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OPTIMALIZATION OF SORBENT FEEDING IN THE DRY METHOD OF FLUE GAS DESULFURIZATION

Piotr Kwiatkowski
Ryszard Zadrąg

Gdank University of Technology
ul. Narutowicza 11/12, 80-950 Gdańsk, Poland
tel.: +48 510848719
e-mail: piotr.kwiatkowski0902@gmail.com, ryszadra@pg.gda.pl

Abstract

The swiftly developing sea transport contributes to a considerable increase of fuel usage in the international shipping, which results in the escalation of toxic compounds emitted into the atmosphere. It is followed by the constantly heightened requirements limiting those emissions. In the case of sulfur oxide emission, inside of SECA (Sulfur Emission Control Area), the maximum content of sulfur in the shipping fuels used on the territorial seas was reduced to 0.1% per mass unit, but at the same time the legislator allows the ability to use a desulfurization installation working in a closed configuration. One of the desulfurization methods fulfilling those requirements is the dry method of desulfurization. In this paper are presented the results of research conducted on this very topic in the Department of Marine and Land Power Plants. The focus is the presentation of formulated characteristics of adsorbent feeding by an injection system dedicated to the dry method.

Keywords: *sulfur oxides, exhaust gas toxicity, exhaust gas desulfurization, dry methods of exhaust gas desulfurization*

1. Introduction

The analysis of the years past shows that sea transport is still dynamically developing, the number of vessels continues to systematically increase, new technologies and technical solutions are being introduced.

Those factors are responsible for getting updated the legal norms concerning the restrictions on the emission of toxic compounds from ship engines. One of the most important legal acts connected to the discussed topic is the MARPOL 73/78 convention, and more specifically a piece of its contents, Annex VI. It defines particular areas as Sulfur Emission Control Areas (SECAs).

Among these areas are the Baltic Sea, North Sea along with Canal La Manche, the area around North America and the Caribbean Sea as well as the areas of some harbors specified by IMO. It also prescribes the maximum content of sulfur in the shipping fuels used by sea vessels, which currently are placed at a 0.1% for ships located in SECAs and up to 3.5% in other areas (fig. 1.)

Meeting these requirements is associated with additional costs that shipowners must bear, and adaptation of the units themselves to the current regulations may take place in several ways:

- replacement of high sulfur fuel with low sulfur diesel fuel oil;
- use of alternative fuels such as LNG, methanol;
- equipping the unit with exhaust after-treatment systems.

The equipment of the unit with devices reducing the emission of sulfur oxides is synonymous with the need to incur investment costs for the reconstruction of the ship and the purchase of this equipment, while we can still use residual fuel. The use of distilled fuel does not require reconstruction of the ship, but it results in a significant increase in the purchase price of fuel, which is associated with very high costs with the intensive use of the ship.

In the case of using alternative fuels, the LNG bunkering facilities in ports are poorly developed, but more and more ports are opting for such installations.

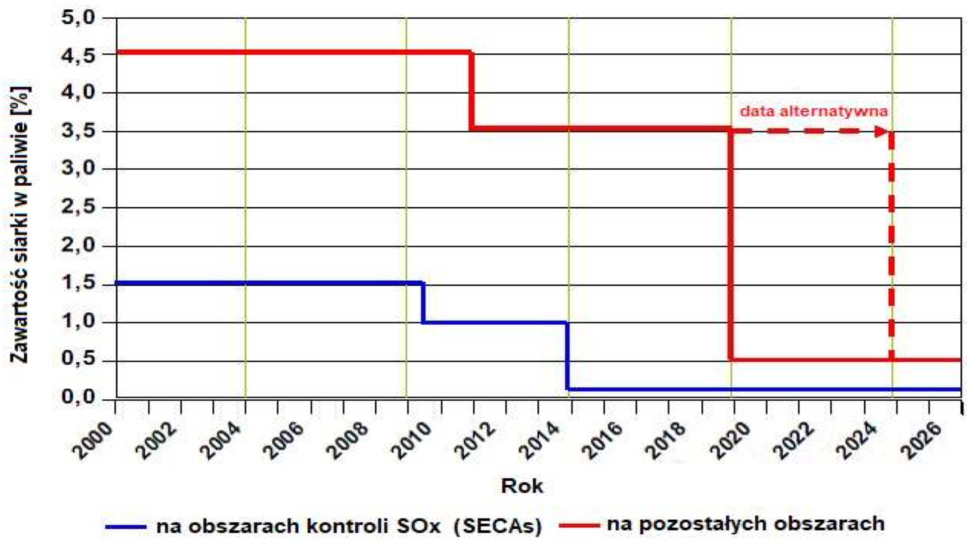


Fig. 1. Permissible percentage of sulfur in fuel [%] for diesel marine engines according to MARPOL 73/78 convention (Annex VI) [3]

2. Dry installations of flue gas desulfurization

One of the flue gas desulfurization systems is a relatively new dry method. Currently, it is used only to a small extent in shipbuilding. Dry processes are carried out by blowing an alkaline adsorbent into the furnace chamber, which reacts with the toxic compounds contained in the exhaust gas (they act on the principle of chemical absorption called chemisorption). Thanks to this process, harmful sulfur oxides are transformed into a stable end product.

The installation in question is equipped with a dry scrubber installed in the exhaust system directly behind the engine, to which toxic fumes move. In addition, many mechanical components such as valves, blowers, pipes or tanks are used in the system (the sorbent must be stored in a dry environment). The system also consists of measuring devices used to control the emission of harmful substances and temperature indicators. The schematic diagram of such an installation is shown in Fig. 2.

The flue gas desulfurization process is as follows: exhaust gases flow into a special jet reactor placed on the flue gas duct, into which a dry adsorbent (solid) is injected, most often placed in the tank above the reactor. Then, the exhaust gas travels through the reactor and finds an adsorbent that retains the solids contained in them and absorbs toxic substances. Finally, the already cleansed exhaust gas flies out of the scrubber and is emitted into the atmosphere, and the used adsorbent is removed in the lower part of the reactor and stored in waste tanks placed under the reactor. The exhaust of units equipped with this system, staying in areas that do not require strict reduction of emissions of sulfur oxides to the atmosphere, can be removed to the atmosphere without having to go through the flue gas desulfurization process, by using a three-way valve.

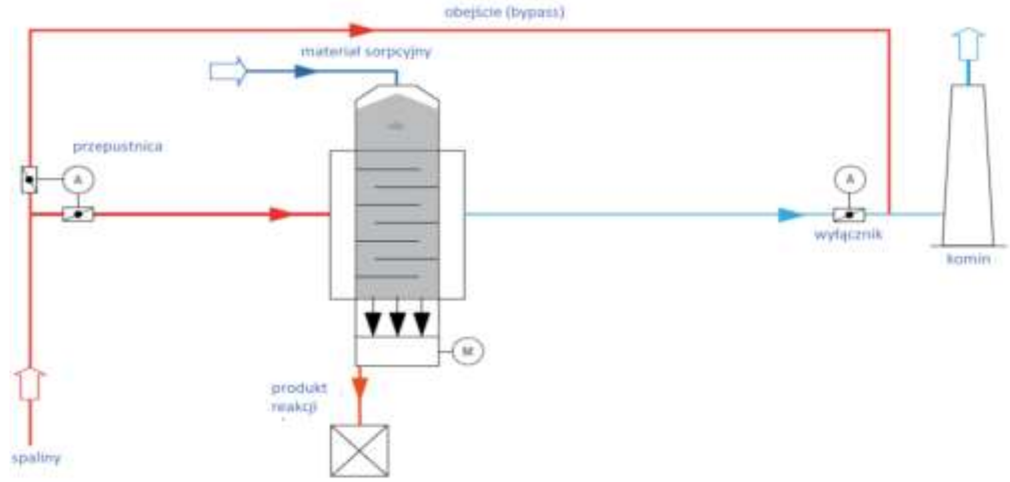


Fig. 2. Schematic diagram of dry flue gas desulfurization installation [4]

3. Development of the characteristics of the adsorbent feeding through the injection system dedicated for the dry method

One of the most important issues, regardless of the desulfurization method used, is the selection of the amount of sulfur oxide reducing agent. In the case of the dry method, it is the amount of adsorbent fed to the engine exhaust system. An equally important problem is also the method of its administration. Thus, for the dry adsorbent delivery system to be efficient, it must be susceptible to control signals. Among the most important of those signals is the injection pressure of the adsorbent, which determines both the quality of atomization and the amount of injected agent. Therefore, the main goal was to develop the characteristics of the adsorbent feed through a dedicated injection system for the dry method.

The characteristics were developed on the basis of empirical studies carried out on a laboratory bench for testing the method of dry sulfur desulphurization of a motor fueled with residual fuel in the Department of Marine and Land Power Plants at the Gdańsk University of Technology. The diagram of the test stand is presented in Fig. 4.

In the reactors used, the function of a fluidized bed reactor was combined with a counter-current to exchange the adsorbent in a fluidized bed. This exchange takes place through the precipitation of reacted sodium bicarbonate on the grate, which is subsequently rotated causing the medium to fall to the bottom of the reactor, and eventually the used adsorbent is removed by drainage. At the same time, a fresh adsorbent will be fed, thanks to the installation of adsorbent feed used in counter-current reactors. This combination positively affects the entire desulfurization process, because it allows continuous reduction of sulfur oxides while refreshing the fluidized bed.

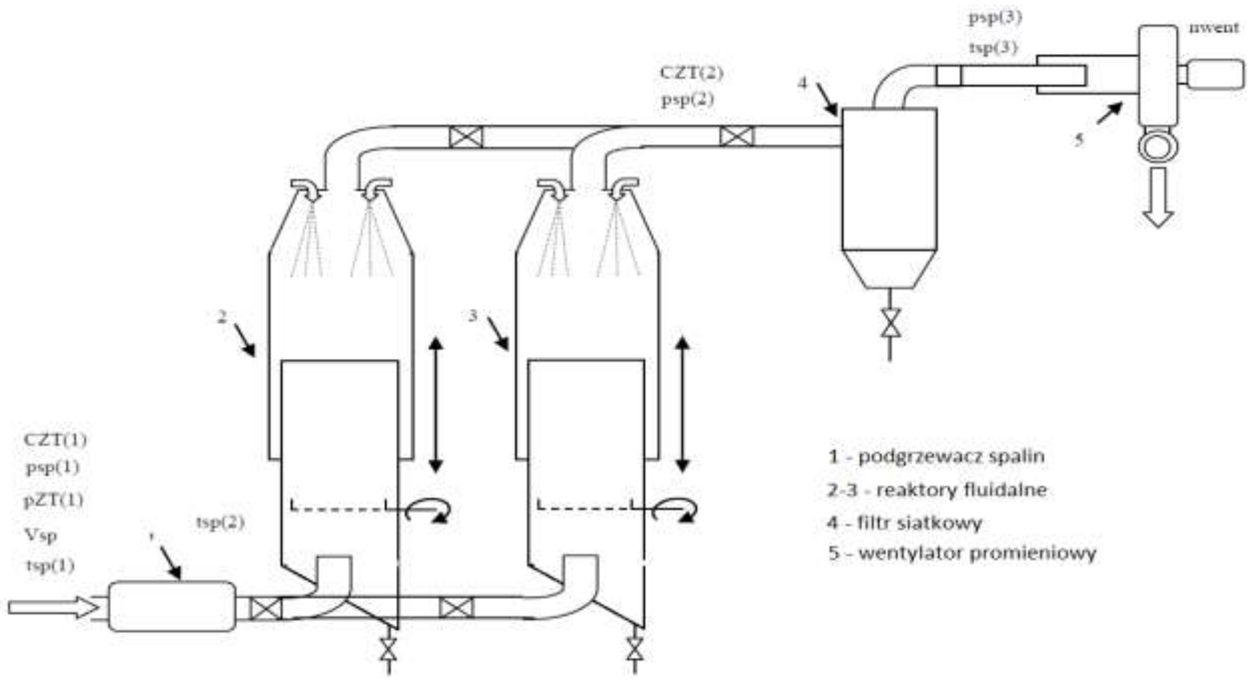


Fig. 4. Scheme of a laboratory test stand for dry flue gas desulfurization [1]

The schematic diagram of the reactor feeding system for the reactor is presented in Fig. 5. The reactant with toxic compounds in exhaust emissions is sodium bicarbonate, with an average granulate diameter of about 140 - 150 µm. The adsorber is supplied to the process reactor in a stream of dry and purified compressed air in an amount of 5 to 15 kg / h (from 1.4 to 4.2 g / s).

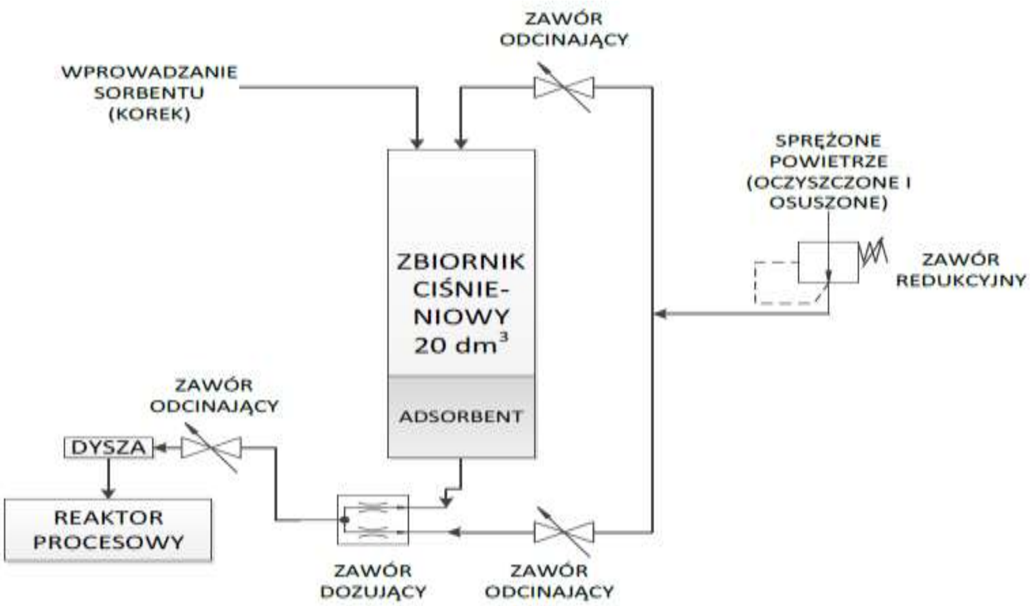


Fig. 5. Schematic diagram of the process reactor feeding system with an adsorbent [2]

The principle of the system operation is as follows: the compressor sucks air from the environment and compresses it to the required pressure (0.8 MPa), then cleansed and dried compressed air is fed into the system where it fulfills two functions: the first - supplying the pressure vessel, and the second - bringing the adsorbent to the nozzle and then to the process reactor. The sodium bicarbonate accumulated in the tank is directed to the dispensing valve, which smoothly adjusts the proportions between the air and the agent in order to optimally select the adsorbent flux.

The solution of the adsorbent supply system created for the needs of the laboratory stand (Figure 5) could not be used for private research related to the determination of the adsorbent injection characteristics due to the lack of control over the amount of injected agent. The main obstacle was the large volume of the pressure vessel used to collect the sodium bicarbonate and the considerable volume of the supply line connecting the control valve with the atomizer placed on the reactor column. Therefore, determining the mass consumption of bicarbonate at its injection into the reactor column would be burdened with a large error, or at least it would be arduous to take measurements. For this reason, a decision was made to conduct a spray test of sodium bicarbonate on other devices where pressure, the dose of compressed air and the dose of adsorbent were adjustable. It was decided to use two spray guns (one with the upper tank, the other with the bottom tank) used in spray painting, which met the requirements in terms of parameters and the diameter of the discharge nozzle.

During the tests, it was decided to use sequential injection for a specified period of time (30 seconds), due to the adsorbent blocking in the spray gun lines. This blocking was caused by the adsorbent structure itself (powder with a low basis weight), changes in its bulk density, and humidity, especially at longer contact with the delivery medium, i.e. compressed air. The sequential injection is one of the ways to achieve the repeatability of the agent's dosing.

The measurements were carried out for the assumed parameters, in all combinations: at three specified pressure settings, three doses of compressed air and twelve dose settings of the adsorbent, which were expressed by the linear dimension of the adjusting screw. The tests were carried out for the following parameters (Table 1):

Tab. 1. Adsorbent feeding settings

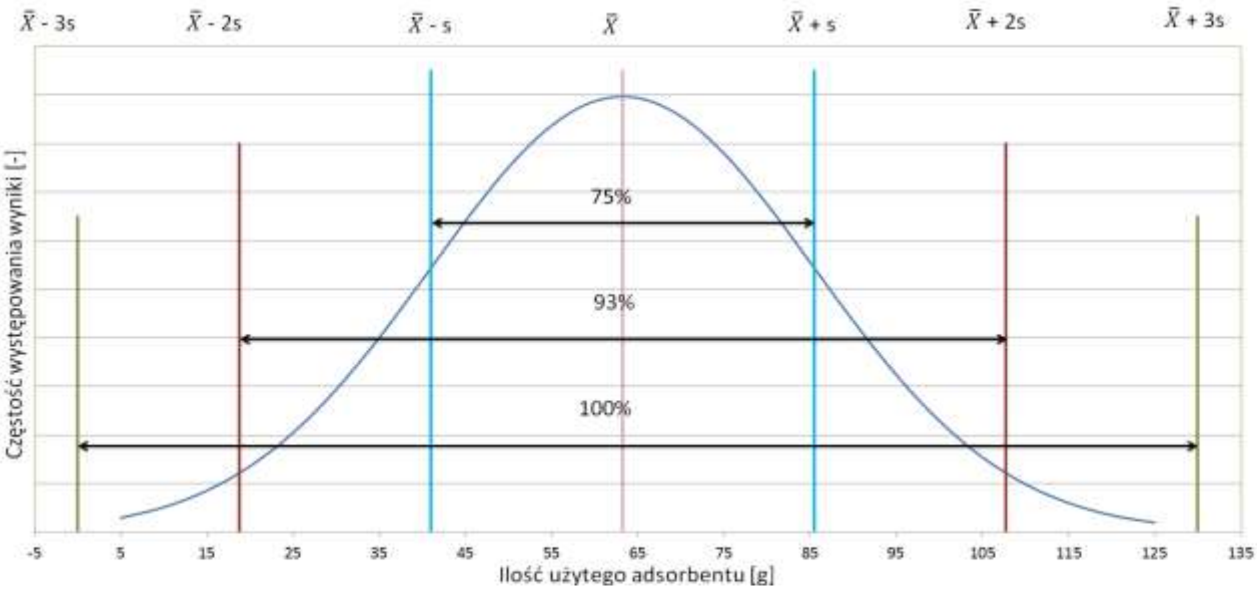
Compressed air pressure [bar]	Dose of compressed air [l / s]	Adsorbent dose adjustment [mm]	
4	2,88	8,04	4,02
		7,37	3,35
5	3,12	6,70	2,68
		6,03	2,01
6	3,36	5,36	1,34
		4,69	0,67

Adjustment of the dose of compressed air and dose settings of the adsorbent were carried out by adjusting the size of the flow channel of these factors in the spray guns. The pressure of the compressed air has been regulated by the use of a pressure regulator.

Already at the outset, the decision was made to abandon the first spray gun model due to the discontinuity of the spray. The focus was on the second model, which was characterized by smoother administration of the agent and relatively high repeatability of the dose of adsorbent ration during injection.

For each combination, the measurements were repeated three times. The flow of the adsorbent flux was then calculated for them and finally the measurement values were averaged for each input parameter setting.

On the basis of the obtained results, deviations from the arithmetic mean of these values were determined and they were presented on the Gaussian curve (Figure 6). It shows that 75% of the measurements are within 45 grams of the used factor, and thus a range was obtained, which can be effectively regulated by the dose of the adsorbent to be administered.



Rys. 6. Deviations of the adsorbent wear results against the background of the Gaussian curie

The characteristics were prepared for all variables settings. Thus, the adsorbent adsorption flow was obtained at a constant pressure, at a constant dose of compressed air and at a constant dose setting of the adsorbent. The next step in the analysis was the selection of functions describing these characteristics.

It was decided to use a polynomial function. In order to select the optimal polynomial degree of flow characteristics, the characteristics for a selected polynomial pressure were set - for a square polynomial and a third-degree polynomial. Then, their deviation errors were determined from the plotted linear function.

This comparison showed that the total sum of these errors is greater when using a square polynomial, and therefore only a third-degree polynomial was used to create further characteristics.

Analysis of the obtained characteristics showed that the highest adsorbent flow, and thus probably the highest efficiency of flue gas desulfurization, is obtained for the compressed air pressure of 5 bar, with its dose setting equal to 2.88 l / s and for setting the adsorbent dose at the level of 5.36 mm pitch of the adjustment screw. The obtained flow for these adjustments is 3.7 g / s and is within the design assumptions for a suitable flow level in the range from 1.4 to 4.2 g / s. Below are presented three characteristics for different constants for the largest received flow (Figure 7-9).

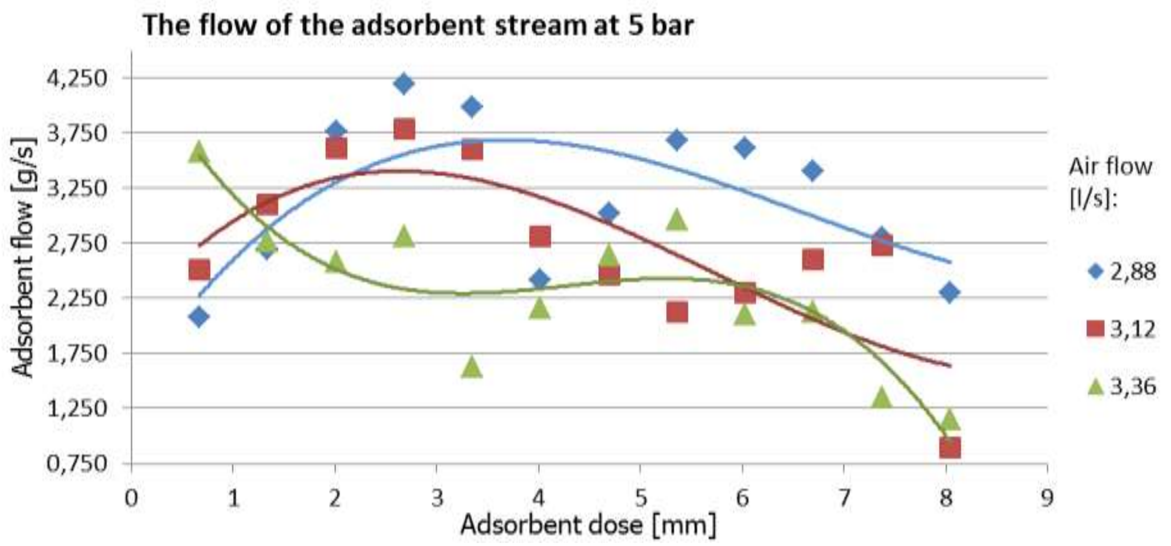


Fig. 7. Characterization of the adsorbent flow at 5 bar

The analysis of the graph (Figure 7) shows that for compressed air flows at the level of 2.88 l / s and 3.12 l / s, its flow increases along with the rise in the adsorbent dose, while the increase for a smaller air stream is greater. After reaching the peak values of the examined function, its gradual decrease occurs. For a compressed air flow of 3.36 l / s, the adsorbent flow behaves unstably.

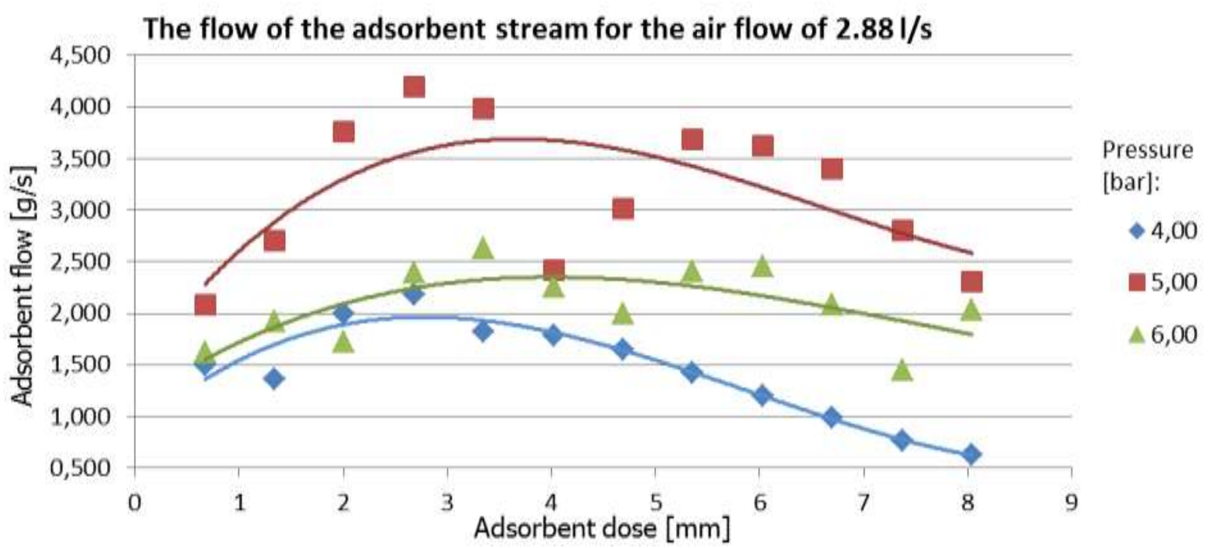


Fig. 8. Flow characteristics of the adsorbent stream for compressed air flow 2.88 l / s

The analysis of the graph (Figure 8) shows that as the adsorbent dose increases, its flow increases gradually until the maximum value is reached. This increase is more intense for 5 bar pressure, in which we achieve the maximum flow in the conducted tests. After reaching this value, the flow characteristics are evenly reduced.

The analysis of the graph (Figure 9) shows that for the pressure of 5 bar and 6 bar, along with the increase of the air flow, the adsorbent flow decreases gradually until the minimum value is reached, after which its visible increase takes place. In turn, for a pressure of 4 bar, the situation is reversed.

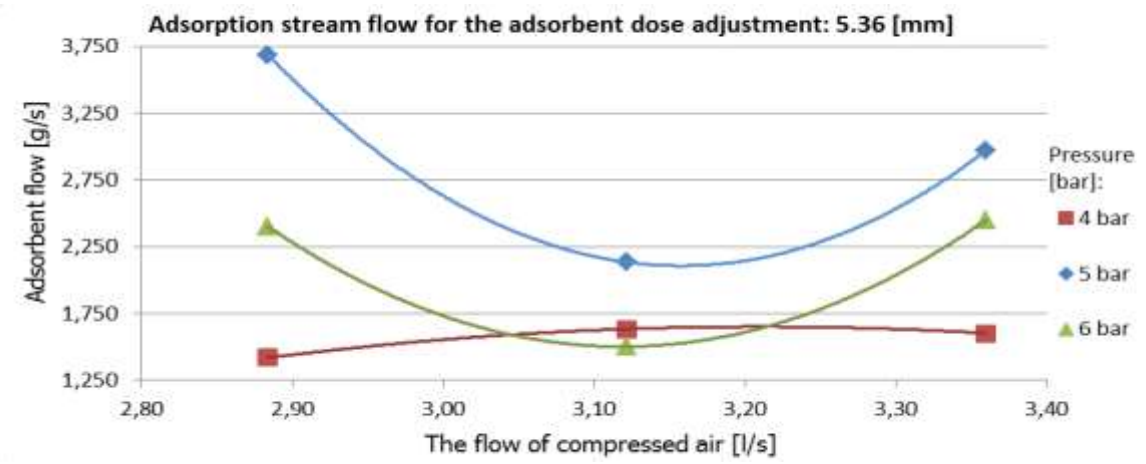


Fig. 9. Flow characteristics of the adsorbent stream for setting the adsorbent dose of 5.36 mm

4. Conclusions

Summarizing the empirical research:

- the largest adsorbent flows obtained at 5 bar;
- in relation to the dose of compressed air, the largest adsorbent flows occur for its dose at the level of 2.88 l / s;
- extreme dose settings of the adsorbent (minimum and maximum) cause a significant decrease in factor flow;
- 16% of results were rejected from the whole pool of tests as they did not fit within the assumed range.

The tests were performed using a sequential injection, which was conducted with appropriate settings for 30 seconds. The abandonment of the continuous adsorbent injection was caused by the blocking of the agent in the spray gun pipes. The injection was carried out manually. It required many hours of monotonous work, based on the constant repetition of the same activity. For this reason, in the future, based on the characteristics created, an automatic injection system can be developed, which enforces sequential clocking. This will allow an obtainment of a constant flow of the adsorbent delivered at regular intervals, which will increase the efficiency of desulfurization of exhaust gases by this method.

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