Methodological approach to determining the area of air recycling on metro lines with double track tunnels

Sergey Zhikharev*

Mining Institute of the Ural Branch of the Russian Academy of Science, Perm, Russia

Abstract. The article discusses the issues of operating existing metro lines with double-track tunnels. Significant differences between average annual, average monthly and extreme values of outdoor air temperature affecting the thermodynamic and thermophysical parameters of the mine atmosphere of subway tunnels, both in Russia and abroad, are analyzed. The results of a comprehensive analysis of the conditions that determine the temperature regime of the lines of double-track tunnels are presented. Air recirculation in the tunnels has been determined considering climatic conditions. Engineering and technical calculations have been carried out in metro tunnels when the seasonal periods of their operation change. Each of these periods is characterized by its own temperature, for example, for the winter period these are: average winter temperatures, temperatures of the coldest month, the coldest five-day period. The obtained results of the research work will make it possible to select the amount of air for each specific variant of the year, which will ensure, during the operation of this kind of metro lines, the standard thermodynamic parameters of the air environment, both in underground stations and in metro tunnels, and possibly lead to a positive economic effect.

1 Introduction

Due to the progressive development of large cities and the settlement of large numbers of people in areas with difficult transport accessibility, the problem of the development of transport communications is becoming more acute. Currently, one of the promising types of urban transport is the metro [1-3]. We believe that it is capable of coping with the growing passenger traffic in large cities. Therefore, it is necessary to pay special attention to the development of metro lines. At the same time, we believe that the development of metro lines will be influenced by various indicators, among which operational indicators play an important role.

The performance indicators discussed in this article depend, first, on both the design excellence and the efficiency of ventilation systems. However, it is worth noting that it will be more influenced by both the intensity of passenger traffic in the metro, as well as the

* Corresponding author: 79213258397@mail.ru
hydrogeological, meteorological and other conditions of the city, according to the climatic zone where it is located.

The relevance of the topic is related to the progressive construction of new metro stations, namely the excavation of double-track tunnels. The main parameter influencing the formation of the microclimate, both at the station and in the transport tunnels, is the air temperature. One of the problems in operating the ventilation of such tunnels is that they lack circulation circuits. While in single-track metro tunnels they exist [1]. It is especially important to consider this issue when connecting two types of tunnels, such as, for example, at stations “N” of the metro line “N”, which will be discussed below.

2 Problem statement

The beginning of work on the construction of double-track tunnels in the city “X” determined the need to substantiate rational schemes for their ventilation.

In subways with double-track running tunnels, due to the lack of circulating air flows, most of the heat, due to the process of air assimilation, is taken along with it through aspiration air removal systems through station shafts. As a result, there is a decrease in the temperature of the mine atmosphere at metro stations in the summer, compared to other metro lines in large cities, which currently use only single-track tunnels. In the winter (cold) period, this will lead to a significant decrease in temperature at the entrance to the running tunnel, as well as at metro stations [1-3].

Such parameters in conditions of: subtropical, Mediterranean and temperate climates with an average annual temperature \(T_{\text{a,1}}\), more than plus 10 °C in megacities similar in climatic conditions to London, Madrid, Rome, in which double-track tunnels are operated, and other cities, lead to positive result. This makes it possible to reduce the air pressure required to maintain the required temperature in subway tunnels [2, 3].

The average annual air temperature in relation to the city of city “X” considered in this article, located in a sharply continental climate, will not exceed values equal to plus 4 °C, and the air temperature outside in the coldest winter month, based on long-term observations, according to meteorological data, can drop to minus 10 °C.

We believe that, according to the conditions described above, the supply of street air into a double-track tunnel with a temperature equal to the temperature of the outside air, i.e. not additionally heated, can and will lead to freezing of those underground sections of tunnels that are directly adjacent to the metro tunnel shafts [1, 4, 5]. In addition, there will be the fact that follows from the above that when the temperature of the outside (street) air drops to values lying about minus 25°C and below (corresponding to the temperature of the coldest five-day period), this cold air having such a low temperature will not have time to warm up. As a result, it will be possible for underground metro stations to receive air flow with a temperature ranging from minus 10°C to minus - 15°C [3, 6, 7].

Currently, to ventilate two-track tunnels, a ventilation scheme like the ventilation scheme for single-track tunnels is used, which, in our opinion, is not correct. In our case, we are talking about a scheme that involves supplying outside (street) air into the tunnel space through metro ventilation shafts located in the center of the metro railway section, at approximately equal distances from neighboring stations (No. “1” and No. “2”) , and forced removal of the outgoing jet from the ventilated space of the metro through ground station shafts (see Fig. 1) [1, 3, 8].
The use of identical ventilation schemes is not correct, if only because the movement of air through single-track tunnels is carried out largely due to the piston effect from the metro cars. Currently, in most countries that have double-track tunnels, the movement of mine air is carried out by creating forced draft. It is created by special mine fans installed in the ventilation units of metro distillation and station mines [9, 10, 11]. Also, a distinctive feature of the aerodynamic processes of mass transfer in single-track and double-track tunnels is the absence of circulation flows, which are created by trains moving in opposite directions [3, 12, 13].

In our case, considered in this article, the transfer of all engineering and technical solutions that have proven themselves in the operation of metro lines with double-way distribution tunnels in a hot climate, to the meteorological conditions of the city “X” located in the UKC, can lead to a violation of sanitary conditions. In addition, the emergence of problems in the operation of drainage systems cannot be ruled out [1, 14, 15].

Thus, the use of ventilation schemes common in Europe and other countries with double-way distillation tunnels in relation to the microclimatic conditions of Russia in most federal districts may require and will require, especially in winter, additional heating of the outside air in one way or another before supplying it to the tunnel space metro, namely distillation mine shafts [1, 11, 13]. This will lead to a reduction in the advantages of using double-way distribution tunnels [1, 3, 16].

Another way to increase the temperature, i.e. additional heating of the street (outside) air supplied to the tunnel can be the forced formation of artificial circulation (closed circular) flows, similar to this kind of flow in single-track tunnels [1]. At the same time, the formation of this kind of flows will occur not due to the movement of rolling stock, which includes more than 5 metro cars, but as a result of the operation of pressure fans installed in mine complexes.

One of the possible aerological ventilation schemes for double-way distilling tunnels, with the help of which forced circulation of air masses in the tunnel space can be ensured, is a heat and mass transfer scheme using a technical (specialized) rigid ventilation structure located at the tunnel arch (false ceiling) [17, 18, 19]. A similar solution has already found its application, for example, in ventilation systems for road tunnels. It allows you to solve complex problems both in removing exhaust gases from vehicles during normal operation of the tunnel, and highly toxic pyrolysis flue gases generated because of an emergency, such as fire and/or fire. The analysis of scientific literature data, carried out by us together with other participants in the research work, showed that the solution described in this article for the use of a specialized ventilation duct for the purpose of ventilation of double-way distribution
tunnels has no analogues, not only in Russia, but also in other countries of the world [1, 20, 21].

The introduction of a specialized ventilation duct into existing metro ventilation systems will make it possible to create recirculation of a previously closed ventilation loop between the station and the central part of the section due to the entry of an additional volume of air into the ventilation duct from the station.

The engineering and technical solution we propose provides for the technological process of organizing air conditioning in winter using controlled refreshing jets. We believe that they will influence the complex physical processes of heat and mass transfer associated with the formation of normalized, i.e. meeting the requirements of regulatory documents on climatology, station microclimate. At the same time, the process of mixing air masses having different temperatures and coming from different places, namely a closed loop and cold outside (street) air should be organized directly in the mine atmosphere of the metro tunnels belonging to the station complex, first it should begin in the supply chamber [1, 3, 22].

![Ventilation scheme for double-way distribution tunnels using a false ceiling in the cold (winter) period](image)

Figure 2. Ventilation scheme for double-way distribution tunnels using a false ceiling in the cold (winter) period (1-double-track tunnel, 2-station metro stations (Station I and Station II), 3-station ventilation duct, 4-station exhaust fans, 5-station ventilation shaft, 6-injection fan, 7-exhaust fans, 8-outdoor air, 9-exhaust air, 10-mixed air flow (closed loop air and fresh outside air), 11-mining tunnel atmosphere, 12-air valve, 13 - air release valves from the ventilation duct, 14 – direction of train movement).

The process of mixing cold outside air, which is forcibly supplied by special mine ventilation units into the supply chamber, where it is directly mixed with warm air coming from the station. The total air flow rate consists of two components, which are the flow rates of supply and circulation air. This total volume of air enters through the supply chamber of the station ventilation shaft (Fig. 2. position 5) into the ventilation duct, through which it continues to move until the middle of the stage. After reaching the middle of the stretch, it is released into the tunnel using a remote-controlled air valve. The valve in the middle (Fig. 2. Valve 13 in the open position 13) can pass the entire volume of air supplied by mine ventilation units. Directly at the point of release, the air flow has the possibility of multidirectional movement, i.e. it moves from the middle of the tunnel both towards one station and towards another (opposite) station located on the same “line” of the metro.

The process of increasing the temperature of the mine atmosphere in the tunnel occurs due to heat, which is removed using gas-dynamic physical processes. These processes are based on the mechanism of thermal conductivity from moving subway trains and other engineering and technical sources during operation, which release thermal energy. Such sources, as a rule, can be, for example, numerous cable lines.

As a result of these complex physical processes, the surface of a special ventilation duct is heated and, as a result, heat from its walls is transferred to the air masses that are moving inside it at that moment. [1, 3, 5].
In our proposed engineering solution, the above-described additional amount of thermal energy can be used both to heat the outside air in the station complex, and for its additional heating in the ventilation duct [1, 10, 15].

If the temperature on the surface is above 0 °C, then we propose, considering the above, to supply only outside air into the station ventilation shaft. In this case, the supply of air naturally heated above 0 °C must be done through open air valves distributed along the length of the tunnel. In this case, it is necessary to provide for the possibility of aerodynamic distribution of the air mass in different directions, i.e. to ensure multidirectional movement towards opposite stations No. 1 and No. 2. In addition, it is necessary to provide for the possibility of forced removal through tunnels using specialized mine ventilation units of air masses contaminated with the products of techno- and anthropospheric activity, primarily from the space of metro stations.

3 Materials and methods

To solve the problems we used an integrated approach consisting in the use of methods of mathematical statistics, methods of computational fluid dynamics, mining thermal physics, as well as computer modeling methods. The research methods and the obtained initial data are based on theoretical and full-scale experimental studies at existing metro facilities. To a greater extent, when solving the problems, particular methods of computational fluid dynamics were used, namely the finite element and finite volume methods when solving the Navier-Stokes equation.

4 Results and discussion

In accordance with the regulatory document of the Russian Federation “Code of rules 131.13330.2012 building climatology” clause 5.17.2 in the cold season (average daily outside air temperature is equal to or below 10°C), as well as “CR 120.13330.2012 METROPOLITEN” clause 5.17.2.1.b - the air temperature at the station should be in the range from 5°C to 16°C.

Based on the results of actual measurements, we calculated air temperatures at various points of the metro, such as the station and the middle of the section.

When carrying out calculations considering that air will be supplied through the ventilation duct in the middle of the stage, we made the assumption that an equal amount of air is distributed in both directions to the stations from the middle of the stage. In addition, the calculations considered: humidity and air density, coefficients from the approximation of the dependence of moisture content on temperature, supplied air flow rates, effective heat capacities, weight flow rates, heat transfer coefficients for different periods of the year, thermal conductivity and thermal diffusivity coefficients.

Based on the results of the calculations, diagrams were drawn up similar to the diagram shown in Figure 3. These types of diagrams displayed the temperatures in various sections of the distillation tunnels, including stations.
Fig. 3. Temperature distribution along the length of the tunnel: - - - - - - direction of air with a positive temperature after mixing the outside and tunnel air; ––––– – direction of air with negative temperature supplied from the surface.

As a result of the obtained temperatures, graphs of the air temperature distribution as they moved from the ventilation shaft to arrival at the station were constructed.

Figures 4 and 5 show the distribution of air temperatures along the length of the false ceiling and tunnel, taking into account (a) and without taking into account (b) air recirculation in winter.

![Diagram showing temperature distribution](image)

**Fig. 4.** Distribution of air temperatures along the length of the suspended ceiling and tunnel: from the middle of the stage to the station for the winter period.

**Fig. 5.** Distribution of air temperatures along the length of the false ceiling and tunnel from the station. "1" to st. "2" for winter conditions.

Designation of lines for the winter period (Figures 4 and 5):
- **Red** - Normative value of temperature;
- **Dark Green** - Tunnel air temperature during cold period when mixed with external (ATCM: -5.5 °C);
- **Orange** - Cold period temperature (coldest month -13.5);
- **Blue** - Tunnel air temperature during the CFDT when mixed with the outside (lowest 14.8);
- **Purple** - CFDT (-24)
In contrast to Figure 4, Figure 5 visualizes the measurement results on the interstation section of the stretch, namely on the section between stations “1” and “2”, while the total length of the tunnel in question was 1,950 m.

According to the data presented in the graphs, we can conclude that the distribution of air temperatures along the length of the false ceiling and tunnel: from the middle of the stage to station “1”, as well as from station “1” to station “2” during the coldest five-day period (-24 °C) and average January temperature (-5.5 °C) without considering recirculation, differ significantly from each other. The creation of recirculation during the cold period of the year has little effect on the formation of temperatures at the metro line station.

Figures 6 and 7 show the distribution of air temperatures along the length of the false ceiling and tunnel, considering (a) and without taking into account (b) air recirculation in the summer.

![Fig. 6. Distribution of air temperatures along the length of the suspended ceiling and tunnel: from the middle of the stage to station “1” for the summer period.](image1)

![Fig. 7. Distribution of air temperatures along the length of the false ceiling and tunnel from the station. "1" to st. "2" for the summer period.](image2)

Designation of summer lines (Figures 6 and 7):

- **Normative value of temperature**;
- **Tunnel air temperature during HDT when mixed with external (22.1)**;
- **Hottest Day Temperature (HDT): 22.3°C**;
- **Tunnel air temperature during summer period of day when mixed with external one (12.6)**;
- **Summer temperature**

When comparing the visualized results of the research work shown in Figures 6 and 7, we can conclude that when using a recirculation air exchange scheme, which ensures recirculation of air masses, in the high temperature range the air is cooled more intensively. This fact that we have established allows us to assume that it is possible to save electricity that is spent on fans. This can be achieved in various ways, for example by turning them off during the summer.
5 Conclusion

The results of our research work are in good agreement with the existing results of other researchers, primarily [1, 3, 10].

Based on the experiments performed and the experimental data obtained, a number of conclusions can be drawn:

During the work, planned ventilation schemes for double-track distillation tunnels were studied. A comparative processing of data from the proposed schemes was carried out, and actions were proposed to reduce the cost of electricity by the enterprise.

The use of a special ventilation duct in a general tunnel air exchange system, in comparison with traditional engineering solutions, will make it possible to eliminate the need for distillation ventilation units. This fact we established emphasizes the feasibility of the proposed air conditioning solutions, primarily for the city “X” [1, 3]. Arranging arological air exchange schemes using the method we propose will significantly increase safety during the evacuation of people in the event of an emergency, which may result in the formation of highly toxic substances and smoke (for example, in the event of a fire in a tunnel). In addition, when the outside air temperature decreases to values ranging from minus 15°C to minus 10°C, it will be possible to provide air heating by mixing it with part of the warm station air, which does not contradict the data of other researchers [1, 3] and the requirements the above regulatory documents, as well as “CR 298.1325800.2017 Ventilation systems of highway tunnels. Design rules”.

Our calculations are in good agreement with the results of other researchers and confirm our assumption that in order to ensure standard climate control indicators on existing metro lines with double-way distribution tunnels, it is necessary to use ventilation schemes based on air circulation between the tunnels and the false ceiling [1, 3].

It has been established that during high summer temperatures it is possible to reduce the electricity consumption of tunnel fans by turning off some of the ventilation units for a specified period. At the same time, the necessary microclimatic parameters of the air at the stations will be ensured using a recirculation ventilation scheme.

In connection with the results obtained, which are of practical interest, we consider it advisable to continue work in this direction.

References

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