THE VARIATION OF TEMPERATURE DROP OF THE COMPRESSED AIR IN PNEUMATIC NETWORK

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Abstract: The purpose of this paper is to determine the temperature drop/meter according to changes in volume flow of compressed air and the difference of temperature between inside and outside the pipeline.

Keywords: the values matrix of temperature drop/meter, pneumatic network

1. GENERAL NOTIONS

Thermodynamically, the pneumatic mining networks are open systems that change with the external environment both energy and mass (in the case of flow losses through leaks).

The energy transfer between opened thermodynamic system and external environment it can be done as heat and mechanical work and through the energy of the mass involved in the mass transfer between the system and the external environment.

In this paper is only the study of the heat propagation through the endlessness cylindrical walls. Since the cylindrical wall is endless it can be avoid the edge effect. The compressed air pipes in hot mines at depths of hundreds of meters can damage the underground climate. In such cases the heat losses are reduced through the pipes insulation or cooling the air.

2. MATHEMATICAL MODEL

The steady heat propagation in the cylindrical surface without internal heat sources defines Laplace's equation, on the 0Z axis is represented the cylinder axle.

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It has been made the assumption that the temperature is stable in the cylinder axle and that it varies only along the radius.

The equation in this case is:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=0 \tag{1}$$

followed by the circle equation:

$$x^2+y^2=r^2 \tag{2}$$

According to Laplace's equation, the transformation from the Cartesian coordinates to cylindrical ones (and in this case only according to the radius) it can be made using the following operation:

$$\frac{\partial T}{\partial x}=\frac{\partial T}{\partial r}\frac{\partial r}{\partial x}=\frac{x}{r}\cdot\frac{\partial T}{\partial r}\,; \quad \frac{\partial^2 T}{\partial x^2}=\frac{\partial^2 T}{\partial r^2}\left(\frac{\partial r}{\partial x}\right)^2+\frac{\partial T}{\partial r}\cdot\frac{\partial^2 r}{\partial x^2} \tag{3}$$

According to the circle equation:

$$\frac{\partial r}{\partial x}=\frac{x}{r}; \quad \frac{\partial^2 r}{\partial x^2}=\frac{y^2}{r^3} \tag{4}$$

have obtained:

$$\frac{\partial^2 T}{\partial x^2}=\frac{x^2}{r^2}\cdot\frac{\partial^2 T}{\partial r^2}+\frac{y^2}{r^3}\frac{\partial T}{\partial r} \tag{5}$$

and

$$\frac{\partial^2 T}{\partial y^2}=\frac{y^2}{r^2}\cdot\frac{\partial^2 T}{\partial r^2}+\frac{x^2}{r^3}\frac{\partial T}{\partial r} \tag{6}$$

the equation resulted:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=\frac{d^2 T}{dr^2}+\frac{1}{r}\frac{dT}{dr}=\frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right)=0 \tag{7}$$

written on the observation *T = T(t)*.

With the condition r ≠ 0 it is getting the solution:

$$T=A\ln r+B \tag{8}$$

which shows that the temperature varies logarithmically with the radius.

In order to calculate the constants *A* and *B* it have been admitted the singular conditions of Dirichlet type:

$$r = r_0; \quad T = T_0$$
$$r = r_1; \quad T = T_1$$

resulting the temperatures field:

$$T = T_0 + \frac{T_1 - T_0}{\ln \frac{r_1}{r_0}} \ln \frac{r}{r_0} \tag{9}$$

the isotherms being coaxial cylindrical surfaces and coaxial with the cylinder axle.

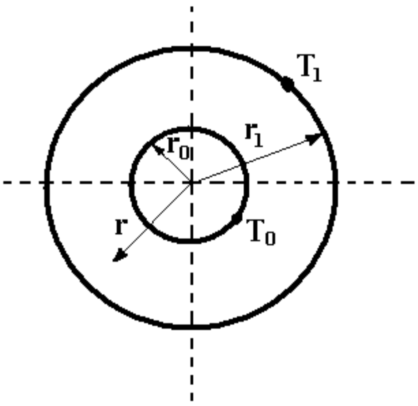

Fig. 1. Numbering range and temperatures

In figure 1 r_0 is the inner radius of the pipe, r_1 is the external radius of the pipe, T_0 the temperature inside the pipe and T_1 is the temperature outside the pipe.

The heat flow density could be calculated using the Fourier hypothesis:

$$\dot{q} = -\lambda \, grad \, T = \frac{\lambda}{r} \cdot \frac{T_0 - T_1}{\ln \frac{r_1}{r_0}} \tag{10}$$

The heat flow that streams through a current cylindrical surface of radius r is calculated below:

$$\dot{Q} = 2\pi r L \frac{\lambda}{r} \cdot \frac{T_0 - T_1}{\ln \frac{r_1}{r_0}} = \frac{2\pi\lambda L (T_0 - T_1)}{\ln \frac{r_1}{r_0}} \tag{11}$$

or it can be rationed to the linear meter of the cylinder pipe:

$$\dot{Q}_L = \frac{\dot{Q}}{L} = \frac{2\pi\lambda(T_0 - T_1)}{\ln\frac{r_1}{r_0}} \left[\frac{W}{m}\right] \tag{12}$$

Generally, in the case of the air-conditioning parameters that matters is the temperature drop on the pipe's length due to the compressed air slacking and to the heat exchange with the pipe's environment. Thus:

$$\frac{\Delta t}{\Delta L} = \frac{\dot{Q}_L}{\dot{V} \cdot \rho \cdot c_p} \left[\frac{{}^0C}{m}\right] \tag{13}$$

where: $\dot{V}$ is the volume flow through the pipe in m^3/s; ρ - the density of the compressed air, the average value on a pipe parcel or on the pipe section; c_p – the isobar heat capacity of the compressed air, which changes insignificantly in this area; λ - the coefficient of the air conduction

3. THE CASE STUDIED

The theoretical relationships deducted in this paper should be validated by applying to a pneumatic plant.

First, are taken into consideration the real values of a pneumatic plant from the Jiul Valley pitcoal mines. Thus, in the pneumatic network is delivering one or more compressors.

The air parameters when sucking are p_1 =1,013 bar and t_1 = 20 ^{0}C, when pressing p_2 =6 bar and t_2 = 60 ^{0}C. The compressor's yield measured with a differential-diaphragm gauge modulus is[1]:

$$\dot{V} = 0.725\, m^3/s \quad \text{or} \quad \dot{V} = 0{,}725 \cdot 3600 = 2610\, m^3/h$$

The pneumatic network has pipes with diameter from 400 mm to 100 mm. The compressors station is installed on the horizontal surface and goes underground where it will branch at the levels towards the work places, stops and investment works. Longer exist an additional network for supplying the underground, used if the main one is damaged.

Usually the pneumatic consumers are: the borers' type PR8 and P 90; pick hammer type CA 14; the pneumatic fans; electro pneumatic fans; winds.

The energy consumption of the air conveyor changes according to the air parameters when sucking and when the pressure from that network in which the energy consumption upsets varies. The pipe's diameters from the pneumatic network are presented in table 1, where d_i and d_e are inside and outside diameters.

Table 1. **The pipe's diameters from the pneumatic network**

d_i (mm)	89	108	133	159	219	273	325	377	426
d_e (mm)	96	116	141	168	233	289	343	393	446

The variation of the temperature drop/meter it will be determined according to the volume flow of the compressed air and the temperature difference between the inside and outside of the pipe. The compressed air at the compressors station exit is hot, a temperature between 40…60 ^{0}C.

The average density of the compressed air is:

$$\rho = \frac{p}{RT} = \frac{6 \cdot 10^5}{287(273+50)} = 6.47\ kg/m^3$$

The coefficient of the air thermal conduction is λ = 0.028 W/(m·K) and $c_p = 1012 \quad J/(kg \cdot K)$.

Assuming the isothermal compression on the pipe's section (5m) or in the case of the buried pipes, the external temperature (of the underground) is considered constant and equal with 20 ^{0}C.

On the other hand, since the thermal resistance of the pipe's wall is negligible just because of the wall's thickness that measures just few mm and the thermal conduction coefficient of the pipe's material approaches 50 W/(m·K), the temperatures difference $(T_0 - T_1) = \Delta T = 50 - 20 = 30^0C$.

The compressed air temperature drop using the relations (11) and (12) is:

$$\frac{\Delta t}{1m} = \frac{2\pi\lambda\Delta T}{\dot{V}\rho \cdot c_p \ln\frac{r_1}{r_0}} = \frac{2 \cdot 3.14 \cdot 0.028 \cdot 30}{0.725 \cdot 6.47 \cdot 1012 \ln\frac{96}{89}} = 0.0148\ ^0C/m$$

or on a section: 0.0148·5 = 0.074 ^{0}C/5m, and at 1 km = 14.8^{0}C.

This value is an informative one. To visualize the results it will be considered a range of values for the temperature difference between inside and outside the pipeline (fig. 4).

It will be considered the variables, the difference $T_0 - T_1 = \Delta T$ according to the climatic conditions for the following range of values: 22; 25; 28; 30; 32; 35 ^{0}C and the volume flow of the compressed air, for the following range of values: 0.725; 1.45; 2.175; 2.9; 3.625.

In figure 2 is presented the matrix of the temperature variation/meter on the pipe's length according to the volume flow and the temperature difference:

$$\Delta t = \begin{pmatrix} 9.995\times 10^{-3} & 0.011 & 0.013 & 0.014 & 0.015 & 0.016 \\ 4.997\times 10^{-3} & 5.679\times 10^{-3} & 6.36\times 10^{-3} & 6.815\times 10^{-3} & 7.269\times 10^{-3} & 7.95\times 10^{-3} \\ 3.332\times 10^{-3} & 3.786\times 10^{-3} & 4.24\times 10^{-3} & 4.543\times 10^{-3} & 4.846\times 10^{-3} & 5.3\times 10^{-3} \\ 2.499\times 10^{-3} & 2.839\times 10^{-3} & 3.18\times 10^{-3} & 3.407\times 10^{-3} & 3.634\times 10^{-3} & 3.975\times 10^{-3} \\ 1.999\times 10^{-3} & 2.272\times 10^{-3} & 2.544\times 10^{-3} & 2.726\times 10^{-3} & 2.908\times 10^{-3} & 3.18\times 10^{-3} \end{pmatrix}$$

Fig. 2. The matrix of the temperature variation/meter on the pipe's length

In figure 3 is presented the temperature drop/meter for constant values of the volume flow and the temperature variation between (22-35) ^{0}C.

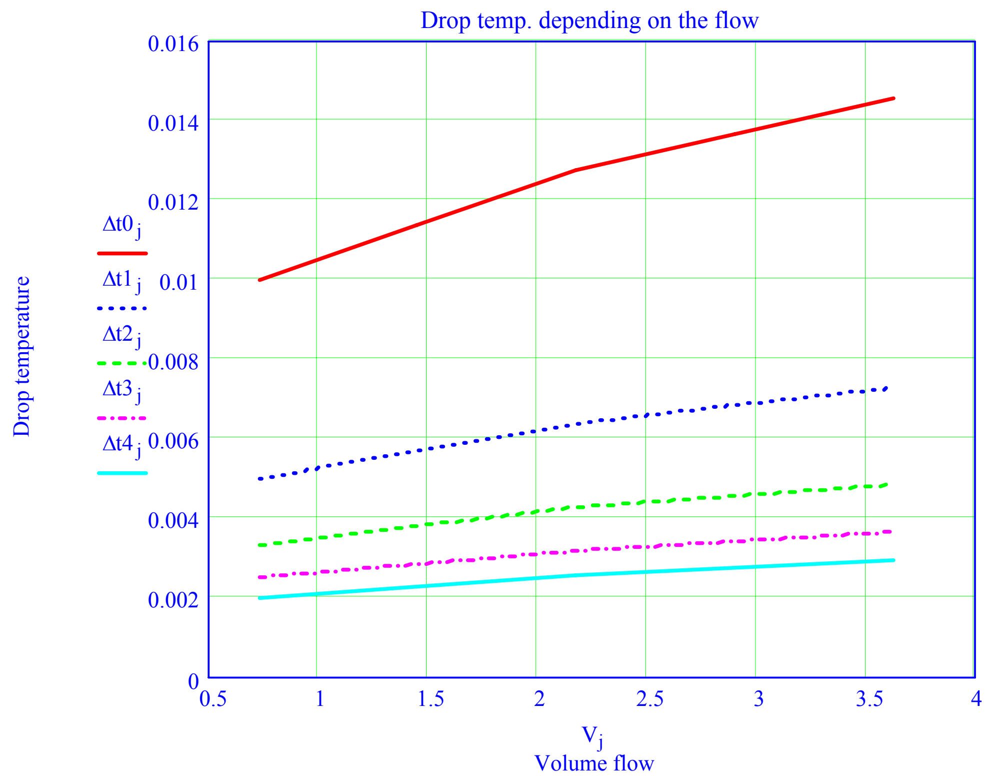

Fig. 3. The temperature drop/meter according to the volume flow

In figure 4 is presented the temperature drop/meter for the values of the volume flow between (0.175-3.625) m^3/s and the imposed temperature variation.

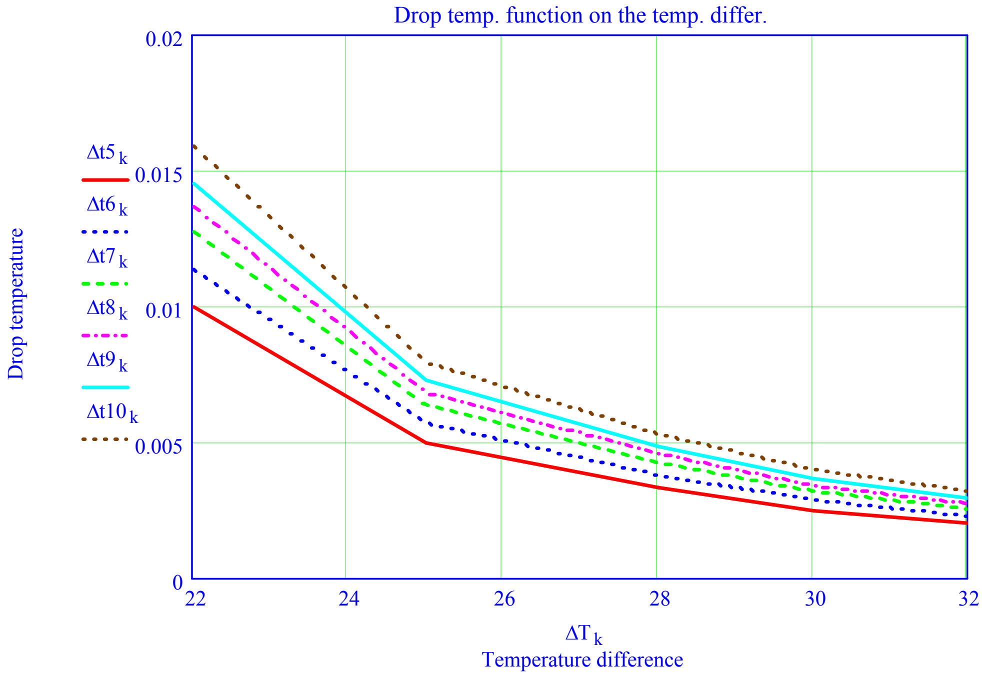

Fig. 4. The temperature drop/meter according to the temperature difference between the inside and outside pipe

4. CONCLUSIONS

The temperature drop/meter registers a linear – logarithmic increase depending on the volume flow along with the increasing of temperature difference as we can see in figure 3.

As the gas volume flow increases, the temperature drop/meter is decreasing, as we can see in figure 3.

For constant values of the difference in temperature between the inside and outside the pipe, the temperature drop/meter decreases along with the gas volume flow increase, as we can see by curves presented in figure 4.

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