Spray Visualization of an Urea Injector in the Deposit Tests of a Heavy-duty ATS System

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Abstract

Selective catalyst reduction systems are one of the most promising technologies to reduce NOx emissions from heavy-duty diesel engines. To meet the Euro VI regulations, the SCR system should achieve high NOx reduction efficiency. In the SCR system, NH_3 is usually supplied by the injection of urea water solution (UWS), therefore it is important to improve the efficiency of UWS minimize urea deposits. In this systems deposit accumulations become one of the major problem to meet Euro VI regulations. In this study, spray behaviours of the urea injectors are investigated on the hot gas test bench. Each parameters such as impingement angles, penetration length of the spray characterization were analysed using high speed camera. Deposit accumulation tests were performed with different urea injection and exhaust mass flow rate. The deposit test show the amount of deposit accumulation are decreased above the 250 degree C. The deposit accumulation region was significantly influenced by the spray density and directions. Deposit weights and deposit localization zones on the exhaust system has a close relationship with spray properties. The UWS had formed with short spray penetration length. Spray and deposit tests showed that most of the deposit formations are directly related droplet size. After the tests, a new spray-based boundary condition map is created for reducing the deposit limits in the system.

Keywords

Urea Injector, deposit formation, spray impingement angle, urea injector control.

Introduction

SCR systems have an important role in the developing industry of ATS. Global regulations limit the emission values under a minimum and the car producers try to reach this values in order to take place in the market. The aftertreatment techniques introduced to follow the emission legislations require a constant improvement process to comply with the gradually more stringent demands. SCR is the system used nowadays to deal with NOx emissions in most heavy-duty vehicles. A reduction of the pollution caused by commercial vehicles has been mainly achieved in the past 15 years [1].

An aqueous-urea solution, AdBlue, is sprayed into the evaporation unit, where urea should decompose to ammonia, the reducing agent. AdBlue is the commercial trademark used for the aqueous urea solution AUS32 (with 32,5 % of technical urea) used in all SCR systems nowadays. The trademark is owned by the German association Verband der Automobilindustrie (VDA). Adblue is injected on the SCR system to reduce the NOx limits. Even if it is a good solution for reducing the emissions, but it produces unwanted deposit on the ATS parts. With the help of deposit accumulation, exhaust back pressure increases and break down by the time.

For the purpose of reducing the deposit and emission by the same time, advanced testing methods are tested. This study is a result of advanced methods of coupled deposit and spray tests for understanding both the fluid mechanics environment of deposit tests and spray characteristics of the commercial injector on deposit formation.

Chemical Background

Adblue is used to prevent the deposit formation in diesel engines and technical properties are given in Table 1.

Physical state:	Liquid
Colour:	Colourless, yellowish
Odor:	Ammoniacal (slightly)
pH:	10
Boiling/condensation point:	103°C
Freezing/melting point:	-11°C
Density:	1,087 to 1,093 g/cm^3 [20°C]
Dynamic viscosity:	0,14 mPa*s

Table 1. Adblue physical properties

In the first process, the most pure one, AdBlue is directly derived from ammonia/urea production process and has no risks of contamination [2]. In the second one, dissolution, Urea is usually solidified and some substances are added to store and preserve it. It's from these additives that AdBlue can be contaminated with dangerous impurities.

AdBlue is delivered from the storage tank into injector and injected directly into exhaust in upstream position to SCR catalyst. This process is controlled by engine control unit (ECU) or Dosing Control Unit (DCU) [3]. After reaching exhaust, AdBlue is immediately evaporated and urea is decomposed. This process is described by following hydrolysis reaction:

$$CO(NH_2)_2 + H_2O \rightarrow CO_2 + 2NH_3 \quad (1)$$

In reality, decomposition of urea is achieved in two steps, where first step is creating intermediate isocyanic acid (HNCO) and one molecule of ammonia by thermolysis of urea [4]. Second step is hydrolysis of HNCO, which leads to products in form of second molecule of ammonia and CO2. This process is described by following reactions:

$$CO(NH_2)_2 \rightarrow NH_3 + HNCO \quad (2)$$

$$HNCO + H_2O \rightarrow NH_3 + CO_2 \quad (3)$$

Once this process is complete, NH_3 could be used in SCR catalyst, which is great storage media for ammonia. Storage functionality of SCR catalyst greatly improves performance of NO_x reduction by maintaining a steady supply of ammonia regardless to rapid NOx variations [4]. This storage function has also a benefit in not having to have exactly matched injections of urea corresponding to rapid changing of NOx levels in exhaust [9]. Urea also could not be injected in temperatures less than 180°C because of hydrolysis kinetics, which is another reason for need of ammonia storage in SCR catalyst during low duty operation [5].

Tests

Deposit is the solid white residue collected on the SCR parts by the time. Deposit formation is the main problems of heavy duty producers and studied by different department in the R&D part. It is not only a design problem but also a calibration based problem of the exhaust system. Different calibration maps are used by the engineers for making the optimum urea (Adblue) dosing. Because the dosing limits are the milestones of the deposit tests. The boundary conditions including the urea dosing, temperature and air flow rate of the burner system is generated by the SCR specialists. The outcomes of the each deposit test is the income of next deposit test because of the different testing points. Test are basically a compound of 2 different tests: Spray Test and Deposit Test. The basic equipment and rig is unique for each test but for the spray monitoring a second test rig is also used.

-Test Equipment

Deposit tests are done in Ford OTOSAN Gölcük Flow Performance and Durability Laboratory. Flow Lab. has capability for both hot and cold flow tests. Burner can run between 50-1200 ºC temperature ranges. Burner simulates the hot gas source of the deposit tests.

Test parts are unmounted specially for the test because the parts are coupled in heavy-duty ATS.

Figure 2. Deposit Test parts

For the temperature control thermocouples are used. K-type thermocouples are preferred for this tests because of the user-friendly testing methods. Calibration of the thermocouples are done weekly according to the calibration procedures. There are 2 thermocouple locations as seen in Figure below. The location of these thermocouples are same with the EGT sensor locations on the truck system. Temperature must be controlled in a medium of 200-450 Celsius. As expected, when the temperature is increased the weight of the deposit is decreased. So, higher temperature values are the best testing points for reducing the weight of the deposits. For this purpose temperature must be controlled in a strict manner to overcome thermodynamic errors.

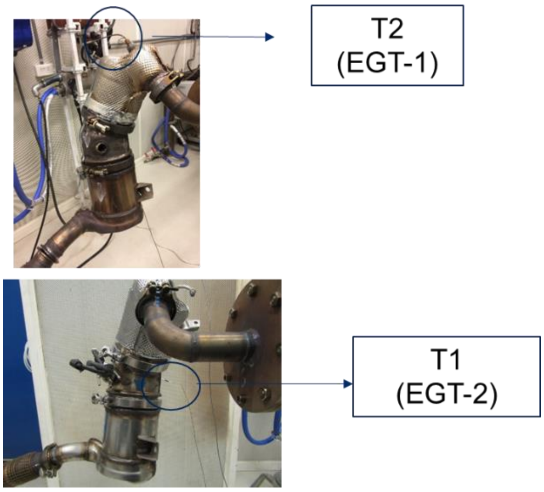


Figure 3. Test Rig and Thermocouple instrumentation.

Test Part-1: Spray Test

The dosing quantity is limited according to the engine regulations. Minimum dosing is 60 mg/s and maximum dosing is 200 mg/s for the tests in this study. The basic view of the tests are given in the figure below. Urea and air is the input of the system, the system with hot gas burner is the exhaust gas source and the injected Adblue is streamed in the SCR system and at the end different amounts of deposits formed and locate at the mixer and other parts.

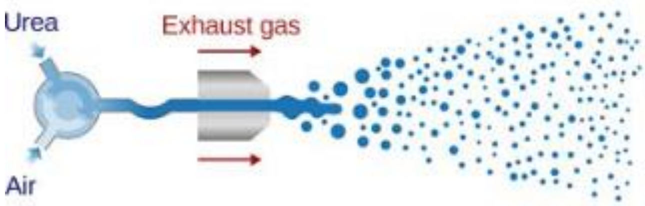


Figure 4. Basic representation of test

The urea injector used in study is a 6-hole commercial Adblue injector. The properties of the injector is given in the Table below.

Table 1. Physical Properties of the commercial 6-hole Adblue injector

	Driven Mechanism	**Pressure**	**Nozzle diameter**	**Nozzle Number**	**Spacing Diameter**
Commercial Injector	pressure	9 bar	130 µm	6	1.9 mm

Urea injector is tested for different injection rates in order to have the spray characteristics. As seen in the figure below, 10 different Adblue flow rates are tested. These test are done additionally to the deposit formation tests. The minimum dosing flow rate is 50 mg/s and the upper limit is 1800 mg/s. Wet surface areas are calculated with an in-house code. Wet surface angles are calculated for 20 mm distance from the needle and spray surface. Visaulization of the Spray Tests are done with a high speed camera with 10000 fps test time and a special spray rig as seen in the figure.

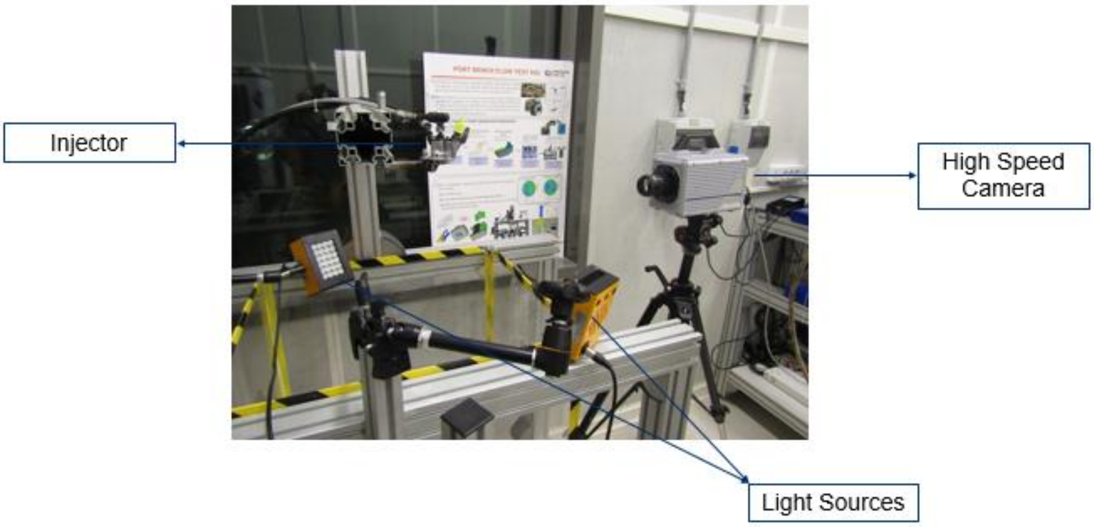
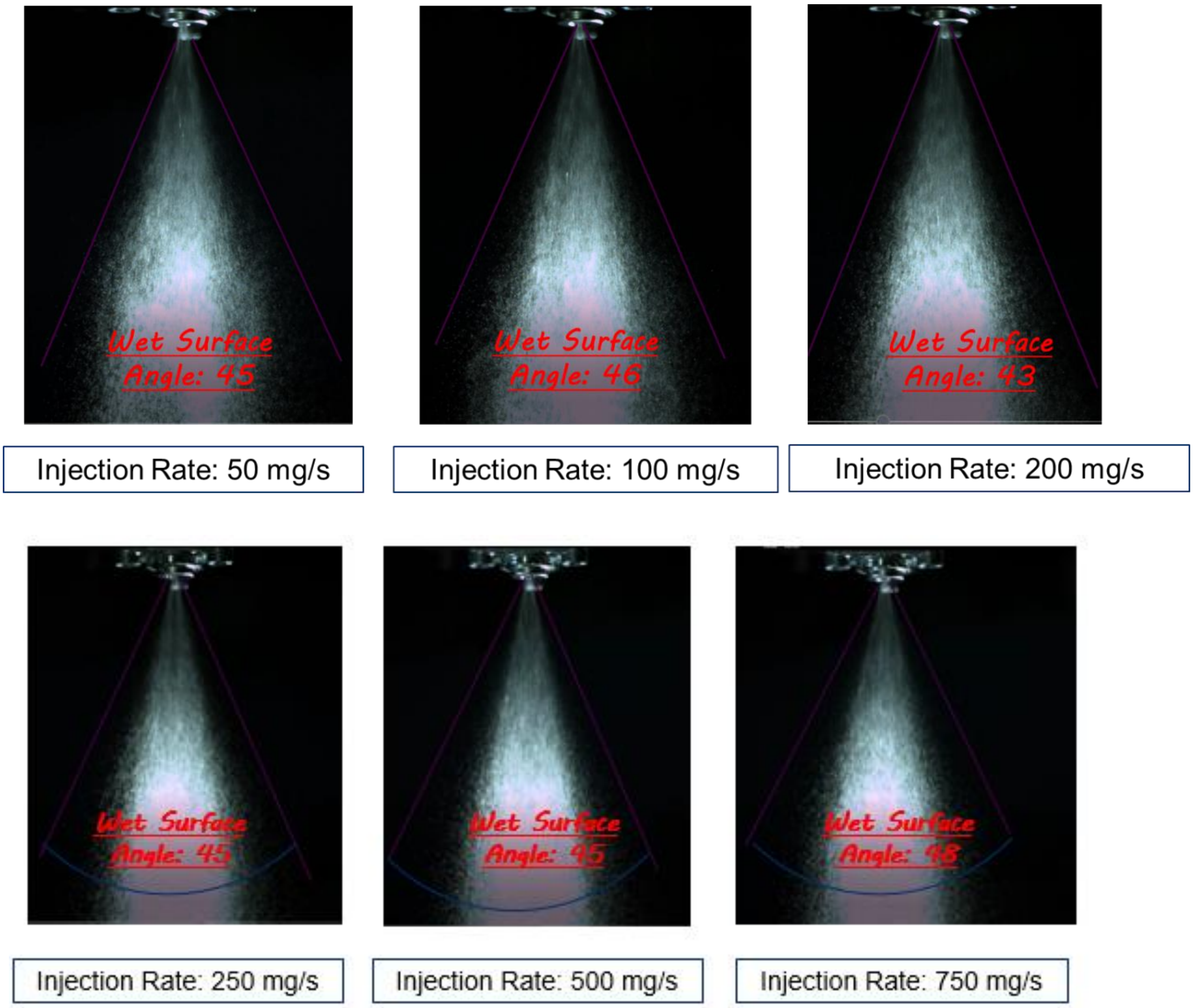


Figure 5. Spray test rig



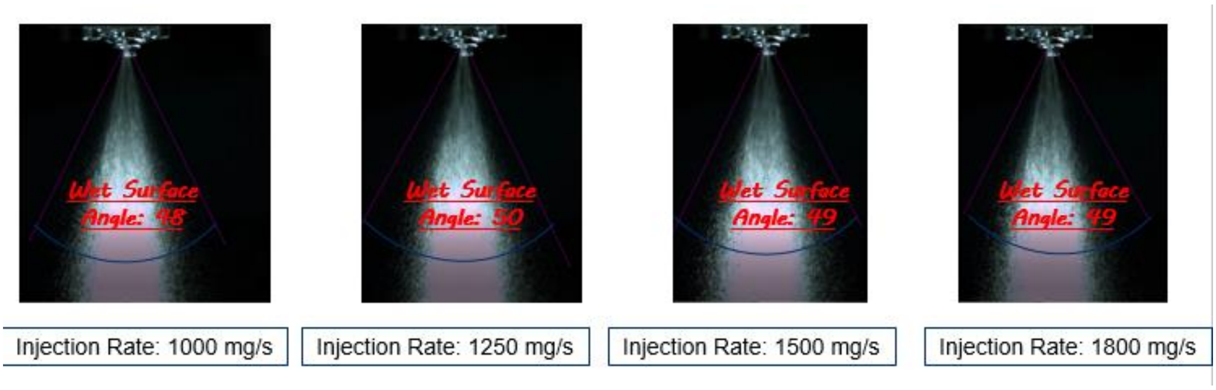


Figure 6. Spray characteristics of the test Adblue injector

Injection characteristics of the commercial injector is also tested. For a test of 0.4 s spray impingement and the wet surface area is visualized.

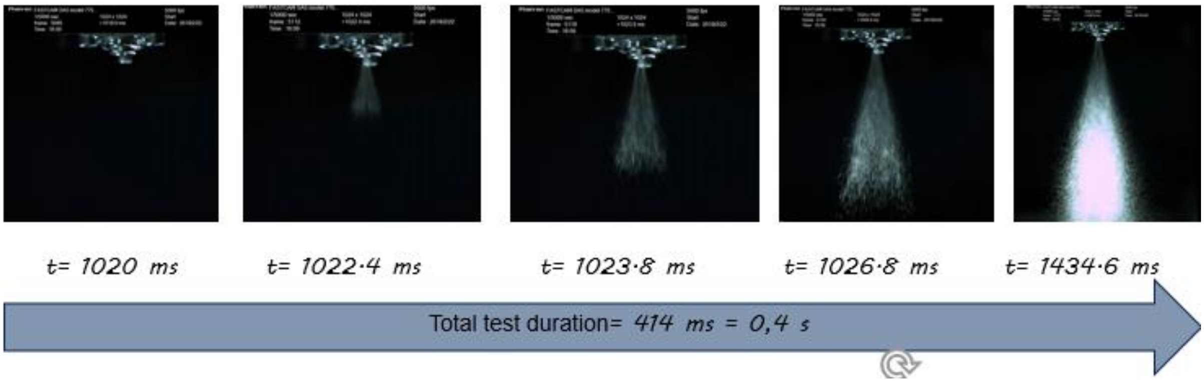
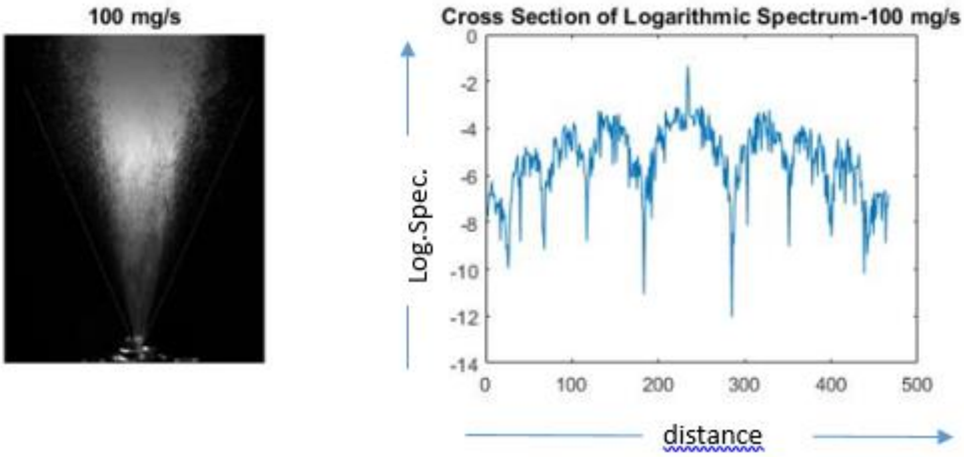


Figure 7. Spray injection time over a test period.

Also, for each test, FFT analysis of spray is done for estimating the degree of uniformity between different tests. For the dosing rates 100 mg/s and 1800 mg/s is given in the below.



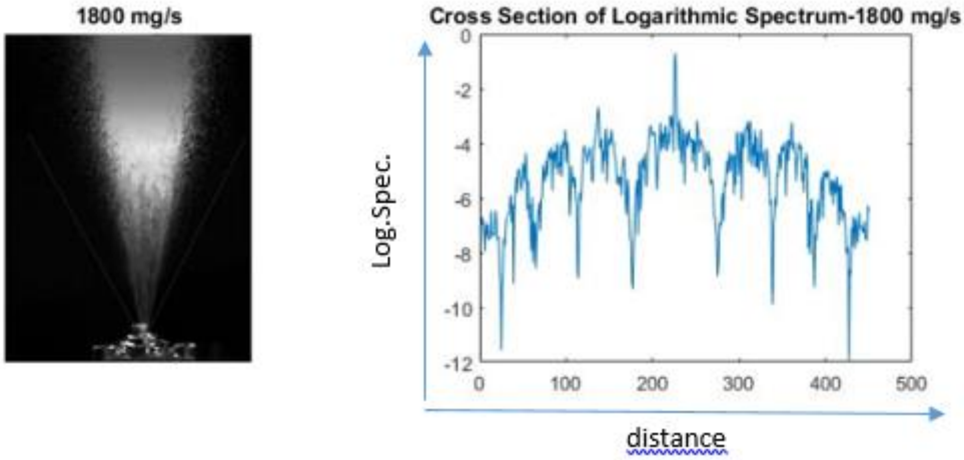


Figure 8. Experimental FFT area of Urea Droplets.

Degree of uniformity_is defined to evaluate the developed droplet distribution within the flow region. To facilitate analysis, a group of specific strips on the processed image are selected as analyzing units. The analyzing unit is regarded as an array of pixel gray values for the convenience of application of FFT (Fast Fourier Transformation).

Test Part-2: Deposit Test

Each tests take 60 minutes and after each test 30 minutes regen is completed. Regen temperature is 650 º C. After each test, both mixer and SDPF is weighted. Marker weight values and after-test weight values are rated for calculating weight difference values. Weight differences gives information about the deposit formation on the part.

Test parts mixer and injector boss is visualized before and after each test. Deposit formation regions and total amount of deposit is analysed for every test.

Figure 9. Images of Mixer and injector boss after the test

Deposit tests are completed for 8 different boundary conditions. For each test, Urea injection flow rate and Air mass flow rate of the system is changed. Mixer weight difference is differs from each other and showed detailly in the figure below:

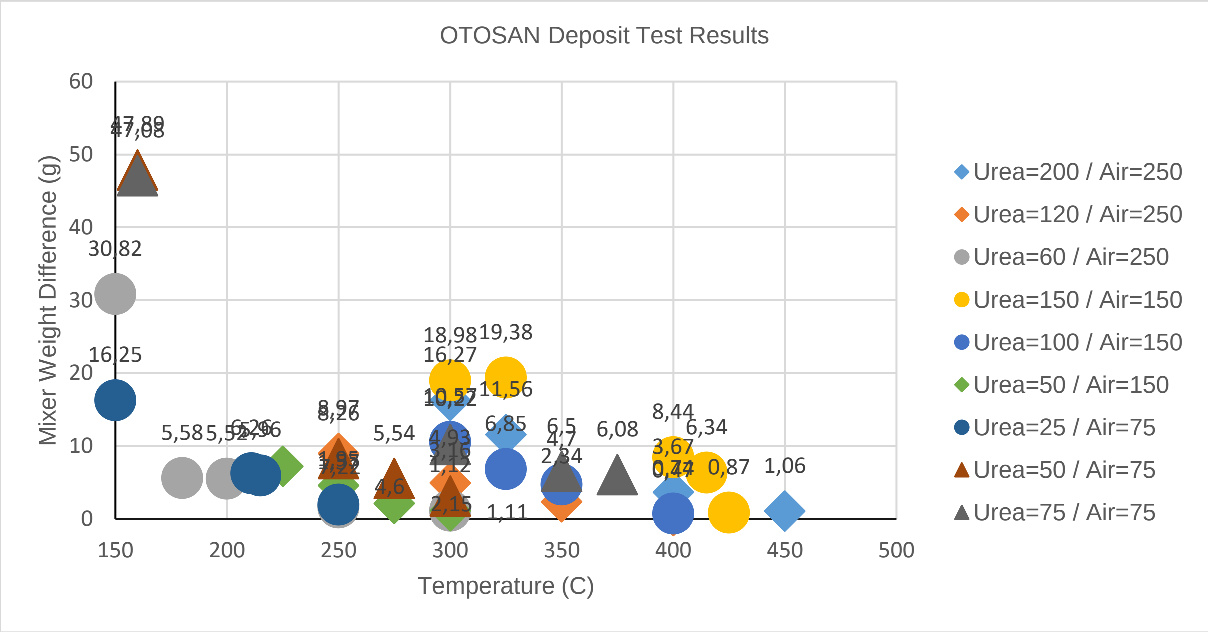


Figure 10. Deposit weight results after the deposit tests

Deposit weights change between 0.5-50 g on the test part. Maximum weights are calculated for minimum temperature values. As temperature increases, deposit amount decreases. Also for the regen process after each test, temperature is 650 C, deposits are cleaned on the test part. So that, as a result, high temperature is a non-deposit limit for exhaust tests.

Conclusions

Deposit test of OTOSAN ATS part is completed in Gölcük Flow Lab for 8 different boundary conditions. Adblue dosing limits, hot gas air flow rate and temperature are the components of the boundary conditions. For the temperature range, 200-450 C is tested. The deposit test show the amount of deposit accumulation are decreased above the 250 degree C. Also, for 450 C deposit weights get minimum values. After each test, deposit amounts are weighted and also visualized for obtaining the localization regions. Commercial 6-hole Adblue injector is used during the tests. The spray impingement and wet surface characteristics are tested in order to see the effect on the deposit formation and localization. Additionally, 10 different spray tests are done for establishing the dosing flow rate effect on the spray-effected area determination. Spray and deposit tests showed that most of the deposit formations are directly related with droplet size, so that experimental FFT diagrams of each test is calculated. After the tests, a new spray-based boundary condition map is created for reducing the deposit limits in the system. As an advanced study, PIV measurement of the same system will be done in Flow Lab facility.

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