Assessment of sludge formation in diesel storage tanks and eradication measures

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Abstract. The sludge formation and its accumulation in fuel tanks cause several problems such as clogging of vent and suction pipes, reduction in fuel quality and tank capacity, and deterioration of tank material. Sludge is a complex composition of water, fuel, sand, waste oil, metals, bacteria, minerals, and other organic matter. It grows with time because of bacterial growth (that feeds on fuel and water), impurities, and the aerobic polymerization of hydrocarbons in the fuel. The main objective of the present work is to delay the sludge from forming in the diesel storage tanks. It aims at breaking down information collected from various sources on how sludge formation occurs with time and produce research results on the chemical analysis performed on a diesel sludge sample collected from a fuel depot. Two experimental cases have been set up to show how stirring affects sludge growth over a period of time. It is observed that the sludge growth is less in the sample that is agitated when compared with the sample without agitation. By taking this into account, a stirring design is proposed and developed. Also, an idea is provided for reducing the metal ions in the sludge, thus maintaining a high-quality fuel ready for dispensing at the fuel stations.

Keywords: Sludge; Diesel; Storage tanks; Chemical analysis; Growth prevention

1. Introduction
Petroleum sludge contains both organic components and heavy metals [1]. Diesel sludge (one of the subdivisions of petroleum sludges) is not a single well-defined product, and its composition varies with location. Most representative hydrocarbons present in it are straight-chain alkanes ranging from C10 to C28. Pristane and Phytane are the predominant branched alkanes identified [2]. Microorganisms homologous to Bacillus mycoides, Paenibacillus lautus, and Rhodobacter spp. are known to be present in diesel sludge [3]. To get an idea about the contaminants present, a typical diesel sludge sample was collected and tested in Maharashtra Enviro Power Limited (MEPL) in their NABL certified laboratory. Following report was generated, showing different parameters and their values (Table 1). Accumulation of large quantities of sludge affects the life of diesel filters, storage capacity, fuel quality, and even reduces tank life. This can also lead to leakages which result in groundwater and soil getting contaminated with petroleum [4]. These days, diesel which is blended with biodiesel such as fatty acid methyl ester (FAME) shows significant operational problems due to sludge (microbial contamination) [5]. The build-up of sludge in many storage tanks is due to the stagnant fuel, rusting of tank, scale formation, organic growth and presence of water content in it. Even the slightest amount of
water is enough to initiate the phase separation of diesel, leading to two layers of different densities at the tank bottom. This water may enter the tank as rainwater, groundwater, or atmospheric moisture. Also, due to the temperature difference between night and day, water condenses and is built upon the inner surface of the tank [6]. Water and other contaminants cannot be completely filtered out as carrying out filtration at a bulk level in depots is not economically feasible. A feasible solution to this problem is delaying the sludge formation by slowing down its growth.

The project aims at coming up with a technique to delay the sludge growth, resulting in a longer time interval between consecutive tank cleaning cycles. This reduction in sludge concentration also helps in avoiding problems in tank calibration and fuel storage, and prevents the sludge from chocking the vent and delivery pipes. Here a time-bound study has been done on commercially available diesel. Impurities were grown by adding water to the diesel samples. One sample was stirred regularly, while the other was left undisturbed. Based on the outcome of the experiments, a stirring design has been proposed for vertical cylindrical storage tanks in the fuel depots. Sludge also contains metallic ions, which because of their size, result in damaging the vehicle carburetors. An idea has been generated to enrich the customer experience at fuel stations.

Table 1. Chemical analysis of the diesel sludge carried out in NABL certified laboratory.

| S.No. | Parameter                  | Value      | CPCB:2009-2010     |
|-------|----------------------------|------------|--------------------|
| 1     | pH                         | 7.33       | 4 - 12             |
| 2     | Calorific Value (cal/gm)   | 1120.2     | <2500 CAL/G        |
| 3     | Loss on Drying (%)         | 76.90      | NOT SPECIFIED      |
| 4     | Loss on Ignition (%)       | 98.07      | <20%               |
| 5     | Ash content (%)            | 1.93       | NOT SPECIFIED      |
| 6     | Oil & Grease (%)           | <1.0       | <4                 |
| 7     | Cadmium as Cd (mg/L)       | <0.1       | <0.2               |
| 8     | Chromium as Cr³⁺ (mg/L)    | <0.1       | NOT SPECIFIED      |
| 9     | Copper as Cu (mg/L)        | <0.1       | <10                |
| 10    | Iron as Fe (mg/L)          | <0.1       | NOT SPECIFIED      |
| 11    | Nickel as Ni (mg/L)        | <0.1       | <3                 |
| 12    | Zinc as Zn (mg/L)          | <0.1       | <10                |

2. Methodology
Two experimental cases were set up to study the effects of stirring on sludge growth. Two steel containers were filled with 800ml of commercially available diesel and 15ml water each. One was kept undisturbed, and the other was stirred at 30rpm for 20 seconds once a day. The samples showed considerable black growth in the container with time. The composition of this black compound is not known and has been referred to as sludge here onwards. The growth of sludge has been recorded with time by capturing photographs of the samples at a regular interval of 20 days. Figure 1 shows the same for the stirred sample. Since the amount of sludge was quite small, quantitative chemical analysis was not feasible. To calculate the amount of sludge formed, the photos of the sample were tessellated into square grids of size 55x55, as shown in Figure 2. Container size was noted, and base diameter was kept as reference, formulation of the amount of volume that a square represented on the grid was carried out. All the calculations being relative to the base diameter, the influence of factors such as the
height of the camera above the sample and angle of tilt was eliminated. Likewise, calculations were done for a period of 100 days, and a graph was plotted between the volume of sludge in cm$^3$ vs number of days, as shown in Figure 3.

\[ y = -0.003630159 + 0.18888x - 0.000312631x^2 + 0.00000173518x^3 + 2.182292 \times 10^{-8}x^4 \]

**Figure 1.** Photos of the stirred sample taken at a regular interval of 20 days.

**Figure 2.** Tessellated photo of the sample (55x55) used for volumetric calculations.

Now in order to extrapolate results curve fitting was done with a 4$^{th}$ order polynomial (Quartic Fitting). Equation obtained is as follows:
Using this calculation can be done on how often the tank requires cleaning. After consulting tank cleaning service providers and fuel depots, it was noted that 1% sludge concentration in a storage tank is the maximum allowable level beyond which problems in functioning start to occur, safety is compromised, and sales at fuel stations is affected. Thus, before this point is reached, sludge needs to be removed. Finding this upper limit for our experiment, back substituting in the equation, 8ml sludge (1% concentration) will be formed in approximately 134 days.

![Graphical plot showing Volume of sludge growth vs Number of days.](image)

**Figure 3.** Graphical plot showing Volume of sludge grown vs Number of days.

![Unstirred sample at the end of 60 days.](image)  ![Stirred sample at the end of 60 days.](image)

**Figure 4.** Unstirred sample at the end of 60 days.  **Figure 5.** Stirred sample at the end of 60 days.

A comparison was carried out between the stirred and unstirred samples on the basis of the sludge growth, and it was found less in the sample which underwent stirring. Figure 4 and Figure 5 show the state of the unstirred and stirred samples at the end of 60 days, respectively. Figure 6 displays the
sludge volume in cm$^3$ vs. time for both samples. Thus, stirring was considered to be a factor in slowing down the sludge formation. After further research on the same, agitation methods can be suggested to the depots and fuelstations.

3. Stirring approach for vertical cylindrical diesel storage tanks at depots

3.1 Design proposal for stirring
Considering stirring as a factor to delay sludge growth, a stirring design has been formulated for vertical cylindrical tanks in fuel depots. Two ways of fuel agitation can be employed, one in the horizontal plane and the other along the height of the tank. Circulation in the horizontal plane makes the sludge pile up at the center of the tank and this could act as a fertile ground for further organic growth. Whereas circulation along the height disperses the contaminants throughout the tank. In the proposed design, circulation along the height has been incorporated. Figure 7 shows the proposed stirring pattern for a diesel storage tank of height 20 meters. Numbers 1, 2, 3, 4, 5, and 6 represent the pump numbers. The directions of pumping are mentioned in Table 2.

Table 2. Type of circulation carried out by each pump.

| Details of the pumps | Direction/Axis of pumping |
|----------------------|---------------------------|
| Pump 1 and 6         | Horizontal                |
| Pump 2, 3, 4, and 5  | Vertical                  |
Figure 7. Proposed stirring pattern for the vertical cylindrical diesel storage tanks. Pumps 1, 2, and 3 are placed diametrically opposite to pumps 4, 5, and 6.

To cover sufficient vertical distance and prevent undesirable turbulence, design is included with 6 pumps. Design is based on pump 3, which is most heavily loaded. Maximum pressure head required to be generated by pump 3, which is 20 meters (15 meters of static diesel head and additional 5 meters head required to pump diesel upwards). Therefore, the individual maximum pressure head required by each pump is 20 meters.

Pressure to be handled by each pump = 850 x 9.81 x 20 = 166.77 kPa

Specifications of a commercially available diesel pump were 220V, 750W. Pressure head developing capacity of the pump is 5 m of diesel. Using model law for pumps,

\[ \frac{H}{N^2 D^2} = \text{constant} \]

For the same rotational speed, to achieve a head of 20 m, pumps have to be scaled by 2 times. Thus, mathematically it can be concluded that to achieve the proposed design of stirring the diesel, we will require pumps double the size of commercially available pumps.

3.2 Effect of stirring
The major drawback with stirring is dispersion of contaminants which would have otherwise settled at the bottom as sludge. These contaminants get carried to gas stations. This could adversely affect the life of filters that are used and may even affect customers’ vehicle life. So, it is better to reduce the concentration of some harmful contaminants in the depots or in the stations. Owing to their large size, heavy metals are the most harmful contaminants. Metallic concentration in the fuel may increase as a result of tank wear. As seen from table 1, diesel sludge contains metal ions like iron and nickel. To counter this issue, a suggestion has been provided using the concept of magnetic separation. Iron and nickel, though present in minute concentrations, greatly affects the life of an engine, destroys the carburetor, and costs heavy to the customer. The method of magnetic separation, which is usually used for iron ore processing, coolant sludge treatment, and separating magnets from clay, could be used to remove considerable amounts of iron, nickel, and mild steel from the contaminated fuel by allowing the fuel to pass through a kidney loop filtration setup, where it will be periodically circulated through a magnetic separator. The magnets attract the heavy ferrous metals, thus reducing the contamination in the fuel to some extent.
4. Conclusions
The rate of sludge growth is analyzed, and the results are extrapolated to find out a suitable tank cleaning time had the same setup been for a real tank. Experimental results have shown a delay in sludge formation when fuel is stirred. Stirring hence has been considered as a measure to slow down sludge formation. A stirring design has been proposed using 6 commercially available pumps. For the industrial implementation of the same, we need to scale up the pump size by a factor of 2. Chemical analysis of the sludge sample has been carried out to find its composition and based on that, and an idea is generated to minimize it.

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