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WET DUST COLLECTION IN SUB-ZERO TEMPERATURES

ODPYLANIE MOKRE W TEMPERATURACH UJEMNYCH

Abstract

The results of experimental studies confirm the suitability of non-freezing liquids for use as dust collecting liquids in equipment working at low temperatures. Based on the completed studies, the hypothesis regarding the impact of liquid viscosity on the effect of releasing the surface collecting the dust particles and, therefore, on the efficiency of the dust collection process cannot be clearly verified. Decreasing the efficiency of dust collection correlated with the increase of liquid viscosity is likely an effect of changing the conditions for the formation of liquid dust collectors.

Keywords: wet dedusting, dedusting efficiency, dedusting in sub-zero temperatures

Streszczenie

Wyniki badań eksperymentalnych potwierdzają przydatność płynów niezamarzających do wykorzystania urządzeniach pracujących w niskich temperaturach. Hipoteza dotycząca wpływu lepkości cieczy na uwolnienie powierzchni wychwytu cząstek pyłu, a w związku z tym skuteczność procesu odpylania nie może być jednoznacznie zweryfikowana. Zmniejszenie skuteczności odpylania związane ze wzrostem lepkości cieczy może być efektem zmiany warunków tworzenia ciekłych kolektorów.

Słowa kluczowe: mokre odpylanie, skuteczność odpylania, odpylanie w temperaturach ujemnych

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The operation of wet dust collection equipment, especially periodic operation, in sub-zero temperatures is problematic and expensive. It requires the use of additional equipment, maintaining an above-zero temperature within the unit or the use of non-freezing liquids for dust collection. The literature regarding wet dust collection lacks the assessment of possibilities and results of tests in the field of dust collection from gas using non-freezing liquids. Despite the fact that the proposed method is expensive, it should be mentioned that in certain conditions, it may be the only solution available. This pertains in particular to the equipment located outside buildings and operating in winter conditions. This equipment, frequently for the lack of indoor installation, operates directly adjacent to industrial systems. Often, their function is a short-term, periodic operation in case of system failure. It is, therefore, vital to maintain their permanent stand-by status by the use of types of liquids, which do not freeze in sub-zero outdoor temperatures as the dust collecting liquid.

In the process of operation, the temperature of the collection liquid can be changed in the course of direct contact heat exchange inside the unit. Temperature changes are accompanied by alterations in the physical properties of the dust collection liquid, in particular – viscosity.

There are no descriptions of theoretical or experimental studies determining the effect of the viscosity of the dust collection liquid on the efficiency of the dust collection process. The reason seems to be the fact that water is the most prominent dust collection liquid and the units most frequently operate in stable temperature conditions.

Discussions substantiating the possibility of the effect of liquid viscosity on the efficiency of the dust collection process can be related both to the analysis of basic mechanisms affecting the deposition of particles on liquid collectors and the conditions of generating said collectors. The transmission of dust particles from gas to the liquid occurs for the most part as a result of inertial effects, catching effect and diffusion. Dust particles are separated in liquid collectors – depending on the type of the wet dust collector: droplets of liquid moving in a stream of aerosol, layers of liquid formed in the unit, surfaces of gas bubbles formed in the barbotage process or wet surfaces of the walls of the unit. One of the tendencies in the development of wet dust collection systems is the introduction of intensive operation units with a large gas phase flow capacity, which would entail an advantageous decrease in the size of the units. In these cases, due to the high relative velocity of the gas and liquid phases, the inertial and direct catching mechanisms have a decisive impact on the dust collection process.

The Warych's monograph [1] contains an extensive description of individual mechanisms on the dust particles deposition on liquid collectors. Descriptions of the mechanisms and their impact on the efficiency of the dust collection process can be found in virtually all monographs, e.g. Warych's [2] or Löffler's [3] addressing the issues of wet dust collection from gas. The literature assigns less significance to the description of the conditions of the generation of liquid collectors and their impact on the efficiency of the dust collection process.

When discussing the mechanism of inertial effects independent from the dust collector, it is generally assumed that in the case of hydrophilic dusts, dust contact with the surface of the liquid is equal to immediate absorption of the dust by the liquid and therefore – immediate release and renewal of the liquid surface for further collisions. In the case of hydrophobic (poor wettability) dusts, the time required for the absorption of the particle by

the liquid may be longer than the time after which the next particle comes into contact with the surface of the liquid. The reduction of the dust collection capacity of the liquid is therefore probable – due to the deflection of the particle approaching the surface of the liquid from the deposited particle. This effect can be considered particularly probable because, in the wet dust collection conditions, more dust collides with each liquid surface element than is required to coat the surface once. Therefore, the rate of particle absorption can be critical in the efficiency of the dust collection process [4]. The rate of particle absorption can be affected not only by the energy required to overcome the surface tension forces, but also the velocity of the particle in a liquid medium, depending on its viscosity.

The efficiency of the dust collection process can be correlated [4] with the rate of binding of dust and liquid, defined as the mass m_s penetrating the liquid surface unit A into the liquid as a result of the collision of dust particles with the surface in a unit of time:

$$r = \frac{m_s}{A \cdot \tau} \tag{1}$$

The rate of binding of dust and liquid depends on the physical and chemical properties of the dust and its susceptibility to wetting, physical and chemical properties of the gas and the dust collection liquid as well as the concentration of the aerosol. In order to verify his hypothesis, Kabsch [4] carried out studies regarding the effect of aerosol concentration on the rate of binding of dust and liquid. The increase in the concentration of dust in gas resulted in an increase of the rate of binding; however, to a lesser degree than would result from linear relationship.

The hypothesis that wettability is significant in the case of inertial particle deposition and rate of penetration of the liquid seems to be justified. The confirmation is the Weber's experiment [5] – shooting 1 mm water droplets with glass and silicone balls. Wettable dust balls immediately penetrated inside the droplets, silicone balls accumulated on the surface.

The analysis of basic wet dust collection models by Semrau, Barth and Calvert [3], no effect of the viscosity of the suspension on the dust collection process was found. Pemberton [6] found that in the case of deposition of particles with poor wettability on droplets, their penetration inside the liquid is necessary and their movement in the liquid is determined by Stokes' law. The rate of movement depends on the medium resistance coefficient and also the dynamic liquid viscosity index. The efficiency of dust particles deposition on droplets as a result of the simultaneous effects of three mechanisms – inertial, impaction, interception and diffusion – is described by a semi-empirical Slinn's formula [7], taking into account the relation between liquid viscosity and gas viscosity.

It is generally believed that there is a specific droplet diameter [8], for which optimum conditions are achieved for the deposition of specific size dust particles, and the efficiency of dust particles deposition on the droplet quickly decreases together with the decrease in particle size.

Upon their analysis of the circulating dust collector operation, Jarzębski and Głowiak [9] found that the inertial dust collision with water droplets is key to the dust collection process. The efficiency of dust particles deposition decreases with the increase in the size of droplets generated in the deposition area. In the case of droplet population with compressed air, the size of the droplets is determined by the Nukijama and Tanasawa formula [10], which indicates that droplet size is positively correlated with the viscosity of the liquid

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phase. An increase in the viscosity can therefore result in a decrease of the dust collection efficiency.

The height of the dynamic foam layer created in the dust collection at a given relative difference between the gas and liquid phase velocities is reduced with the increase in the liquid viscosity [11], resulting in decreasing effectiveness of the dust collection system.

It should follow that a similar effect also applies to the layer of intensive barbotage and the droplet–splash layer often occurring in dust collection systems.

In summary, it can be said that the literature describes cases, which could warrant conclusions regarding the effect of liquid viscosity on the efficiency of the dust collection process. This effect can be observed when considering the inertial effects as well as variables, together with the change in viscosity, generation conditions and sizes of the created collectors.

Since, in the case of wet dust collection in intensive operation units, the inertial mechanism is key to the efficiency of the process, it was decided to conduct model tests on a modified circulating system. The construction of the model unit was simplified compared to classic circulating dust collectors. The two-chamber structure was abandoned, the "dirty" chamber was included in the guide channel. In this case, all dust particles are captured in one unit volume. The separation of dust particles in the unit occurs on droplets generated in the guide, in the intensive barbotage zone formed near the aerosol outlet from the guide, on the wetted surfaces of the guise, in the layer of liquid flowing from the guide (water curtain) and in the droplet-splash layer. In the conditions of developed unit operation, there is a possibility of generating almost all types of liquid collectors occurring in wet dust collection processes.
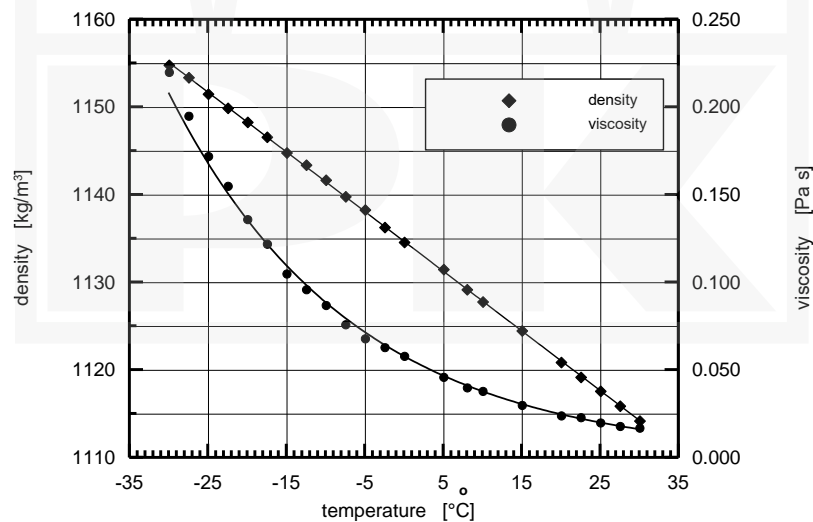

Fig. 1. Relationship between density / non-freezing liquid dynamic viscosity index and temperature

The tests were conducted using a non-freezing liquid with viscosity strongly reacting to changes in the temperature. The relationship between density / non-freezing liquid dynamic

viscosity index and the temperature is presented in the diagram – figure 1. Due to the high dynamic viscosity, the liquid was mixed with water in a 1:1 ratio. This decreased the dynamic viscosity of the solution, which in the temperature range of: - 10°C to 15°C changed between 0.004 and 0.00081 Pa·s. At this concentration, the crystallisation temperature for the liquid is - 37°C, which is important for use in actual industrial conditions.
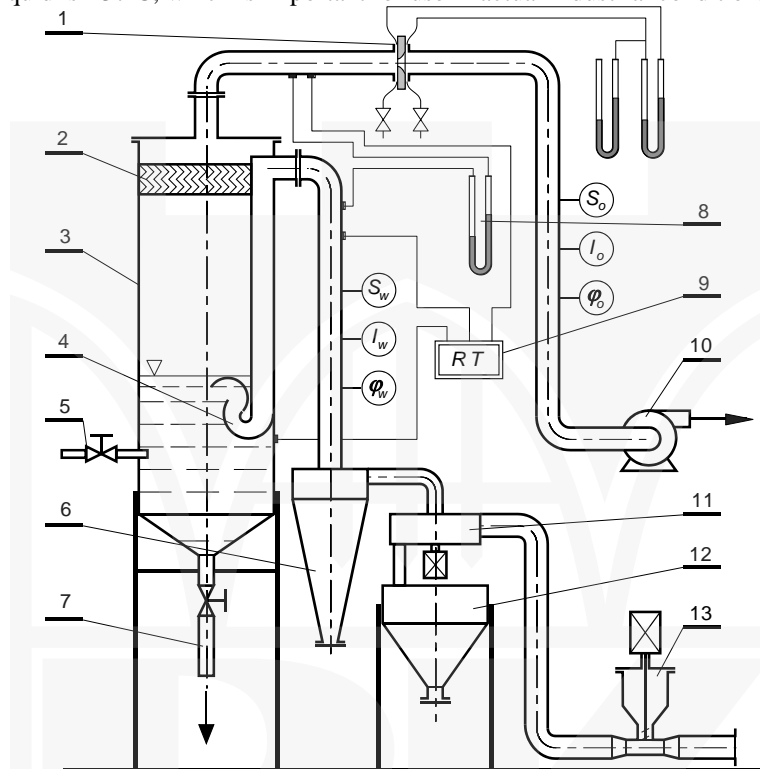

Fig. 2. Testing unit setup
1 – measuring orifice, 2 – liquid trap, 3 – rotoclone, 4 – guide, 5 – water supply, 6 – sorter discharge cyclone, 7 – suspension discharge from the rotoclone, 8 – measurement of the pressure drop on the rotoclone, 9 – thermometer, 10 – exhaust fan, 11 – sorter, 12 – tank for oversize particles separated in the sorter, 13 – dust batcher, S_w, S_o – dust concentration measurement system, I_w, I_o – grade composition measurement system, φ_w, φ_o – gas moisture content measurement system

A testing unit presented in figure 2 was constructed in order to conduct the tests. The main component of the unit is the rotoclone–type circulating dust collector /3/. The aerosol was created by introducing dust to the inlet pipeline with a batcher /13/. The application of a batcher with efficiency adjustment enabled the creation of the desired dust concentration on the dust collector inlet. Since talc was used as test dust, a pneumatic sorter /11/ was installed on the inlet pipeline to stop dust grades over 20 µm. The dusty gas travelled via the inlet pipeline through the guide /4/ into the process area of the unit. From there, purified gas was exhausted by the outlet pipeline, through the liquid trap /2/. The flow of the gas

was generated by the exhaust fan /10/, its expenditure was measured by a quadrant measuring orifice /1/. The expenditure of the gas flowing through the system was adjusted by changing the amount of "false" air introduced to the pipeline directly before the exhaust fan. A pressure gauge /8/ enabled the measurement of the drop in the pressure of gas flowing through the unit and the thermometer /9/ indicated the temperatures of gas in inlet and outlet pipelines as well as the temperature of liquid in the unit. Similar system for the measurement of dust concentration $/S_w$, $S_o/$, grade composition $/I_w$, $I_o/$ and gas moisture content $/\varphi_w$, $\varphi_o/$.

The overall efficiency of the dust collection process was calculated based on the measurements of dust concentrations in specific cross-sections of the inlet and outlet pipelines. The concentrations both in the inlet and outlet pipelines were determined based on the collected gas samples from which the dust was separated through filtration.

In order to determine the grade-based efficiency of the dust collection process for the tested unit, the grade composition of the aerosol was measured before and behind the dust collector. Cascade impactors [12] were used to determine the grade composition. This method enabled measurements by sampling the aerosol directly from the pipeline, without the need to separate the required amount of liquid beforehand.

The results of talc collection tests using non-freezing liquid, i.e. the overall efficiency and grade-based efficiency, are presented as a table and on diagrams – figures 4 and 5. Testing was conducted at three temperatures: $t = -10°C$, $t = 0°C$ and $t = 15°C$, with the corresponding viscosities of: $\mu = 0.004$ Pa·s, $\mu = 0.0056$ Pa·s, $\mu = 0.0081$ Pa·s.

Table 1

**Changes in dust collection liquid viscosity and overall efficiency
in relation to temperature measurement**

measurement temperature	dynamic viscosity coefficient	overall efficiency
°C	Pa·s	%
- 10	0.0081	97.8
0	0.0056	98.8
15	0.0040	99.5

Very high overall talc collection efficiencies of 97.8%, 98.8% and 99.5% were obtained in testing conditions. The achieved efficiencies of talc separation in ambient temperatures were higher than in the case of dust collection with the use of pure water only [13]. It can be said that the high efficiency was a result of low, compared to water, surface tension of the liquid of $61.4·10^{-3}$ N/m in $t = 15°C$. As the temperature rises, the viscosity of the liquid and its surface tension decrease. The assessment of the effects of individual physical and chemical properties on the dust collection process efficiency was impossible. An instrument capable of measuring the surface tension of liquids in sub-zero temperatures was not available. According to table data, the surface tension for water changes by $4·10^{-3}$ N/m when the temperature changes by 20°C. Based on that, it can be expected that the effect of temperature on the surface tension of the liquid applied in the tests would be rather minor –

this, unfortunately, was not confirmed with an experiment. Following this assumption, obtaining such minute changes in overall efficiency with doubling the dynamic viscosity index questions the previously stated hypothesis regarding the effect of viscosity on the efficiency of particle absorption inside collectors and releases their surface. Also small are the changes in the efficiency of capturing particles smaller than 2 micrometres in the efficiency range of 97.1% to 85.6% as presented in figures 4 and 5. Decreasing the efficiency of dust collection correlated with the increase of liquid viscosity is likely an effect of changing the hydrodynamic conditions of the system, which affects the formation of liquid dust collectors. The hypothesis, however, applied to particles with poor dynamic wettability and the wettability properties of dust could have improved together with the decrease in the surface tension of the liquid.
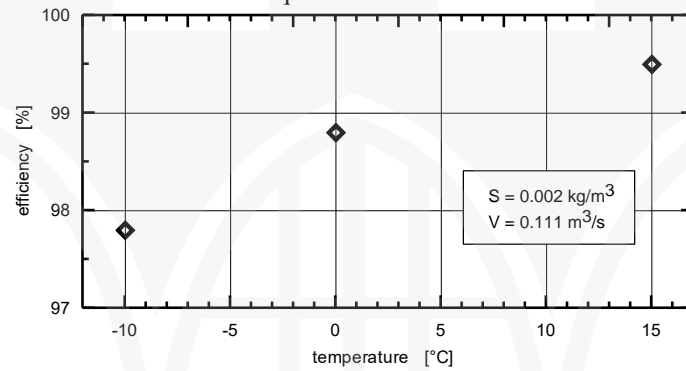

Fig. 4. Relationship between the overall efficiency of the dust collection process in non-freezing liquid and temperature
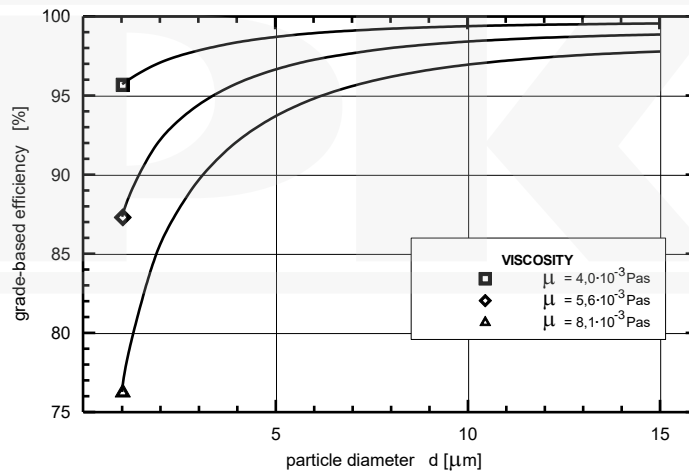

Fig. 5. Relationship between the grade-based efficiency of the dust collection process in non-freezing liquid and temperature

Therefore, based on the completed studies, the hypothesis regarding the impact of liquid viscosity on the effect of releasing the surface collecting the dust particles and, therefore, on the efficiency of the dust collection process cannot be clearly verified. The results confirm the suitability of non-freezing liquids for use as dust collecting liquids in equipment working at low temperatures.

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