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THE IMPORTANCE OF THE WF COEFFICIENT IN FORECASTING CLIMATIC CONDITIONS IN COAL EXCAVATIONS

The article presents the results of research on the formation of the WF coefficient in coal excavations. The WF coefficient determines the share of the wet surface of the excavation sidewall. The wet part of the excavation sidewall is covered partly by the water film, which evaporates, lowering the temperature of this surface. This coefficient is one of the principal parameters used in forecasting the changes in temperature and humidity of the mine air occurring on the way of contact between the excavation sidewall and the flowing air. During the determination of the coefficient value, the criterion of equality of the actual and forecasted ratios of sensible heat to total heat was assumed in the research methodology. Values of the WF coefficient in the examined excavations generally vary within the range of 0,1-0,6, and they are mostly dependent on the parameters related to the period of ventilation.

Keywords: longwalls; mining aerology; climate hazard prognosis; heat flux calculations; coal entries

1. Introduction

Forecasting the changes in the air temperature in mining excavations can be approached in many different ways. Deterministic methods with several simplifying assumptions are usually used for this purpose. The amount of heat released from the rock mass to the flowing air is calculated using Newton's conduction law. The changes in the sidewall temperature are determined by the solutions of Carslaw and Jaeger's differential equation of thermal conductivity [1]. A separate problem is the proper implementation of the process of moisture absorption by the mine air and its influence on the air and sidewall temperatures. At least four different approaches can be distinguished on this issue. The first one [2] assumes that the increase of specific humidity of

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air in the excavation section is directly proportional to the product of the share of the wet part of the excavation perimeter (WF coefficient), the difference between the specific humidity of air in the saturation and current state, the coefficient of humidity absorption. In addition, it is assumed that the ratio of the moisture and heat transfer coefficient is determined by the Lewis ratio. The increase in humidity is entirely at the cost of a decrease in air temperature. Later, the described approach was extended with the diffusion of water vapour from the rock mass [3]. In this case, some portion of the increase in air-specific humidity does not contribute to the decrease in air temperature.

In papers [4-7], it is proposed to distinguish the temperature of the sidewall into dry and wet (cooler) parts. Moisture evaporation takes place at the expense of air temperature and heat flowing from the rock mass. The temperature of the wet side surface can be calculated iteratively by using the equilibrium condition between the heat stream flowing into the wet surface and the sensible and latent heat streams absorbed by the air. It is also possible to adopt R. Ramsden's simplification, assuming that the difference between the dry and wet surface of the excavation is equal to the psychrometric difference of air [7]. In the mentioned studies, the WF factor determines the increase in specific air humidity and related decrease in air temperature. It influences the amount of heat flowing into the excavation from the rock mass as a result of sidewall temperature variation.

In papers [8,9], a correction factor called the thermal phase change coefficient of humidity is adopted. It determines the proportion between the fluxes of sensible and latent heat. Over the last 50 years, there have been successfully published papers concerning the influence of selected factors on the formation of the mentioned coefficient in mining excavations of the Upper Silesian Industrial Region [10-13]. In the approach presented in papers [8,9], the necessity of determining the moisture take-up coefficient and the WF coefficient is eliminated indirectly. Indirectly, because in the applied formula for the thermal phase change coefficient of humidity calculations [12], the author introduces an empirical coefficient depending on the degree of the excavation wetness.

It may be noted that the knowledge regarding the formation of sidewall wetness and factors affecting it is useful in forecasting changes in temperature and humidity of mine air, regardless of the adopted model of heat exchange. Bearing this in mind, it was decided to carry out research aiming to investigate the factors influencing the formation of WF. The second objective was to formulate empirical relations for estimating the values of this coefficient in coal excavations. For this purpose, the measurements of temperature, chemical composition, velocity and quantity of flowing air were collected. The surveys were carried out in selected excavations. Besides the ventilation measurements, additional data, including the mining and geological conditions were used to determine the actual and predicted values of heat fluxes. The calculated fluxes were used to test the consistency of the ratio between sensible and latent heat fluxes in both cases. In the determination of the ratios between sensible and latent heat fluxes, the thermal phase change coefficient of humidity was used. The adopted heat transfer model [6] is currently used in CLIMSIM [14] and VENTSIM [15]. The coefficient values were determined iteratively so that the actual and predicted ratios of sensible and latent heat fluxes (values of the phase change coefficient of humidity) were approximately equal. In the following sections of the paper, the research methodology is discussed in more detail. The influence of selected factors on the distribution of the coefficient in question is determined. The scale of discrepancies between the absolute values of the actual and predicted heat fluxes is examined, and the following conclusions are presented.

2. Methodology

In selected entries and longwalls, the following measurements were carried out: dry and wet bulb temperatures with the use of an Assmann psychrometer, average air velocity measured with electronic anemometers, and concentrations of oxygen, carbon dioxide, methane and carbon monoxide analysed with the use of multi-gas detectors or chromatographic analyses of pipette samples. Along with the measurements of temperature and airflow velocity, the excavation dimensions were measured, which made it possible to calculate its cross-sectional area (total and free for airflow) and to determine the amount of flowing air. The analysis of changes in carbon dioxide content was used to extend the model of heat exchange between the excavation sidewall and the flowing air presented in [6] with the heat stream related to oxidation of the coal face. It was assumed here that the measure of the intensity of coal oxidation in the excavations under study is the amount of carbon dioxide released. The drilled entries were ventilated by combined duct ventilation with a main pressing duct and auxiliary duct connected with a dust collector.

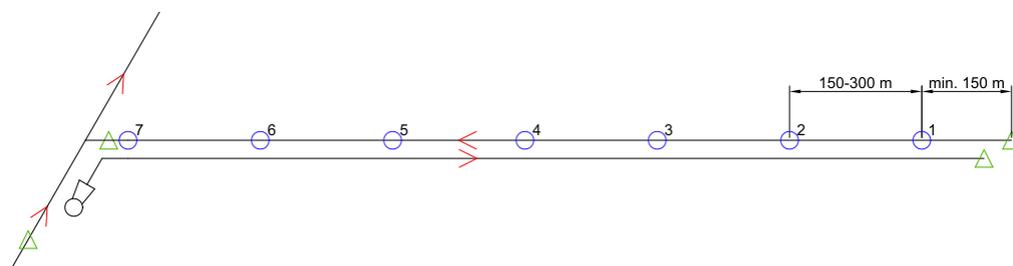


Fig. 1. Scheme of measurement location in an area of excavation ventilated by duct ventilation
 where: ○ – measurement stations of air temperature, humidity and velocity,
 Δ – measurement stations of gases concentration

Measurements of the air: temperature, velocity, and volume flow used in this analysis were carried out at the stations located along the air return path. The intervals between the following points did not exceed 300 m. The number of the measurement stations was dependent on the current length of the excavation (400-2968 m). The presented scheme (Fig. 1) shows an example of the location of the measurement stations. The samples for chemical composition analyses were taken: in front of the inlet to the main fan, in the heading face, and the cross-section of the outlet from the excavation. Concentration measurements in the heading face were made when the dedusting equipment was not in operation. In longwalls, measurements of the: temperature, velocity, and air quantity, as well as the samples for the chromatographic analyses were taken at the intake and outlet cross-sections of the excavations.

The research included only longwalls ventilated in the Y method with refreshment by the tail-gate, although the U method is prevailing in the Polish mining industry [16]. Longwalls ventilated in the U direction are not included in the research because the air heated and humidified in goaf returns to excavation in the second half of the length [17,18]. The influence of heat released to the goaf in longwalls ventilated in the U direction is so significant that it could distort the balance of sensible and latent heat gains between the excavation sidewall and the flowing air, which is the subject of the research. Measurements both in entries and in longwalls were performed at monthly

intervals. The results of the measurements were used to calculate the actual heat fluxes and the phase change coefficients. The calculations were conducted according to relations 1 and 2 [19].

$$q^* = \frac{\Delta i \cdot M_{da} \cdot 1000}{F_{av}} = \frac{[c_{da} \cdot \Delta t + r_w \cdot \Delta x] \cdot M_{da} \cdot 1000}{B_{av} \cdot L_{es}} \quad (1)$$

where:

- q^* — actual value of heat flux between two following measurement stations, calculated on the results of ventilation measurements, W/m^2 ;
- Δi — increase of specific enthalpy of air between two following measurement stations, kJ/kg ;
- M_{da} — mass flow of dry air between two following measurement stations, kg/s ;
- F_{av} — average sidewall area of between two following measurement stations, m^2 ;
- Δt — increase of dry bulb temperature of air between two following measurement stations, $^{\circ}C$;
- Δx — increase of specific humidity of air between two following measurement stations, kg/kg ;
- c_{da} — specific heat of dry air, $kJ/(kg \cdot K)$, 1,005;
- r_w — water evaporation heat, kJ/kg , 2450;
- B_{av} — average perimeter between two following measurement stations, m ;
- L_{es} — length of excavation section between two following measurement stations, m .

$$c^* = \frac{c_{da} \cdot \Delta t}{c_{da} \cdot \Delta t + \Delta x \cdot r_w} \quad (2)$$

where: c^* — thermal phase change coefficient of humidity between two following measurement stations, calculated on the results of ventilation measurements, $\%/100$.

The determination of specific humidity and air mass flow requires the estimation of air pressure at the measurement points. For this purpose the relation 3 [20] was used.

$$p = 101325 - 12 \cdot Z \quad (3)$$

where:

- P — air pressure, Pa ;
- Z — depth at measurement station, m .

The perimeters of the entries (yieldable arches) at the measurement stations were determined from their cross-sectional areas by the relation 4 [21].

$$B = 4,16 \cdot \sqrt{A} \quad (4)$$

where:

- B — excavation perimeter, m ;
- A — cross-sectional area of the excavation, m^2 .

Tables 1 and 2 show the ranges of the variability of the measurement results: air temperature, velocity, quantity, and carbon dioxide concentration. The tables contain information characterising the lengths of the measuring sections (distances between successive measuring points), primary

TABLE 1

Variation ranges of input data for the determination of WF values in driven corridor excavations

Exca- vation	Z m	ϑ °C	t °C	t_w °C	Δt °C	u m/s	L_{es} m	L_e m	τ days	A m ²	B m	A* m ²	k_c %/100	V m ³ /min	ΔV m ³ /min	C_{eo} %	C_d %	C_h %	V_h m ³ /min	V_{eo} m ³ /min	N
entry 2	892- 946	31,6- 33,0	23,2- 30,4	21,2- 28,2	0,0- 2,0	0,59- 0,84	150- 300	1588- 2968	17- 297	25,0	20,8	17,9	0,22	637- 900	10-50	0,12- 0,22	0,11- 0,16	0,11- 0,16	405- 580	902- 940	43

where: Z – depth of the excavation (measurement point), ϑ – primary temperature of the rock mass in the excavation at the depth of the measurement point, t – air temperature of dry bulb thermometer, t_w – air temperature of wet bulb thermometer, Δt – air temperature of dry bulb increase in measuring sections (distance between two measurement points), u – mean air flow velocity, L_{es} – length excavation between two following measurement points, L_e – length of whole excavation, τ – ventilation period, A – cross-section area of the excavation, B – perimeter of the excavation, A* – cross-section area of the excavation free to air flow, k_c – share of coal in the excavation perimeter, V – mean air flow, ΔV – change of air flow in measuring section caused by leakage of duct (driven corridor excavations) or escapes of air into goaf (longwalls), C_{eo} – carbon dioxide concentration in the cross-section of the driven excavation outlet, C_d – carbon dioxide concentration at the main ventilator inlet, C_h – carbon dioxide concentration in the face of heading, V_h – air flow in the cross-section of the main duct outlet, V_{eo} – air flow in the cross-section of the excavation outlet.

TABLE 2

Variation ranges of input data for the determination of WF values in longwalls

Excavation	Z m	ϑ °C	t °C	t_w °C	Δt °C	u m/s	L_e m	τ days	A m ²	B m	A* m ²	k_c %/100	V m ³ /min	ΔV m ³ /min	ΔCO_2 %	N
longwall 2	950- 977	42,6- 43,0	27,6- 30,8	23,4- 26,8	2,6-3,0	1,89- 1,91	187- 196	0,88- 6,00	23,0- 24,5	19,7- 20,2	12,0	0,14-0,15	1362- 1374	<20	0,03- 0,07	6
longwall 3	829- 856	38,9- 39,2	25,0- 30,2	21,2- 27,4	2,6-4,4	1,69- 1,78	223	0,78- 1,37	15,2- 16,4	17,1- 17,5	10,0	0,12-0,13	1014- 1044	<20	0,04- 0,06	7
longwall 4	993- 1032	44,3- 45,2	20,8- 32,4	16,8- 29,6	7,6-9,2	3,19- 3,35	232	0,98- 3,75	18,7- 21,8	18,3- 19,3	6,0	0,13-0,15	1148- 1206	<60	0,04- 0,09	9
longwall 5	816- 823	38,6- 38,8	26,2- 30,4	22,0- 26,8	3,8-4,0	1,94- 2,68	241	1,94- 2,13	26,3	20,8	10,0	0,17	1164- 1605	<10	0,05	2

where: ΔCO_2 – carbon dioxide concentration increase in excavation.

temperatures of the rock mass, depths of the measuring points, ventilation periods and shares of coal in the excavation perimeter. The data, whose ranges of variation are presented in Tables 1 and 2, constituted the input data set for the conducted research.

The information in Table 1 shows that due to the short intervals between the following measurement points, the changes in air expenditure in entries were small. Therefore, when determining the heat fluxes, the influence of duct leakages could be neglected. In longwalls (Table 2), the examined escape of air was practically imperceptible to the overall volume flow in the excavations. It can be observed that the number of measurement points was sufficient in the determination of the heat gains and examination of their nature. If the change in the airflow was much higher, e.g. more than 20%, then due to greater variation in the speed and quantity of flowing air, the application of relation of 1 would be erroneous. In the cases under consideration, the amount of air escaping into the goaf was comparable to the error resulting from the accuracy of the airflow velocity measurement (0,01 m/s).

As outlined in the introduction to the paper, the values of the WF coefficient were determined to ensure a condition presented in equation 5 for each section between the following measurement stations.

$$c \approx c^* \quad (5)$$

where: c — thermal phase change coefficient of humidity based on the predicted sensible and latent heat fluxes, %/100.

The thermal phase change coefficient of humidity c can be calculated by the relation 6 [19]:

$$c = \frac{q_s}{q} = \frac{q_s}{q_s + q_l} \quad (6)$$

where:

- q_s — sensible heat flux absorbed by the flowing air from the moist excavation sidewall surface, W/m^2 ;
- q — heat flux (total) absorbed by the flowing air from the moist (moist \neq completely wet) excavation sidewall surface, W/m^2 ;
- q_l — latent heat flux absorbed by the flowing air from the moist excavation sidewall surface, W/m^2 .

The sensible heat flux absorbed by the air from the excavation sidewall surface is described by the following relationship:

$$q_s = q_{sd} \cdot (1 - WF) + q_{sw} \cdot WF \quad (7)$$

where:

- q_{sd} — heat stream (sensible) absorbed by the flowing air from the dry sidewall surface, W/m^2 ;
- q_{sw} — sensible heat flux absorbed by the flowing air from the wet sidewall surface, W/m^2 .

The latent heat flux is determined by the equation:

$$q_l = q_{lw} \cdot WF \quad (8)$$

where: q_{lw} — heat stream absorbed by the flowing air from the wet sidewall surface, W/m^2 .

An increase in the value of the WF coefficient results in a decrease in q_s and increases in q_l and c . To determine the appropriate values of the coefficient (satisfying the condition given in eq. 5), it is necessary to know the fluxes: q_{sd} , q_{sw} and q_{lw} . The heat flux absorbed by the flowing air from the dry sidewall of the excavation could be determined by relation 9.

$$q_{sd} = \alpha \cdot \frac{G}{Bi} \cdot (\vartheta - t_{id}) + q_o \quad (9)$$

where:

- α — heat transfer coefficient, $W/(m^2/K)$;
- G — Gibson number;
- B_i — Biot number;
- ϑ — primary rock mass temperature, $^{\circ}C$;
- t_{id} — dry bulb air temperature in the cross-section of the inlet to excavation segment, $^{\circ}C$;
- q_o — heat flux released during low-temperature oxidation of coal, W/m^2 .

The values of geothermal parameters (rock thermal conductivity and diffusivity coefficient) were determined by the empirical relationships depending on the share of coal in the excavation perimeter [21]. The overall heat flux absorbed by the flowing air from the wet sidewall surface of the excavation is described by the relation:

$$q_w = \alpha \cdot \frac{G}{Bi - G} \cdot (\vartheta - t_{ws}) + q_o \quad (10)$$

where:

- q_w — heat stream absorbed by the flowing air from the wet sidewall surface, W/m^2 ;
- t_{ws} — temperature of the wet surface of the excavation sidewall, $^{\circ}C$.

Simultaneously, stream q_w is the sum of the sensible and the latent heat flux (eq. 11).

$$q_w = (q_{sw} + q_{lw}) \quad (11)$$

where:

- q_{sw} — sensible heat flux absorbed by the flowing air from the wet sidewall surface, W/m^2 ;
- q_{lw} — latent heat flux absorbed by the flowing air from the wet sidewall surface, W/m^2 .

These two further fluxes are defined by equations 12 and 13.

$$q_{sw} = \alpha \cdot (t_{ws} - t_{id}) \quad (12)$$

$$q_{lw} = \frac{\alpha}{\sigma} \cdot (x_{ws} - x_i) \cdot r_w \quad (13)$$

where:

- q_{lw} — heat stream absorbed by the flowing air from the wet sidewall surface, W/m^2 ;
- σ — mass (moisture) transfer coefficient, $kg/(m^2/s)$;
- x_i — specific humidity of air in the cross section of the inlet to excavation segment, kg/kg ;
- x_{ws} — specific humidity of saturated air in the temperature of the wet surface of the excavation sidewall, kg/kg ;
- r_w — water evaporation heat, kJ/kg , 2450.

In engineering practice, determining the mass (moisture) transfer coefficient between the water surface and the air is usually based on Lewis' ratio. The ratio is expressed by equation 14 [22].

$$\frac{\alpha}{\sigma} = c_{da} + c_{wv} \cdot x_i \quad (14)$$

where:

- c_{da} — specific heat of dry air, kJ/(kg·K), 1,005;
 c_{wv} — specific heat of water vapour, kJ/(kg·K), 1,864;

The procedure of iterative determination of fluxes: q_w , q_{sw} and q_{lw} comes down to finding such a value of t_{ws} for which the condition in eq. 11 would be met. In the first step, it is usually assumed that the temperature of the wet surface of the excavation sidewall is equal to the value of wet bulb temperature at the inlet to excavation segment.

The heat flux emitted during low-temperature oxidation of the coal face can be determined by the results of laboratory analyses of air composition – pipette samples or multi-gas detector indications. In the case of longwalls, the following relation was used:

$$q_o = \frac{\left(\frac{\Delta CO_2}{100} \cdot V \cdot \rho_{CO_2} \cdot \frac{12}{44} cv \right)}{F_e} \quad (15)$$

where:

- ΔCO_2 — percentage increase in concentration of carbon dioxide in the excavation, %;
 V — air flow in the excavation, m³/s;
 ρ_{CO_2} — carbon dioxide density, kg/m³;
 cv — calorific value of carbon, kJ/kg, 26395 – entries, 28700 – longwalls;
 F_e — overall sidewall area of excavation, m².

In entries, calculations of the heat flux from low-temperature oxidation of coal are somewhat more complex. The reason is the variability of airflow in the excavation caused by air inflows from the duct. In the research, the following relation was used:

$$q_o = \frac{\left(\frac{M_{CO_2}}{100} \cdot \frac{12}{44} cv \right)}{F_e} \quad (16)$$

where: M_{CO_2} — mass flow of carbon dioxide emitted in the excavation, kg/s.

The mass flow of carbon dioxide emitted along the measurement section was calculated using the formula:

$$M_{CO_2} = [C_{eo} \cdot V_{eo} - (C_d \cdot V_d + C_h \cdot V_h)] \cdot \rho_{CO_2} \quad (17)$$

where:

- C_{eo} — carbon dioxide concentration in the cross-section of the excavation outlet, %/100;
 C_d — carbon dioxide concentration in duct, %/100;

- C_h – carbon dioxide concentration in heading, %/100;
 V_{eo} – air flow in the cross-section of excavation outlet, m³/s;
 V_d – air flow in duct, m³/s;
 V_h – air flow in heading, m³/s.

The presented methodology assumes that the dominant source of heat (both sensible and latent) is the exchange between the excavation sidewall and the flowing air. This kind of assumption needs to be verified. Therefore, after determining the values of the WF coefficient, it was decided to investigate the discrepancies between the real and the predicted value of the heat flux (formula 18).

$$\delta = \frac{q^* - q}{q^*} \quad (18)$$

where: δ — relative error between the real and the predicted value of heat flux, %/100.

A wide range of information was used during this study. Besides the parameters relating to the physical state of the air, broad scope of data characterising mining and geological conditions were also employed. Upon designing the research methodology more confidence was given to the physical parameters of air than to other data. For this reason, the research methodology relies mainly on the criterion presented in eq. 5 rather than the minimisation of discrepancies between predicted and actual heat fluxes. Discrepancies, after determining their causes, could be corrected with additional relationships developed under statistical methods. The entire calculation procedure presents a diagram in Fig. 2.

3. Discussion of the results

Due to the wide range of output data, the analysis was limited to the most significant parameters (c^* , q^* , q , q_o , WF , and δ). Table 3 shows the ranges of variation of the listed parameters. From the original dataset (115 cases), 14 of them did not meet the condition: $|\delta| \leq 100\%$ and were eliminated from further analysis. After exclusion, the share of data related to entries remains at the same level (72%).

TABLE 3

Summary of selected output parameters

Excavation	c^*	q^*	q	q_o	WF	δ	N
	%/100	W/m ²	W/m ²	W/m ²	%/100	%/100	
Entry 1	0,23-0,30	2-12	2-9	0-2	0,07-0,29	0,03-0,96	32
Entry 2	0,12-0,31	3-12	3-11	0-4	0,11-0,33	0,01-0,74	41
Longwall 1	0,20-0,29	53-81	72-101	25-47	0,41-0,48	0,15-0,57	7
Longwall 2	0,25-0,43	46-95	81-153	28-67	0,33-0,57	0,17-0,86	4
Longwall 3	0,17-0,26	56-109	84-106	28-42	0,48-0,55	0,01-0,50	6
Longwall 4	0,21-0,29	155-233	102-153	27-63	0,38-0,48	0,30-0,48	9
Longwall 5	0,23-0,24	79-111	72-85	30-42	0,54-0,58	0,10-0,24	2

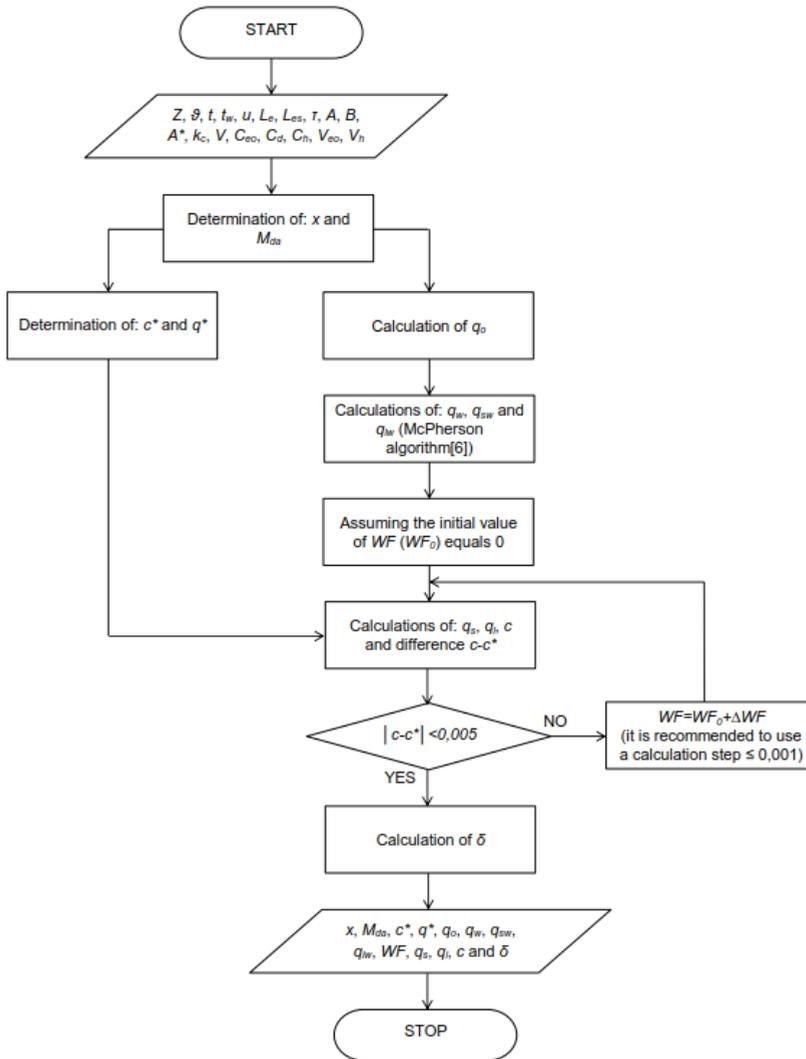
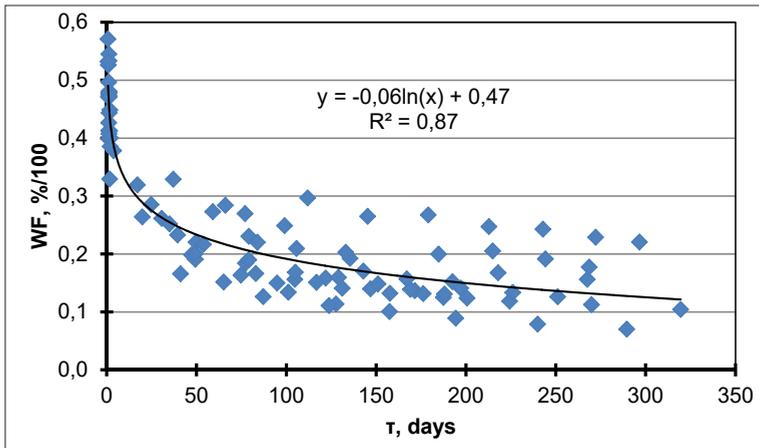
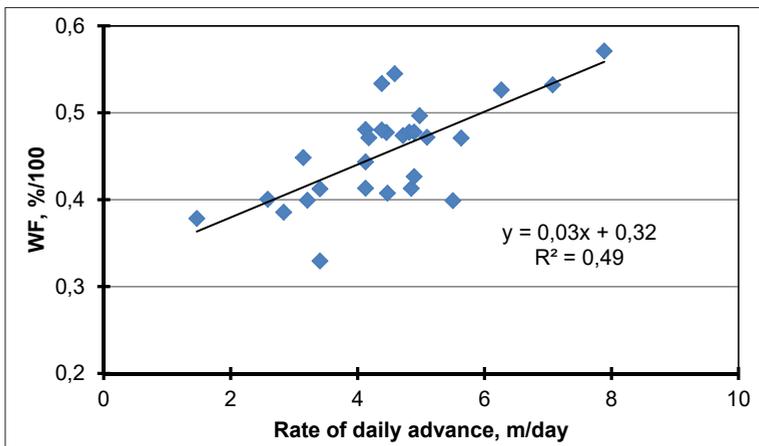


Fig. 2. Scheme of the calculation procedure

The output data indicates that the ventilation period is mostly correlated with WF formation (Fig. 3).

A higher fitting index can be obtained if the product of the ventilation period and the flow rate is taken into account ($R^2 = 0,88$). The distribution indicates that in a relatively narrow range of τ (close to 0), there is a strong diversification of WF . The mentioned scope is characteristic of longwalls. The observation reflects Fig. 4, which shows the formation of the WF against the average daily progress.

The rate of daily advances is a quotient of the length of the working interval to the ventilation period. The following graph (Fig. 5) shows that the values of the WF coefficient increase

Fig. 3. Formation of WF as a function of τ Fig. 4. Formation of WF as a function of the rate of daily advance

proportionally to the amount of the actual heat flux. This relationship characterises a high correlation index. Unfortunately, in the case of longwalls ($q^* > 50 \text{ W/m}^2$), the fit is poor.

The analysis of air temperature impact on the formation of WF is redundant. In the case of galleries, the results of measurements are instantaneous from the perspective of ventilation periods duration.

The basis of the WF calculations was the fulfilment of the condition: $c \approx c^*$ (eq. 5). Therefore, the formulas shown on the graphs (Fig. 3-5) should be sufficient to correct predictions of the air relative humidity changes. It is indispensable to estimate the discrepancies between the real and the predicted absolute increments of air humidity. Assuming that the forecast error of the air relative humidity change is marginal, the divergences of $\frac{\Delta t}{\Delta x}$ are negligible. Thus, the

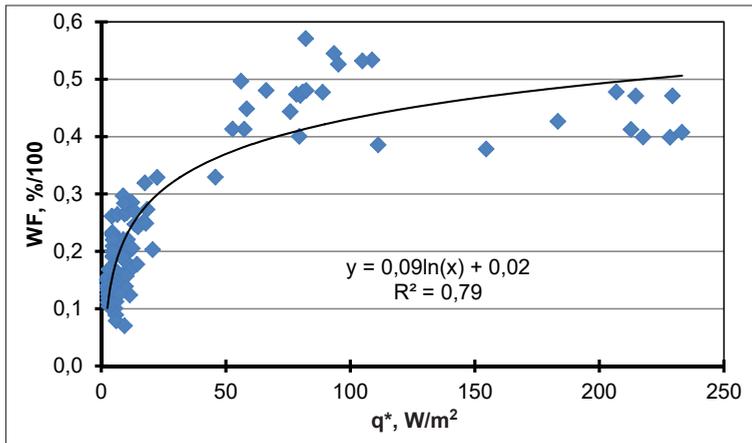


Fig. 5. Formation of WF as a function of the real heat flux

investigation of the discrepancy between the real and predicted absolute air humidity increments can rely on the formation of δ .

The next step of the analysis focused on the results of δ calculations. The average value of the relative error module $|\delta|$ for both entries and longwalls is quite similar (40% for galleries and 33% for longwalls). In the case of longwalls, some errors result from heat flux overestimation. It may be caused by assuming too short ventilation periods compared to the real values. Less precision in determining the time of excavation ventilation results from high volatility in the extraction advance. In the case of entries, one of the reasons could be the accuracy of the ventilation measurements associated with relatively small temperature increments. To test this hypothesis, the cases for which: $\Delta t > 0,4^{\circ}\text{C}$ were removed from the database. The relative error increased to 41%, which means that the accuracy remains around a similar level. The impact of ventilation measurement precision did not interfere with the conclusions of the conducted research.

In addition, low-temperature oxidation of coal plays a significant role in the forming climatic conditions in coal excavations. During the calculations, the chromatographic analyses were taken into account. The samples were collected at the headings and nearby the excavations outlets. Hence, the heat fluxes are averaged over the entire length of excavations. The surveyed sections characterise broad variability of ventilation periods, and this parameter (more precisely Fourier number) also influences the heat flux from low-temperature oxidation [23]. The use of average values for short-ventilated sections can generate underestimation, but in the case of long-ventilated ones, it could result in revaluation. In predicting climatic conditions, the relationships determining heat fluxes from low-temperature oxidation of coal may be helpful [24,25].

4. Conclusions

The results of the performed research allowed the author to formulate the following conclusions about the formation of the WF coefficient in mining excavations:

1. Values of the WF coefficient in excavations generally fall within a wide range from 0,1 to 0,6. In longwalls, the scope of the values is much closer and is within 0,3-0,6.

2. Among the parameters considered in the analysis, the ventilation period is the most correlated with the formation of the WF coefficient ($R^2 = 0,87$).
3. Prognoses based on the adopted heat exchange model [6] and empirical results of WF formation studies (Fig. 3-5) should be enough to ensure the high accuracy of the ratio: $\frac{\Delta t}{\Delta x}$.
The average relative error of the heat flux is about 40%. According to the variety of variables and complexity of calculations, the scale of error can be considered acceptable.
4. The formulated relationships can be successfully applied in performing forecasts of climatic conditions utilising *Ventsim* software.
5. It is vital to conduct further research on the formation of the WF coefficient. The following works should be aimed at more detailed measurements in longwalls and the applicability of the formulated relations in forecasting climatic conditions in the headings of drilled excavations.

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