STUDY OF POROSITY AND PERMEABILITY OF AIR FILTER MATERIAL IN RESPIRATORY PROTECTION FILTERS

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ABSTRACT

The objective of this study is the filtering of tissue permeability and the characterization by means of permeability tests, and on the process of coal particle retention in breath protection filters.

The porosity of a filter, defined as the ratio between the void volume inside its fibres and the total volume, is a static parameter that provides point source information about the initial conditions of the filtering tissue. When excessive deposits of particles on the fibres occur, there is an increase of resistance to the air flow that can produce discomfort in use and reduced efficiency. For that reason, initial porosity of air filters for breath protection is relatively high, with a range of values between 60% and 90% being frequent.

Filter and respirator efficiency depends primarily on the filtering material used in its elaboration, and on the number and thickness of the different layers they are made of. Generally, the higher the efficiency the bigger the resistance both to breathe and elimination of generated heat and humidity.

The permeability of a filter is the flow of air that passes perpendicularly through the area of the filtrating tissue at atmospheric pressure (EN ISO 9237: 1995). It is, therefore, a dynamic parameter that allows the estimation of maximum time breathing protection equipment can be used, establishing an acceptable limit for permeability or saturation downfall.

The permeability of nine sampless have been measured against particles P1, P2 and P3, with a fixed test depression of 60 Pa, before and after being used in an atmosphere containing a suspension of coal dust. Brand new filters have different mean values of permeability compared to the air flow; its value doubles when the efficiency class is changed from P3 (Rm: 0,13) to P2 (Rm: 0,27) and to P1 (Rm: 0,54). In addition, after a time period of use of 120 minutes, the higher permeability of the filter decreases due to air particles capture, being such a reduction in class P2 filters (4,32 %) respect to class P1 ones (2,68%) and even less in class P3 ones (0,38 %).

Key words: permeability, porosity filters, breathable dust, coal

INTRODUCTION

The objective is the study of filter tissue porosity and characterization by means of permeability tests the process of coal particle retention in filters of respiratory protection.

The filter and mask efficiency depends essentially on the filter material with which they are made and on the number and thickness of the superimposed layers of the filters and masks. Generally, the higher the filter tissue efficiency the greater the resistance offered in the breathing and the elimination of the generated heat and humidity.

Filter permeability is the amount of the air flow that crosses perpendicularly the filter tissue area during a certain time at atmospheric pressure (IN ISO 9237: 1995). Therefore, it is a *dynamic* parameter that allows us to estimate the maximum time of use of breathing protection equipment, establishing an acceptable limit for permeability or saturation downfall.

The permeability of nine filter tissue samples have been measured against particles P1, P2 and P3, establishing a test depression of 60 Pa, before and after being used in a suspension coal dust atmosphere. The masks with new filters have different permeability average values of air passage; its value duplicates when diminishing its efficiency class: P3 (Rm: 0,13), P2 (Rm: 0,27) and P1 (Rm: 0,54). In addition, a decrease of the filter permeability by capture of particles of the air takes place after 120 minutes of use. Filter permeability being higher in those of P2 class (4.32 %) with respect to those of P1 class (2,68%) and P3 class (0.38 %).

1 FILTER CHARACTERISTICS OF BREATHING PROTECTION EQUIPMENT

Filter equipment as individual breathing protection equipment in a work atmosphere with suspension particles are usually used. Filter equipment is evaluated depending on two basic filtration parameters; the efficiency (retained particles) and their pressure drop (resistance to the respiratory flow) [1].

A filter or mask is made up of a series of layers formed by interwoven fibers, randomly oriented. This three-dimensional structure of filters or masks has larger orifices than particles then they need to retain, so that an excessive pressure drop is not caused(figure 1).

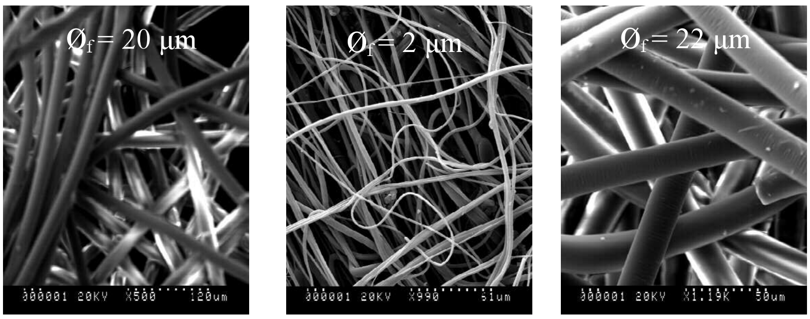


Figure 1: Images by Scanning Electron Microscope (SEM)
of fibre that form the three layers of the filter 4 P2

If the orifices are significantly reduced or obstructed by an excessive particle deposition, a high resistance to the air passage is created and thus the filter might be uncomfortable (figure 2).

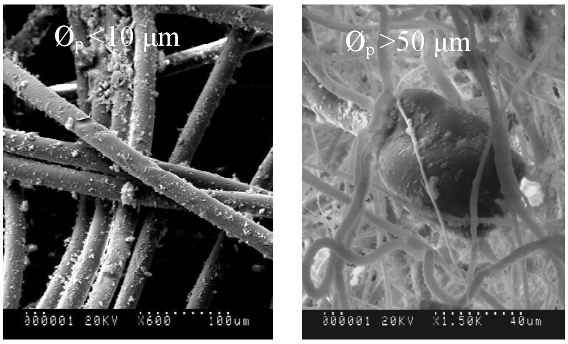


Figura 2: Coal particle retained by and between fibers of a filter

Another important parameter to consider for the choice of breathing protection equipment is the investment and replacement cost that it has with respect to it's competitors.

2. POROSITY

2.1 Theoretical filter porosity

The theoretical filter porosity is defined as the relation between the existing void volume inside its fibers and their total volume. In order to calculate the masks porosity a cylindrical sample of the same diameter and the thickness of the filter layers are prepared. The theoretical filter porosity can be calculated by means of the following expression [1].

$$p = V_h/V_t = (V_t - V_s)/V_t = 1 - [(m_f/\rho_{fb})/(\pi r^2 . e)] \qquad (1)$$

To calculate the volume of each tissue sample the filter thickness is taken as the height and its weight is obtained by means of a precision scale. The fibers´ density is obtained by knowing the materials that are each filter is made of (information provided by the manufacturers).

The porosity average value of the analyzed filters according to the grade of efficiency of the 9 tissue samples with a radio size standardized as shown in figure 3

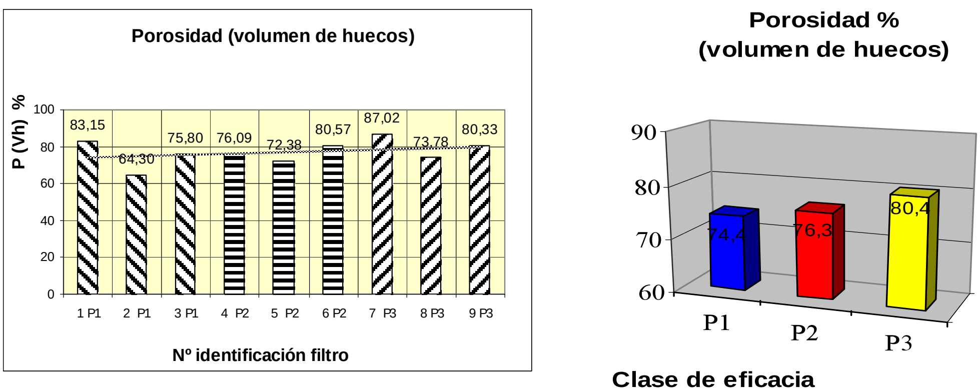


Figure 3: Theoretical porosity expressed in void volume

The initial porosity is a static parameter that characterizes the different filter types existing on the market. The filters of breathing protection have a very porous structure to reduce the air passage resistance, with relatively high values of porosity, from 60 % to 90 %.

2.2 Mercury intrusion porosimetry (MIP)

It is possible to resort to the mercury intrusion porosimetry (MIP) to obtain fast and reproducible results on the size of pores. Porosimetry is a generally used technique to determine the pore size distribution and the open porosity of a material.

To force the mercury insertion in the filter pores, it is necessary to increase the system pressure. The pressure exerted on the sample and the crossed pore diameter, considering this last one cylindrical, is related by means of the Washburn equation [2].

$$D^{\vartheta} = \frac{-4\gamma.\cos\vartheta}{\Delta p} \qquad (2)$$

The sample analyses have been done in the Superior Council of Catalysis and Petroleum-Chemical Researcher Institute (CSIC), in the Technical Laboratory of the Support Unit to the Investigation, by means of a porosimeter (Automated Mercury Porosimeter) model 9220 AutoPore II V3.03 Micromeritics.

Each pressure value corresponds to the mercury volume that is introduced in the solid. By means of the Washburn equation (2) the pore average diameter corresponding to the mercury volume introduced is obtained.

Has been calculated the theoretical porosity and the porosity obtain by mercury intrusion porosimetry (MIP) for the tissue samples of the 9 filters of breathing protection. The results are shown in figure 4.

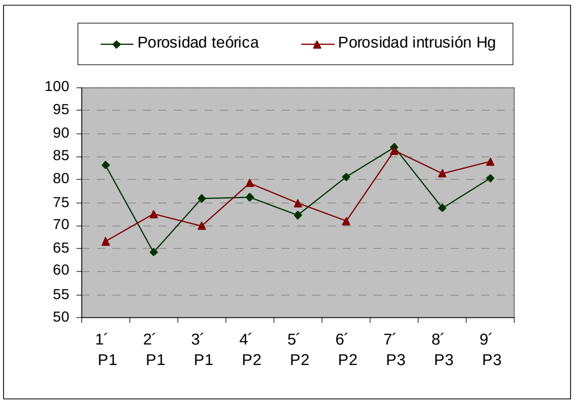


Figure 4: The results of theoretical porosity and intrusion porosity for 9 filter of breathing protection.

3. AIR PERMEABILITY

The filter permeability is defined as the amount of air that goes perpendicularly through the surface of a tissue sample during a certain time, in the surface established conditions of the test and pressure drop [3].

Cylindrical tissue sample make up for all the test filters of the same effective radius (1.73 cm) and height the corresponding thickness of the filter (0.09 cm - 0.49 cm). The filter tissue sample is placed on a calibrated orifice (tissue samples- support) and is made to circulate by means of aspiration, airflow (figure 5). The suction flow provided by a vacuum pump is increased progressively until the fixed depression of 60 is reached Pa [4].

The air flow is measured by means of a rotameter with a different maximum flow, in order to choose the most suitable, depending on the greater or lesser permeability of the tested material. The air flow is accurately controlled by frequency variation equipment that operates on the vacuum pump. The pressure gradient is measured by a digital micropressure gauge.

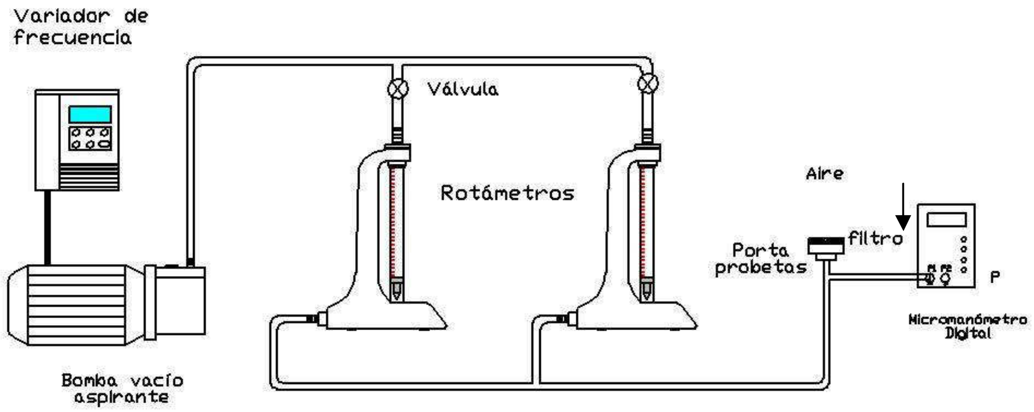


Figure 5 Test setup diagram of air passage permeability

The filter tissue permeability is obtained by dividing the air flow rate by the effective tissue area, according to the equation (3):

$$R = q_v/A \quad (3)$$

The air passage permeability values for the filter tissue samples, obtained respectively before and after being used during 120 minutes in a suspension coal dust atmosphere are shown in figure 6.

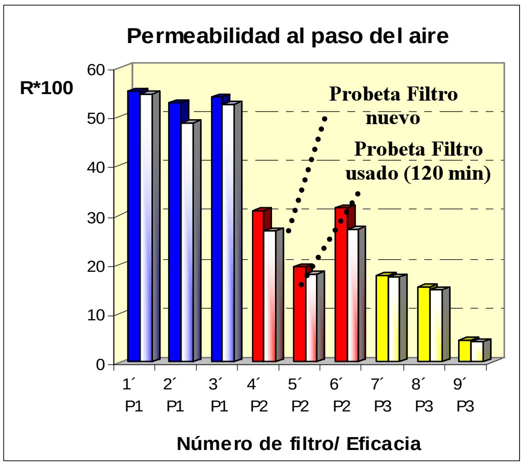
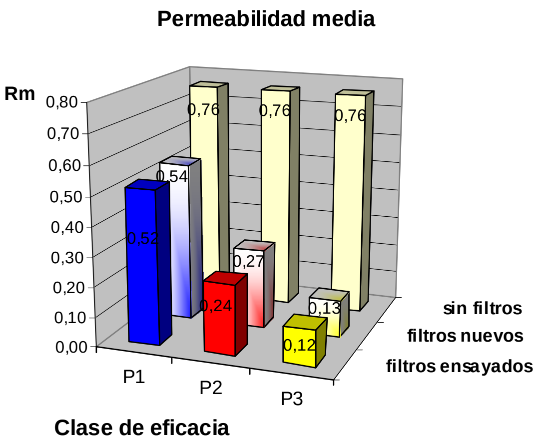


Figure 6: Results of the permeability test of nine new/used filters of respiratory protection

The masks´ new filters have a different permeability average value to air passage, their permeability value duplicates while their efficiency diminish class from P3 (Rm: 0,13) to P2 (Rm: 0,27) and to P1 (Rm: 0,54). In addition, the filter permeability diminishes in a 120 minute period because of the capacity to capture air particles. In P2 efficiency class (4.32 %) the permeability is higher than in P1 efficiency class (2,68%) and it is lower in the P3 efficiency class (0.38 %).



Filtro	Disminución de R (%)		
Clase de eficacia	Sin filtro	Filtros nuevos	Filtros ensayados
P1	0	29,11	31,79
P2	0	64,43	68,75
P3	0	83,59	83,97

Figure 7: Diminution of the average permeability (%) depending on the efficiency class

4. RELATIVE COST

In order to compare the cost of several filters and choose the most suitable for each situation, the dimensionless factor called relative cost is used (CR).

Javier R. Sanchez et al. [5] used as a comparative parameter the relative cost of several filter tissues used in the production of bag filters. For this they chose the average value, the most commonly used in practice.

For breathing protection equipment, to be able to compare the cost of the different models available on the market. Both the filter cost and its support unit should be taken into account. After having added both factors, the average price of all the masks is calculated. To that amount is assigned the value of the unit, this average value is taken as a base in order to calculate the relative cost of each unit.

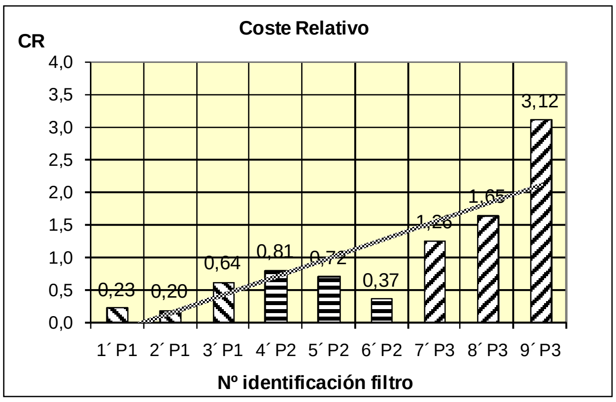


Figure 8: Relative cost of the 9 filters of respiratory protection

If RC < 1 filter cost is less than average value
If RC > 1 filter cost is more than average value

In the following graph (figure 9) the average value of the relative cost depending on the efficiency grade of the analyzed filters. Obtained values for the sample of 9 commercial filters studied are 0.36 (for the P1 class), 0.63 (for the P2 class) and 2.01 (for the P3 class).

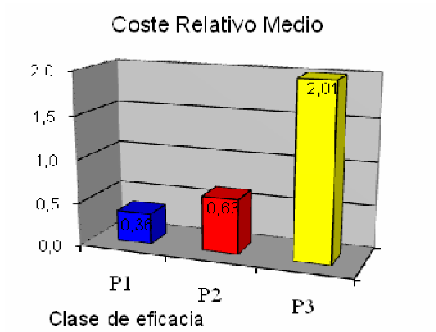


Figure 9: Relative average cost depending on efficiency class.

5 RESULTS AND DISCUSION

The filter porosity is a static parameter that gives necessary information about the initial state of the filter tissue. The initial filter porosity of the breathing protection is relatively high, with values ranging from 60 % to 90 %.

The filter permeability is a dynamic parameter that allows estimating the maximum time for use of breathing protection equipment, establishing an acceptable limit of permeability or saturation downfall.

The permeability average value of the initial air flow (see figure 6) is doubled when changing filter efficiency class from P3 to P2 and from P2 to P1. In addition, permeability by capture of particles of the air decrease in the filter of the P2 (4.32 %) efficiency class, P1 (2,68%) and less than in the filter of the P3 efficiency class (0.38 %).

As tested filter efficiency increases, a slight increase of the porosity and there is a strong decrease of permeability is produced. An important increase of the breathing resistance takes place when using filter units with P2 and P3 efficiency class versus P1.

In a work atmosphere with reduced dust suspension amounts, the filters 1 P1, 2 P1 o 6 P2, which have low relative cost and a high permeability, can allow a more intensive work rate.

The relative average cost value, depending on the efficiency grade of analyzed filters, is multiplied by two (approximately) when changing efficiency class filter from P1 filter to P2 filter, and is multiplied by five when it is changed to P3 filter.

6 NOMENCLATURES

R: air passing permeability ($l.min^{-1}.cm^{-2}$)
q_v: rate of breathe in air flow ($l.min^{-1}$)
A: tested tissue area (cm^2)
p: porosity (%)
V_h: void volume (cm^3)
V_t: filter total volume (cm^3)
V_s: solid volume (cm^3)
m_f: filter mass (g)
ρ_{fb}: fibres average density which form parts of the filter ($g.cm^{-3}$)
$Ø_f$: fibres average diameter which form parts of the filter layers (μm)
Øp : particle diameter (μm)
h= e : filter thickness (cm)
$V_t = \pi r^2.e$: filter tissue sample volume (cm^3)
CR: relativ cost (dimensionless)
D: pore equivalent diameter (μm)
γ: 485 mercury surface tension ($din.cm^{-1}$)
θ: mercury contact angle del mercury with the pore walls (130 º)
p: pressure applied to the system ($kg.cm^{-2}$)

7. REFERENCES

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