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EGZOS SİSTEMLERİNDE DEPOZİT TESTLERİ VE DEPOZİT DOZLAMA HARİTASININ ÇIKARILMASI

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Özet: Bu çalışmada, FORD OTOSAN tarafından tasarlanan egzos sistemlerinin deposit testleri tamamlanmış ve deposit haritalama algoritması geliştirilerek, ideal dozlama değerlerine ait deposit-haritası geliştirilmiştir. Testler, 36 test noktası için koşulmuştur. Testler sonrasında, hesaplanan sonuçlar MATLAB programı kalibrasyon modülü yardımıyla optimize edilmiştirve C++ tabanlı bir kod yardımıyla deposit haritası oluşturulmuştur. Bu harita sayesinde, uygun sozlama kalitesi, ideal sıcaklık değerleri öngörülebilir hale gelmiştir. Harita değerleri girdi olarak kullanılarak, deposit oluşmayan egzos sistemleri elde edilebilir hale gelmiştir.
Anahtar Kelimeler: Depozit oluşumu, SCR sistemleri, depozit testleri, depozit-harita algoritması, depozit haritası.

DEPOSIT TESTING IN EXHAUST SYSTEMS AND DEPOSIT MAPPING STRATEGY

Abstract: In this study, deposit formation tests of a designed exhaust system of FORD is completed, deposit mapping algorithm is created by in-house code and a map of optimum dosing is generated. Tests are repeated for 36 testing points. After the tests, measured data is optimized in MATLAB and with calibration module using a C++ based algorithm, deposit map is created. With the help of deposit map, exact dosing quantity and optimum temperature values can be predicted. By taking the calculated map values in deposit map as input, non-deposit exhaust system can be achieved.
Keywords: Deposit formation, SCR system, deposit testing, deposit-map algorithm, deposit map.

INTRODUCTION

Constantly growing demands on emission control require more efficient ways of taking care of emissions. The aftertreatment techniques introduced to follow the emission legislations require a constant improvement process to comply with the gradually more stringent demands. To meet increasingly stringent emission legislations, selective catalytic reduction (SCR) becomes an essential aftertreatment technique (Geas, 2002). SCR is the system used nowadays to deal with NOx emissions in most heavy-duty vehicles. An aqueous-urea solution, AdBlue, is sprayed into the evaporation unit, where urea should decompose to ammonia, the reducing agent. This is a critical step because the NH3 amount available heavily affects the final nitrous oxides reduction to nitrogen. With a growing concern for environmental problems, engine emission regulations are becoming increasingly stringent (Heuvel, 1998). Using European heavy duty emissions regulations as shown in Figure.

Selective catalytic reduction (SCR) has become the mainstream approach for removing heavy-duty (HD) diesel engine NO_x emissions (Heuvel, 1998). Highly efficient SCR systems are a key enabling technology allowing engines to be calibrated for very high NO_x output with a resultant gain in fuel consumption while still maintaining NO_x emissions compliance. One key to the successful implementation of high efficiency SCR at elevated engine out NO_x levels is the ability to introduce significantly more AdBlue into the exhaust flow while still ensuring complete ammonia production and avoiding the formation of deposit.

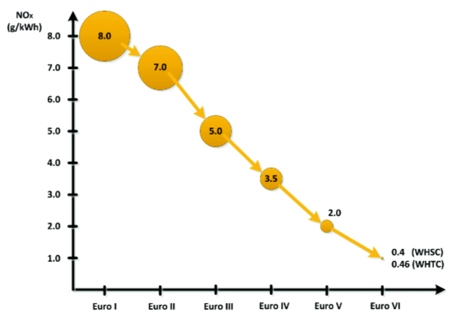

Figure 1. NOx limits of European heavy duty emissions regulations

Deposit is the unwanted output of the SCR system. The collected deposit on SCR system increases the back pressure. Back pressure is defines as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system.

Dosing Technique and Deposit Testing

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). In the first process, the most pure one, AdBlue is directly derived from ammonia/urea production process and has no risks of contamination (Havenith, 1997). 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 used to prevent the deposit formation in diesel engines and technical properties are given in Figure 2.

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

Figure 2. Adblue physical and chemical properties

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) (Amon, 2009). After reaching exhaust, AdBlue is immediately evaporated and urea is decomposed. This process is described by following hydrolysis reaction:

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

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 (Gekas, 2002). 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:

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

$$HNCO + H_2O \rightarrow NH_3 + CO_2$$

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. 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 (Fritz, 1999). 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.

The objective of this study is to show the deposit formation experimentally and numerically model the deposit map and predict the dangerous regions having high deposit risk. Problematic parts for deposit formation such as inejctor, mixer and catalyst is investigated as in Figure 3.

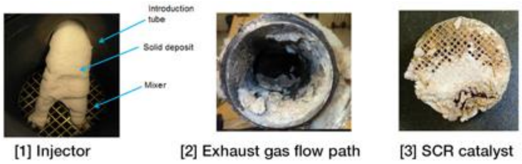

Figure 3. Deposit formation in SCR system

Deposit limits can be calibrated up to limits. These limits are air, dosing and pollutant limited up to the regulations. In every engine fuel economy standards minimize the exhaust gas characteristics. For testing accurate exhaust system, detailed information of the ATS should given. This study produces a map for deposit formation paralel with the test results, so that the flow in the exhaust system can be controlled and optimum deposit limits can be reached.

For that kind of studies, it is important to realize that the SCR system is extremely good at converting NOx, provided it is operated under the right conditions. In particular, if the ammonia storage level on the catalyst is known, if the temperature is in a reasonable window, and if the feedgas Nox concentration is known, it is quite easy to get good NOx conversion. The capability of a control strategy can therefore not be evaluated by comparing NOx conversion over an emissions cycle with known conditions. The difficult requirements of a urea SCR control strategy are to trade off NOx conversion against ammonia slip, and to do so in the face of uncertainity. Among the major noise factors affecting system performance are:

– NH_3 storage;
– NO_x concentration in the feed gas;
– Urea input (injector uncertainty as well as urea concentration);
– Drive cycle;
– Sensor uncertainty.

In this study, with a minimum effected loss, SCR system is tested to get deposit and optimize the tested values in

MATLAB environment and calibrate the values in order to get a map for deposit formation.

Testing Capacity

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.

Before the tests, clean mixer and SDPF is weighted in order to determine marker weight values.

Figure 4. Ford OTOSAN Gölcük Flow Lab..

Each tests take 60 minutes and after each test 30 minutes regen is completed. Regen temperature is 650ºC. 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. 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. 36 tests and 36 regen are completed for this study.

MAPPING METHODOLOGY

An exhaust aftertreatment system can be mathematically modelled using a series of coupled differential equations. Aspects in which can modelled include but are not limited to fluid flow, wave dynamics, heat transfer, material stresses and chemical kinetics.

In order to create the map of the deposit amount on the mixer weight difference, a table with the input and the output data is created.
The table includes the boundary conditions: Urea injected amount, Air of the system for the test condition and the Temperature of the system.

For design a calibration data MBC model of the MATLAB R2016b is used by in-house C++ based code. Model-Based Calibration ToolboxTM from The MathWorks has been used to fully optimize a base-engine calibration to meet cycle-based emissions and fuel economy targets as well as local combustion noise targets and mechanical limits. Multimodels were used to build a collection of local models that behave as global models at the discrete speed/load test points. This facilitates the use of sum constraints to represent drive cycles and gradient constraints to ensure smooth calibration tables.

If a specific uncontrolled, but measurable noise factor is found to be adversely skewing data, more points can be added, and the effect of the noise can be modeled.

The test schedule should be broken into manageable pieces that run for only several hours at a time. In between each batch of testing, a few points should be repeated to verify that something hasn't significantly shifted in the exhaust system. For example, if a leak occurs, careful inspection of the rig stability check points can help find the issue and prevent more questionable data from being acquired. Rerunning common points will also help identify deteriorating performance of the exhaust system.

After all of the data have been recorded, they can be collected into a common file for import into Model-Based Calibration Toolbox. Additional calculations can also be added to the data set if they are needed, but were not available in real time during testing. Obviously, the details of this process step depend on the specific test systems being used.

One-stage model includes Urea injection, exhaust gas temperature, Air of the system, mass flow ratios of Urea and Air, temperature ratios of Urea and exhaust. Deposit is the response of the calibration model.

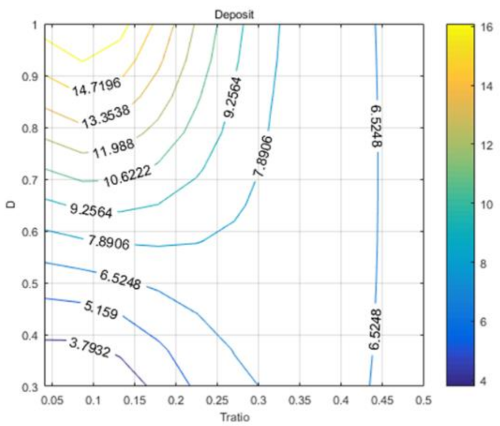

Figure 5. Deposit Map

After data has been imported into Model-Based Calibration Toolbox, models can be built for each of the responses that relate to limits, optimization objectives, or alternate calibration inputs.

A Latin Hypercube Sampled (LHS) DoE form is much more appropriate as it distributes points evenly throughout the calibration space as seen in Figure 6.

The deposit should be mapped in fine increments to verify that there are no unexpected results anywhere in the map. The full load curve can be extracted from the maps at the targeted deposit levels; however, this is a region that is extrapolated as in Figure 6.

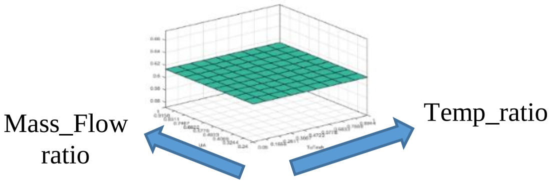

Figure 6. Deposit DOE Model

The most important outcome of the screening DoE is finding the boundaries of after treatment system operation. These boundaries when viewed in the multidimensional space of the input parameters are never really rectangular because the systems interact with each other. Therefore, the structure of the DoE must be set up to find these curved surfaces. If a traditional D-optimal DoE were used, many of the points would fail as these DoEs tend to focus on the rectangular borders of the calibration space. A Latin Hypercube Sampled (LHS) DoE form is much more appropriate as it distributes points evenly throughout the calibration space.

The final form of the deposit map is as seen in Figure-7. Axis of the graph is labeled as ratio in order to see the differential growth. D is the ratio of mass flow rates (Urea/Air). T_{ratio} labels the ratio of temperatures of Urea and Air.

$$D = \frac{Mass\ Flow\ Urea}{Mass\ Flow\ Air}$$

$$T_{ratio} = \frac{Temperature\ of\ Urea}{Temperature\ of\ Air}$$

The output of the test is defined as a ratio of 2 components in order to see the improvement. D means the ratio of mass flow rates of Urea and Air.

T_{ratio} illustrates the ratio of temperature of Urea and Air. D-T_{ratio} is plotted in the figure below to show the dangerous zones for deposit formation risk. Deposit weights higher for high T_{ratio} values. This results gives the information for Air Temperature limits. If the air temperature is high deposit is low.

Also, for high air values, high deposit zones are formed. Minimum deposit is seen for lower injection levels at minimum air values.

Figure 7 gives information about the restricted areas for urea dosing process. Deposit weights on the Figure 7 is given in gram. Figure on right in also shows the restricted zones for Air and temperature of the system. Between Air 120-210 kg/hr there is a high deposit zone. Air below 120 kg/hr is safe and forms less deposit according to Figure 5.

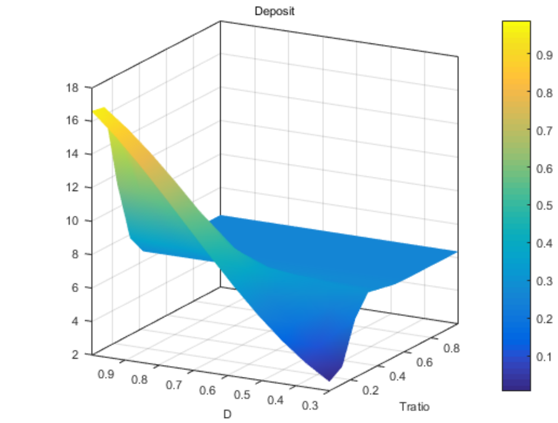

Figure 7. Deposit Map

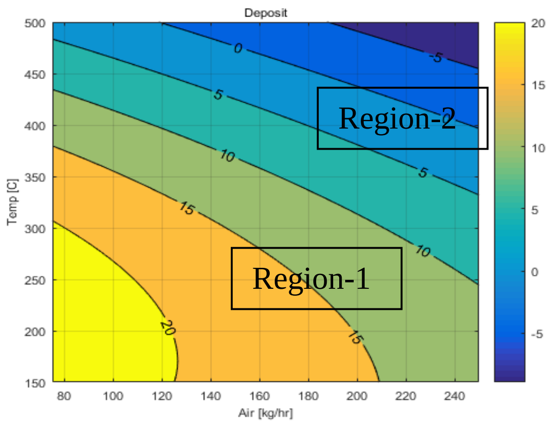

Figure 8. Contour plots of Deposit

Another visualization form of deposit map is as shown in Figure 8. This form of deposit mapping is more understandable than Figure 7. Restricted areas are clear and shown on map in Region-1. As seen, low temperature and low dosing performs high deposit. Also, high dosing and low temperature collects more deposit.

Minimum deposit areas are collapsed on Region-2. For high temperature and low dosing, minimum deposit formed and also, high dosing and high temperature is ideal for low deposit formation.

CONCLUSION

36 deposit tests are completed for different boundary conditions in Ford OTOSAN Gölcük Flow Performance and Durability Laboratory. After each test 36 regen is completed for SCR cleaning process. After each test mixer and SDPF weight difference is investigated. With the help of weight difference data, deposit formation algorithm is generated. Deposit algorithm includes dosing quantity, temperature and deposit weights. This code is the key point of deposit map. A Deposit map is created for those 36 test by using this algorithm. Deposit map gives information about the no-deposit zones,

restricted boundary conditions for more deposit formation etc. By using that map, calibration data of the SCR system can be formed. Deposit map also allows the test people, without making more test, some boundary conditions can be predicted. It gives time and cost reduction for the testing labs.

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