An Experimental Investigation of Deposit Formation Behaviour in Urea SCR System Using Diesel and Bio Diesel Exhausts.

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Abstract

With increasing application of urea Selective Catalytic Reduction(SCR) for NO_x emission reduction, improving the system performance has become a high priority. Continuous operation at various conditions with high NO_x reduction is possible but one problem that threatens the life and performance of these systems is urea deposit and ammonia slip towards environment when deposit depletes. This urea deposit formation characteristics varies with type of exhaust gases when bio diesel up to 20% blend becomes the fuel substitute. A number of experiments were conducted in which amounts of deposits were estimated using the method of Gravimetric analysis for exhaust gases of diesel and 10% blend biodiesel fuel for different mass flow rates and exhaust gas temperatures. Urea deposits were found in all tests conducted under typical exhaust gas temperatures (90-150^{0}C), mass flow rates. The temperature and mass flow rate were the main parameters that affect the deposit formation of urea, irrespective of engine used. It is concluded from present study that deposit formation of urea is lesser for biodiesel exhaust than diesel exhaust in SCR system.

1. Introduction

In the Selective Catalytic Reduction (SCR) technique used for automotive diesel engines, Urea Water Solution (UWS) is injected to exhaust gases .The formation of NH_3 out of UWS droplets follows several principles [1].

1. Evaporation of water from fine spray of UWS droplets,

$$\mathbf{(NH_2)_2CO(l) \rightarrow (NH_2)_2CO(s) + H_2O(g)} \quad (1)$$

2. Thermolysis of urea into ammonia and iso-cyanic acid,

$$\mathbf{(NH_2)_2CO(s)NH_3(g)HCNO(g)} \quad (2)$$

3. Hydrolysis of iso-cyanic acid,

$$\mathbf{HCNO(g)+H_2O(g) \rightarrow CO_2NH_3(g)} \quad (3)$$

NO_x can be successfully removed from lean diesel exhaust gases by using selective and catalytically supported reduction reactions. Ammonia reacts selectively with NO_x in the presence of oxygen to the harmless products nitrogen and water vapour. The following three overall SCR reactions are considered [1].

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O \quad (4)$$

$$4NH_3 + 4NO + 2NO_2 \rightarrow 4N_2 + 6H_2O \quad (5)$$

$$8NH_3 + 6NO_2 \rightarrow 7N_2 + 12H_2O \quad (6)$$

In spite of this technology is implemented by some of the automobile companies, there are some problems still existing like wall deposition, lower NH_3 conversion efficiency, lower NO_x conversion efficiency, NH_3 slip, poisoning of catalyst etc. However, deposit formation is serious concern as it blocks the flow system on continuous usage. When urea or its by-products become deposited on the inner surfaces of the system including walls, mixers, injector housing and substrates it can create problems of back pressure and material deterioration. In addition, deposits as a waste of reagents can negatively affect engine operations, emissions, performance and DEF economy. Further, the deposits reduce the metal surface area over walls and mixer which reduces further evaporation of UWS.Additionally,the depletion of deposits may lead to ammonia leakage to the environment.

Henrik Smith et.al. [2] found that deposits appeared to grow linearly with time and the locations of the main deposits remain identical in each experiment and an increase of the UWS injection rate solely shifted the deposit location. Vadin O. Strots et.al. [3] found that deposit formation is highest at low exhaust gas (< 200°C) and at low ambient temperatures (< -3°C), high DEF injection rate (0.15 g/s), and low exhaust flow rate. Under these conditions, 25% to 65% of injected urea could get converted into deposits. Colin L. Weeks et.al. [4] observed that most of the urea deposits formed at a low temperature contained urea, yet the Thermogravimetric analysis(TGA) studies on both pure urea and the deposits samples show that it will thermally decompose to cyanic acid at 200°C.Thomas L. McKinley et.al [5] predicted that atomization of UWS significantly affect urea decomposition. Tae Hyun An et.al [6] found that various parameters such as the injector and injection angles and an exhaust gas temperature significantly affect the urea evaporation.

The above literature reveals that the there are no much of studies presented on factors affecting deposit formation especially when the species of exhaust gas varies, which invokes the researchers to do study on deposit formation when engine runs with typical biodiesel blend. The comparative study of deposit formation is taken up to come up when both diesel and biodiesel (B5-B20) exhaust gases present.

The variance which help the SCR designers to do SCR system modification accordingly.

2. Experimental

2.1 Experimental Setup

Usually SCR systems are built on particular automobile based on several factors like mass flow rate, space constraints, etc. As such there is no universal testing instrument to test the performance of SCR system on deposit formation behaviour. Based on the basic requirements for the experiment, the test rig was developed. The exhaust line is refabricated in order to collect the deposits for gravimetric analysis(weight analysis). The details are shown in Fig.1

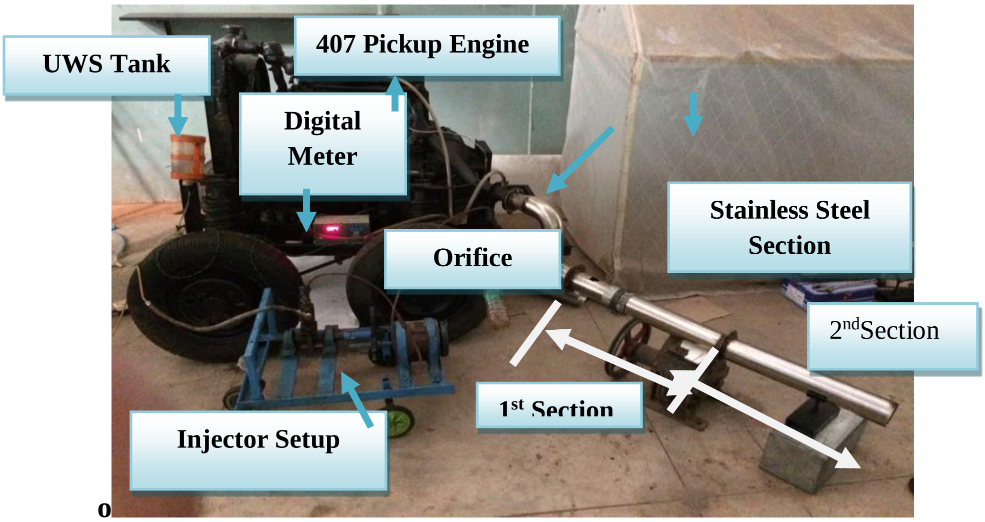

Fig. 1 Experimental Setup

2.2 Engine

The engine used in our experimentation was SFC 407 pick-up as shown in Fig.1 Following table 1 gives the specifications of the engine.

Table 1 Specifications of Engine

Make	TATA
Engine	4SP Water Cooled
Power	55.2 KW (75HP) @ 3050 rpm
Torque	245 Nm @ 1400-1600 rpm
Engine cylinders	Four-cylinders
Displacements (cc)	2956
Fuel used	Diesel and Biodiesel

2.3. Gravimetric Analysis of Deposits

To evaluate the amount of deposits, 2 regions are considered in the exhaust line. They are sections of pipe from injection point of lengths 0.56m, 0.44m in succession (Fig.1) Thin cylindrical metallic foils of stainless steel (SS) with same roughness value as that of pipe are inserted in the above two regions. They are namely foil-1, foil-2 as indicated in Fig. 1. For regular intervals, the weight difference of foil-1, foil-2 and mesh are recorded in the scale having accuracy level upto ±10mg.

3. Results and Discussion

Experiments were conducted on Four-Cylinder, 4-Stroke medium duty engine and SFC 407 Four-Cylinder, 4-Stroke engine. The exhaust flow rate and temperature varie with engine load conditions and experiments were conducted for UWS flow rate of 4ml/min. The exhaust gas temperature varies within the range of 70-150^{0}C. Usually in SCR applications in heavy duty engines, the temperature varies 300-450^{0}C. The present study involves the low temperature operation which reveals only deposit formation characteristics which occurs at low exhaust temperature. Study also involves to check the suitability of SCR system for medium to heavy duty engines. Study also reveals about the variation in characteristics of deposits with biodiesel usage. The low temperature enables only evaporation of water, by which urea decomposition will be minimum and only urea deposit yields. The urea deposit varies with kind of exhausts like diesel exhaust or biodiesel exhaust etc as on possible fuel alternative. A comparative study on deposit formation for these kinds of exhausts undertaken.

3.1 Gravimetric Analysis of deposits

The method followed to quantify deposit formation in our experiment is Gravimetric Analysis as explained earlier. The amount of deposits with respect to time estimated. The time dependent natures of deposits in various test conditions are depicted subsequent sections.

3.1.1 When Engine runs with Diesel

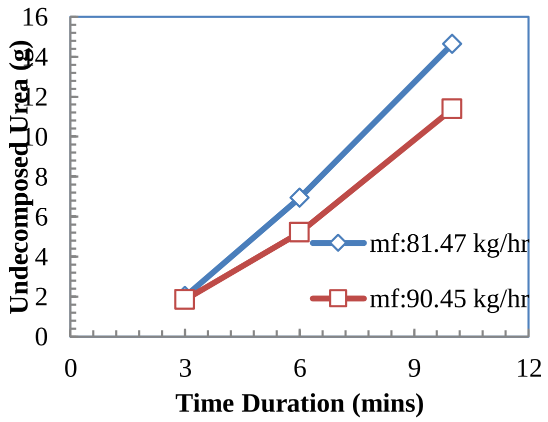

Fig. 2 Undecomposed urea vs time duration for diesel as fuel for different mass flow rates

From the above graph(Fig.2) it is clearly inferred that the deposit formation of urea is inversely proportional mass flow rate of exhaust gas. Higher the mass flow rate of exhaust gas, greater the ability to carry the UWS droplets in the exhaust line. For higher mass flow rates, the intensity of turbulence increases which increases the automization and mixing process. This leads to increased evaporation and urea decomposition causing decreased deposit formation. Further, as the mass flow rate increases, disintegration of droplets increases due to increased turbulence. Turbulence also shears the deposit layer which is in liquid form.

3.1.2 When engine runs at Biodiesel Blended Upto 10%

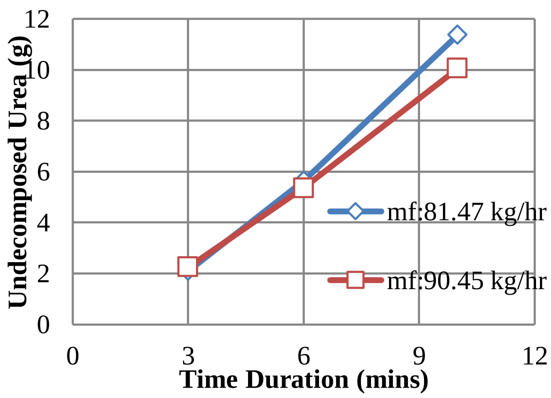

Fig. 3 Undecomposed urea vs time duration for biodiesel as engine fuel for different mass flow rates

In case of biodiesel exhaust, characteristics deposit formation of urea is similar to that of diesel exhaust interms droplet dispersion because mass flow rate is more or less independent of fuel (diesel or bio diesel blended). Additionally, mass flow rate increases temperature, which increases possibility of complete reaction i.e. deposit formation is inversely proportional to temperature. The amount of deposit found decreasing with biodiesel exhaust compared to that at diesel exhaust for both flow rates (Fig.3).

From the above studies, the time dependent nature of deposit formation of urea for diesel and biodiesel exhausts was similar. Further, in deposit formation perspective, the flow rate has substantial effect as it alters the momentum of droplets as well as dispersion characteristics which was discussed in earlier studies by the authors [7].

3.1.3. Nature of deposits when diesel and bio diesel are used

Fig.4(a,b) depict the nature deposits formed when UWS is injected when both diesel and biodiesel exhausts were used . In case of diesel exhaust, deposits are completely white resembling colour of urea, when diesel exhaust persists while bio diesel exhaust the urea deposits were turning to golden-yellowish in colour, because of colour nature of biodiesel. In the case of bio-diesel exhaust the deposits found lesser due to higher NO_x content in biodiesel and difference in wetting characteristics over the metal surface when UWS is sprayed. The sticky nature of bio diesel over the surface reduces the deposits. Entrapment of un burnt bio diesel into urea deposits and gumming nature do not act like precursor for further deposition.

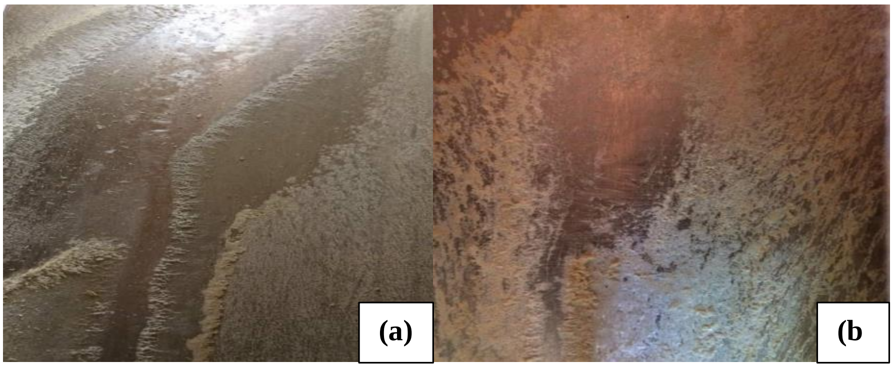

Fig.4.Typical structure of deposits when engine runs with (a) Diesel (b) Bio-Diesel blend 10%

Conclusion

The deposit formation is more pronounced at lower exhaust temperatures which decreases as temperature increases showing inverse relation.. For the same temperature, as the mass flow rate of exhaust gas increases the residence time decreases leading to reduced deposit formation.

The difference is that at lower exhaust gas temperatures, the amount of deposits sticking on is significantly higher. These deposits require very high temperatures to decompose. The fuel nature has detrimental effect on the deposit formation as we noticed deposits of urea is lesser for biodiesel than diesel, due to excess NO_x content in biodiesel exhaust and also due to wetting and sticking characteristics of biodiesel over metallic surfaces. Deposit formation for biodiesel exhaust is lower due as bio diesel exhaust induces lesser wetting characteristics on pipe wall.

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