THE NECESSITY OF FRAGMENTING ADBLUE DROPLETS IN SCR SYSTEMS

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Abstract: *The primary goal of this research is to explore and contribute towards achieving the objectives set by the European Commission for the Euro 7 emission standards. These objectives focus on reducing the maximum permissible limits for nitrogen oxides (NOx) and carbon monoxide (CO) emissions to levels of 60 mg/km for NOx and 500 mg/km for CO, applicable regardless of the engine type, whether diesel or gasoline. The present study specifically addresses the role of AdBlue droplet fragmentation in diesel engines and its impact on the reduction of NOx emissions. Additionally, the efficiency of advanced fragmentation methods, such as the use of piezoelectric generators, and their effect on decreasing NOx emissions will be examined. Meeting the Euro 7 standards necessitates detailed and innovative analyses regarding the optimization of fuel jet fragmentation to maximize the efficiency of the NOx reduction process.*

Keywords: *AdBlue, Jet Fragmentation, Piezoelectric Effect, Nitrogen Emissions, SCR Catalyst*

1. The process of reducing nitrogen oxides (NOx) emissions in vehicles equipped with diesel engines

Considering the objectives of the European Union, the primary focus of this scientific study is on the development and assessment of an innovative system aimed at optimizing the process of reducing nitrogen oxides (NOx) emissions in vehicles equipped with diesel engines. This system aims to improve the mixing and distribution of AdBlue solution in the piping preceding the SCR catalyst, with the goal of preventing the formation of solid deposits and maximizing the efficiency of NOx conversion, both during cold starts and during short-distance travel.

1.1. The necessity of fragmenting AdBlue droplets in SCR systems

Fragmentation of AdBlue droplets in the exhaust gas flow is essential for improving the efficiency of the emission reduction process in diesel vehicles equipped with Selective Catalytic Reduction (SCR) systems. AdBlue, primarily composed of high-purity urea dissolved in demineralized water, is used in SCR systems to convert nitrogen oxides (NOx) in exhaust gases into nitrogen (N2) and water (H2O), which are harmless to the environment. The NOx reduction process in SCR involves a chemical reaction between NOx and the urea in AdBlue to produce nitrogen and water. For this reaction to be efficient, AdBlue droplets need to be uniformly distributed in the exhaust gas flow. This is achieved by fragmenting the AdBlue droplets into smaller particles, which can better disperse in the exhaust gases, ensuring a more complete interaction with the nitrogen oxides.

The dispersion and fragmentation of the AdBlue solution contribute to the enhancement of the pseudosublimation process that occurs instantaneously in SCR systems. In pseudosublimation, the liquid first transforms into vapors, and then the vapors directly transition into a solid state. The methods of injecting the AdBlue solution into the exhaust piping of internal combustion engines vary depending on the configuration of the SCR system and its intended application (trucks, ships, generators, factories, etc.), [1], [2], [4].

The techniques for dispersing AdBlue include:

- Injection through a nozzle,
- Primary fragmentation (dispersion),
- Secondary fragmentation.

The characteristics of the resulting jet and dispersion method [3] are influenced by:

- The internal geometry of the injection nozzle,
- The injection pressure of the solution,
- Pressure and temperature levels within the exhaust piping.

A schematic diagram governing the NOx conversion process in the case of AdBlue injection is presented in Figure 1. It illustrates how the interaction between the exhaust gases and the AdBlue solution occurs, resulting in the thermal and mass transfer of the particles, which experience their transition from the liquid to the gaseous state through the process of vaporization. The five regions of the dispersed AdBlue jet can be identified, as well as the details of the disintegration process.

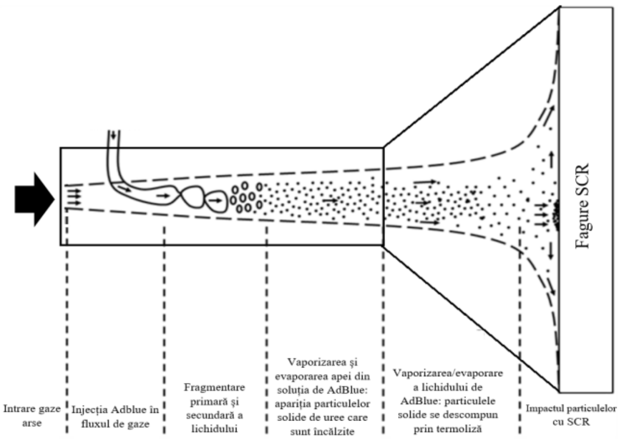

Figure 1: *The interaction between exhaust gases and the AdBlue solution containing a dense particle layer in a spraying process.*

In the first region, the entry of exhaust gases can be observed at a transient nature of flow rate and temperature. In the second section, the injection of AdBlue into the gas flow occurs. The third section is where primary and secondary fragmentation or dispersion of the substance jet takes place. There is a vaporization of the jet, followed by the evaporation of water and consequently the appearance of solid urea particles (the pseudosublimation phenomenon). These are heated up to region five, where the decomposition of the solid particles occurs through thermolysis. In the last region, an area represented by the SCR honeycomb, highlights the impact of the decomposed substance particles, which subsequently undergo a chemical conversion through catalysis. To avoid residual deposits, precise fragmentation and dispersion are necessary. The evolution and growth of AdBlue crystals are due to the thermal process and conditioned by as precise atomization as possible. Defective injection or under unfavorable conditions can lead to an increased quantitative impact of the substance on the surface of the piping, which also highlights the study of the liquid film.

2. Contributions to the addition of AdBlue in SCR systems for the improvement of nitrogen oxides

A schematic diagram is presented in figure 2 according to [5], representing the configuration implemented in laboratory tests to study the intensification of heat transfer and implicitly the optimization of NOx conversion for the implementation of the principle in SCR systems.

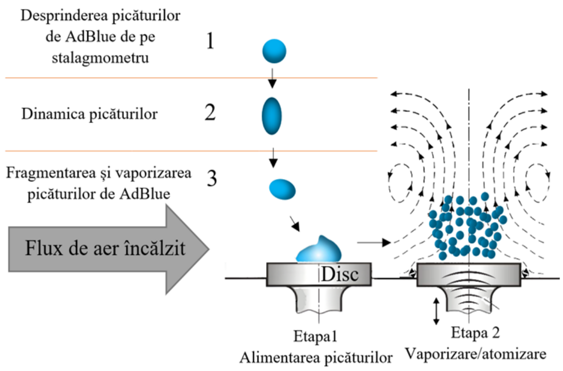

Figure 2: *Schematic diagram of the experimental process.*

Phase 1 of the process begins with the detachment of an AdBlue droplet from the stalagmometer. Initially, the droplet falls perpendicularly onto the surface of the disk, as its dynamics are solely influenced by gravity. Subsequently, the droplet follows a slightly curved trajectory, being influenced by both gravity and the flow of heated air. Once the droplet reaches the heated surface, it undergoes a "bursting" phenomenon and fragments into smaller droplets.

Phase 2 of the process involves the intensification of the fragmentation phenomenon under the influence of ultrasonic vibrations. This leads to the formation of atomized spherical nano-droplets of AdBlue that spread across the entire surface of the disk, thus facilitating the process of vaporization and the transfer of mass and heat.

Among the key aspects in this field is the efficient heating and vaporization of AdBlue before entering the catalyst, particularly during the engine's transitional heating period until it reaches the operating temperature. In current configurations, AdBlue is injected into modern diesel engines' exhaust galleries before the SCR systems, for the elimination of pollutants and neutralization of NOx.

Vaporization occurs in both volume and on surfaces, with the latter studying the influence of vaporization in an ultrasonic field.

In practice, AdBlue consists of 32.5% urea and 67.5% water, so when the water evaporates, the urea tends to crystallize and causes deposits on the walls of the exhaust system and at the entrance to the microchannels of the SCR system, hindering their proper functioning and performance.

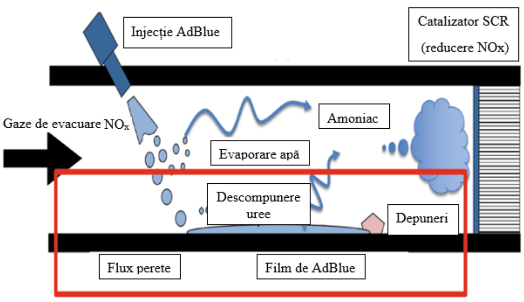

Figure 3: *The Phenomena Occurring Before the Catalyst (SCR).*

Figure 3 illustrates the phenomena occurring around the AdBlue injection system. This work aims to find solutions for reducing urea crystallization [5], particularly in the microchannels of the SCR system, using a process that utilizes ultrasound. Also, the effect of vibrations on crystal deposits during the evaporation of atomized AdBlue droplets in a high-temperature gaseous environment and upon direct contact with a heated disk is being investigated. The mechanism of the crystallization process and the microscopic deposition of the formed crystals are examined in detail, both in the presence and absence of vibrations. The characteristics of the formed crystals and their rate of development depend on the working temperature of the gaseous medium, which can be controlled through efficient preheating methods, immediately after starting the engine, until the operating temperature is reached. The use of this method contributes to avoiding deposits of isocyanic acid, biuret, for example, on SCR system components, directly impacting the performance and durability of the SCR catalyst.

3. Contributions regarding the AdBlue injection method on a piezoelectric concentrator

The detailed description of the vaporization system for the AdBlue solution, equipped with a piezoelectric element and injector, is illustrated in Figure 4. In this system, the exhaust gases, indicated as number 1, are initially directed towards the Particle Filtering Device (DPF) and the Diesel Oxidation Catalyst (DOC), marked in the diagram as number 2. After passing through these components, the gases are then redirected to the pseudosublimation area, marked as number 4. In this region, the injection process of the AdBlue solution takes place, facilitated by the injector identified as number 3. This system is designed to ensure an efficient and optimized distribution of the AdBlue solution in the exhaust gas flow, thus contributing to the efficient reduction of NOx emissions through the selective catalytic reduction process.

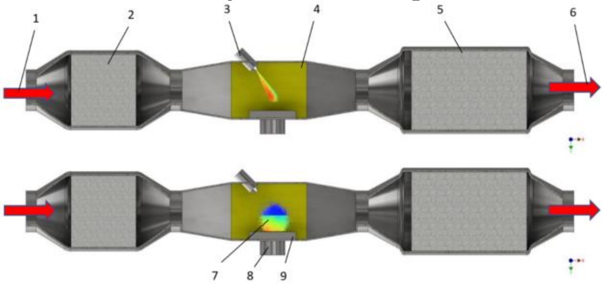

Figure 4: *The structural solution of the SCR system with piezoelectric element*

The AdBlue solution injection process is characterized by the fact that it is introduced into the exhaust gas flow at a higher pressure than the gases flowing through the entire system. This procedure ensures that the AdBlue solution reaches the surface of the piezoelectric element, numbered 8. At the top of this element, there is an attached disc, and as a result of the pressure difference, an instantaneous fragmentation of the AdBlue solution, indicated by the number 7, occurs.

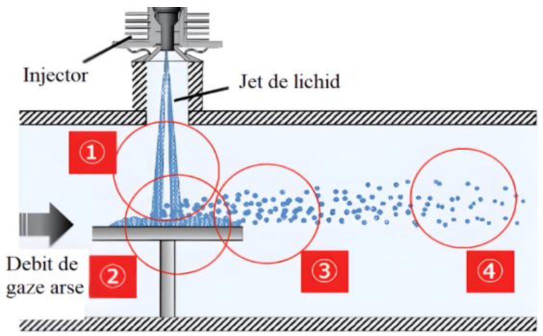

Figure 5: *The phenomena occurring and the dispersion mode of the injector and piezoelectric element configuration.*

The liquid jet injection process (figure 5) [5], in this case involving AdBlue, begins at moment 1, when the jet is introduced into the exhaust gas flow by the dedicated AdBlue injector. The liquid jet moves towards the surface of the piezoelectric element, marking phase 2 of the process. This initial interaction is influenced by the flow rate of the exhaust gases, which creates an initial fragmentation of the AdBlue jet.

The fragmentation of the jet is further enhanced in phase 3 of the process, due to the vibrations generated by the piezoelectric element.

Phase 4 represents the outcome of the combination of the two previous interactions. In this phase, the fragmented AdBlue droplets undergo diffusion and thinning in the flow of burnt gases. This process leads to an increased contact between the AdBlue droplets and the combustion gases, which ultimately contributes to the improvement of mass and thermal transfer. These complex stages of fragmentation and diffusion are essential for the efficiency of the Selective Catalytic Reduction (SCR) process through the uniform distribution of the AdBlue solution in the exhaust gas flow.

4. Results

Figure 8 represents the results obtained during laboratory tests [5], in which the functionality of the atomization device with a piezoelectric element was evaluated. These tests could include information on the uniformity of liquid spraying, the size of the particles resulting from atomization, and other parameters relevant to the specific application.

Figure 6: *The distribution of AdBlue droplets in the case of an injection system on a piezoelectric element.*

Figure 6 illustrates the initiation moment of the injection process within a system utilizing a piezoelectric element powered by an ultrasonic generator at a frequency of 40 kHz. When the liquid comes into contact with the piezoelectric element, an instantaneous fragmentation occurs, resulting in an immediate increase in the contact surface area with nitrogen oxides (NOx). The analysis is conducted using the MATLAB program (Figure 7), alongside preliminary data from Table 1.

Figure 7: *The distribution of AdBlue droplets in the piezoelectric system*

Table 1: *"Preliminary data obtained.*

Np	Dmedp [μm]	Dmaxp [μm]	SMD [μm]	Ng	Dmedg [μm]	Dmaxg [μm]	Aj [mm^2]
68	21	45	0	1789	150	458	50

Figure 8 illustrates the distribution of particles generated by the piezoelectric system in the presence of a compressed air jet. The process of disintegrating the AdBlue droplets contributes to reducing their diameter, which is situated in a range between 10 and 5 μm. The study conducted [5] has highlighted an increase in the contact surface area with NOx. The examination also included aspects related to the characteristics of the droplets, which are influenced by the presence of a piezoelectric element in the injection system [5]. The data obtained by the Matlab software through Figure 8 are found in Table 2.

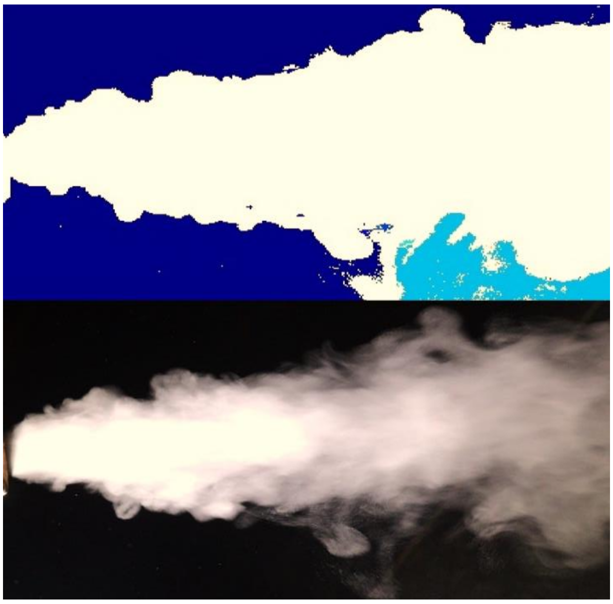

Figure 8: *Distribution of AdBlue droplets in the case of the compressed air.*

Table 2: *The Data Obtained by the Matlab Software.*

Np	Dmedp [μm]	Dmaxp [μm]	SMD [μm]	Ng	Dmedg [μm]	Dmaxg [μm]	Aj [mm^2]
62	11	58	0	1879	243	1500	82

5. Conclusions drawn for the case of the piezoelectric spraying

From the specialized literature, it has been observed that ultrasonic waves have a sound wave propagation speed that is conditioned by the nature of the medium they travel through, allowing them to propagate directionally in a narrow beam. In this case, the wavelength is larger than the distance between the atoms in the molecules of the AdBlue liquid. The application of ultrasonic waves in the atomization process allows for the creation of fine droplets with diameters under 10 μm, with reduced energy consumption.

The atomization process of AdBlue leading to the creation of fine droplets favors efficient vaporization of the liquid before entering the SCR catalyst. Vaporization of the AdBlue liquid amplifies the evaporation of water.

Ultrasonics can be used to prevent or reduce the crystallization of urea in AdBlue by generating mechanical vibrations that simultaneously influence the intensification of the vaporization process. Experiments conducted highlight the fact that atomization of AdBlue with the aid of ultrasonics is a promising technology.

6. References

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