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# THE APPLICATION OF OXYGEN CONSUMPTION CALORIMETRY TO DETERMINE THE FLAMMABILITY OF CHLOROPRENE CONVEYOR BELTS

# WYKORZYSTANIE KALORYMETRII ZUŻYCIA TLENU DO OCENY PALNOŚCI CHLOROPRENOWYCH TAŚM PRZENOŚNIKOWYCH

Conveyor belts, as currently in coal mines, present a considerable fire risk, and therefore an important consideration is that these they should be fire resistanton. The paper presents a new methodology of investigation of conveyor belt flammability, worked out on the basis of the oxygen consumption calorimetry method, using Thornton's rule (according to which the heat released during the combustion of the organic materials — per specific mass of oxygen consumed — is constant). By this means it is possible to calculate the heat released during combustion of the conveyor belt located in the full-scale fire-testing gallery, using the formula (12). The heat released during the combustion of conveyor belts located in a fire-testing gallery depends on the length of the conveyor belt being burned (Fig. 3). The total heat released (*THR*) and the average effective heat of combustion ($HOC_{av}$) (Table 1) determined by means of the cone calorimeter method further allows for the determination of the heat released during the fire in the fire-testing gallery. The heat released during the fire of the conveyor belt calculated using the above methodology demonstrates the correlation with the length of the conveyor belt burned in the fire-testing gallery (Figs. 4 and 5). The correlation demonstrated leads to the development of a methodology allowing the length of the conveyor belt which would be burned during the fire in the fire-testing gallery to be predicted on the basis of the results of the cone calorimeter test (Figs. 6 and 7; formula 14 and 15). The critical temperature of the belt's surface (formulas 16–20) — representing the belt's surface temperature during ignition — may be determined based on the time *of sustained* ignition obtained using the cone calorimeter method. It is the correlation binding the critical temperature of the belt's surface with the length of the belt burned in the fire-testing gallery (Fig. 8) that allows for the determination of the limit value ($T_{ig,cr}$ = 264°C) which further establishes the criterion for fulfilling currently applicable fire safety regulations for the full-scale gallery test.

**Key words:** conveyor belt, flammability, gallery test, cone calorimeter

Taśmy przenośnikowe stosowane w kopalniach stwarzają duże zagrożenie pożarowe, w związku z czym wymaga się, aby były one trudno palne. W pracy przedstawiono nową metodę badania palności

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taśm przenośnikowych, która opracowana została w oparciu o kalorymetrię zużycia tlenu, wykorzystującą regułę Thorntona, według której ciepło wydzielane podczas spalania substancji organicznych, w odniesieniu do jednostki masy zużytego podczas spalania tlenu, ma wartość stałą. Wykorzystując wzór (12) można obliczyć ilość ciepła wydzielającego się podczas spalania taśm przenośnikowych w sztolni pożarowej. Ciepło wydzielone podczas spalania taśmy w sztolni pożarowej zależy od długości spalonego w sztolni odcinka taśmy (rys. 3). Oznaczone za pomocą kalorymetru stożkowego: całkowita ilość wydzielonego ciepła (*THR*) i średnie efektywne ciepło spalania ($HOC_{av}$), pozwalają na obliczenie ciepła, jakie wydzieli się podczas spalania taśmy w sztolni pożarowej (tabl. 1). Obliczone w ten sposób wartości ciepła, które wydzieli się podczas spalania taśm wykazują korelację z długością odcinków taśm spalonych w sztolni pożarowej (rys. 4 i 5). Zależności te pozwalają na prognozowanie na podstawie wyników badań uzyskanych przy użyciu kalorymetru stożkowego długości odcinków taśm, które spaliłyby się w sztolni (rys. 6 i 7, wzór 14 i 15). Na podstawie oznaczonej przy użyciu kalorymetru stożkowego wartości czasu potrzebnego do wystąpienia zapłonu taśmy można obliczyć krytyczną temperaturę powierzchni taśmy (wzory 16–21), określającą temperaturę powierzchni taśmy w chwili zapłonu. Zależność pomiędzy krytyczną temperaturą powierzchni taśmy a długością odcinka taśmy, która uległa spaleniu w sztolni pożarowej (rys. 8), pozwala na określenie wartości granicznej ($T_{ig,cr}$ = 264°C) stanowiącej kryterium spełnienia wymagań palności na poziomie obecnie obowiązującym dla sztolni pożarowej.

**Słowa kluczowe:** taśma przenośnikowa, palność, badanie, sztolnia pożarowa, kalorymetr stożkowy

## 1. Introduction

Conveyor belts are most important products made from non-metallic materials used in the coal mining process. The specific conditions under which the conveyor belts operate make them to become one of the major exogenic fire risks in coal mines. Fires of conveyor belts are to blame for the death of numerous workers and also considerable losses of mine assets. These fire statistics particularly demonstrate the fire risk related to the operation of conveyor belts. In exact numbers, two hundred and forty two (242) miners died in the years 1947–1989 in fires resulting from conveyor belt ignition in Polish mines alone (Zyska 1992). Similar accidents also took place in other countries. The tragic fire in the Creswell Mine, UK back in 1950 cost the lives of 80 miners (Cutler 1979), 27 miners were killed in 1984 in the Wilbert Mine, US (Luzik 1990) and 73 miners died in 1988 in one of the Japanese mines (Zyska 1992). Therefore, in countries mining coal there is a need for fire regulations covering conveyor belts which are designed for underground coal transportation. The belt is considered as fire resistant if:

- it does not catch fire when the belt becomes jammed and the drum keeps on turning, despite an increased temperature of the belt and drum,
- the flames do not propagate faster on the conveyor belt than on other materials located in the fire zone and the fire is extinguished outside the fire zone.

As for the time being there is no uniform, universal method on the basis of which it is possible to determine conveyor belt flammability. On the contrary, at present conveyor belt flammability is determined according to arbitrarily assumed flammability criteria. As a result of this situation it is difficult to compare the levels of risk for the same material used for the fabrication of conveyor belts, based on results obtained from numerous test methods — as they do not provide universal consistent information and strongly reflect the specific test conditions. Fortunately, over the years, fundamental research in combustion processes has led to the development of bench-scale fire tests that measure the important aspects of flammability and can interpreted in terms of underlying theories of combustion. This further leads to a more precise definition of phenomena, such as ignition, flame propagation, heat release rate, closely related to the course of the fire. The above parameters may be determined using the cone calorimeter and further used for the purpose of building the simplified models of conveyor belt fires.

## 2. A theoretical basis for oxygen consumption calorimetry

In 1917, W.M. Thornton (1917) showed that the heat released during the complete combustion of the majority of liquid and gaseous organic materials has a constant value in respect of the specific mass of oxygen consumed. In 1980 C. Huggett (1980) proved that the same rule also applies to solid organic materials and gave the average value — which totals to 13.1 kJ · kg$^{-1}$. Thus the Thornton rule allows for the calculation of the amount of heat released during fire, based on the measurement of the oxygen consumed in the process and provides the basis for a method of determining the heat release rate. This method is applied in the majority of fire tests (oxygen consumption calorimetry). The method based on the oxygen consumption during the fire of the organic materials has been stated to be the most accurate and simple way to practically measure the dynamics of the heat released. The very basic requirement for the application of the oxygen consumption method is to ensure the possibility to collect all the combustion products, which are usually removed through the duct extracting combustion gases — the combustion gas velocity is being sampled as well as the gas composition. W.J. Parker (1984) published equations allowing for the calculation of the amount of heat released during the fire (based on the oxygen consumption method) for numerous practical applications.

The total amount of heat released during the fire may be calculated by means of the formula:

$$Q_{tot} = (X^{0}_{O_2} V_0 - X^{S}_{O_2} V_S) \rho_{O_2} E \tag{1}$$

where:

- $Q_{tot}$ — total heat released rate [MW],
- $X^{0}_{O_2}$ — oxygen concentration in the incoming air (molar fraction),
- $V_0$ — volume flow of air into the combustion zone [m$^3$ · s$^{-1}$],
- $X^{S}_{O_2}$ — oxygen concentration in the combustion gases leaving the combustion zone (molar fraction),
- $V_S$ — volume flow of gases flux leaving the combustion zone [m$^3$ · s$^{-1}$],

$\rho_{O_2}$ — oxygen density [kg · m$^{-3}$],
$E$ — heat released during the combustion of the organic materials per unit mass of oxygen consumed, assuming that carbon goes to carbon dioxide (E = 13.1 MJ/kg).

In order to simplify the implementation of formula (1), the heat released during the combustion can be standardised to the unit of oxygen volume at the reference conditions of 25°C:

$$E' = \rho_{O_2} E \tag{2}$$

where:

$E'$ — heat released during the combustion of the organic materials per unit of consumed oxygen mass at the reference conditions of 25°C, assuming that carbon goes to carbon dioxide ($E$ = 17.2 MJ/kg).

Thus formula (1) describing the total heat released would take the form:

$$Q_{tot} = (X^0_{O_2} V_0 - X^S_{O_2} V_S) E' \tag{3}$$

Formula (3) is ideally suited for use at test facilities in which the oxygen concentration is measured with a paramagnetic analyzer (high temperature cells). This requires removal of moisture from the sampling stream, and then the oxygen concentration in the analyzer will differ from that in the exhaust duct. Because of the fact that the ratio of oxygen to nitrogen concentration in the analyzer is same as in the exhaust gas, it was found that the implementation of the expression $Z$ would facilitate the calculation of the dynamics of the heat release:

$$Z = \frac{X^S_{O_2}}{X^S_{N_2}} = \frac{X^A_{O_2}}{X^A_{N_2}} \tag{4}$$

where:

$X^S_{N_2}$ — nitrogen concentration in the combustion gases leaving the combustion zone (molar fraction),
$X^A_{O_2}$ — oxygen concentration in the combustion gases determined in the analyzer (molar fraction),
$X^A_{N_2}$ — nitrogen concentration in the combustion gases determined in the analyzer (molar fraction).

The ratio of oxygen to nitrogen concentration in the air supplied to combustion zone is given by formula (5):

$$Z_0 = \frac{X^0_{O_2}}{X^0_{N_2}} = \frac{X^{A_0}_{O_2}}{X^{A_0}_{N_2}} \tag{5}$$

where:

$X^0_{N_2}$ — nitrogen concentration in the air supplied to combustion zone (molar fraction),

$X^{A_0}_{O_2}$ — oxygen concentration in the air supplied to combustion zone determined in the analyzer (molar fraction),

$X^{A_0}_{N_2}$ — nitrogen concentration in the air supplied to combustion zone determined in the analyzer (molar fraction).

The mass conservation rule provides that:

$$X^0_{N_2} V_0 = X^S_{N_2} V_S \tag{6}$$

From formula (4), (5) and (6) it follows that:

$$\frac{Z}{Z_0} = \frac{X^S_{O_2}}{X^0_{O_2}} \frac{V_S}{X_0} \tag{7}$$

Substituting formula (3) with (7):

$$Q_{tot} = \left(1 - \frac{Z}{Z_0}\right) E' X^0_{O_2} V_0 \tag{8}$$

From formula (8) it seems that the heat released during the combustion process can be expressed in terms of the ratio $Z/Z_0$.

In the case of that the oxygen concentration being measured by means of a paramagnetic analyzer $Z$ and $Z_0$ may be calculated using the below given formulas:

$$Z = \frac{X^A_{O_2}}{1 - X^A_{O_2} - X^A_{CO} - X^A_{CO_2}} \tag{9}$$

$$Z_0 = \frac{X^{A_0}_{O_2}}{1 - X^{A_0}_{O_2} - X^{A_0}_{CO_2}} \tag{10}$$

Thus combining formula (8), (9) and (10) the following may be obtained for the heat released during combustion:

$$Q_{tot} = \left[1 - \frac{X^A_{O_2}}{X^{A_0}_{O_2}} \left( \frac{1 - X^{A_0}_{O_2} - X^{A_0}_{CO_2}}{1 - X^A_{O_2} - X^A_{CO} - X^A_{CO_2}} \right)\right] E' X^0_{O_2} V_0 \tag{11}$$

In the case that the content of moisture and gaseous impurities in the combustion air as well as the content of carbon monoxide (CO) in the combustion gases are small and can be neglected and also carbon dioxide ($CO_2$) is being removed from the oxygen analyzer, the formula (11) may be simplified to the following form:

$$Q_{tot} = \frac{X_{O_2}^{A_0} - X_{O_2}^{A}}{1 - X_{O_2}^{A}} E' V_0 \tag{12}$$

Formula (12) may be used in the case that $V_0$ (volume flow of air into the combustion zone) is being determined in a direct way. The investigation of conveyors belt flammability in the fire testing gallery fulfills the conditions given above.

### 3. Investigation of conveyor belts flammability using the cone calorimeter

The cone calorimeter is currently the most widespread apparatus using the oxygen consumption method, in use for bench-scale investigations of material flammability. The cone calorimeter was constructed at National Bureau of Standards (USA) by V. Babrauskas (1984). The cone calorimeter consists of a conical heater comprising a 5-kW electrical heating element, a spark igniter, a mass sampling device, a combustion gas removal system with an oxygen analyzer and a flow-meter for combustion gas sampling as well, as a computer for data acquisition and data analysis purposes (Fig. 1). Conveyor belt flammability investigations utilising the cone calorimeter were carried out according to the procedure included in ISO 5660 standard, applying a horizontal

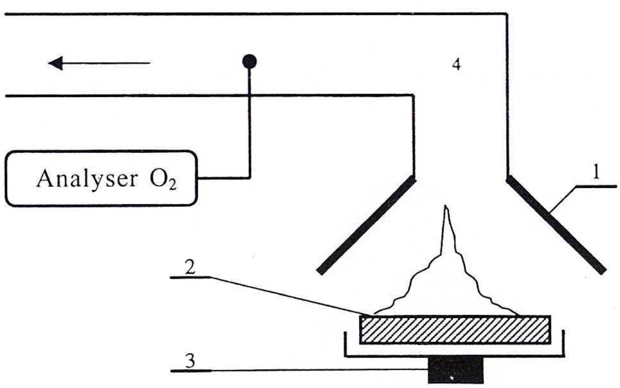


Fig. 1. Diagram of the cone calorimeter
1 — cone shaped electrical radiator, 2 — the sample holder, 3 — device for continuous sampling of the mass of examined sample, 4 — exhaust system removing the combustion gases

Rys. 1. Schemat kalorymetru stożkowego
1 — promiennik elektryczny w kształcie stożka, 2 — badana próbka, 3 — urządzenie do ciągłego pomiaru masy badanej próbki, 4 — wyciąg odprowadzający produkty spalania

TABLE 1

The results of the flammability of chloroprene conveyor belts using the cone calorimeter

TABLICA 1

Wyniki badania palności taśm przenośnikowych chloroprenowych metodą kalorymetru stożkowego

| Item. | Sample reference No. | Density of the heat flux 50 kW · m$^{-2}$ | | | Density of the heat flux 75 kW · m$^{-2}$ | | |
|---|---|---|---|---|---|---|---|
| | | Time to ignition, $TI$ [s] | Total heat release, $THR$ [MJ · m$^{-2}$] | Average effective heat of combustion, $HOC_{av}$ [MJ · kg$^{-1}$] | Time to ignition, $TI$ [s] | Total heat release, $THR$ [MJ · m$^{-2}$] | Average effective heat of combustion, $HOC_{av}$ [MJ · kg$^{-1}$] |
| 1 | 310/97 | 101.8 | 168.72 | 13.38 | 33.33 | 198.55 | 14.75 |
| 2 | 329/97 | 66.94 | 112.49 | 13.58 | 23.73 | 151.90 | 19.23 |
| 3 | 316/97 | 65.27 | 143.70 | 12.10 | 18.84 | 185.23 | 15.70 |
| 4 | 20/96 | 64.39 | 122.80 | 9.57 | 23.21 | 233.63 | 15.24 |
| 5 | 26/97 | 71.86 | 84.38 | 8.87 | 29.68 | 133.53 | 12.97 |
| 6 | 280/97 | 47.41 | 120.20 | 14.56 | 19.49 | 141.69 | 19.80 |
| 7 | 100/97 | 28.64 | 188.49 | 16.19 | 29.58 | 179.85 | 16.40 |
| 8 | 69/97 | 41.24 | 131.51 | 13.89 | 16.70 | 219.55 | 17.89 |
| 9 | 25/96 | 41.79 | 204.69 | 19.40 | 17.87 | 203.31 | 18.23 |

positioning of the belt sample and irradiance level of 50 and 75 kW/m$^2$. The results of the belt conveyor flammability investigations are presented in table 1 (Wachowicz 2000).

## 4. Prediction of the conveyor belt flammability in the full-scale gallery test using the cone calorimeter

Conveyor belt flammability as determined by means of full-scale gallery test is characterized by the ability of the belt fire to extinguish itself outside the fire area (the assumption for the test are the conditions wherein the fire is initiated by burning 300 kg of a dry pine wood — (see Fig. 2). The maximum allowable length of the conveyor belt which may be burned during the fire (40 m), determines the criterion for fulfilling the test conditions. It is possible to calculate the amount of heat released during the conveyor belt combustion in the fire testing gallery on the basis of oxygen consumption calorimetry (Wachowicz 1997). It was found that there is a linear correlation (13)

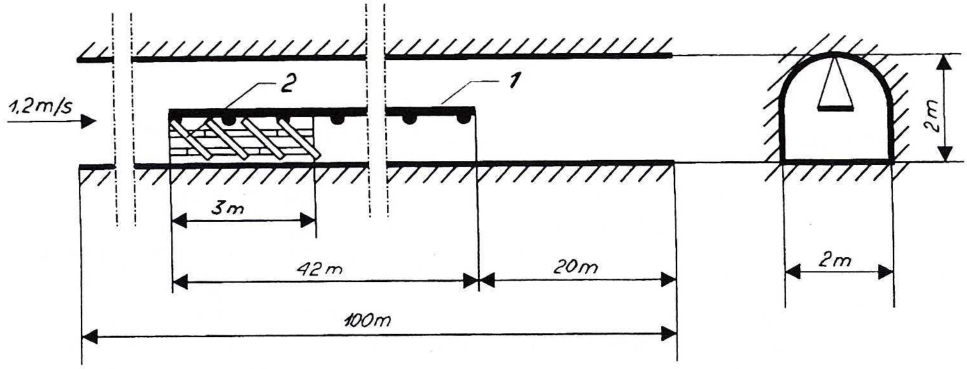


Fig. 2. Diagram of the fire-testing gallery for investigation of the conveyor belts flammability
1 — the sample of testing belt, 2 — pine wood for initiating fire

Rys. 2. Schemat sztolni pożarowej do badań palności taśm przenośnikowych
1 — próbka taśmy przenośnej, 2 — podpałka (drewno)

between the heat released during the conveyor belt flammability test and the length of the burned conveyor belt (Fig. 3).

$$Q = 182L_s - 473 \tag{13}$$

The correlation coefficient was found to be $r = 0.9606$, with a certainty the confidence level of 99% (Wachowicz 2000).

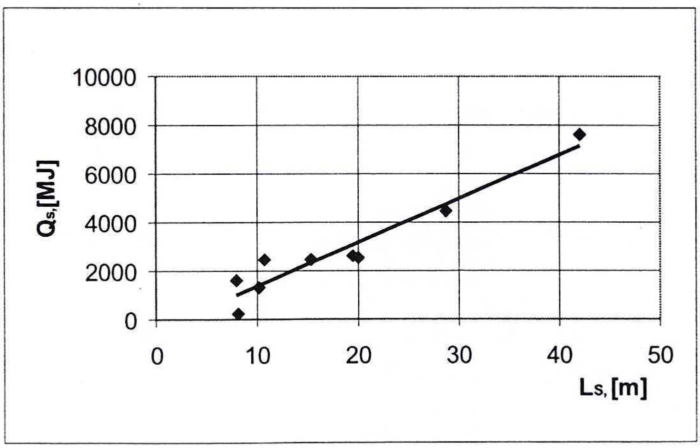


Fig. 3. Correlation between the amount of heat released and the length of the conveyor belt burned in the fire-testing gallery

Rys. 3. Zależność pomiędzy rzeczywistą ilością wydzielonego ciepła a długością odcinków taśm spalonych w sztolni pożarowej

The parameters determined by means of the cone calorimeter are very useful for constructing models of heat released during conveyor belts combustion in the fire-testing gallery (Wachowicz 1998a). The above model would allow for the prediction of the results of the full-scale conveyor belt flammability tests, using the parameters worked out using the cone calorimeter approach. The basic principle of the model is that:

- the combustion process of the conveyor belt in the fire-testing gallery is similar to the combustion process of the conveyor belt in the cone calorimeter test,
- the heat released during the conveyor belt combustion in the fire-testing gallery is proportional to the length of the burned conveyor belt.

Having accepted the above assumptions for the known length of the belt conveyors burned in the fire testing gallery, it becomes possible to calculate — based on the total heat released (*THR*) and the average effective heat of combustion ($HOC_{av}$) determined using the cone calorimeter approach — the amount of heat released during the combustion of the relevant piece of the conveyor belt (Wachowicz 2000). Results of calculations using data obtained from the cone calorimeter approach (for the heat flux of 75 kW/m$^2$) are presented in table 2.

There is the linear correlation (14) between the amount of heat released during the combustion of chloroprene conveyor belts in the fire testing gallery, calculated on the

TABLE 2

Heat released during chloroprene conveyor belts combustion in fire-testing gallery, calculated using the value of total heat released (*THR*) and average effective heat of combustion ($HOC_{av}$)

TABLICA 2

Ilość wydzielonego podczas spalania taśm przenośnikowych chloroprenowych w sztolni pożarowej obliczona na podstawie całkowitej ilości wydzielonego ciepła (*THR*) i średniego efektywnego spalania ($HOC_{av}$)

| Item. | Sample reference No. | Calculated heat released during conveyor belts combustion in fire-testing gallery [MJ] | |
|---|---|---|---|
| | | $Q_{THR}$ | $Q_{HOC}$ |
| 1 | 310/97 | 784 | 1 585 |
| 2 | 329/97 | 623 | 1 474 |
| 3 | 316/97 | 935 | 1 760 |
| 4 | 20/96 | 1 250 | 2 190 |
| 5 | 26/97 | 1 026 | 1 982 |
| 6 | 280/97 | 1 381 | 2 654 |
| 7 | 100/97 | 1 798 | 2 827 |
| 8 | 69/97 | 3 147 | 5 706 |
| 9 | 25/96 | 4 270 | 6 600 |

basis of the total heat released (*THR*) obtained from the cone calorimeter approach (Table 1) and the length of the respective conveyor belt burned (Fig. 4).

$$Q_{THR_{75}} = 106L_S - 222 \tag{14}$$

The correlation coefficient was found to be $r$ = 0.9734 with the a certainty level of 99%.

The correlation between the amount of heat released during the combustion of chloroprene conveyor belts in the fire-testing gallery, calculated on the basis of average effective heat of combustion ($HOC_{av}$) and the mass of the respective belt conveyor burned was shown on Fig. 5. The correlation may be described with the following formula.

$$Q_{HOC_{75}} = 18.81m_s - 327 \tag{15}$$

The correlation coefficient was found to be r = 0.9869 with a certainty level of 99%.

The nomographs, figures 6 and 7, using the total heat released (*THR*) and the average effective heat of combustion ($HOC_{av}$) obtained from the cone calorimeter tests, allow for the direct read-out of the predicted amount of heat to be released in the full-scale gallery test.

The above correlations and the ability to calculate the heat released during the combustion of the conveyor belts in the fire-testing gallery, based on the results obtained using the cone calorimeter approach allows the elaboration of the new method for investigation of the conveyor belts flammability, which is significantly simplified and which is also cheaper than the old full-scale gallery test (Wachowicz 1998b, 1999).

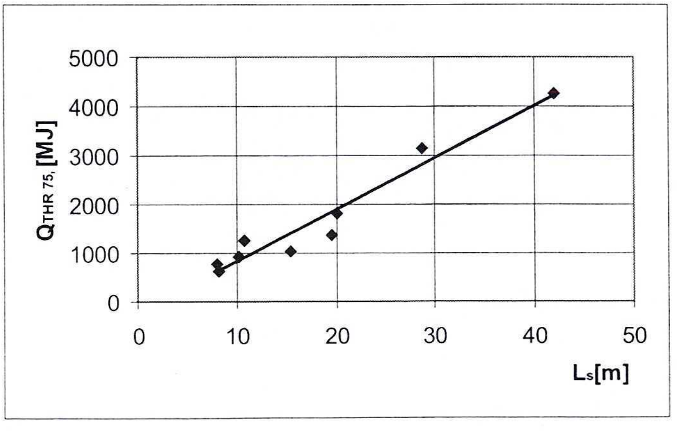


Fig. 4. Correlation between the amount of heat released, calculated from the $THR_{75}$ and the length of the chloroprene conveyor belts burned in the fire-testing gallery

Rys. 4. Zależnoś pomiędzy ilością wydzielonego ciepła obliczoną na podstawie $THR_{75}$ a długością odcinków taśm chloroprenowych spalonych w sztolni pożarowej

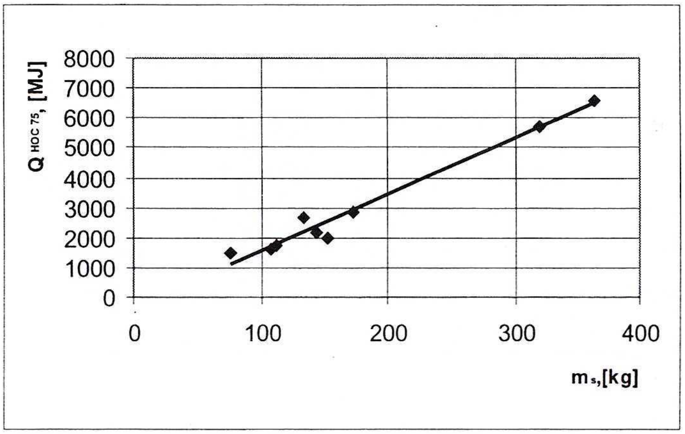


Fig. 5. Correlation between the amount of heat released, calculated from the $HOC_{75}$ and the mass of the chloroprene conveyor belts burned in the fire-testing gallery

Rys. 5. Zależność pomiędzy ilością wydzielonego ciepła obliczoną na podstawie $HOC_{75}$ a masą taśm chloroprenowych spalonych w sztolni pożarowej

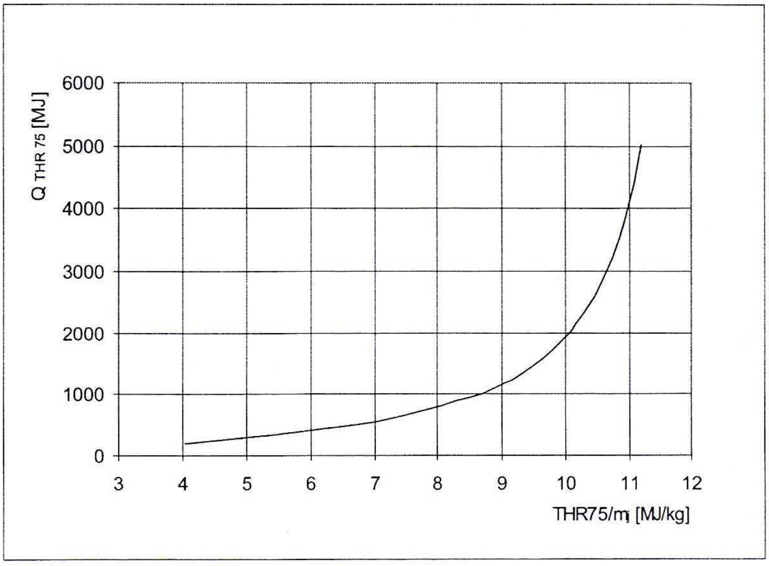


Fig. 6. The amount of heat released during the combustion of the chloroprene conveyor belts ($Q_{THR_{75}}$) calculated on the base of total heat released ($THR$) measured using the cone calorimeter

Rys. 6. Ilość ciepła wydzielająca się na podstawie spalania taśmy przenośnikowej chloroprenowej ($Q_{THR_{75}}$) obliczona na podstawie całkowitej ilości wydzielonego ciepła oznaczonego przy użyciu kalorymetru stożkowego ($THR$)

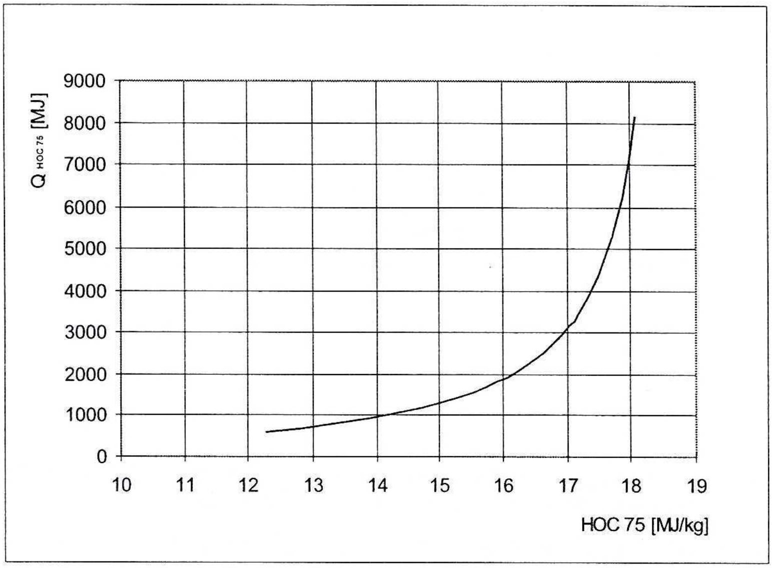


Fig. 7. The amount of heat released during the combustion of the chloroprene conveyor belts ($Q_{HOC_{75}}$) calculated on the base of effective heat of combustion (*HOC*) measured using the cone calorimeter

Rys. 7. Ilość ciepła wydzielająca się na podstawie spalania taśmy przenośnikowej chloroprenowej ($Q_{HOC_{75}}$) obliczona na podstawie efektywnego ciepła spalania oznaczonego przy użyciu kalorymetru stożkowego (*THR*)

## 5. The ignition of conveyor belts

To ignite a solid material, it must be heated to such a temperature that the released volatile products of its thermal decomposition form a mixture with the air in the flammability range. In the cone calorimeter, time to ignition data can be measured for specified constant heat fluxes of the heater, typical for the specific fire conditions. During the cone calorimeter test the ignition of the mixture of thermally decomposing volatile products with air is initiated with the electrical spark or pilot flame, and the measured parameter determines the time to ignition for a given heat flux.

The critical temperature of the belt surface, $T_{ig}$, has a characteristic value for the material of which the belt is made. The critical surface temperature may be calculated, based on the data obtained from the cone calorimeter test, namely from the time to ignition, $t_{ig}$, for the specific heat flux.

Q. Jianmin (1992) published the formula allowing for calculation of the critical surface temperature:

$$\frac{1}{\sqrt{t_{ig}}} = \frac{2}{\sqrt{\pi k \rho c}\,(T_{ig} - T_{\infty})}(\dot{q}_e'' - 0.64\dot{q}_{cr}'') \tag{16}$$

where:

$t_{ig}$ — time to ignition [s],
$k\rho c$ — thermal inertia [kW · m$^{-2}$ · °K$^{-4}$ · s],
$T_{ig}$ — critical belt surface temperature [°K],
$T_\infty$ — ambient temperature [°K],
$\dot{q}_e''$ — external heat flux [kW · m$^{-2}$],
$\dot{q}_{cr}''$ — minimum flux for ignition [kW · m$^{-2}$].

Assuming, that

$$\dot{q}_{cr}'' = Y \tag{17}$$

$$\frac{1}{\sqrt{t_{ig}}} = X \tag{18}$$

the formula (16) may be written in the form of a linear function:

$$Y = c_1 X + c_2 \tag{19}$$

where:

$$c_1 = \frac{\sqrt{\pi k\rho c}}{2(T_{ig} - T_\infty)} \tag{20}$$

$$c_2 = 0.64\varepsilon\sigma(T_{ig}^4 - T_\infty^4) \tag{21}$$

Determining the time to ignition using the cone calorimeter at least for two different values of irradiance levels, it becomes possible to calculate the critical belt surface temperature, $T_{ig}$, using the known values of parameters $X$ and $Y$ (Wachowicz 2000). The results of the calculations were given in table 3 ($T_{ig}$ is shown in °C).

The critical temperature of the conveyor belt surface, $T_{ig}$, determines the surface temperature at the ignition point. Thus, this can be considered as a parameter, determining the material's susceptibility for ignition. The correlation between the critical temperature of the conveyor belt surface and the length of the burned conveyor belt in the fire-testing gallery is shown on Fig. 8 and may be written as formula (22):

$$T_{ig} = 1292 L_s^{-0.43} \tag{22}$$

The correlation coefficient was found to be $r = 0.8957$ with a certainty level of 99%.

The correlation described with formula (22) allows for calculation of the critical surface temperature for the conveyor belts made from chloroprene, for actually corresponded criterion of conveyor belt flammability using the full-scale gallery method (the maximum allowable length of the belt, which may be burned in the fire-test gallery comes to 40 meters). The limit value of the critical temperature of the conveyor belts

TABLE 3

Parameters describing the ignition phenomenon of the chloroprene conveyor belts

TABLICA 3

Parametry charakteryzujące zjawisko zapłonu chloroprenowych taśm przenośnikowych

| Item. | Sample reference No. | The critical surface temperature $T_{ig}$ [°C] | The length of the belt burned in fire-testing gallery [m] |
|---|---|---|---|
| 1 | 310/97 | 523 | 7.9 |
| 2 | 329/97 | 488 | 8.2 |
| 3 | 316/97 | 582 | 10.1 |
| 4 | 20/96 | 476 | 10.7 |
| 5 | 26/97 | 325 | 15.4 |
| 6 | 280/97 | 334 | 19.5 |
| 7 | 100/97 | 370 | 20.0 |
| 8 | 69/97 | 358 | 28.7 |
| 9 | 25/96 | 245 | 42.0 |

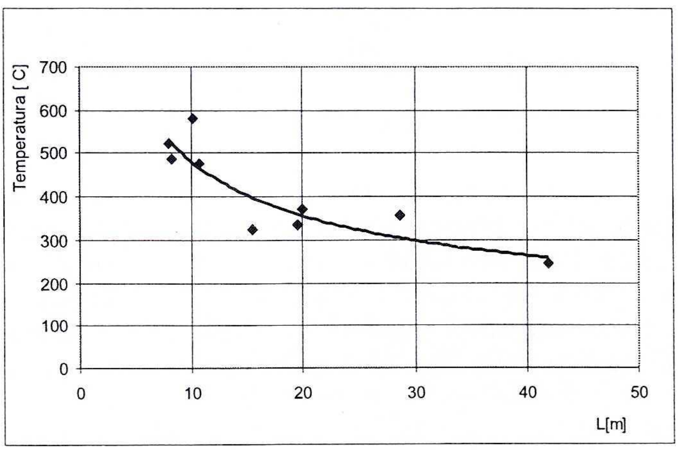


Fig. 8. The correlation between the critical surface temperature of chloroprene belts and the length of the conveyor belts burned in the fire-testing gallery

Rys. 8. Zależność temperatury krytycznej powierzchni taśmy od długości odcinka taśmy spalonego w sztolni pożarowej

surface comes to $T_{ig,cr}$ = 264°C. That means that the chloroprene conveyor belts, for which the critical surface temperature calculated, according to the above procedure, comes to be below 264°C, do not meet the full-scale test requirements.

## 6. Summary

The paper presents method for a investigating the flammability of conveyor belts, applying the oxygen consumption calorimetry. The investigations described in the paper, make it possible to present the results of conveyor belt flammability in the fire-testing gallery as the function of the amount of heat released during the belt combustion in the fire-testing gallery. It is therefore possible to calculate the theoretical amount of heat released during the fire in the gallery, based on the characteristic parameters obtained using the cone calorimeter method — the total heat released (*THR*) and the average effective heat of combustion ($HOC_{av}$). The correlation between the amount of heat released during the belt combustion in the fire-testing gallery, calculated on the basis of the results of flammability parameters obtained by the cone calorimeter method, and the length of the belt burned in the fire-testing gallery make it possible to create a new method for testing conveyor belt flammability. The method allows for the prediction of the amount of heat, which would be released during the conveyor belt flammability test in the fire-testing gallery. The nomographs prepared allow for an immediate and direct read-out of the heat released during the belt combustion in the fire-testing gallery and also for the prediction of the length of belt which would be burned in the full-scale test. It is thus possible to preserve and match the same flammability criteria as for the currently applied method (full-scale fire gallery method) and determine the belt‘s ability to extinguish itself outside the fire area. Because of the relatively simple testing procedure and low costs the new method may find a wide implementation for the flammability testing of conveyor belts. Compared to the fire-testing gallery the new method is significantly quicker (2–3 hours), requires a significantly smaller sample (three samples sized 100 × 100 mm) and the results obtained are much more accurate and repeatable.

The cone calorimeter gives the possibility to determine the ignition time of the conveyor belt samples. This parameter allows for calculation of the critical surface temperature of the belt, the value which is characteristic for the materials from which the belt is made. The correlation between the critical temperature of the belts surface and the length of the belt burned in the fire-testing gallery allows for the calculation of the limiting value of critical surface temperature ($T_{ig,cr}$ = 264°C). It is thus possible to determine, that conveyor belts, for which the critical surface temperature comes to a lower value than the limiting one would be totally burned in the fire-testing gallery based on the above correlation.

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