EXPLOSION HAZARD OF DOWTHERM

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ABSTRACT

The formation conditions and the specific features of burning of an explosion-hazardous aerosol formed upon emergency outflow dowtherm from process equipment are studied. Dowtherm is a high-boiling combustible liquid, used as a heat carrier. It is shown that burning of the aerosol proceeds slowly, but a high pressure is developed. It is established experimentally and analytically that the time of existence of the aerosol is within the range of 10 min. The probability of an explosion at plants producing chemical fibres is estimated and it is shown that such plants are explosion-safe.

Keywords: Dowtherm, explosion, VAM explosion pressure, VAM burning velocity, aerosol formation, VAM lifetime, probability of explosion.

Dowtherm (a mixture of 26.5% of diphenyl and 73.5% of diphenyl oxide) is a high-boiling liquid, used in industry as a high-temperature heat carrier. In the case of emergency depressurization of process equipment, in which Dowtherm is in a heated state under pressure, it undergoes atomization, partial evaporation, a liquid aerosol, and, eventually, an exlosion-hazardous vapour-aerosol mixture (VAM) is formed. For estimating the explosion hazards in the industrial premises, calculated in accordance with the standards adopted in the USSR[1] from the equation:

$$\Delta P=\frac{m\,H_m P_o\,z}{V_{pr}\,\rho C_p T_o K_1}\approx 9.575\cdot 10^{-2}\frac{m\,H_m\,z}{V_{pr}}, \quad (1)$$

where ΔP - is the excess pressure developed in the industrial premises upon formation of the explosion-hazardous mixture (VAM) therein (at ΔP>5 kPa the premises belong to the category of explosion-hazardous ones), kPa; m - is the quantity of dowtherm that comes into the premises in an emergency situation and forms an explosion-hazardous aerosol, kg; H_m - is the heat of Dowtherm combustion, kJ/kg; P_o - is the initial (atmospheric) pressure, kPa;
$Z=\frac{\text{Quantity of dowtherm in combustible VAM (kg)}}{\text{Quantity of dowtherm in VAM formed out } m}$ is the coefficient of participation of dowtherm that has entered the premises in the formation of the explosion-hazardous mixture; V_{pr} - is the free volume of the premises, m^3; ρ - is the density of air in the premises, kg/m^3; C_p - is the heat capacity of air in the premises, kJ/kg·K; T_o - is the initial te mperature in the premises, K; K_1 - is the coefficient that takes into account leakiness of the premises (is assumed to be equal to 3), it is necessary to know: what quantity of dowtherm will get into the premises as a result of emergency with the process equipment, what part of the dowtherm will pass into the vapor-aerosol state, and also the value of the coefficient z. For estimating the probability of creation of an explosion-hazardous mixture in conformity with the Standard[2], it is necessary to have data on the lifetime (time of existence) of the ex-

plosion-hazardous VAM. The present paper is devoted to solving these problems and also to studying the specific features of VAM burning-out.

An experimental investigation of VAM formation upon outflow under pressure of a prescribed weighed sample of dowtherm, heated (to T_{boil}), or overheated (above T_{boil}), from a special vessel into a space defined by a film, was carried out by trapping the condensed part of dowtherm[3]. The results of this investigation are presented in Fig.1 as the dependence of the dowtherm fraction (φ) on its initial weighed sample passing into the suspended state and forming VAM.

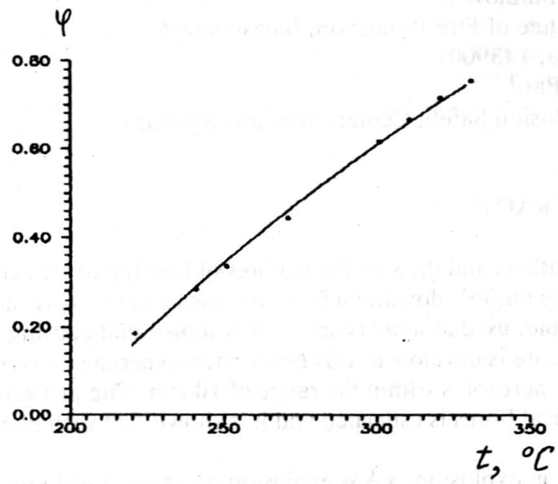

Fig. 1. Dependence of φ on temperature t, °C

From these data seen that at the maximal temperature, permissible in the technological process, the value does not exceed 0.7. The process of VAM burning-out was investigated[3] in a cube-shaped chamber having a volume of 1 m^3. In these experiments the maximal explosion pressure (P_{max}) and the rate of its buildup $(dP/dt)_{max}$ were determined, as well as the lifetime of the explosion-hazardous VAM and other specific features of the process. In these experiments dowtherm heated to a prescribed temperature was supplied into the chamber, and the resulting VAM was ignited with the help of an electrically heated wire. In the course of the experiments it was established that upon supplying about 500 g of dowtherm into the chamber at 350 °C the value Pmax reached about 9 MPa and the value $(dP/dt)_{max}$ with the ignition delay time from 40 to 60 s varied from 12.7 to 23.3 MPa/s (for comparison the value $(dP/dt)_{max}$ for the aerosols of polymers reaches 45 MPa/s and that of dyes comes up to 75 MPa/s [4]). Tentative calculations of the rate of flame propagation, carried out by following the procedure described in [5] with allowance for the temperature rise caused by the introduction of heated Dowtherm into the chamber, gave the value 0.23 m/s. Such velocity of flame propagation characterizes dowtherm as a very slowly burning substance (for comparison: the flame propagation velocity of conventional organic substances is about 0.5 m/s). At the same time, P_{max} proved to be unusually high. In individual experiments its value exceeded the thermodynamic one, calculated for the case of complete dowtherm burning-out. This fact may be explained by cracking with the formation of gases from the aerosol particles yet unburnt. Such a mechanism is supported in [6].

Burning-out of the aerosol is characterized by being multistage and by its oscillatory conditions. Particularly strong oscillations are observed in the case of VAM burning in a non-tight chamber. This is connected with gasdynamic effects taking place upon outflow of gases from the chamber. The limit value (for burning) of the weighed sample of dowtherm was about 0.25 kg/m^3 , this being considerably higher than the lower limit of ignition of the dowtherm vapors (about 0.05 kg/m^3 according to the data reported in [7]). From the ratio of these values and taking into account aerosol diffusion in the free space (local explosion-hazardous mixtures in the premises), the value of the coefficient z in Equation (1) can be assumed to be 0.1.

The lifetime of the explosion-hazardous aerosol was found from the time of keeping the ability of burning by the aerosol. The results of these experiments are presented in Fig.2, from which it is seen that at the 0.5 kg weighed sample of dowtherm, optimal for burning, and at the maximal process temperature of 325 °C the VAM lifetime was about 300 s.

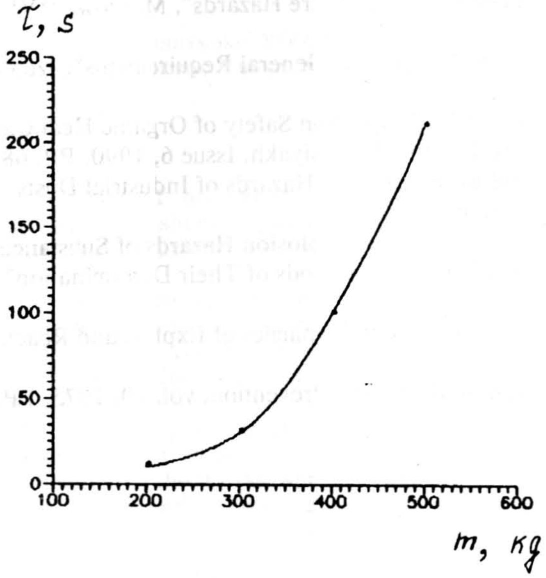

Fig. 2. Dependence of the lifetime of explosion-hazardous VAM (τ, s) on weighed sample of dowtherm (m, g)

The VAM lifetime was investigated analytically by considering two processes: Stokes precipitation of large drops and Brownian motion of small drops, accompanied by collision of the drops and their coagulation.

The rate of drops precipitation (V) was calculated in conformity with Stokes' law:

$$V=\frac{2}{9}r^2 g\frac{(p'-p)}{n}, \tag{2}$$

where n is the coefficient of dynamic viscosity, r is the drop radius, p', p is the viscosity of the liquid and air. As a result of calculation it was established that an appreciable rate of precipitation (on the order of 10^{-2} m/s) is displayed by drops of more than 20 μm in diameter.

Brownian motion is characterized by the law of Einstein-Smoluchowski, according to which

$$x^2=2D\tau, \tag{3}$$

where x is the averaged shift of the particles, D is the coefficient of diffusion.

The lifetime of the explosion-hazardous VAM was assumed to be the period, during which the VAM concentration will become smaller than the inflammability limit (C=50 g/m^3). In results of this calculations it was estimated that the time of lowering of the aerosol density, when the size of drops ranges within 5 to 10 μm, to the concentration lower than the inflammability limit is about 500 s. This result, with taking into account the adopted assumptions, is fairly consistent with the experimental measurements (according to which the existence time of the explosion-hazardous VAM is about 300 s). For practical purposes, with a safety factor, this time can be assumed equal to 600 s.

The probability of an explosion accident at plants producing chemical fibres, calculated by following the procedure described in[2], with the help of the above result and statistical data, turned out to be about $3 \cdot 10^{-8}$ $year^{-1}$, this being almost two orders of magnitude lower than the value permissible according to [2], equal to 10^{-6} $year^{-1}$. Thus, said plants are not explosion-hazardous and, consequently, they do not require costly explosion-proof electrical equipment.

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