Analysis of fraction distribution of the water drops stream generated by the spraying nozzles of new KOMAG design

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Analysis of fraction distribution of the water drops stream generated by the spraying nozzles of new KOMAG design

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Abstract. Theoretical backgrounds of airborne dust control with use of atomized stream of liquid are presented. Testing procedure, with a special attention paid to analysis of drops fraction distribution, is presented on the example of new nozzle design developed at KOMAG. The method for calculation of absorption surface is discussed. The test results are used to analyse operational parameters of the nozzle which are important for the dust control systems.

1. Introduction

A precipitation of dust particles with the use of atomized water stream is a commonly known method and it is often used both in the mining industry and other branches of industry. A combination of water drops generated by spraying nozzles with airborne dust particles is the main principle of dust control. There are several mechanisms of combining dust particles with water drops such as [1]:

- inertial,
- catching,
- diffusive.

When combining a water drop with a dust particle, its mass increases, what results in its faster settling on specially installed baffles (Figure 1) [2-4].

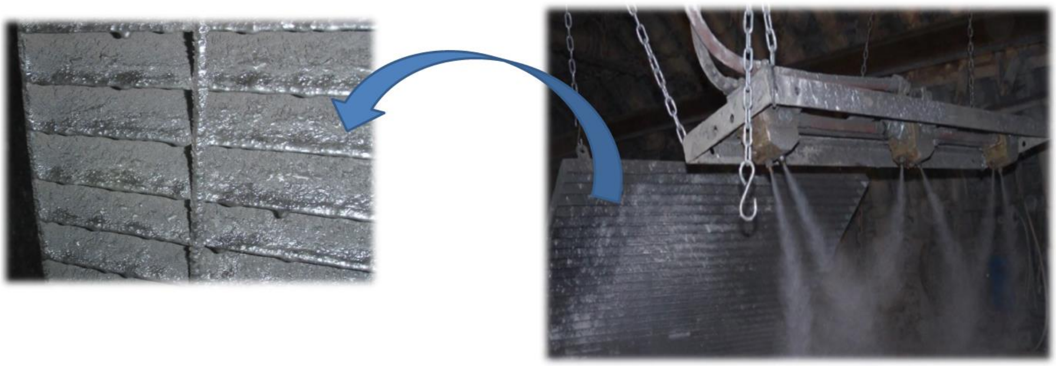


Figure 1. Settling of water drops with dust particles on specially installed baffles [2].

In order to increase the efficiency of combining dust particles with water drops, the area of dust absorption, i.e. the total surface area of all the drops of the spray stream should be maximized without changing their total volume.

An effectiveness assessment of the stream generated for a dust reduction systems should be carried out by analyzing the water drops fractional distribution in the spraying stream. The drops in the sprayed water stream make a typical heterogeneous (polydisperse) system, which is characterized by a large spread of drops diameters. An even larger spread occurs in drops surface areas and their masses. The polydisperse system, which is a sprayed water stream, can be presented graphically in a form of a volumetric distribution curve (volume share) in each range of drops diameters [1, 5-6]. To describe exactly a microstructure of the sprayed liquid, a total number of drops in a representative sample for analysis should be counted, measuring the diameters of the counted drops simultaneously. Then the total range of measured diameters should be divided into a dozen or so or several dozen diameter ranges, depending on the required accuracy and measurement method. Once the drop diameters, their number and volumetric in each interval are known, a quantitative, superficial or volumetric histogram is created. An example of a volumetric histogram is shown in Figure 2. By smoothing the stepped curve, showing the volumetric percentages of drops in individual diameter ranges, a volumetric distribution curve of drops with determined diameters can be obtained.

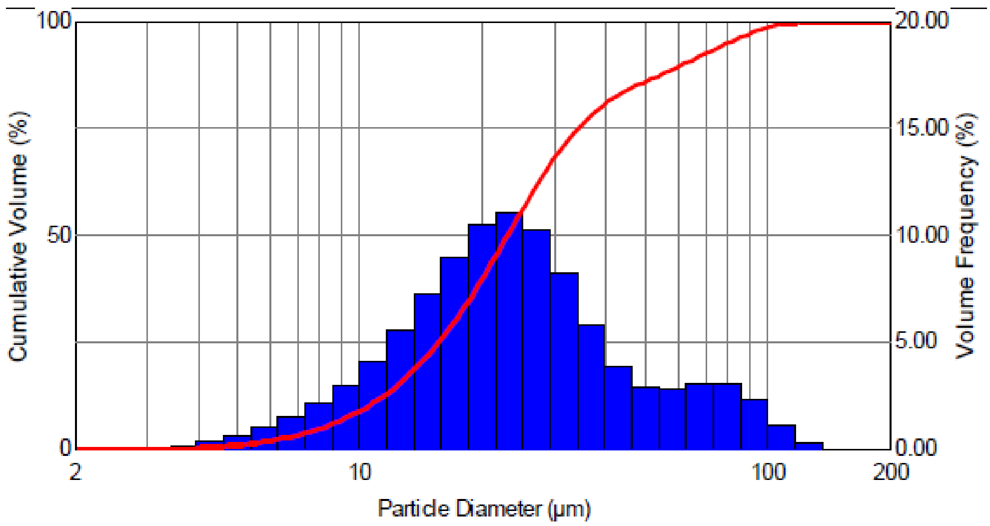


Figure 2. Exemplary of volumetric share of drops in each diameter range and the cumulative curve [1].

Due to a differentiation of drop sizes, it is necessary to characterize a taken drop sample by equivalent diameters. The equivalent diameter is an apparent quantity, which is characterized by a set of identical drops in place of the real drop population. The mean diameter, depending on the method of its calculation, determines the property of a set of drops such as: number, diameter, surface area and volume and it is a pictorial quantity used to assess a dispersion quality [5-7]. Due to a destination of the developed nozzle solution, i.e. dust control, in the part concerning an analysis of the test results, the D32 Sauter volumetric-superficial equivalent diameter was used. This diameter is the diameter of equivalent homogeneous set with the same total volume and the same total surface area of all the drops as in the real set (Figure 3) [5-7].

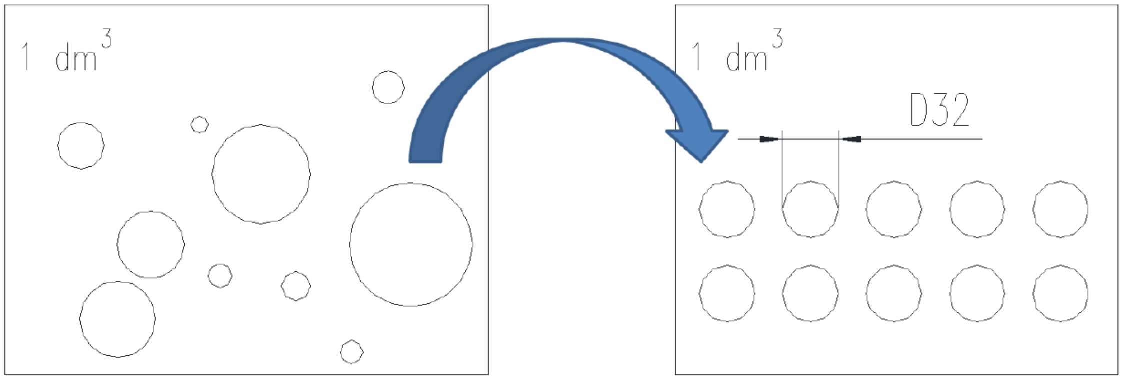


Figure 3. Illustration of Sauter's diameter definition [own report]

2. Absorption surface area calculation method

Knowing the Sauter's D32 equivalent diameter and the flow rate of media feeding the spray nozzle, we are able to calculate the total surface area of generated drops. In all the calculations, it is assumed that a drop has the shape of an ideal sphere whose surface area and volume is calculated from the following formula (2.1):

$$P_k = 4\pi \cdot r^3 \tag{2.1}$$

where:
P_k - surface area of a single drop, m^2,
r - drop radius (0.5 of D32 Sauter's diameter), m.

In turn, the volume of drops of D32 Sauter's diameter is calculated from the following formula (2.2):

$$V_k = \frac{4}{3}\pi \cdot r^3 \tag{2.2}$$

where:
V_k - volume of a single drop, m^3,
r - drop radius (0.5 of D32 Sauter's diameter), m.

A generated absorption surface area can be determined for a unit of time or spraying media flow rate. In the paper [8] authors suggested the following three variants of the parameter describing the spraying stream in form of absorption surface area of generated drops:

- **PA/T** - Absorption surface area of all the water drops in the spraying stream generated over time T equal to 1 min.
- **PA/W -** Absorption surface area of all the drops in the spraying stream generated at spraying of 1 dm^3 of water.
- **PA/P -** Absorption surface of all the drops in the spraying stream generated while using 1 Nm^3 of air.

Knowing the volumetric flow rate of water in the water pipeline feeding the nozzle Q_w and the volume of a single water drop according to the Sauter's equivalent diameter, we are able to calculate the equivalent number of all the drops in the spraying stream generated in a given time unit (min). The number of drops n_t is calculated from the following formula:

$$n_t = \frac{Q_w}{V_k} \quad (2.3)$$

where:
n_t - equivalent number of drops generated within 1 min,
Q_w - water flow rate, $\frac{\mathrm{m}^3}{\mathrm{min}}$,
V_k - volume of a single water drop, m^3.
The total absorption surface area generated by a nozzle during 1 minute is calculated from the formula:

$$PA/T = n_t \cdot P_k \quad (2.4)$$

where:

PA/T - absorption surface area generated within 1 min, m^2,

n_t - equivalent number of water drops generated *within 1 min,*

P_k - surface area of a single water *drop,* m^2.

Knowing the volume of a single water drop according to the Sauter's equivalent diameter, we are able to calculate the equivalent number of all the drops n_w in the spraying stream, generated from $1\ dm^3$ of water. The number of drops n_w is calculated from the following formula:

$$n_w = \frac{1\ dm^3}{V_k} \quad (2.5)$$

where:
n_w - equivalent number of water drops generated from $1\ dm^3$ of water,
V_k - volume of a single drop, m^3.
The total absorption surface area generated by a nozzle from 1 dm^3 of water is calculated from the following formula:

$$PA/W = n_w \cdot P_k \quad (2.6)$$

where:
PA/W - absorption surface area generated from 1 dm^3 of water, m^2,
n_w - equivalent number of drops generated from 1 dm^3 of water,
P_k - surface area of a single water drop, m^2.

To calculate the equivalent surface area of all the water drops generated from 1 Nm^3 of air, the time t of nozzle operation, required for using 1 Nm^3 of air, should be specified. It is calculated from the following formula:

$$t = \frac{1\ Nm^3}{Q_p} \quad (2.7)$$

where:
t - time of nozzle operation required for *using* $1\ Nm^3$ of air, min,
Q_w - air flow rate, $\frac{\mathrm{Nm}^3}{\mathrm{min}}$,
The number of equivalent water drops n_p , generated by the nozzle during the time needed for using 1 Nm^3 of air, is calculated from the formula:

$$n_{wp} = t \cdot n_t \quad (2.8)$$

where:
n_p - equivalent number of water drops generated from 1 Nm^3 of air,
t - time of nozzle operation required for using 1 Nm^3 of air, min,
n_t - equivalent number of drops generated within 1 min,

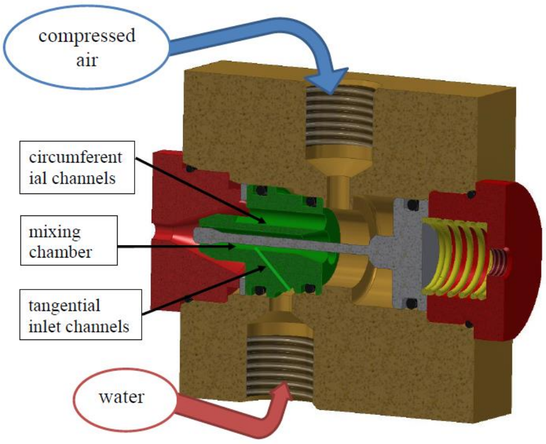
The total absorption surface area of water drops generated by a nozzle from 1 Nm^3 of air, is calculated from the following formula:

$$PA/P = n_p \cdot P_k \tag{2.9}$$

where:
PA/P - absorption surface area generated from 1 Nm^3 of air, m^2,
n_p - equivalent number of water drops generated from 1 Nm^3 of air,
P_k - surface area of a single water drop, m^2.

3. Test of operational parameters of the spraying nozzle designed at KOMAG

Testing the operational parameters of a new design spraying nozzle consisted in a drops fraction distribution analysis as well as in a consumption of spraying media in relation to assumed supply pressure. A self-cleaning DSD type nozzle, presented in Figure 4, was tested.



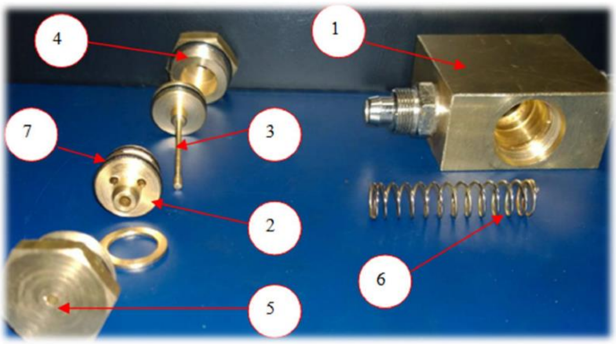


Figure 4. Self-cleaning nozzle components: 1 - connecting body, 2 - internal nozzle, 3 - needle with piston, 4 - outlet sleeve, 5 - plug, 6 - spring, 7 - seals [9].

Tests of operational parameters of the DSD self-cleaning nozzle were conducted according to the accepted testing methodology. They consisted in recording, using the appropriate equipment, the following parameters:

- distribution of drops diameters in the sprayed liquid stream,
- supply pressure and the volumetric air flow rate in the air pipeline, supplying the nozzle,
- supply pressure and the volumetric water flow rate in the water pipeline, supplying the nozzle,

The schematic diagram of the test stand is shown in Figure 5, and Figure 6 shows the view of this stand during the measurements.

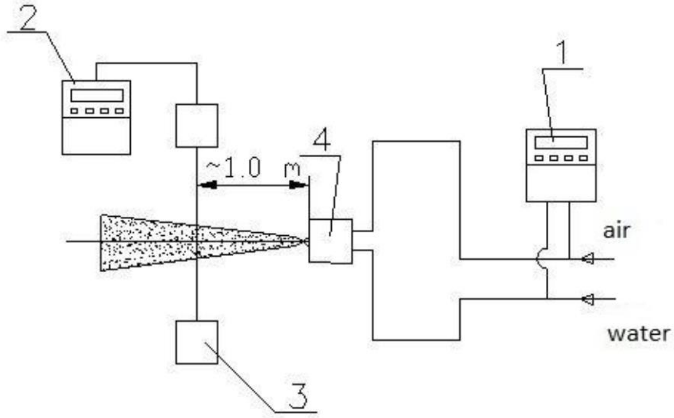


Fig. 5. Test stand (Bałaga, Jaszczuk, 2016; Siegmund, 2017): 1- media measuring system (water and air), 2- recording equipment of drops analyser, 3- drops analyser, 4- air-water nozzle with fixing body.

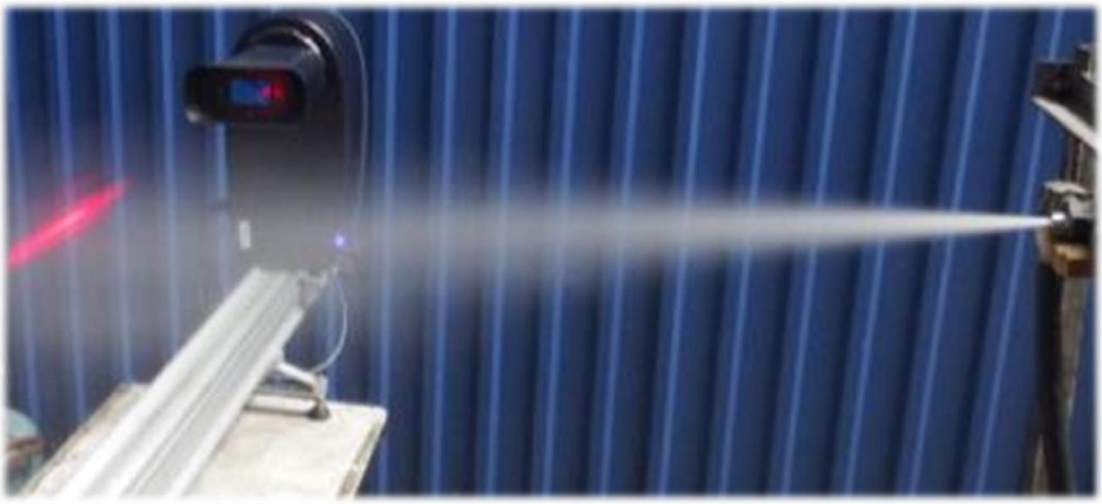


Figure 6. View of the test stand during the measurement of fractional distribution of drops generated by DSD nozzle [9].

In the DSD nozzle tests, measurements were taken for the same water and air pressures, i.e.; 0.3; 0.4; 0.5 and 0.6 MPa. The same pressures of water supply and compressed air resulted from by the nozzle design, which ensured its correct operation only in the case of the same pressure values. The nozzle construction enables its adaptation to a few variants of water supply (by using a different number of water inlet holes). It is also possible to operate a nozzle without a cleaning needle.

The DSD nozzle tests were carried out for the following configurations of mixing chamber supply and outlet cleaning system:

three 0.8 mm dia water inlet holes with a closing needle (nozzle type; DSD - K1),

one 0.8 mm dia water inlet hole, without a closing needle (nozzle type; DSD - K2),

one 0.8 mm dia water inlet hole, with a closing needle (nozzle type; DSD -K3).

The results of testing the spray stream parameters for each K configuration are presented in Table 1. Basing on the measured water and compressed air flowrate as well as D32 Sauter's equivalent diameter, the absorption surface area of the generated spraying stream was calculated.

Table 1. Test results of various self-cleaning nozzle configurations [9].

DSD – K1 - configuration 1- 3x 0.8 mm inlet hole,
DSD – K2 - configuration 2- 1x 0.8 mm inlet hole without the cleaning needle,
DSD –K3 - configuration 3- 1x 0.8 mm inlet hole with the cleaning needle.

Nozzle type	Pressure of supplying media water/air [MPa/MPa]	Water flow rate [dm³/min]	Air flow rate [Nm³/min]	D32 Sauter's diameter [μm]	Absorption surface area PA/T [m²]	Absorption surface area PA/W [m²]	Absorption surface area PA/P [m²]
DSD-K1	**0.3/0.3**	0.32	0.042	43	44.7	139.5	1063.1
	0.4/0.4	0.41	0.062	41	60.0	146.3	967.7
	0.5/0.5	0.5	0.072	41	73.2	146.3	1016.3
	0.6/0.6	0.64	0.081	39.8	96.5	150.8	1191.1
DSD-K2	**0.3/0.3**	0.2	0.072	21	57.1	285.7	793.7
	0.4/0.4	0.22	0.103	19	69.5	315.8	674.5
	0.5/0.5	0.24	0.129	18	80.0	333.3	620.2
	0.6/0.6	0.3	0.181	17	105.9	352.9	585.0
DSD-K3	**0.3/0.3**	0.15	0.059	21	42.9	285.7	726.4
	0.4/0.4	0.2	0.089	18	66.7	333.3	749.1
	0.5/0.5	0.22	0.116	16	82.5	375.0	711.2
	0.6/0.6	0.24	0.144	16	90.0	375.0	625.0

Basing on the data from Table 1, comparative graphs for all the tested DSD self-cleaning nozzle configurations were developed. Figure 7 shows a graph of changes in the water flow rate in relation to the pressure of the supplying media. The volumetric water flow in the nozzle with three water inlet holes configuration was about 2 times larger than the flow for the nozzle with one water inlet hole configuration, irrespective of the cleaning needle installation. It should be noted that its absence has a minor effect on the water flow rate increase in relation to configuration with the cleaning needle.

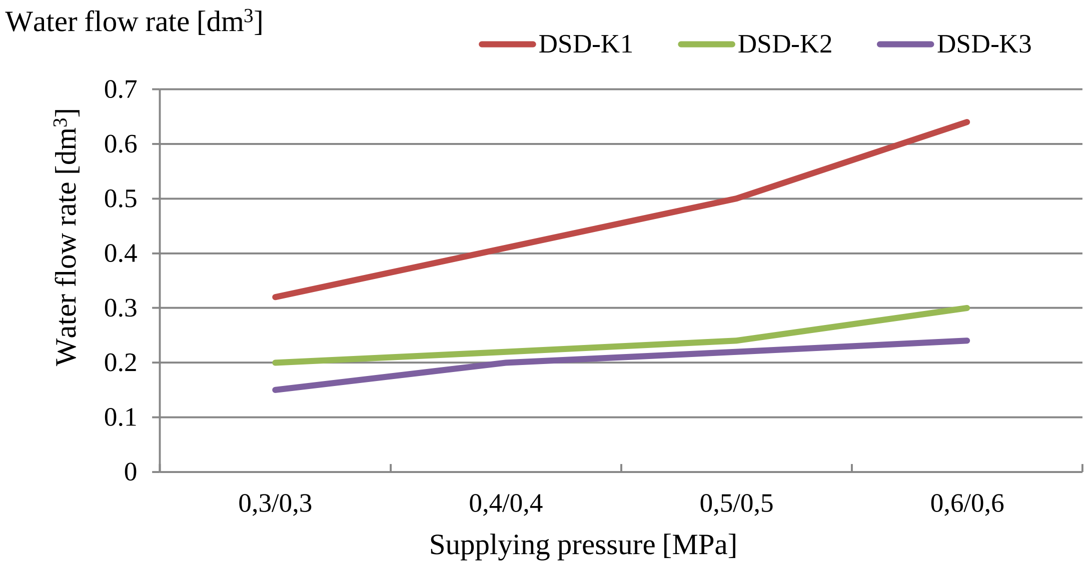


Figure 7. Measurement of fractional distribution of drops diameters [9].

Figure 8 shows a graph of changes in the basic quality parameter of the spraying stream, which is the D32 Sauter's equivalent diameter, in relation to the supplying media pressures. The D32 diameter at the three water inlet holes, for different pressure values, varied between 40 and 45 μm. Supplying water through only 1 inlet hole resulted in a generation of a spraying stream in the range of water unit <20 μm. An impact of the cleaning needle on a fractional distribution of drops in the stream is practically unnoticeable.

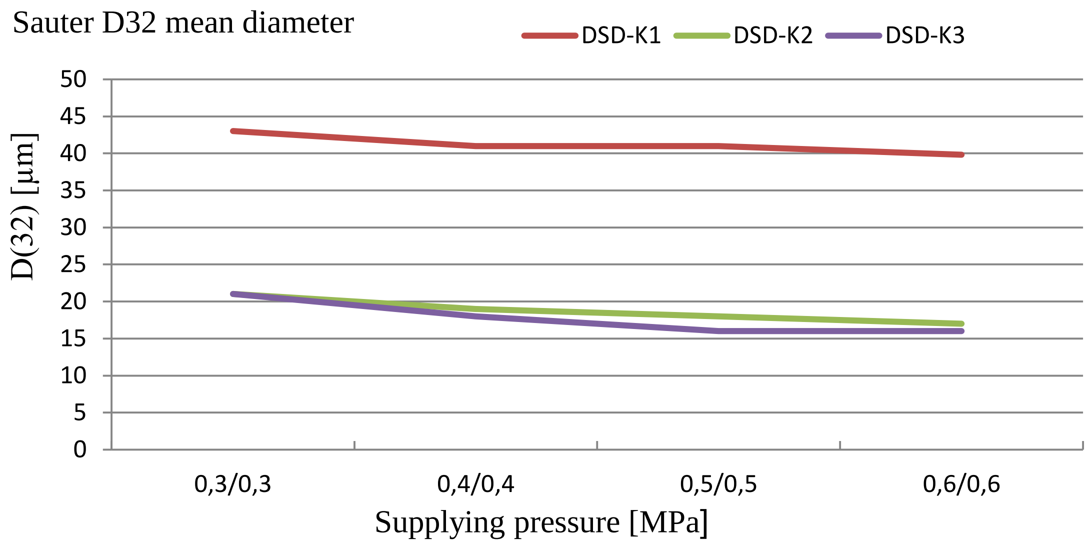


Fig. 8. Characteristic (D32) equivalent diameter in relation to supplying media pressures [9].

Fig. 9 shows a graph of changes in the PA/T absorption surface areas in relation to the supplying media pressures. All the configurations of the self-cleaning nozzle tend to increase the absorption surface areas proportionally to supplying pressure increase. The configuration of the nozzle with three water inlet holes, despite of using about twice the volume of water, generated the smallest absorption surface area. An impact of the cleaning needle is only important for extreme supplying pressures, where the area of absorbed surfaces is reduced in relation to the configuration without the cleaning needle.

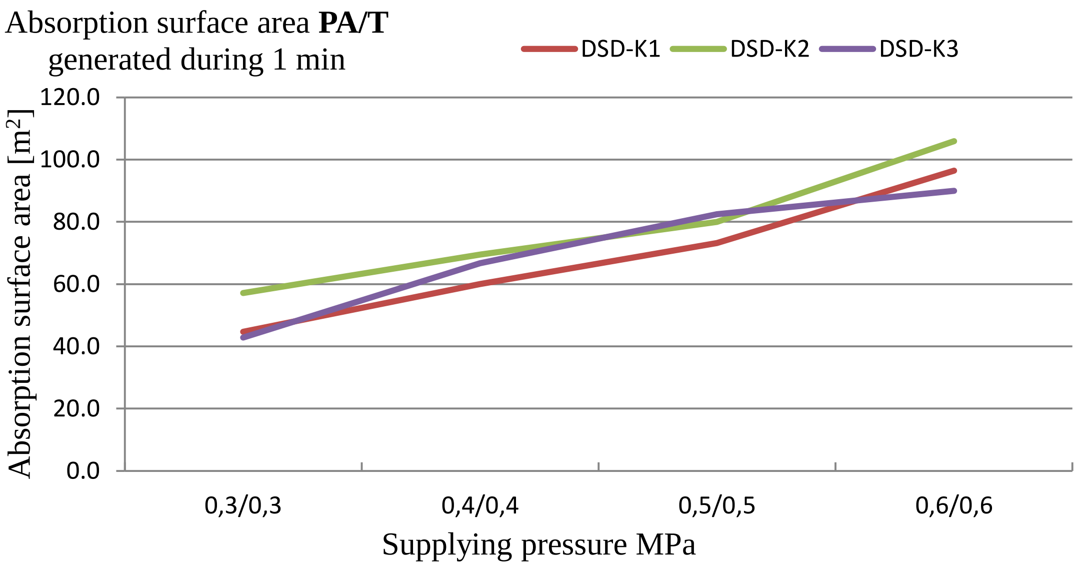


Figure 9. Absorption surface area PA/T in relation to supplying media pressure [9].

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Figure 10 shows a graph of changes in PA/W absorption surface areas in relation to the supplying media pressures. Comparing the areas of the absorption surface generated from one dm^3 of water, a much higher efficiency of the nozzles in the configuration with one water inlet hole can be noticed. They produce the absorption surface area about 2.5 times larger.

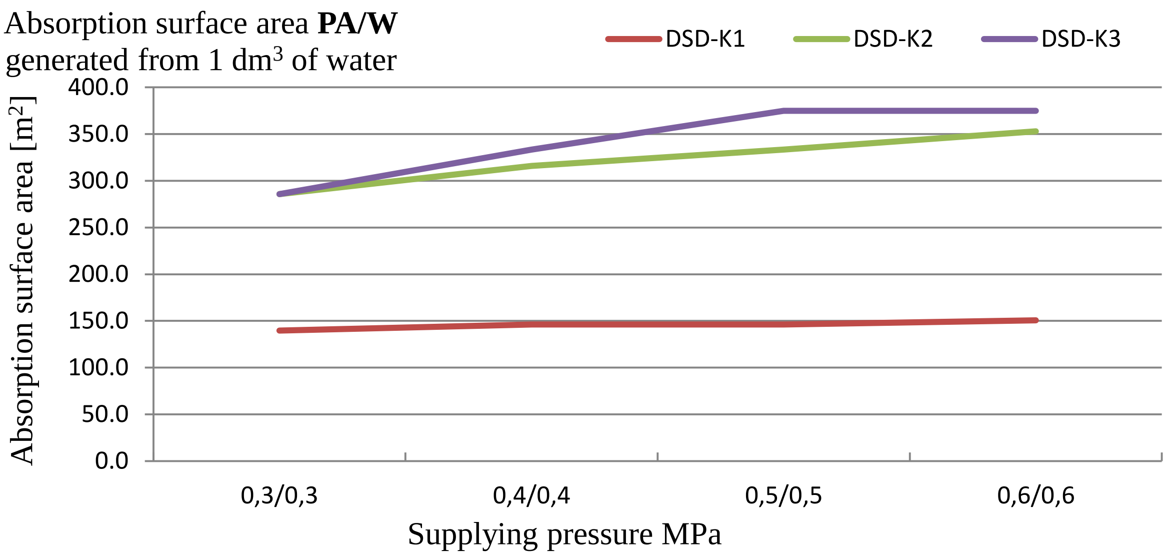

Figure 10. Absorption surface area PA/W in relation to supplying media pressure [9].

Figure 11 shows a graph of changes in PA/P absorption areas in relation to the supplying media pressures. Comparing the absorption surface areas, generated from 1 Nm^3, we observed 60-70 % higher efficiency of the nozzle in K1 configuration in relation to K2 and K3 configurations

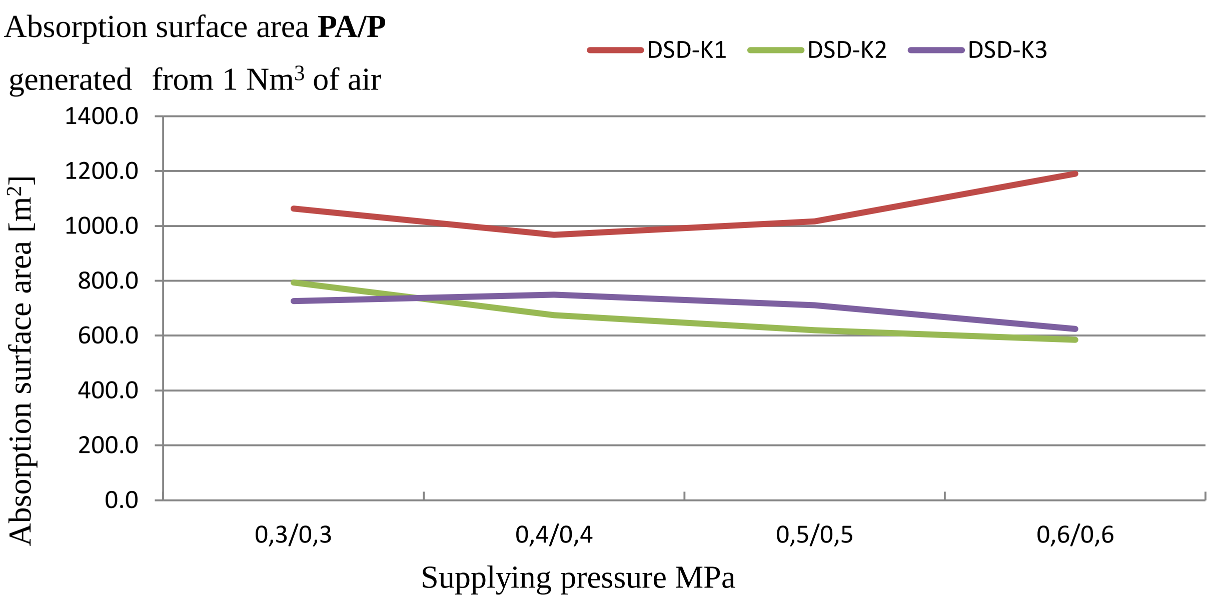

Figure 11. Absorption surface area PA/P in relation to supplying media pressures [9]

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4. Summary and conclusions

The presented nozzle assessment procedure in terms of a degree of water drops atomisation allows for a determination of equivalent absorption surface areas of the spraying water stream. An introduction of parameters, directly specifying the total surface area of the generated drops to a common engineering practice, simplifies a process of selecting nozzles for spraying systems [10]. The suggested parameters, describing an absorption surface area of drops in the generated stream should, according to the authors, be included in nozzle datasheets, as they provide information about nozzle operational parameters and indirectly about their dust control effectiveness. This parameter, in the author's opinion, will facilitate a selection of a correct type of a spraying nozzle for a designed spraying installation made by designers and users of spraying systems.

During the tests of the DSD type spraying nozzles it was found as follows:

- a high degree of atomisation of the spraying stream in the result of using only one 0.8 mm dia water inlet hole,
- insignificant impact of the needle on the distribution of the D32 characteristic diameter,
- a nozzle with three 0.8 mm dia water inlet holes, generated in the same time, the same absorption surface area as a nozzle with one 0.8 mm dia water inlet hole, at the water consumption 2 ÷ 2.5 times smaller.

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