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Ensuring air quality in the work area when forming polyamide threads

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ABSTRACT

The world growth of polyamide threads production with a simultaneous increase in the number of occupational diseases of operators affect the need for the studies of discharge mechanism of pollutants and activities for the reduction of increased concentrations of polluting compounds in the air of working area. Following studies of sanitary and hygienic work conditions and pollutant discharges of low molecular weight compounds (LMWC) of caprolactam in the work area during the formation of polyamide threads it was revealed that the largest number of LMWC discharges are in the areas of high turbulence air of blower ducts. A complex of methods for the labor protection based on the research of air condition and particle distribution along the height of the ducts and in the production area is proposed. This comprehensive solution includes predictive control of blowing air pressure and formation temperature, as well as identifying a minimum pollution location to place control room equipment in. Implementation of the developed methods will lead to reducing the risk of elevated concentrations of hazardous substances and ensuring the ambient air quality in the production area.

1. Introduction

Considering the occupational safety in manufacturing of polyamide fibres through a chain of manufacturing processes (polymer synthesis, preparation of spinning paste for thread forming, formation of threads, their heat treatment and drawing, and textile use), and based on the analysis of the plant working conditions, there was revealed a risk of elevated concentrations of low molecular weight compounds in operators' workplace ambient air.

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The relevance of research on pollutant discharges of low molecular weight compounds (LMWC) of caprolactam and its oligomers is explained by an increased incidence of respiratory diseases in polyamide thread-forming operators with an almost fourfold excess of MPC (MPCukr. = 10 mg/m3) (Denisova 2005).

Therefore, the work is aimed to ensure air quality in the work area of thread-forming operators, and, consequently, to create better working conditions and reduce the incidence rate in workers. To comply with the EU standard for caprolactam (cl) aerosol concentrations in the work area air (5 mg/m3) will be an important task.

2. Methods

The parameters of ambient air were controlled using a standard technique in compliance with sanitary regulations DSN - 3.3.6.042-99. The technological parameters of the manufacturing process and the quality characteristics of threads were monitored in compliance with standard GOST 2263-2002. The ejection and turbulence areas in the blower duct were studied using a directed flow of soap bubbles. A point-estimate method was developed to carry out experimental studies of LMWC discharges and their distribution in the work area air. The experimental results were assessed by methods of mathematical statistics and systems analysis (two-factor variance analysis of effects of distance and time spent by operators in the polluted area, least-squares method for development of mathematical models of pollutant discharges and predictive control of airflow, mathematical method of linear programming to establish minimum values to locate minimally polluted safe areas). We used Microsoft Excel, OpenOffice Calc and MathCad.

3. Analysis and discussion of the results of experimental studies

Effects of caprolactam concentrations in the forming work area air on the incidence of respiratory diseases in operators were assessed using a comprehensive approach aimed to creating a safe and healthy working environment and based on the results of monitoring air pollution in the work area, production workload and incidence rate (Denisova 2010).

After processing the data collected at Chernigovskoe chimvolokno OJSC, it was established that the incidence of respiratory diseases in workers is directly proportional to concentrations of caprolactam in the air (C_{cl}):

$$\zeta = a + b \cdot C_{cl}$$

where ζ - specific incidence rate (number of respiratory diseases per 100 people per year),
a, b - constants.

The constant a defines a relatively constant number of respiratory diseases that is independent of the working environment, and $b \cdot C_{cl}$ is a criterion for increasing the number of diseases caused by elevated concentrations of hazardous substances in the air. Modifying this parameter can not only reduce the number of respiratory diseases, but also bring significant economic benefits.

Using a correlation coefficient of 0.85, the equation is represented as follows:

$$\zeta = 44,84 + 8,53 \cdot C_{cl} \qquad (1)$$

Considering the above, it was established that decreasing the concentration by 1.0 mg/m3 reduces by 16% the total number of respiratory diseases in workers. The calculated dependences are obtained for the first time.

The studies showed that decreasing LMWC discharges from blower ducts is a necessary but not sufficient condition for work safety of thread-forming operators. In the previous studies (Bhuvanech 1990, Azarov 2004) showed in order to solve the problem of increased air pollution personal protective equipment should be used, but it is known that its regular use is extremely uncomfortable for employees. Therefore this issue requires a comprehensive solution that includes not only reducing the risk for exposure to a pollution source in technology terms, but also reconstruction of general and local ventilation systems, reducing working shifts time, placing control room equipment in areas with minimal air pollution, the stimulation of the use of personal protective equipment for respiratory protection (PPERP) by workers.

For operators, the risk of staying inside the work area with consideration for pollutants distribution in it was assessed using the elaborated point-estimate method for estimation of LMWC discharges (Denisova 2010). The data were processed using two-factor variance analysis, where the factors were the distance and the time of the operator's exposure within the hazardous area, and the response function was sediment accumulations on test indicators. The analysis showed that the most hazardous area in terms of air pollution is located at 0.5 m from the front edge of the blower duct. Pollutant accumulation on this site is increased by about 10% per hour. Since the operator workplace is within this distance, the use of PPERP is required, and the shift time may be reduced as dictated by specific conditions of production. The obtained results differ significantly from those of previous studies by Pankeeva A.M. (Pankeev, Cherednichenko, Korneeva 2005) where it was assumed that the contamination has even distribution along the height and the distance from the blower ducts.

Minimally polluted areas suitable for the operator's stay were selected using point method findings, where measurement points were placed over the entire area. A design diagram of pollution flow directions is shown in Fig. 1.

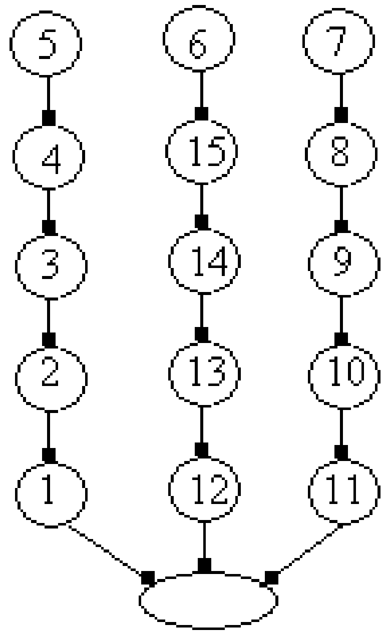

Fig. 1. Design diagram of analysis of pollution flow directions in the formation area

The experimental research data were processed using the linear programming method with search for minimum through flows. Calculations show that the minimum air pollution in the thread-forming area is located at points 3, 11, 12. It was found out that the optimal place for control room equipment would be an area (see Fig. 1, an area near point 12) 1.5 times less polluted than the average for the site, and 6.5 times less polluted than in the area of maximum discharges.

Air supplied by general ventilation was estimated using a point method for assessing pollution. Since the supply-and-exhaust ventilation in thread-forming areas adds blowing air to forced air, the following equation was used for calculations:

$$Ccl = (\overline{\Sigma q_i} \bullet n \bullet k \bullet S_d)/[S_{ti} \bullet (V_1+V_2 \bullet n)], \quad (2)$$

where is the average weight of sediment on test indicators;

n - number of blower (working) ducts;

k - factor of conversion of point method data to LMWC concentration defined by standard methods (experimentally, k = 2,17);

S_d - front surface area of the blower duct, m_2;

S_{ti} - surface area of test indicator, m_2;

V_1, V_2 - air supplied to the area and a separate workplace, respectively, m3/h.

Using known values of $\overline{\Sigma q_i}$, n, V1, this equation allows to calculate a nomogram (Fig. 2: 1 – t_f = 548 K;

2 – t_f = 555 K; 3 – t_f = 567 K) to determine V_2 required to ensure a given LMWC concentration under any changes in process variables, the number of workplaces and the range of threads.

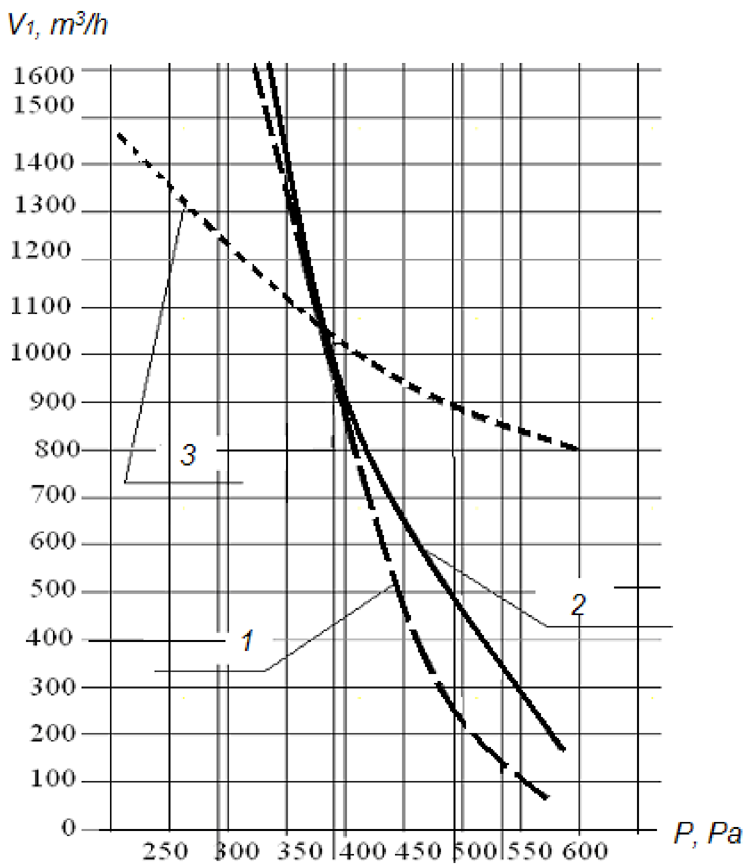

Fig. 2. Nomogram of required air exchange depending on cooling conditions to ensure C_{cl}=MPC/2

On the basis of the above, the rise of formation temperature tf up to 567 K leads to increasing of LMWC concentrations at all process levels except for the blower air pressure, P = 294 Pa. Therefore, the inflow changes slightly at this temperature. When t_f = 555 K and t_f = 548 K, pressure reduction leads to increasing C_{cl} concentrations and requires a significant increase in air exchange. When the area performance changes at constant parameters of threads cooling, V_1 is directly proportional to the number of workplaces. A change in the shop productivity also leads to a change in formation rate and linear density of threads, and requires new values for factors $\overline{\Sigma q_i}$ and V_1 of the equation (2).

Applying the above method to other factories manufacturing anide polyamide, polyester and polyamide threads of another linear density requires updated quantitative values of the factors that affect airflow.

Manufacturing application of the developed methods can reduce concentrations of pollutants (caprolactam) in the air of forming areas by ΔC_{cl} = 43% (calculated using the equation (2)), meet the international standards for caprolactam aerosol concentrations in the work area air (5 mg/m3), and reduce the incidence of respiratory diseases in workers by Δζ = 28% (calculated using the equation (1)).

The solutions obtained can be used not only in manufacturing other ranges of polyamide threads, but also in manufacturing polyester, anide polyamide and other synthetic threads, which are formed in a similar pattern of melting. They also can be used to improve the engineering, economical and environmental performance of closed ducts.

Implementation of air pollution-reducing methods at thread-forming operator workplaces also has a social effect and an economic impact on the overall plant performance, which leads to increasing the professional activity period of workers and labour productivity, reducing staff turnover and sick leave costs paid by a company, savings in raw materials that evaporate and are irretrievably lost.

4. Conclusion

It was developed a set of methods to improve sanitary and hygienic work conditions of thread-forming operators; this makes it possible to reduce concentrations of pollutant discharges of LMWC in the air of thread-forming areas by 43%, and meet the international standards for caprolactam aerosol concentrations in the air of thread-forming areas (5 mg/m3). As a result, the number of respiratory diseases in workers will be decreased by 28%. In addition to the process method, this comprehensive solution includes predictive control of LMWC concentrations in the work area air in case of process modifications, and a formula that takes into account the simultaneous intake of blower air and general dilution air to ensure air quality in the work area.

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