184.80	7.61	107.97	−3.50
2013–14	189.24	2.40	105.52	−2.27
2014–15	189.43	0.10	84.16	−20.25
2015–16	202.85	7.08	46.17	−45.14
2016–17	213.93	5.46	47.56	3.02
2017–18 (P)	220.43	3.04	56.43	18.65

MMT million metric tons, *P* provisional of methanol usage compared to conventional fuels for harnessing the same engine power output. Higher energy-to-cost ratio compared to conventional fuels is the most important feature of methanol i.e. it's per unit energy cost is significantly lower than conventional fuels, which makes it cheaper to operate the vehicles on per km basis. Other developing countries like China have already started mass production of methanol and dimethyl ether (DME) using coal as a feedstock (Yang and Jackson 2012). In China, it is mandatory to blend small fraction of methanol with gasoline for vehicular application and DME is blended with liquefied petroleum gas (LPG) for household stoves and water heaters. There are 44 regional standards already adopted by China by FY 2009 for low methanol blends.[1] In China, several automotive companies participated enthusiastically in this green methanol economy (GME) vision initiative and demonstrated methanol-fuelled models. These include Chery Automobiles, Shanghai Maple Automotive, Chang's Auto Group and Greely Group.

In India, methanol seems to be a better alternate compared to hydrogen, biodiesel and electric batteries and it can reduce 10% crude oil dependency by 2022 and reduce GHG emissions by 33–35% (Natarajan 2018). According to the Geological Survey of India, the country has 315 billion tonnes of coal resources as on April 2017,[2] out of which only less than 25% can be utilised in power plants and for Industrial use. 75% of Indian coal reserves have high ash content, which prohibits its commercial utilisation. Therefore, ministry of road transport and highways, National Institution for Transforming India (NITI Ayog) are preparing a road map to reduce crude import bill by up to US$100 Billion by 2030 by adopting 'Methanol Economy' (Methanol Economy 2018). This vision can be achieved if all segments of road transport shift from conventional fuels to alternative fuel to a large extent. Two-wheelers are the most dominant segment in Indian road transport sector, compared to other segments such as three-wheelers, four-wheelers and heavy-duty vehicles as shown in Fig. 4.1,[3] therefore their methanol adaptation will be crucial for achieving this national mission.

Indian two-wheelers segment is the largest vehicle class with variety of two-wheelers such as mopeds, scooters, and motorcycles. During FY 2017–18, two-wheelers industry showed a total sale of ~20 million units in Indian market with 20% increase in exports. The sales for FY 2017–18 showed that sales of scooters and motorcycles increased by ~20% and ~14% respectively, however sales of mopeds declined by ~3.5% compared to sales in FY 2016–17.[4]

Most two-wheelers in India use small SI engines in which the combustible fuel-air mixture is prepared outside the engine using carburetor. Sometimes these two-wheelers face startability issues due to inferior vaporization characteristics of gasoline in cold climatic conditions due to domination of high boiling point hydrocarbons known as 'heavy ends' (Sharma and Mathur 2012). These hydrocarbons remain

[1]Standards for methanol blends. https://www.iea-amf.org.

[2]India's coal reserves estimated at 315 billion tonnes—ministry. https://www.indoasiancommodities.com/2018/03/07/indias-coal-reserves-estimated-315-billion-tonnes/.

[3]Two-wheeler industry. www.fintapp.com.

[4]Two-wheeler statistics. http://www.siamindia.com/pressreleasedetails.aspx?mpgid=48&pgidtrail=50&pid=413.

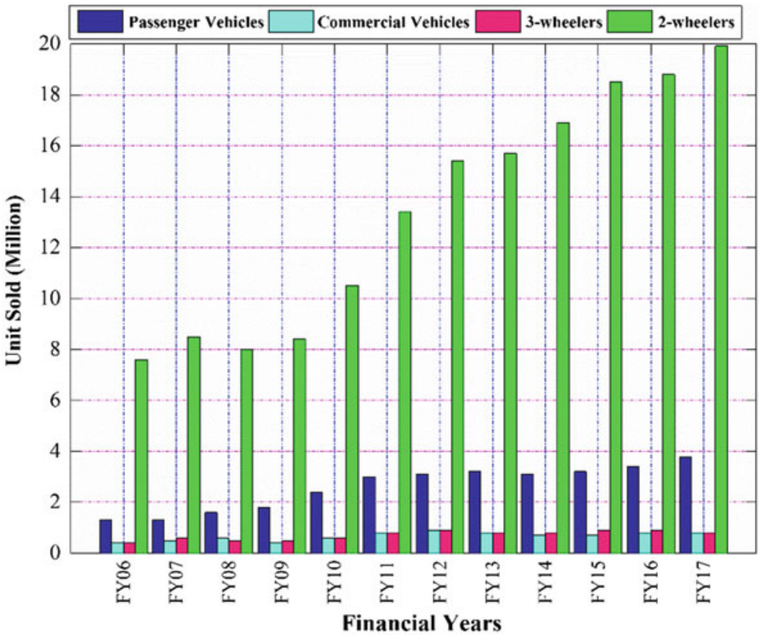


Fig. 4.1 Indian automotive sector (see Footnote 4)

in liquid form and stick inside the combustion chamber walls, leading to startability issues. Therefore, it is important to consider the design aspects of carburetor so that such issues can be avoided. A carburetor is designed to perform three main tasks namely fuel atomization, fuel vaporization, and fuel-air mixing.[5] Following factors are important for these tasks: (i) Time available for fuel-air mixing; (ii) Temperature of the incoming air; (iii) Boiling range of fuel; and (iv) Length of manifold used to connect a carburetor and the test engine.

Primarily, carburetor prepares three types of mixtures: rich mixture for idling condition, lean mixture for superior fuel economy, and stoichiometric mixture for achieving complete combustion. The carburetor has to supply the required air-fuel ratio at steady-state and transient conditions of the vehicle. Steady-state means vehicle can run at a constant speed and achieve constant power output from the engine. Transient condition means speed and load of the vehicle varies continuously, thereby getting variable power from the engine.

[5] Fuel system. https://svce.ac.in/departments/auto/Lesson%20plan/II%20YEAR%20CLASS%20NOTES/AT6301/UNIT%20II.pdf.

4.2 Methanol as an Alternative Fuel for Vehicles

Methanol offers numerous advantages over conventional fuels such as gasoline, compressed natural gas (CNG), and diesel. Some of the advantages are:

- Methanol is a colorless, volatile, and flammable liquid, having lower molecular weight compared to conventional fuels.
- Methanol can be produced from coal, biomass, and MSW or from stranded natural gas[6].
- Methanol has inherent fuel oxygen, which reduces harmful tailpipe emissions. Presence of –OH radicals improves the combustion.
- Methanol has higher latent heat of vaporization, which provides extra cooling effects, which improves brake thermal efficiency and reduces the NO_x emissions.
- Methanol is a safer transport fuel due to significantly higher self-ignition temperature, hence is recommended as an alternate to conventional fuels. Due to this, methanol-fuelled engine can be operated at higher compression ratios, which results in higher thermal efficiency compared to gasoline engines.
- Methanol burns without black smoke at high temperatures (Cheng et al. 2008).
- Methanol is a sulfur-free fuel, which results in zero-sulfur based tailpipe emissions such as SO_2 and SO_3.
- Methanol is degradable in aerobic (in the presence of air) and anaerobic (in the absence of air) conditions without any bioaccumulation.
- Accidental methanol release into environment is less harmful compared to spills of crude oil or gasoline.

Due to these advantages, methanol seems to be a strong contender as an alternate fuel for IC engines, especially for SI engines. High octane rating of methanol also makes it more suitable for SI engines, however utilization of pure methanol in an SI engines is a challenging task due to the following reasons.

Methanol Availability: India is in nascent stage of methanol production for fuel use. As of now, only five Indian companies namely Gujarat Narmada Valley Fertilizer and Chemicals Limited, Deepak Fertilizers, Rashtriya Chemicals and Fertilizers, Assam Petrochemicals and National Fertilizers Limited are producing methanol as commodity chemical. Methanol production data from domestic companies of India is given in Table 4.2.

Above data shows that India cannot shift to 100% methanol for transport sector at this stage, without augmenting its methanol production capacity, especially from domestic resources such as high-ash coal, MSW and low value biomass. Therefore, it is logical to utilize low fraction of methanol blends with conventional fuels, until domestic production reaches up to the desired level.

Technological Challenges: Methanol has higher latent heat of vaporization compared to gasoline, which is one of the main reason for modifications in the existing engines. Major modifications for methanol adaptation include advancement in spark

[6]Methanol as an alternative transportation fuel in the US: options for sustainable and/or energy-secure transportation. https://afdc.energy.gov/files/pdfs/mit_methanol_white_paper.pdf.

Table 4.2 Domestic methanol production in India[a]

Financial year	Domestic production (MT)	Consumption (MT)	Exports (MT)
2010–11	0.375	1.14	0.044
2011–12	0.360	1.44	0.120
2012–13	0.255	1.47	0.185
2013–14	0.307	1.54	0.082
2014–15	0.210	1.80	0.049
2015–16	0.163	1.83	0.044

[a]India's Leapfrog to methanol economy. http://www.niti.gov.in/writereaddata/files/document_publication/Article%20on%20Methanol%20Economy_Website.pdf
MT million tons

timing for carburetor-assisted vehicles and correction in fuel maps and spark timing for port fuel injected engines/vehicles. Methanol is more corrosive than gasoline, which adversely affects elastomers (soft components used for seals and fuel lines) as well as metal components (pumps, lines, and spigots) (Brinkman et al. 1994). Relatively lower energy density of methanol compared to gasoline is another major concern of methanol, which requires more amount of methanol blend to be injected for producing same power as gasoline. This also requires modifications in fuel injection parameters as well as fuel delivery system. This aspect also supports gradual shift from gasoline to methanol so that modifications can be done in an orderly manner.

Formaldehyde Emissions: Methanol-fuelled vehicles emit higher formaldehyde emissions compared to gasoline-fuelled vehicles. Formaldehyde reacts with the atmospheric gases and forms formic acid which is hazardous for humans and animals.[7] Zhao et al. (2011) performed a comparative study of formaldehyde emissions using four different vehicles of 1.8 L capacity. They reported significantly higher formaldehyde emissions from methanol-fuelled vehicles compared to baseline gasoline fuelled vehicles.

Public Acceptance: Methanol is highly poisonous for the nervous system. Ingestion of 28.5 g methanol can cause irreversible injury to the nervous system, blindness, and even death.[8] It has been reported that a person can die due to consumption of 15 mL liquid containing 40% methanol (Naraqi et al. 1979). Hence lower blend (M15) is a more feasible solution, keeping in mind the public perception of methanol being poisonous. Once public is comfortable using lower methanol blends as fuel, higher blends of methanol could be introduced to power the transport sector.

[7]Formaldehyde. https://en.wikipedia.org/wiki/Formaldehyde.

[8]Methanol Institute. https://biodiesel.org/docs/ffs-methanol/faq-about-the-safe-handling-and-use-of-methanol.pdf?sfvrsn=6.

4.3 Construction of Carburetor

The carburetor works on the principle of pressure difference across a throat, in which air exerts a pressure force on its contact surface and pressure difference causes the flow of fuel in the form of spray in depression zone. This pressure difference principle is used in the carburetor to supply the air-fuel mixture as per engine requirement at different engine operating conditions. During suction stroke, piston moves from the top dead center (TDC) to the bottom dead center (BDC), which creates vacuum in the engine cylinder. In a carburetor, intake air passes through a narrow area created by venturi. Venturi is a tube with a continuously decreasing cross-sectional area up to the throat. When air passes through the throat, velocity of air increases, which reduces the pressure (Bernoulli's principle).

$$\frac{P}{\rho g} + \frac{V^2}{2g} + Z = \text{Constant} \tag{4.1}$$

where, $\frac{P}{\rho g}$ = Pressure head

$\frac{V^2}{2g}$ = Velocity head

Z = Potential head

This causes pressure difference between the fuel tank in the carburetor and the throat, which are connected by an orifice, resulting in fuel-flow from the orifice into the incoming air stream (Bansal 2004). Carburetor has a mixture outlet and air inlet area at the same level, which results in zero potential head, therefore maximum pressure head generated at the throat area leads to discharge of fuel into the air stream, as shown in Fig. 4.2.

The pressure difference varies with the engine speeds proportionally. Generally suction pressure (vacuum at the carburetor throat) of a 100 cc engine varies from 36.7 kPa at idling to 2.3 kPa at 90 Kmph vehicle speed. Different parts of carburetor such as air adjusting screw, pilot jet, main jet, jet needle, needle jet, air adjusting screw, rpm screw, float valve and float for delivering required air-fuel ratio are discussed below.[9]

Air Screw: It is a slotted brass screw used to adjust the air-flow rate for idling at the air inlet side of the carburetor. This air screw provides flexibility to adjust the air-flow rate so that required air-fuel ratio for idling during different seasons can be maintained (Table 4.3).

Pilot Jet: It is a medium size jet with metering holes to adjust the required air-fuel ratio. It meters the fuel quantity during starting and idling in the first quarter of throttle opening. It can be used either in a lean pilot jet setting or in a rich pilot jet setting. Lean pilot jet setting is not suitable for engines at low engine speeds, however rich pilot jet setting creates problems in engine starting. Available size for the pilot jet

[9]Keihin carburetor jetting. https://static1.squarespace.com/static/5be4d5b35ffd2095efa9bdff/t/5bf1a09b6d2a7391b5a84730/1542561947962/KeihinCarbJetting-2015.pdf.

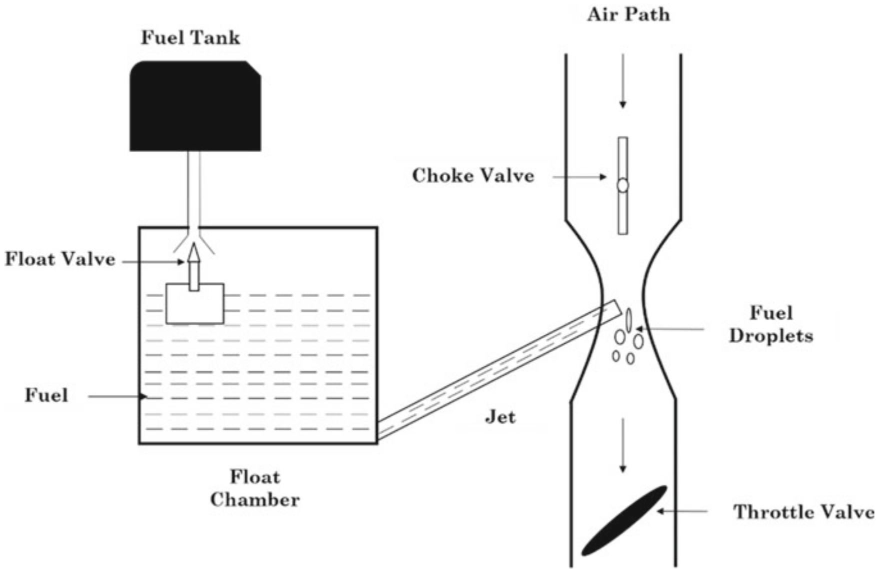


Fig. 4.2 Venturi

Table 4.3 Atmospheric conditions[a]

Seasons	Temperature (°C)	Density (kg/m^3)
Winter	−5 to 25	1.316–1.184
Summer	30–50	1.164–1.093
Rainy	20–40	1.204–1.127

[a]Air density. https://www.engineeringtoolbox.com/air-density-specific-weight-d_600.html

varies from #35 to #80, where the number represents the diameter of the metering hole (×10 μm) (see Footnote 9).

Needle: It is a most critical part of the carburetor, which affects air-fuel ratio from the first quarter to the third quarter throttle opening. Different geometrical parameters such as diameter, length, and taper section affect the functioning of needle. Needle diameter controls the air-fuel ratio during the first quarter throttle opening position. At lean diameter setting, engine loses power during third quarter throttle opening however rich diameter setting results in choked condition. Needle length is determined by clip position (number of grooves) on the top position of the needle. Needle length ranges from #1 to #5, where #1 corresponds to the leanest setting of the carburetor, and #5 corresponds to the richest setting of the carburetor. The taper section is an angle available on the lower end of the needle, which affects the air-fuel ratio between medium loads to the maximum load range. It affects the size of the main jet since leaner needle taper requires richer main jet to fulfil the engine requirements.

Main Jet: It is a jet having a single metering hole for adjusting the required air-fuel ratio during the third quarter to fourth quarter throttle opening positions. It does not play any significant role during the first quarter to third quarter throttle opening positions. Lean main jet setting causes detonation and rich main jet setting affects the sound quality of vehicle especially from the silencer. Generally available sizes for the main jet ranges from #90 to #230, where the number presents the diameter of the metering hole ($\times 10\ \mu m$) (see Footnote 9).

Float Chamber: It is used to reserve the fuel inside the carburetor at constant level at constant height. High fuel level inside the float chamber discharges more fuel quantity from the jets, and low fuel level discharges lower fuel quantity from the jets. Both conditions adversely affect the engine operation.

Float Valve: It is used to maintain a constant level of fuel in the carburetor during engine operations. It helps during transient driving conditions when the fuel requirement varies continuously.

RPM Screw: It is a slotted brass screw used for adjusting the fuel-air mixture quantity during idling. Its position defines a default jet needle lift position in idling. High jet needle lift results in more quantity of fuel-air mixture supplied to the engine, which increases the engine speed. On the other hand, low jet needle lift results in a less mixture quantity being supplied to the engine, which reduced the engine speed.

Needle Jet Holder/Emulsion Tube: It is used to accommodate jet needle during various throttle positions. In the first quarter throttle opening, emulsion tube accommodates more height of the jet needle, which results in a small fuel quantity emerging from the main jet. In the second quarter throttle opening, emulsion tube accommodates lesser height of jet needle, which results in more fuel quantity emerging from the main jet compared to the first quarter throttle opening. In the third quarter throttle opening with lesser height of the jet, needle accommodates inside the emulsion tube, which results in more fuel quantity emerging from the main jet compared to the second quarter throttle opening. In fourth quarter throttle opening, entire jet needle comes out of the emulsion tube, leading to maximum fuel quantity emerging from the main jet compared to other throttle opening positions.

Choke: It is used for cold starting. During winters, low atmospheric temperature results in inferior spray atomization and vaporization of fuel in the carburetor. This leads to cold startability issues of the engine. This can be resolved by supplying a rich fuel-air mixture using choke.

Needle Jet: It guides the jet needle, and provides a path, through which it enters the emulsion tube.

4.3.1 Conventional Carburetors

There are three types of conventional carburetors namely horizontal draft, updraft and downdraft (Fig. 4.3). In a downdraft carburetor, air flows from upward to the downward direction due to gravity. In an updraft carburetor, air flows from downward to the upward direction, against the gravity. Engine with this type of carburetor

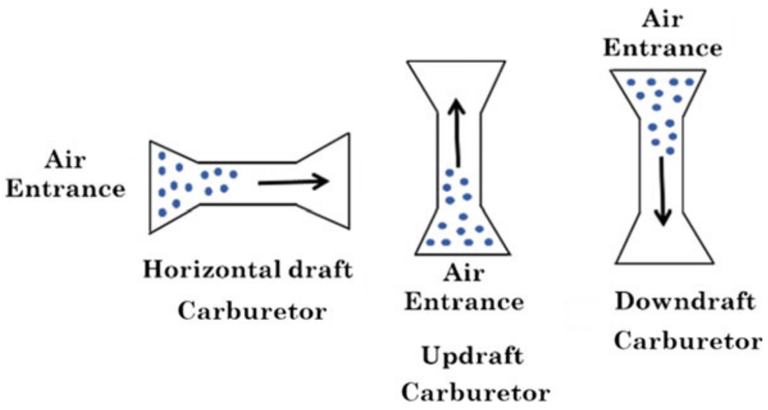


Fig. 4.3 Carburetor based on air supply direction

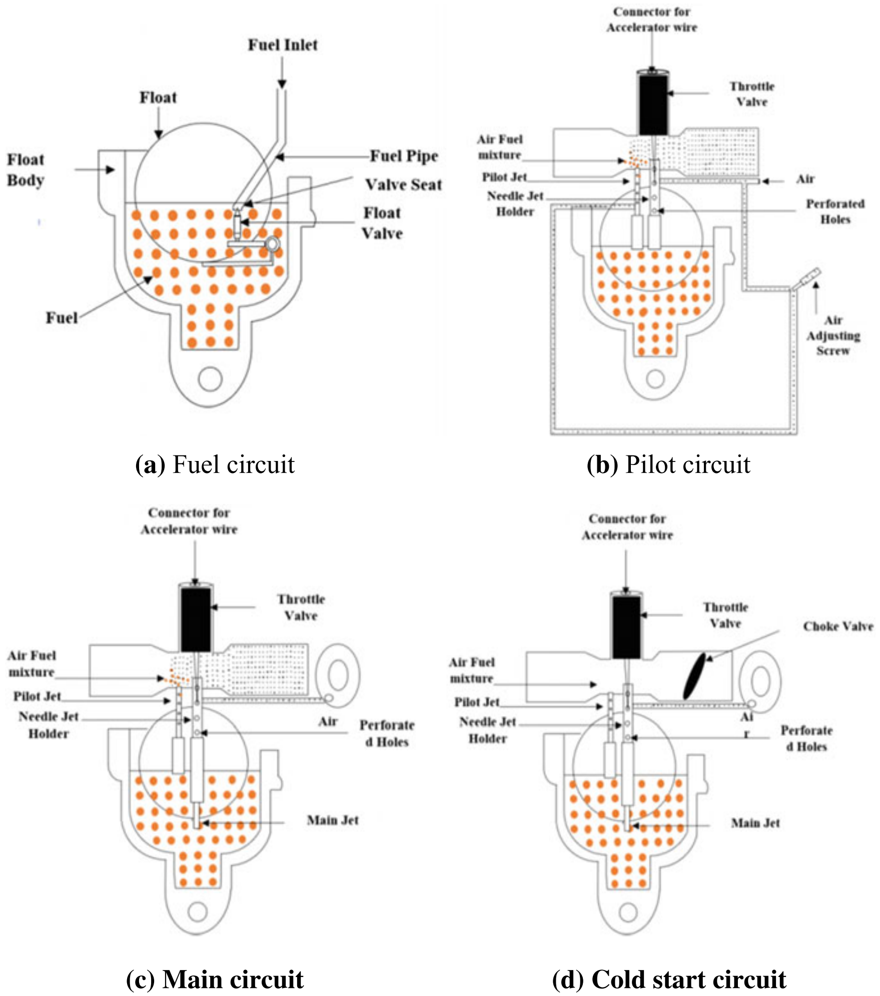
provides low mechanical efficiency because it requires an additional device to force the air-flow against the gravity. Therefore it has become obsolete now. In a horizontal draft carburetor, air flows in horizontal direction. This type of carburetor is used, where size of the carburetor is rather constrained. Downdraft and horizontal draft carburetors are more popular and widely used for vehicular application. These carburetors give higher mechanical efficiency of the engine compared to the engine equipped with updraft carburetor. Modern carburetors have some unique features, which provide superior fuel economy compared to conventional carburetors. Modern carburetors are explained comprehensively in the next section.

4.3.2 Modern Carburetors

In the modern carburetors, venturi size varies according to throttle position, which makes them different from conventional carburetors. Venturi size increases when the throttle position changes from idle to wide open throttle (WOT) position and decreases when it changes from WOT to idling position; thereby pressure difference remains constant at the throat. Therefore variable venturi type carburetor is called as 'constant velocity' or 'constant vacuum-type' carburetor. Base on variable venturi type, it can be classified as PB type carburetor and CV type carburetor.

4.3.2.1 PB Type Carburetor

PB type carburetor is used in both two-stroke and four-stroke small SI engines, with the engine capacity varying from 50 to 100 cc. It is a lightweight, compact and



(a) Fuel circuit **(b)** Pilot circuit

(c) Main circuit **(d) Cold start circuit**

Fig. 4.4 Schematic of various circuits in a PB type carburetor

horizontal draft type carburetor, generally having a mounting angle of 5° to 15°.[10] Air-fuel ratio adjustment can be made by using an air screw. Generally, this type of carburetor is available with different venturi sizes (such as 14, 16, 18 and 20 mm air inlet bore diameter) compatible with atmospheric temperatures varying from −30 to +80 °C.

PB type carburetors have four different circuits namely fuel inlet circuits, pilot circuits, main circuit and cold-start circuit (Fig. 4.4). The drivers use different throttle positions to meet different conditions on the road such as traffic, full speed on

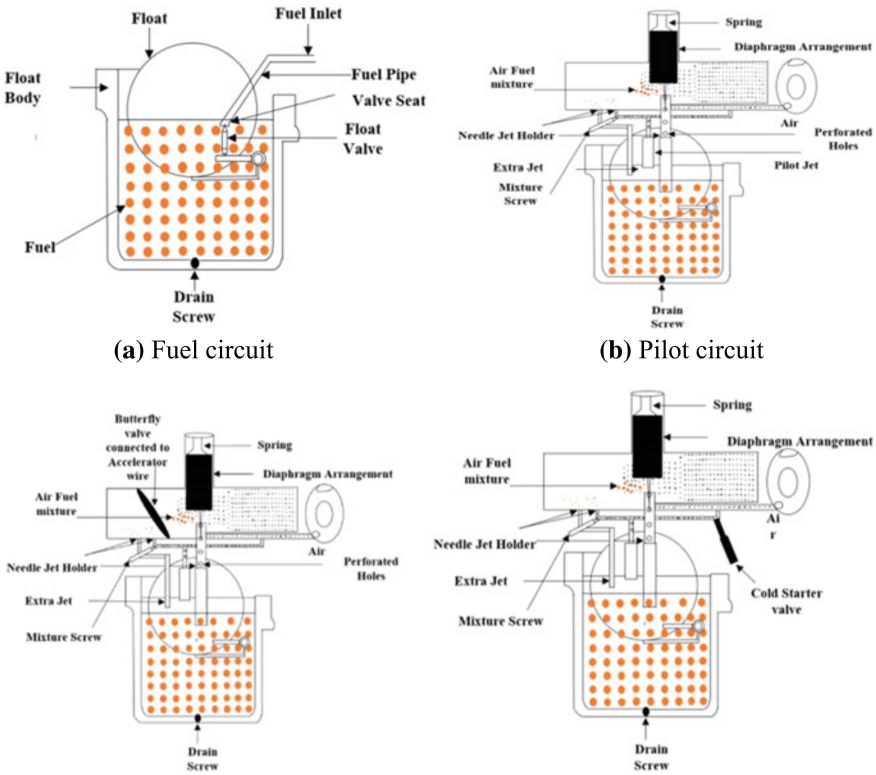
[10]PB type carburetor. http://www.keihinfie.com/html/pbtype.htm.

highways, and coast down. As shown in the fuel circuit (Fig. 4.4a), fuel comes from the fuel tank to the float chamber where the float valve maintains a constant fuel level. Drop in fuel level changes the float position thereby float valve opens up for entry of the fuel into the float chamber. Float valve controls the fuel delivery from the fuel tank to the float chamber. Figure 4.4b shows the pilot circuit, which works during idling to the first quarter throttle opening positions. The air-fuel ratio can be adjusted using this circuit, where the air flow can increase or decrease to supply rich/ lean mixture using the air adjustment screw. Figure 4.4c shows the main circuit, which works from the first quarter throttle opening positions to the WOT position. Accelerator wire directly connects to the throttle valve for regulating different throttle positions in order to ensure better drivability. Figure 4.4d shows the cold starting circuit, where the choke valve is used to prepare rich fuel-air mixture via blocking the air passage from the main intake air path. This circuit is usually deployed by the driver during winter season so that the engine starts quickly and cold-starting issues can be tackled.

4.3.2.2 CV Type Carburetor

CV type carburetor is used in both two-stroke and four-stroke small SI engines, with the engine capacity varying from 50 to 200 cc. It is a lightweight, compact, horizontal draft type carburetor. In this type of carburetor, mixture quantity can be adjusted by the mixture screw. Generally, the carburetor is available with different venturi sizes (such as 18, 20, 22, 24 and 26 mm air inlet bore diameter), which are compatible with different atmospheric temperatures ranging from −30 to 80 °C.

CV type carburetor follows four different circuits namely fuel inlet circuit, pilot circuit, main circuit and cold-start circuit, in order to meet different engine requirements as per different load conditions ranging from idle to full load conditions via transient conditions (Fig. 4.5). Figure 4.5a shows the fuel circuit, through which the fuel supply from the fuel tank to the float chamber takes place, essentially for creating a fuel reserve in the float chamber, so that issues with pulsating fuel levels could be avoided, particularly under transient conditions. The float valve is used for maintaining a constant fuel level in the float chamber. Figure 4.5b shows the pilot circuit, which gets activated during idling to first quarter throttle opening position. Here, Pilot jet directly connects to the by-pass holes situated after the butterfly valve, in order to run the engine during idling. Figure 4.5c shows the main circuit, where a diaphragm arrangement is used to lift the jet needle, which gets activated during the first quarter to third quarter throttle opening positions. Here the butterfly valve operates in sync with the accelerator for achieving different throttle positions as per requirements. Figure 4.5d shows a cold-start circuit, where a cold-start valve is used for supplying fuel rich mixtures by blocking the small air passage and utilizing extra jets for making a fuel rich mixture. This circuit helps drivers during winters, when ambient temperatures are significantly lower compared to summer.



(a) Fuel circuit **(b)** Pilot circuit

(c) Main circuit **(d)** Cold-start circuit

Fig. 4.5 Schematic of various circuits in a CV type carburetor

4.4 Methanol Fueling in Two-Wheelers

Various techniques to induct M15 in carburetor assisted SI engine included blending and fumigation. Blending is most reliable techniques for M15 utilization in IC engines. Both techniques are explained in the following sub-sections.

4.4.1 Methanol Blending

Methanol is blended with gasoline outside the fuel tank to prepare homogeneous miscible blend to supply the carburetor. M15 blend is emerging as a very popular blend for two wheeler applications. M15 induction is the most economical because it does not require any hardware modifications in the engine nor does it require any external device for separate methanol induction. Based on different mixing devices, blending can be divided into three types namely (i) ultrasonication blending, (ii) mechanical agitator blending, and (iii) magnetic stirrer blending. Ultrasonication blending is a process where sound waves are utilized for agitating the molecules of M15 at micro level for homogeneous mixing of methanol with gasoline such that phase separation can be avoided. In this blending method, a sample of M15 was put in a flask, dipped into the water bath, and sound waves are generated at different frequencies. Frequency defines how often molecules vibrate for preparing homogeneous M15 blend.

Mechanical agitator blending is the blending where a small impeller is used for preparation of M15 blend into a mixing glass/plastic vessel. Centrifugal force is utilized for mixing of molecules of gasoline and methanol. In this blending method, mechanical agitator provides flexibility to utilize different motor rpm for blend preparation.

Magnetic stirrer blending is the one where a rotating magnetic field is enforced by a stirrer bar, which spins quickly for preparation of homogeneous M15 blend. This blending is preferable compared to mechanical agitator blending because it does not have a moving external part, which can damage the mixing glass/plastic vessel.

Further, the blending methods can be divided into four types based on endothermic reactions, used for the preparation of homogeneous blending.[11] These techniques include (i) splash blending, (ii) sequential blending, (iii) ratio blending, and (iv) wild/side stream blending. In splash blending, 85% gasoline and 15% methanol are splashed one after another into the fuel supply tank using fuel meters. In sequential blending, fuels mix sequentially using the same fuel meters. In ratio blending, 85% gasoline and 15% methanol are mixed into the fuel supply tank simultaneously using two flow meters in the downstream connection. In wild/ side stream blending, 85% gasoline is mixed with 15% methanol, and blending occurs upstream of the larger delivery fuel meter. Several researchers have investigated variety of methanol blends for different engines/ vehicles, and their results are summarised in Table 4.4.

Above-mentioned studies showed that M15 can be used as a substitute fuel in SI engines. In general, researchers found that NO_X emissions decreased and CO, HC emissions increase for methanol blends compared to baseline gasoline.

4.4.2 Methanol Fumigation

In this method, M15 is injected into the intake manifold of the engine to prepare homogeneous gasoline-methanol-air mixture for smoother combustion. Homogeneous mixture helps to overcome cold-starting problem, which mostly occurs during the starting of a methanol-fuelled engine. This method is considered as the preferred method for M15 utilization because it reduces the effect of high latent heat of vaporization of methanol due to separate injection in the intake manifold. In fumigation

[11] Renewable fuels blending solutions—measurement solutions. http://info.smithmeter.com/literature/docs/tp0a015.pdf.

Table 4.4 Vehicle studies on different methanol blends

Researcher	Fuel used	Engine test bed/vehicle/simulation	Conclusions
Li et al. (2015)	G100 G85M15	Motorcycle	Using G85M15, HC and CO emissions decreased and NO_X emissions increased, compared to G100
Zhao et al. (2011)	G100 G85M15 G80M20 G70M30 G50M50 G15M85	Passenger car	Using methanol blends, CO and HC emissions decreased and NO_x emissions increased compared to G100
Wu et al. (2016)	G100 M100	Engine test bed	M100-fuelled engine showed reduction in CO and HC emissions however NO_x emissions increased compared to G100
Liu et al. (2007)	G100 G90M10 G80M20 G70M30	Engine test bed	Using M30, HC emissions reduced during cold-start and warm up period and CO emission reduced
Elfasakhany (2015)	G100 G97M3 G93M7 G90M10	Engine test bed	CO_2 emissions increased by ~3, 8 and 9.2% for 3, 7 and 10% methanol blended in gasoline. CO emission decreased by ~17.7, 51.5 and 55.5% for 3, 7 and 10% methanol blended in gasoline. HC emissions decreased by ~19.6, 16 and 26% for 3, 7 and 10% methanol blended in gasoline
Vancoillie et al. (2013)	G100 M100	Engine test bed	NOx and CO_2 emissions reduced by 5–10 g/kWh and ~10% compared to gasoline
Iliev (2015)	G95M5 G90M10 G80M20 G70M30 G50M50 G100	Simulation	CO and HC emissions decreased with increasing methanol content compared to G100. Lowest CO and HC emissions were observed for G50M50. NOx emission increased with increasing methanol content in test blend
Canakci et al. (2013)	G95M5 G90M10 G100	Passenger car	**At 80 km/h speed** CO_2 emission decreased by ~11.3 and 3% compared to G100 using M5 and M10. HC emissions decreased by ~35 and 30% compared to G100 using M5 and M10. NOx emissions decreased by ~9 and 1.3% compared to G100 using M5 and M10 **At 100 km/h speed** CO_2 emission increased by ~0.3% using M10 and decreased by ~7% using M5 compared to G100. HC emissions decreased by ~10 and ~17% using M5 and M10 respectively compared to G100. NOx emissions decreased by ~5% using M5 and increased by ~2.8% using M10 compared to G100

(continued)

Table 4.4 (continued)

Researcher	Fuel used	Engine test bed/vehicle/simulation	Conclusions
Ozsezen and Canakci (2011)	G95M5 G90M10 G100	Passenger car	HC emissions decreased by ~16 and 10% using M5 and M10 compared to G100. CO emission increased by ~1.2% at 80 and 100 km/h vehicle speed using M5 and M10 compared to G100. NO_X emissions decreased by ~1.8 and 2.3% using M5 and M10 compared to G100
Elrod and Bata (1991)	G80M20 G100	Engine dyno	**At 2200 rpm** CO emission decreased by ~18%, HC emissions increased by ~144%, and NO_X emissions decreased by ~14% for M20 compared to G100 **At 2500 rpm** HC emissions decreased by ~143%, and NO_X emissions decreased by ~47% for M20 compared to G100

method, two carburetors are used, where one is used for gasoline and another is used for methanol supply (Fig. 4.6). Fumigation can also be achieved by both mechanical and electronic fuel injection techniques. Mechanical technology is the one where throttle opening of both carburetors was controlled mechanically in such a way that 85% v/v gasoline and 15% v/v methanol is supplied to the manifold to prepare a homogeneous mixture for engine operation. In electronic fuel injection technique, throttle opening position was controlled electronically using either a small circuits or ECU, which control fuel quantities supplied into the manifold to be 85% v/v gasoline and 15% v/v methanol. However, this method increases the net weight of the system since an additional, second carburetor is employed for methanol induction (Abedin et al. 2016). No research has been reported for methanol introduction in SI engine using two carburetors. Globally, this method is in the nascent stage because electronic injectors are preferred for fuel induction these days. Some Indian companies are however considering introduction of this method because Indian market is price sensitive, and carburetor is ~70% cheaper compared to fuel injectors.

Blending is a preferred over fumigation due to following reasons.

Economical: Blending inducts M15 in manifold using existing carburetor whereas fumigation requires an additional carburetor for induction of 15% v/v methanol separately. Further, a separate tank is also required to store methanol for supplying 15% v/v methanol to the additional carburetor. If mechanical fuel induction technology is employed for methanol induction, then additional mechanical components are required. If electronic fuel induction technology is employed, then it requires an additional electronic circuit to ensures required opening of throttle positions for both carburetors. Additional carburetor, additional fuel tank, additional mechanical controls/ electronic circuit results in higher cost for separate 15% v/v methanol supply.

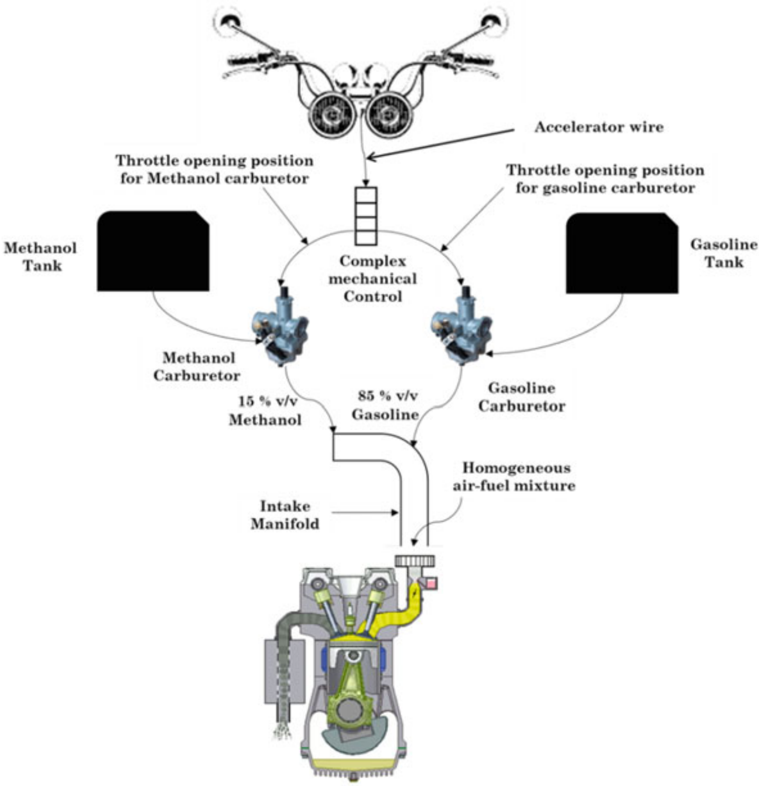


Fig. 4.6 Fumigation technology

Therefore blending method is considered to be economical compared to fumigation technology.

Technical: Blending inducts homogeneous fuel-air mixture (15% v/v methanol and 85% v/v gasoline) into the manifold, which avoids cold-start problems in the vehicle. Fumigation inducts methanol separately in the intake manifold, which creates cold-start issues because methanol has high latent heat of vaporization and during suction stroke, less time is available for homogeneous air-methanol-gasoline mixing, which eventually leads to inferior combustion. Therefore, blending is preferred because homogeneously mixed blends quickly ignite, resulting in higher break thermal efficiency.

Functional: Fumigation requires additional mechanical/ electronic components to induct 15% v/v methanol separately, whereas, blending does not require any additional component for fuel supply. Requirement of additional components in fumigation causes mechanical losses, thereby resulting in lower mechanical efficiency compared to blending. Hence blending is a preferred method for M15 induction into the engine. Existing carburetors are designed optimally for maximum fuel economy

Table 4.5 Properties of gasoline, methanol and M15

Property	Gasoline	Methanol	M15
Chemical formulae	C_4–C_{12}	CH_3–OH	–
	Incorporate one space before C_{12}	Incorporate one space before OH	
Liquid density (kg/m^3)	740	798	748.7
Lower heating value (MJ/kg)	42	20.1	38.7
Stoichiometric air/fuel ratio	6.5	15.05	14.25
Octane number	90–100	109	–

and minimum tailpipe emissions. However both test fuels have different physico-chemical properties (Table 4.5). Induction of M15 into existing engines using existing carburetors is therefore quite challenging. All these challenges are mentioned in the following section.

4.5 Technical Challenges of Methanol-Fuelled Carburetor Operated Vehicles

- Introduction of 15% v/v methanol into 85% v/v gasoline makes a leaner mixture for optimally designed existing carburetor because methanol has ~50% inherent oxygen in its molecular structure.
- M15 has ~38.715 kJ/kg energy density whereas gasoline has ~42 kJ/kg energy density, which results in drivability issues.
- Latent heat of vaporization of M15 is higher than baseline gasoline, which causes poor spray atomization of the fuel injected by existing carburetor jets.
- M15 is quite corrosive, and can corrode sensitive carburetor components such as float valve, jet needle, and emulsion tube. Due to its corrosive nature, sometimes it reacts with 'o' rings of the float chamber and makes powdered residues, which can possibly clog the fuel supply.
- M15 has higher latent heat of vaporization, leading to inferior combustion if existing spark timings are used for igniting the fuel.
- For stoichiometric mixtures, complete combustion takes place therefore it is important to compensate for the difference in stoichiometric air-fuel ratio of any new fuel. Stoichiometric air-fuel ratios for gasoline and M15 are 15.05 and 14.25 respectively as calculated subsequently. M15 stoichiometric air-fuel ratio is ~5% lower than baseline gasoline. However due to use of additives, gasoline stoichiometric A/F is considered to be 14.7 generally.

Stoichiometric Air-Fuel ratio calculations for gasoline:

$$C_8H_{18} + 12.5\,(O_2 + 3.76\,N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2$$

$$\frac{\mathrm{ma}}{\mathrm{mf}} = \frac{12.5(32 + (28 * 3.76))}{96 + 18} = \sim 15.05$$

Stoichiometric Air-Fuel ratio calculation for M15;

$$0.85\,C_8H_{18} + 10.56\,(O_2 + 3.76\,N_2) + 0.15\,CH_3OH \rightarrow 6.95\,CO_2 + 7.72\,H_2O + 39.7N_2$$

$$\frac{ma}{mf} = \frac{10.56(32 + (28 * 3.76))}{0.85(96 + 18) + 0.15(32)} = \sim 14.25$$

Some essential modifications in PB type carburetor (vehicle with 50–100 cc engine capacity) and CV type carburetor (vehicle with 50–200 cc engine capacity) are required to be done for M15 adaption, in order to avoid drivability issues due to above-mentioned challenges.

4.6 Action Plan for Developing M15-Fuelled Dedicated Carburetors for Two-Wheelers

For India, M15 is considered as the best fuel option for small SI engines used in two-wheelers. However there is a need for some design modifications in the existing carburetors. Apart from carburetor, development of the new design of air inlet venturi is also required for adaptation of M15. Few other important steps for adaptation of M15 in two-wheeler sector are given below.

- Development of compatible material for carburetor components
- Development of optimized geometry of main jet and needle jet
- Emission regulations compliances for M15-fuelled vehicles
- Modifications in air bleeder holes and cost reduction
- Reduction in existing venturi dimensions and cost reduction
- Trials of newly designed carburetor on vehicle using M15 and Gasoline
- Durability studies of the carburetor
- Homogeneous blending of 85% v/v gasoline and 15% v/v methanol
- Development of compatible materials for nozzle
- Certification of M15 as automotive fuel based on its physico-chemical properties

4.7 Conclusions

In this chapter, a comprehensive review of the carburetor technology and its classifications are presented. Main objective of this chapter was to explore the scope of methanol as an alternative fuel in carbureted two-wheelers. In India, 100% replacement of gasoline with methanol is very difficult due to very low domestic methanol production compared to potential demands, technical difficulties associated with methanol utilization in existing engines, high formaldehyde emissions and public acceptance. Therefore, M15 has been planned to be introduced as SI engine fuel to start with. M15 would play a vital role to reduce India's high fuel import bill and promote development of indigenous technology for converting waste resources such as MSW, high ash coal and agricultural residues to methanol. M15-fuelled vehicles offer superior economic benefits compared to gasoline-fuelled vehicles. Utilization of M15 in carbureted vehicles has several challenges though, which need to be resolved before its large-scale implementation. Few carburetor components such as metering holes of the main jet and diameter of the jet needle would be required to be optimised. Relatively bigger metering hole diameter compared to existing jets can resolve the issue of lower energy density of methanol. Reduction in the air inlet diameter of the carburetor is necessary to meet the transient conditions by achieving stoichiometric mixture. Overall, M15-fuelled vehicles are capable of offering superior drivability compared to gasoline-fuelled vehicles. M15 is capable of meeting upcoming Bharat Stage-VI emission legislations, which is a quite challenging task for existing gasoline-fuelled vehicles.

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