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A Comprehensive Review of Ultrasonics Application in Detection of Fuel Adulteration

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Abstract:-Gasoline, diesel, biodiesel, and ethanol are major fuels used for transport and electricity generation globally. Consumers are facing the fuel adulteration threat. Adulterants are blended to this to these fuels with other inexpensive boiling point range hydrocarbons containing more or less similar composition leading to degrade or alter the quality of the base fuels. Those adulterants are blended by the business vendors for the high-profit margins. Various physical and chemical methods are available to detect/estimate the fuel adulteration; however, most of these methods are laboratory-based and expensive. Introduction of ultrasonic-based fuel detection techniques provided the on-field system for detection/estimation of adulterants presents the fuel. Ultrasonic based methods proven have to be easy, quick and inexpensive. We believe that this is the first review article presenting an exhaustive review of the ultrasonic application in detection/estimation of adulterants present in the automobile fuel. The scope of the article is to review various works on fuel adulteration process detection/estimation using ultrasonic sensor based techniques.

Keywords:-Fuel adulteration, Ultrasonic, Gasoline, Diesel, Transducers, Air pollution.

I. INTRODUCTION

Air pollution has been increased due to the excessive use of fossil fuels since from the beginning of the industrial revolution. The automobile sector has considered as a major consumer of petroleum products and asignificant contributor to air pollution[1]–[5]. Adulteration is one of the major problems in developing countries like China, India, Brazil, Greece etc[6]–[10]. Adulteration in automobile fuels is often occurring in day to day modern life. It is a very significant problem which requires immediate attention for its solution. The adulterants are generally inexpensive and low-quality liquids which are miscible with the pure samples of fuels and their presence will reduce the quality of the fuel sample. The effects of these adulterants will bring threat to the living beings and environment etc. The presence of diesel and kerosene in gasoline produces enormous smoke and pollutes the environment[11]–[16]. The major cause of the adulteration is due to the heavy taxation on petroleum products particularly in countries of SouthAsia[2], [3], [7], [8], [17].The fact that adulteration of petroleum products such as gasoline and diesel, is difficult to detect, combined with various tax structure makes such adulteration financially attractive, even though such practice is illegal. Generally, diesel is adulterated by mixing kerosene and gasoline is adulterated by mixing diesel. The expected percentage of adulteration is 10% to 30% by volume in both practices. It is very difficult to detect the adulteration when there is a 10%, but more than 30% can be easily detected by the consumer from the engine performancedegradation caused by adulterated fuel. To monitor the adulterations effectively, it is very necessary to check fuel quality at the fuel distribution stations itself. The equipment or tools used for this purpose should be portable and detection/estimation technique must be easy and quick.

Severalnumbers of test methods have been developed for detection/estimation of adulteration in automobile fuels. Some physical and chemical methods, such as FTIR(Fourier transform infrared) spectroscopy[18], synchronous fluorescence[19], gas chromatography[20], evaporation test (ASTM D3810), ash content determination (ASTM D482), distillation test (ASTM D86), density test (ASTM D4052) and use of various chemical markers are being used as techniques for detection/estimation of constituents in the fuel samples, however no method can be recognized as perfect for estimation quantities of adulteration[4], [6], [10], [21]. Fibre optic sensors have also beenutilized in estimating adulteration in gasoline and diesel by kerosene[22]–[24].Some other adulteration detection/estimation techniques which are less sensitive to adulteration are titration[25] and optical[23], [26] techniques. Inview of the limitations of physical and chemical methods, some researchers have recommended and adopted ultrasonic interferometers[26], [27] for ultrasonic wave velocity, refractive index, density and compressibility of kerosene, gasoline, diesel, kerosene and binary mixtures to estimate the percentage of adulteration[26]–[31]. The applicability of ultrasonic waves for detection/estimation of adulteration provides easy, quick and inexpensive technique.

Very few number of research studies have been carried out to detect/estimate the fuel adulteration using ultrasonic. There is a requirement to conduct anintense research study to develop ultrasonic based sensor devices for effective on-field detection of fuel adulterants. This review article describes in detail of the ultrasonic based sensors design and modeling methods for implementation in detection/estimation of fuel adulteration.

A. Detection/Estimation of Fuel Adulteration Using Ultrasonic

B. Liu et al.[31]had described an ultrasonic based method to determine water concentration in ethanol fuel using artificial neural networks. In this study, adulteration of ethanol was simulated by blending anhydrous ethanol with known concentrations of water. In this experimental study, anhydrous ethanol and water were distilled by using Millipore water purification system. A total of 21 sample mixtures of ethanol-water were prepared with concentrations of water between 0% to 100% with intervals of 5%. The prepared samples were put in a temperature controlled circulating-liquid bath, and speed of ultrasound was assessed at varying temperatures between 10ºC and 40ºC. This experimental setup shown in **Fig.1**consists of a computer, pulse-receiver,sample holder,digital oscilloscope, and a temperature acquisition system. The system employed an ultrasonic transducer with 2.25MHz central frequency and diameter of 10mm. An ultrasonic pulse-receiver was used to drive the ultrasonic transducer. The pulse-receiver was operated in apulse-echo mode, and the two-channel digital oscilloscope captured the signals which are received and transmitted by the transducer.In this study, resonance technique was adopted to assess the speed of ultrasound. In this resonance technique, a short electrical pulse was applied to a piezoelectric transducer, and the electrical signal is transformed into an acoustic wave, which propagates through the medium. A brass cup was built and positioned at a distance of 27mm from the surface of the transducer. The propagated sound waves reflected back from the brass cap and returned to the transducer. The amount of time elapsed between the transducer and the brass cap was used to estimate the speed of ultrasound in the sample.

The signals attained by the oscilloscope were transmitted to a computer through a general-purpose interface bus. Averaging the pulses transmitted from the oscilloscope reduced the error of random noises. The temperature assessment system consists of a shielded input/output connector block, which is employed to obtain the temperature readings from the J-type thermocouple (temperature range −40º to +750 °C), and a data acquisition (DAQ) terminal box transmitted the temperature readings to the computer. The ultrasound and temperature signal data were captured using program scripted in MATLAB (version 7.11.0). The sample holder was immersed in a temperature – controlled circulating-liquid bath unit, which can control the temperature of coolant between 30ºC and 100ºC. In the sample holder, the space between the transducer surface and brass cap (acoustic path) was filled with sample.

Ultrasound speed and temperature measurements were utilized to assess the concentration water in ethanol using two mathematical models. The first model was designed based on statistical curve fitting to the experimental data, and the second model was designed based on a feed forward, back-propagation neural network(BPNN) algorithm. Proposed models were validated by preparing known concentrations of ethanol and water mixtures. It has been showed that water concentration in ethanol-water mixtures can be assessed by using thespeed of ultrasound and temperature of themixture with a standard error of prediction of 12.4% with anempirical model and 8.6% with theneural network model.

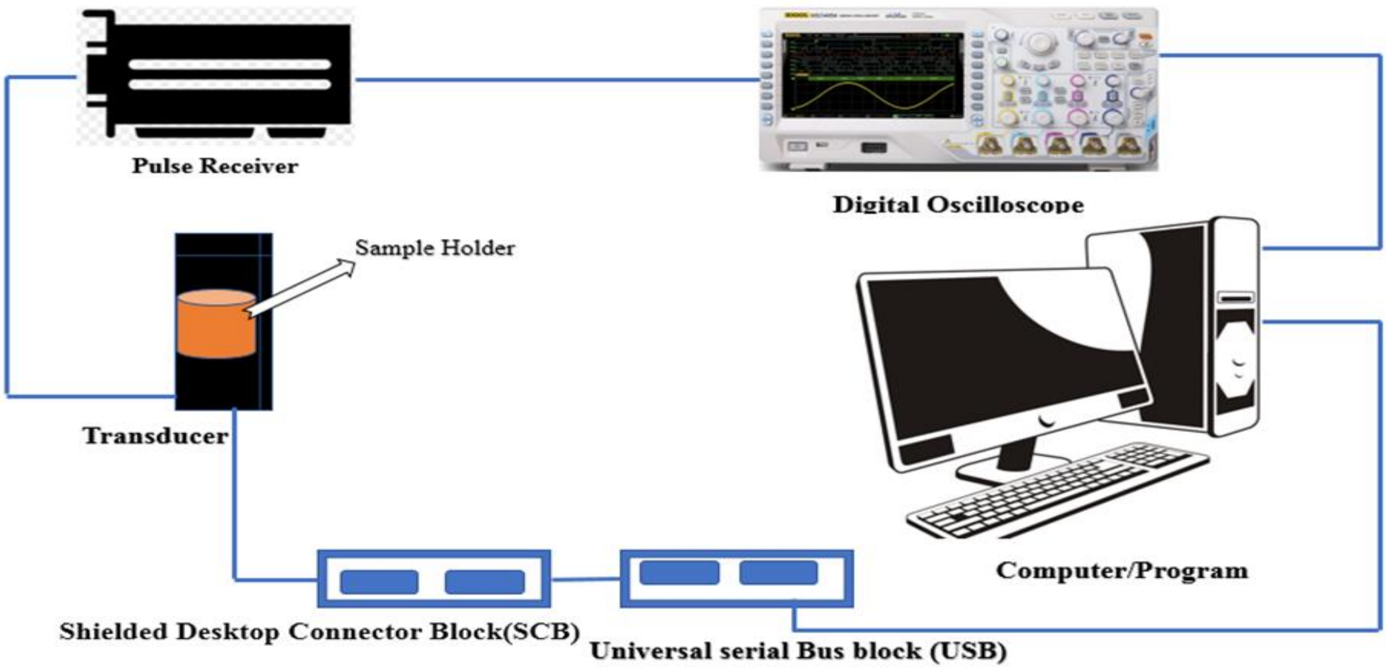

Fig 1.Experimental Setup and the Components of the System

Yusuf C and his co-workers[32]proposed a sensor system that can assess the concentration of alcohol present in the mixture composed of water and ethanol using ultrasound waves. It has been established that water-ethanol mixtures can constitute acoustic velocities higher than the individual acoustic velocities of ethanol and water. In this study, Acoustic density and velocity of the mixture have been measured simultaneously to estimate the concentration of alcohol in the mixture. The sensor system, using Scholte waves, enables measurements inside a closed container through a wave guide, without mixture exposed to air. Following an exhaustive dispersion analysis, Scholte waves are used through mode conversion from Lamb waves employing a piezoelectric transducer mounted on a thin wave-guiding plate to estimate the density and acoustic velocity of such mixtures.

Monique K et.al [2] had described a detection technique to estimate the biofuel ethanol adulteration using ultrasonic measurement method. This experimental study has been carried out based on the measurement of ultrasonic propagation velocity and attenuation to detect the adulteration in thesample. The samples used in this experimental study were blends of ethanol and water, and ethanol from thecommercial store. The samples were poured into a glass cylinder of 35mm diameter and 80mm height and its bottom were completely sealed with a polyvinyl chloride(PVC) film. Distilled water used in thereference sample and the sample to be evaluate contained a blend of ethanol and water with aconcentration range of ethanol from 89.94% to 93.71% by mass. The concentrations were accurately estimated using the gas chromatography [2]. In a transmitter/receiver scheme, a waveform generator was employed to excite the transducer (Transmitter) with $20V_{p-p}$. The signal from the transducer (reception) was digitized with an oscilloscope. One pair of 15MHz –central frequency transducers was employed to transmit and receive the signal. Representation of experimental setup has shown in **Fig.2**.LabVIEW 8.5 was used to calculate the attenuation, propagation velocity, and related uncertainties. The calibrated digital thermometer was used to calculate the temperature of thesystem.

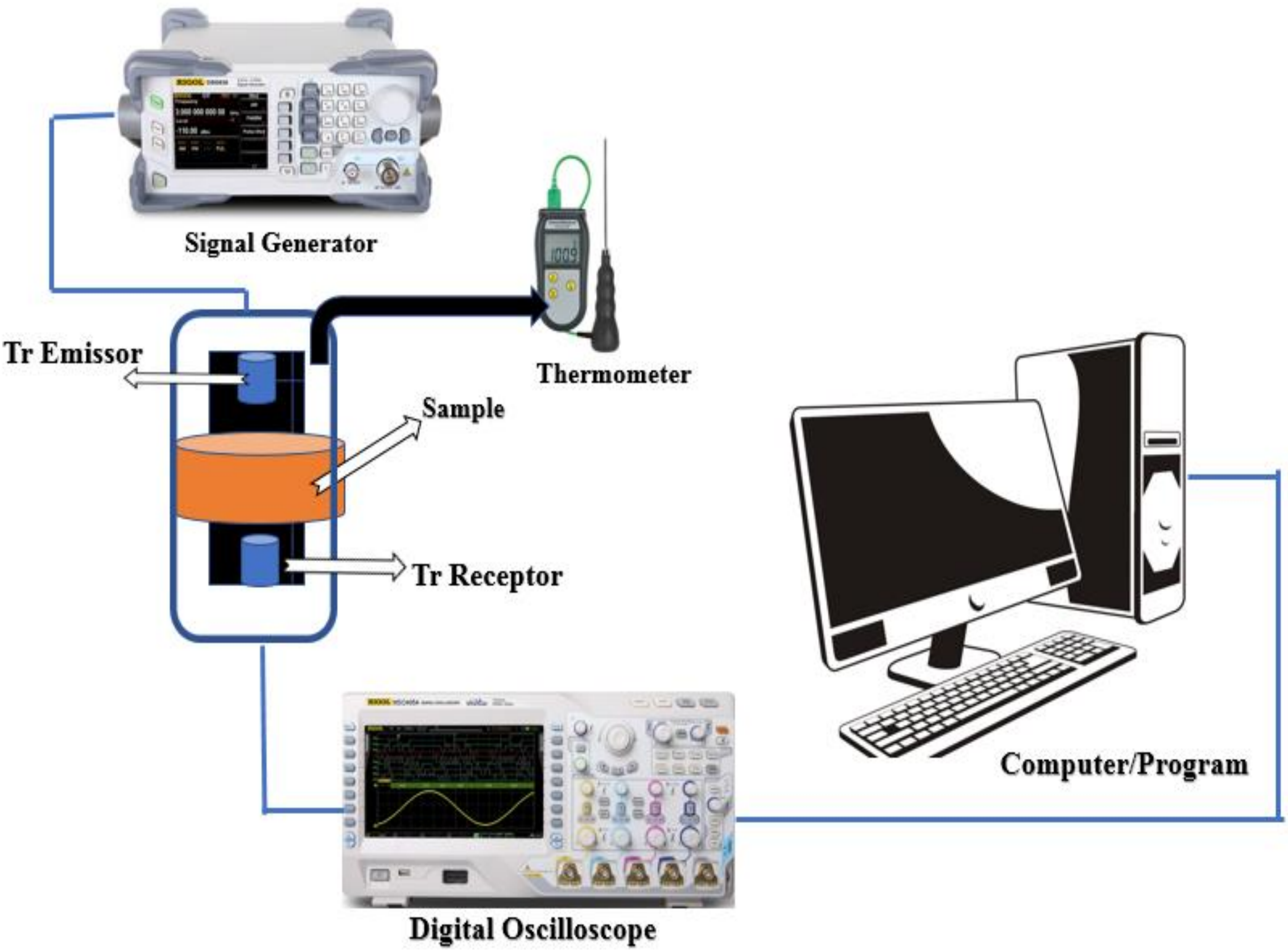

Fig.2: Experimental Setup and Components of the System.

Anotherexperimental study has beencarried out to assess the percentage of adulteration present in the gasoline using ultrasonic propagation velocity and attenuation.The test samples were used in this experiment are mixtures of gasoline and various organic compounds: concentrations of anhydrous ethanol with gasoline varying in mass from 52.3% to 80.3%, pure gasoline, mixtures of gasoline, commercial gasoline and organic solvents such as hexane,toluene, and turpentine.The samples were arranged in a cylindrical glass recipient with 35mm diameter and 80mm height, with its boundaries sealed with 12 µm thick plastic film (polyvinyl chloride –PVC). Distilled water used as areference sample to measure the ultrasonic parameter. The temperature ranges between 22.2ºC to 23.1ºC was recorded during the all the measurements.Transmission and reception technique has been employed with two transducers. The arbitrary wave generator was used to excite the transmitting transducer, which produces 20 cycles of sinusoidal waves of 20V peak to peak at afrequency of 15 MHz The transmitted signals were detected by the reception transducer and by using oscilloscope signals were digitalized. The both transducers had 15MHz central frequency and they were arranged 10mm apart.A digital thermometer was used to monitor the temperature. Each sample was evaluated five times under the repeatability conditions[30].

Anil Kumar et al.[33]implemented an ultrasonic based method to determine the percentage of adulteration present in the fuel sample. It has been described that adulteration leads to the change in the viscosity as well as thedensity of the fuel. Since the both parameters show significant influence on thespeed of the ultrasound in a fluid, it is predicted that speed of ultrasound in the unadulterated fuel would be different from that in adulterated fuel.The working principle of this experiment is to determine the speed of sound by calculating the time taken by the ultrasound to travel a known distance (Generally termed as the Time of flight). The two basic methods have been proposed to determine the Time of flight: a) Pulse echo method b) Continuous wave method.

a). Pulse Echo Method

The experimental setup of this method consists of signal source, ultrasonic transmitter TX and receiver RX, reflector, signal processing unit and display. The block diagram of theexperimental setup is shown in **Fig.3.** Ultrasonic transmitting transducer serves as transmitter TX as well as receiver RX. A pulse of acoustic energy emits when transmitter excited by the electrical signal of ultrasonic frequency and receiver receives the incoming signal after reflection from the target. The time delay T_D between the transmitted and received pulse is determined. To determine the speed of sound, the value of T_D is substituted in the equation of speed of sound which is given by $V_s = 2d/T_D$, where'd' is thedistance between the ultrasonic TX/TR and the reflector. The signal processing unit has been used to measure the T_D more accurately.

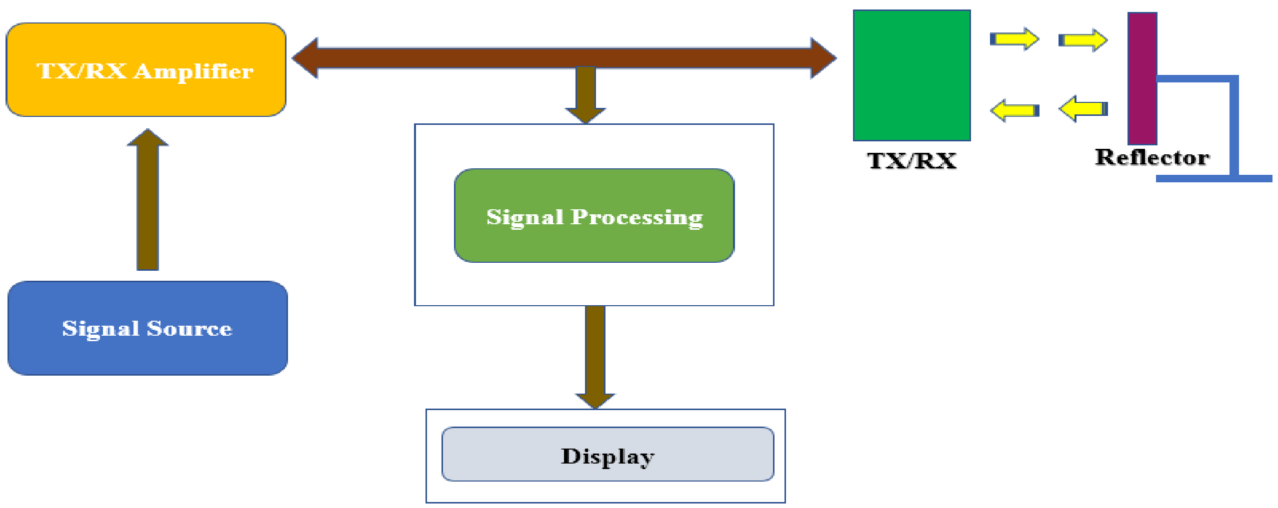

Fig.3: Block Diagram of Experimental Setup

b). Continuous Wave Method

The typical experimental setup of this method consists of signal source, power amplifier, transmitter, receiver, signal-processing unit and display.The block diagram of theexperimental setup is shown in **Fig.4.**The medium has excited with acoustic vibrations of signal frequency. The received signal is computed to measure the time-delayed replica of the transmitted signal. The time delay (T_D) is the sum of the transit time (Time of flight) of the ultrasound of acoustic signal anddelay produced by the transducers and electronic circuits. The transit time is given by the phase difference between the transmitted signal and received signal. Continuous wave method can be applied to estimate the velocity of fluid flow. In this method, measurements are more sensitive to external noise so that this method does not seem to have attracted much.

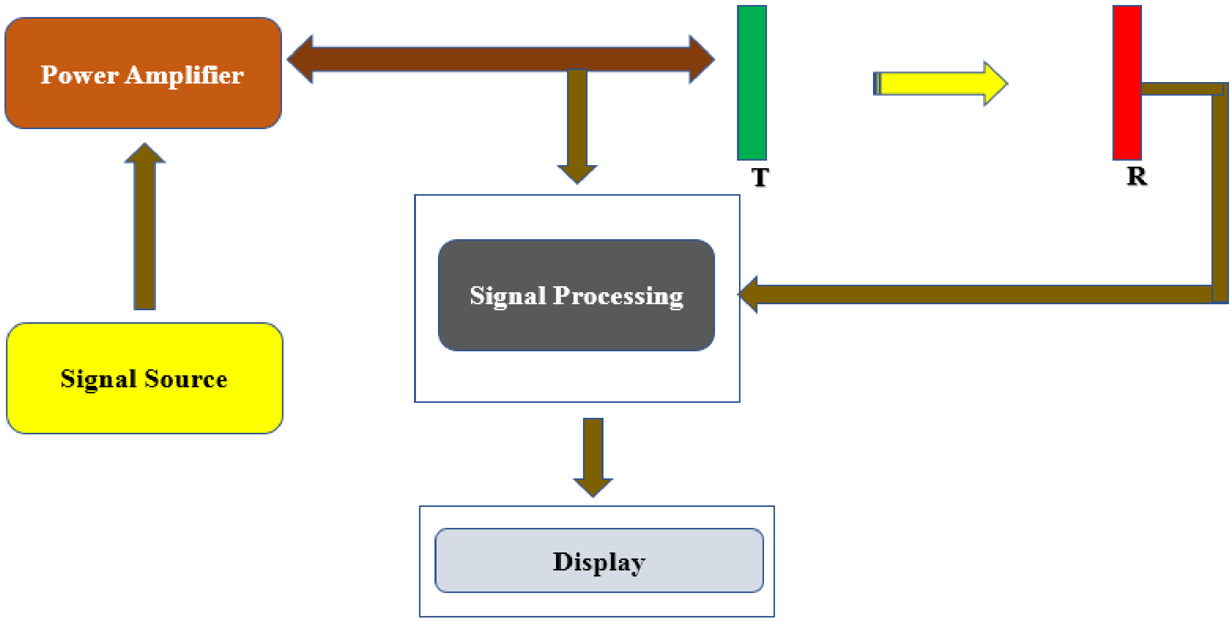

Fig.4: Block Diagram of Experimental Setup

Sharma R.K et.al[29] performed an experimental study to estimate the percentage of adulteration present in the gasoline and diesel using ultrasonic. The ultrasound speed in the not adulterated and adulterated gasoline and diesel has been estimated using pulse echo method. It has been noted down that adulteration results in achange in the calculated speed of ultrasound, which can be standardized in terms of adulteration percentage. It is observed that the speed of ultrasound in samples of gasoline increases with respect to increase in adulteration percentage while the same in the samples of diesel decrease with adulteration percentage. The speed of sound graph has been plotted as a function of density to estimate the percentage of adulterants present in the gasoline and diesel samples. An unexpected outcome has been observed that the speed of sound is increased with the increase in density of the fuel sample for both in gasoline and diesel. Authors in this experimental study have not been attempted to validate the unexpected outcome of their experiment.

II. CONCLUSION

The quantum of petroleum products exploitation around the world is growing due to increase in population, automobiles, urbanization, industries, development activities and transformations in life style, which leads to pollution in the environment. Fuel adulteration leads to economic losses, air pollution and huge scale deterioration in the performance of automobile engines.In most of the analytical techniques for monitoring adulteration, selectivity, sensitivity, accuracy, precision, and robustness remained crucial factors that governed their efficiency and popularity. Most of the physicochemical techniques utilize the higher quantity of samples and they are laboratory based techniques and expensive. Quick, on thefield and inexpensive technique such as ultrasonic would be the better choice for the detection/estimation of fuel adulteration. This article has reviewed some of the important research reports, which involved ultrasonic based techniques for detection/estimation of adulterants present in the automobile fuel.

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