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Explosion Suppression of Combustible Polymer Dust in the Fabric Filter

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Abstract: Combustible dust explosions are a risk in any industry that produces dust particles as a final product or as waste. Most organic substances can ignite dust particles with a subsequent explosion, together with a large amount of metal dust, if they accumulate. There is the possibility of dust particles being swirled simultaneously with possible initiation. Fabric filters operate as one of the possible variants of dust accumulation. A large amount of dust is concentrated in them in a swirled and settled state. In the case of initiation, e.g., by hot sparks, e.g., welding, cutting, electric sparks arising from the action of static electricity, overload, or short circuit, it may ignite with a subsequent explosion. However, to eliminate the risk of fabric filter explosion, it is possible to use the method of tertiary anti-explosion protection, explosion suppression. This method has been used successfully for many years. The principle is elementary. During the explosion, a vent opens on the surface or side of the vessel. Thus, the explosion pressure inside the container is reduced without damaging it (Snoeys et al., 2012).The article provides instructions for calculating the relief surface of the fabric filter using the European standard EN 14991. The results of the fire explosion parameters of the dust in the fabric filter are also part of the article.

Keywords: Explosion, fire, combustible dust, suppression of explosions, fabric filter.

1. Introduction

Fabric filters operate in the industry to clean discharged gaseous particles, so they are one of the most important devices used for environmental protection. The principle of their operation is the effective removal of industrial dust, especially their fine particles. The flowing air with dust particles passes through the filter, which captures the dust particles on the surface of the filter to form a so-called filter cake. The formation of dustcake divides into three stages: deep, intermediate, and surface filtration. Filter cleaning (regeneration) from the filter cake is usually performed with compressed air directed into the filter (Arymbayeva& Van Hess, 2020).

Fabric filters are generally part of a system that removes dust particles from technological devices. This system will usuallynot remove all dust particles. Still, a well-designed dust removal system can reduce the risk of fire and the subsequent explosion of combustible dust particles. However, to remove dust particles, ducted ventilation is used to remove dust particles from the point of origin to a fabric filter, known as local exhaust systems. Safety requirements are given in the European Technical Standard EN 12779.Dust removal equipment usually consists of four components:

1) Suction head for capturing dust particles from the dust source.
2) Piping system transporting dust to the dust filter.
3) Dust filter removing dust from the air.
4) Fan with sufficient power and energy (Bhuiyan, 2020).

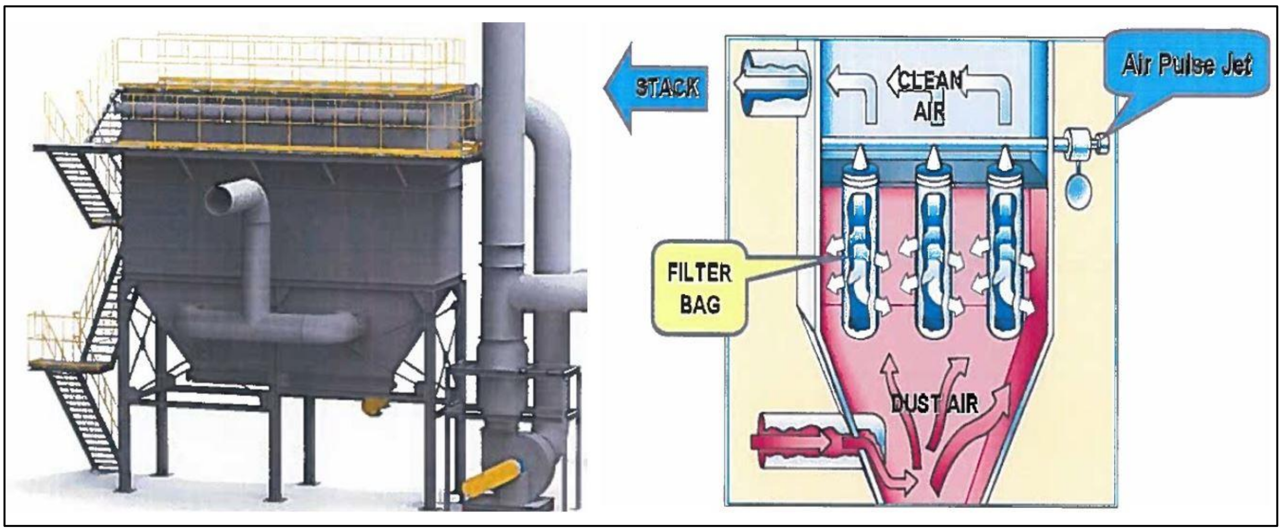

Figure 1: Fabric filter and the principle of its operation

The essence of a fabric filter is a dust filter. Filtration performance affects the operational energy consumption and performance of the fabric filter (Xingcheng et al., 2019).In the past, dust filters were made from a non-woven fabric whose goal was to create an effective porous barrier against pollutants. These were materials of natural origin, for example felt. The majority of manufactured filters are currently made from synthetic materials. These are mainly polyester and polypropylene in various classes and qualities (Origins and Selection of Filter Element Configurations Currently Used in Dust Emission Limiting Systems, 1996). Polytetrafluoroethylene (PTFE) uses as another synthetic material for the production of filters. Deqiang Jiang et al. in 2008 compared the efficiency of a PTFE filter with a polypropylene needle felt filter, and the conclusions showed a 99.99% efficiency of the PTFE filter. Talc and limestone were used as test dust. The fabric filter under consideration (Figure 1) is in a company that processes polymeric substances. The resulting product is a modified polypropylene granulate. It is a hose filter with automatic time-dependent flushing with compressed air (regeneration). The pulse method employs regeneration. Filters remove the filter cake by spraying high-pressure air fed into the hose filters 5 to 7 times per second. The filter medium is made of polyester (PET) and is antistatic (surface resistivity is $<10^6 \Omega$). The separated dust collects in the lower part of the filter unit and removes via a screw rotary feeder into a large-volume plastic bag under the filter. The technical data of the fabric filter are shown in Table 1.

The fabric filter collects a mixture of polypropylene and polyethylene, whose dust particles have been the cause of several serious accidents (Seonggyu, 2019). The ability of polypropylene to produce combustible dust having combustible and explosive properties is well known, so it is necessary to consider explosive preventive measures during its processing (Jie et al., 2019). Polyethylene has similar properties and a high risk of explosion during its transport through pipelines, conveyors or its accumulation in silos, fabric filters, and similar equipment (Kai et al., 2021).

Table 1: Fabric filter technical data

Dimensions (h, w, d,)	3.90 m × 6.93 m × 2.28 *m*
Filtration Area	453 m^2
Filtration Speed	1,43 $m \cdot min^{-1}$
Number of filter sleeves	280
Pulse method	Air Pulse Micro-Venture Type
Filter pocket-size	⦰ 156 mm × 3500 *mm*
Compressed air	4 to 6 *bars*

The Czech state standard ČSN 12 7040 states that in an environment with a risk of fire or explosion transmission, it is necessary to prevent transmission between individual parts of the air handling equipment with a suitable safety device. No combustible dust explosion protection system is installed in the case of the fabric filter mentioned. Combustible dust, unlike gases and vapours, can create local concentrations by swirling a local layer or pile of dust. Combustible dust divides according to the cubic constant K_{St} into three classes, 1 to 3 (Damec, 2005). To ignite combustible dust and start a fire, the combustible substance must be ignited. Initiation is the most crucial factor in development. This statement is supported by the fact that if initiation does not occur, the fire cannot occur (Martinka et al., 2012). The European technical standard EN 1127-1defines initiation sources capable of igniting a dust-air mixture. Possible ignition sources for combustible polymer dust include hot surfaces, flames, sparks, and electrical equipment.

The term explosion suppression refers to a means of protection for vessels that prevents unacceptably high pressures from developing inside the vessel during an explosion. It is the most popular method of explosion protection extensively described in technical literature and technical standards, for example, in the European technical standard EN 14491 (Taveau, 2014). In the initial stage of the explosion, the weakened areas (relief holes) in the walls of the vessel are opened, and burning or non-burning material, including flue gases, are released. Thus, the pressure inside the vessel is reduced.

2. Method

First, it is necessary to define the chemical composition of the dust and its fire and explosion characteristics. The chemical composition of a substance affects its calorific value, the amount of combustion air, the combustion temperature, and the course of combustion. Fundamental chemical analysis defines the content of water, ash, and volatile combustibles according to the technical standards CSN 44 1377, ISO 1171 and ISO 562.

Swirled dust's fire and explosion characteristics are stated in the European technical standards EN 14034.The test equipment for determining the explosion parameters of combustible dust (maximum explosion pressure p_{max}, maximum increase in explosion pressure rise $(dp/dt)_{max}$, lower explosive limit LEL) is an explosion chamber resistant to explosion pressure with a volume of 1 m^3. However, it is possible to use an explosion chamber with a volume of 20 *l* as an alternative. The use of other types of explosion chamber is possible if they are in accordance with the above technical standards, e.g., the explosion chamber KV 150MV with a volume of 365 *l* (Kuracina, 2021). The basic principles of operation of explosion chambers already were described by R. K. Eckhoff, W. Bartknecht and P. Field.

The determination of the minimum ignition temperature of swirled and settled dust is defined by the European technical standard EN 50281-2-1, divided into methods A and B. Method A determines the minimum temperature of the hot surface during which decomposition or ignition of the dust of a specified thickness, deposited on this hot surface. This method is suitable for industrial equipment with a thin dust layer on a hot atmosphere surface. Method B defines the minimum temperature of the hot surface at which the swirled dust sample ignites. Method B works as an additional test after method A.

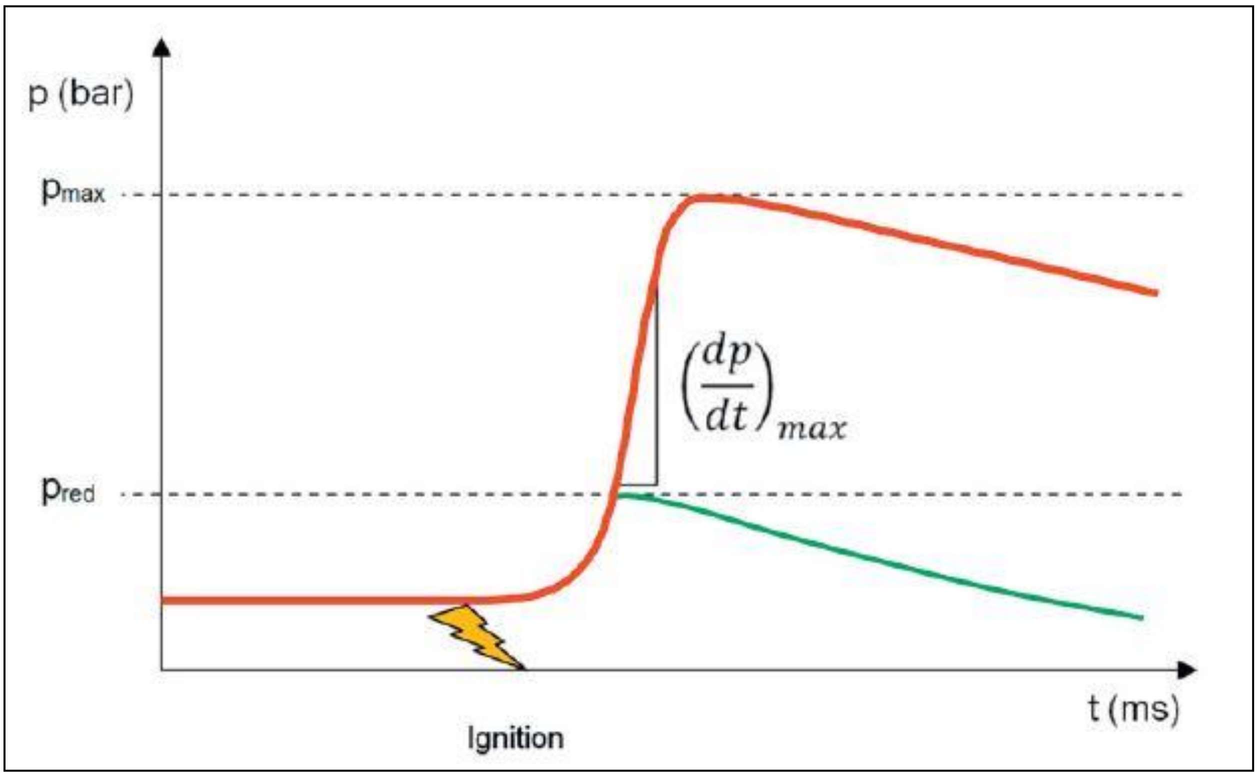

Figure 2: Explosion suppression during a dust explosion(Taveau, 2014).

The suppression ofexplosion allows the pressure created during the explosion inside the vessel to be safely released outside the vessel to the surrounding environment. Figure 2 shows the development of the maximum explosion pressure p_{max}, when the vessel may explode (red curve), and the static opening pressure p_{stat} (green curve), which is significantly lower than p_{max}(Taveau, 2014). Therefore, while calculating the relief area, it is necessary to know the following data:

1) Constructional pressure of the vessel.
2) Explosive properties of dust.
3) Shape and size of the vessel.
4) Static opening pressure.
5) Swirled dust conditions inside the vessel and other requirements.

If materials classified as hazardous to health can be released or dust or flue gases can pose a danger to the environment, you cannot use explosion suppression. However, if there is no other alternative to venting the explosion, it is necessary to identify the hazardous area.

Explosion suppression only reduces explosion pressure, so it does not prevent an explosion or extinguish a fire. There is a risk of pressure in the vicinity of the vessel with flying debris and flames, so appropriate safety measures are necessary.

Computation of the size of the relief holes it is essential to know the following data:

1) Vessel volume.
2) Length to diameter ratio for corresponding vessel shape $\frac{L}{D}$.
3) The position of the relief equipment.
4) Construction pressure of the vessel $p_{red,max}$.

All parts of the vessel exposed to explosion pressure (for example, valves, pipes) are taken into account, and the construction pressure of the weakest part is considered the construction pressure of the vessel (EN 14491, 2013).

3. Findings and Discussions

Fundamental chemical analysis and laboratory tests to determine the fire and explosion characteristics proved the combustible and explosive properties of the dust. According to the cubic constant K_{St}, the dust explosion class is specified as St1. This category includes most organic dust, such as the pure form of polyethylene, polypropylene, cellulose, or wood. Table 2 shows the measured values.

Table 2: Fire technical characteristics of dust

Medium grain size	0.040 mm
Ignition Temperature of Sedimented Dust	negative to 400 °C
Ignition temperature of swirled dust	560 °C
Lower explosion limit at an initiation energy of 10 kJ	≤ 750 $g \cdot m^{-3}$
Lower explosion limit at an initiation energy of 2 kJ	Negative $g \cdot m^{-3}$
Maximum explosion pressure p_{max}	1.40 bar
Maximum rate of explosion pressure rise $(dp/dt)_{max}$	112 $bar \cdot s^{-1}$
Constant K_{St}	30 $m \cdot bar \cdot s^{-1}$
Explosion class	St1

Source: Author's findings

A. Fabric Filter Relief Surface

The size of the relief openings *A* is calculated for a vessel filled with swirling dust with an optimal dust concentration with adequate measures taken to prevent flame propagation and overpressure: $0.1 bar \leq p_{red,max} < 1.5\ bar$ according to the equation:

$$A = B\left(1 + C\ \cdot \log\frac{L}{D}\right)$$

where:

$$B = \left[3.264\ \cdot\ 10^{-5} \cdot p_{max}\ \cdot K_{St} \cdot\ p_{red,max}^{-0.569}\ +\ 0.27 \cdot (p_{stat} - 0.1) \cdot p_{red,max}^{-0.5}\right] \cdot\ V^{0.753}$$

$$C = \left(-\,4.305\ \cdot \log p_{red,max} + 0.758\right)$$

The values of pressure quantities necessary for the calculation are:

$p_{stat} = 0.1\ bar$

$p_{red,max} = 1\ bar$

B. Calculation of the Ratio of Vessel Length to Diameter $\frac{L}{D}$

The fabric filter has a space with polluted air and an area containing clean air. The clean air compartment includes the inner space of the filter bags and other accessories in case the dust separates from the air on the outer surface of the filter.

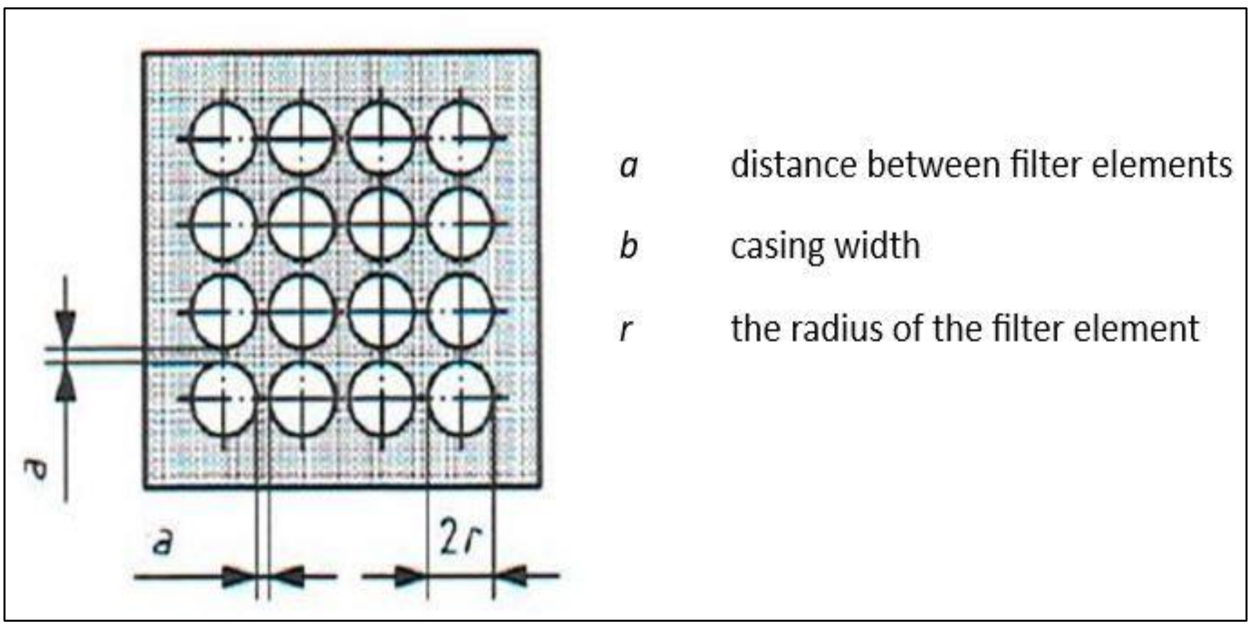

Figure 3: Filter element arrangement (EN 14491, 2013)

For example, suppose that the distance *a* between the filter elements is greater than the radius of the cylindrical filter sleeves. In that case, it is possible to subtract the entire volume of the filter sleeve casing from the volume of polluted air, according to Figure 3.

If it is possible to subtract the entire volume from the filter sleeve casing, the expression is: $a \leq r$. The filter sleeves in the given fabric filter have the following dimensions:

a = 100 mm

r = 78 mm

In this case, the above expression does not apply, so that the volume of the filter sleeves casing cannot be subtract. The fabric filter diagram for the relief area calculation is shown in Figure 4where:

l_1 = 6.7 m

l_2 = 6.1 m

l_3 = 4.5 m

w_1 = 2.3 m

w_2 = 1.1 m

w_3 = 0.4 m

V_f = 54 m^3 (Volume of the filter part)

h_1 = 1.4 m

h_2 = 0.7 m

h_3 = 0.4 m

L_{eff}= 1.5 m (Effective flame path)

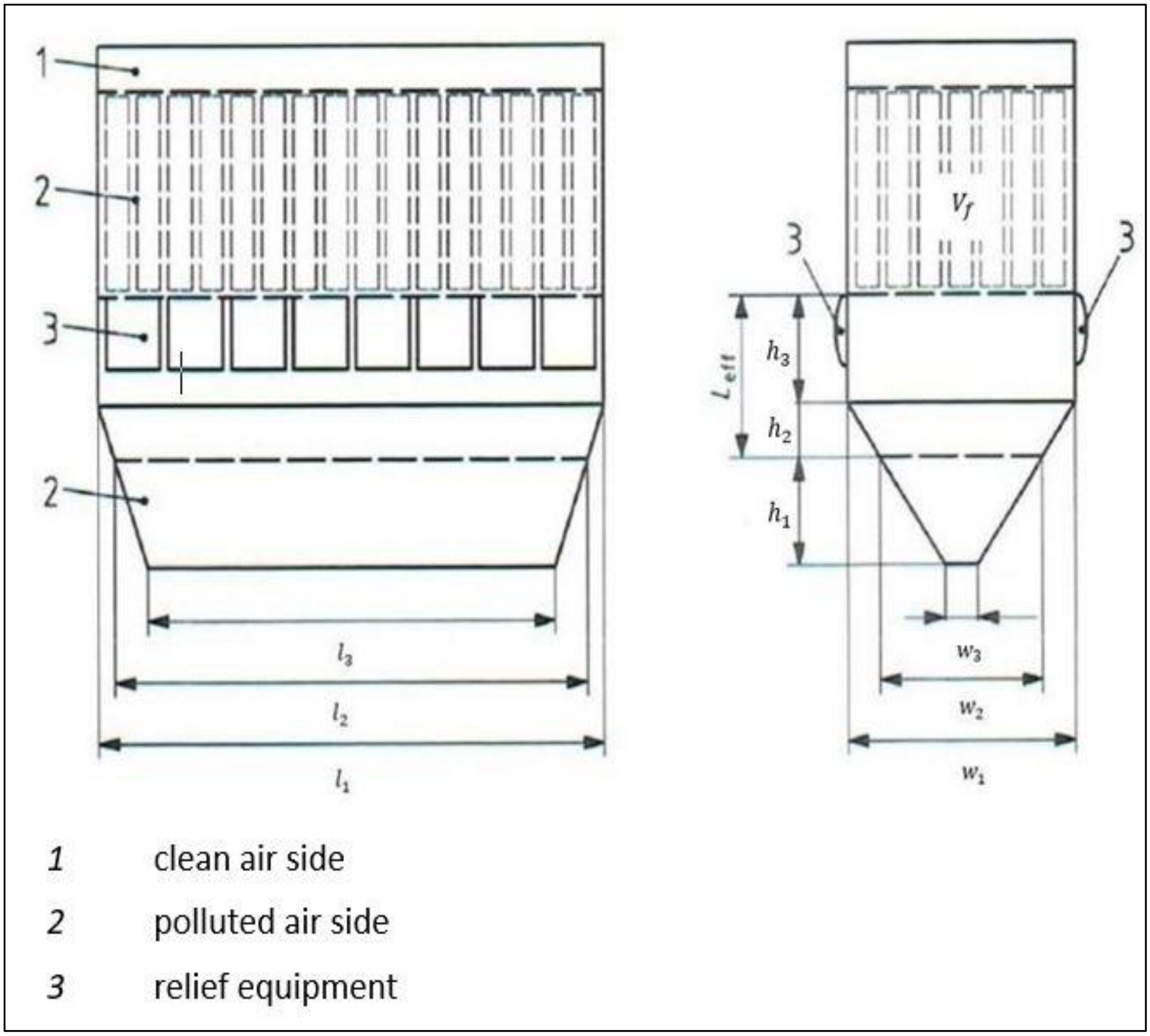

Figure 4: Fabric filter diagram(EN 14491, 2013).

The volume calculation applies to the rectangular part of the fabric filter V_p:

$$V_p = V_f + l_1 + w_1 + h_3 = 54 + 6.7 + 2.3 + 0.4 = 63.4\,m^3$$

Volume of the conical part of the fabric filterV_k:

$$V_k = \frac{h_1 + h_2}{3} \cdot \{l_3 \cdot w_3 + (l_3 \cdot w_3 \cdot l_1 \cdot w_1)^{0.5} + l_1 \cdot w_1\} =$$

$$V_k = \frac{1.4 + 0.7}{3} \cdot \{4.5 \cdot 0.4 + (4.5 \cdot 0.4 \cdot 6.7 \cdot 2.3)^{0.5} + 6.7 \cdot 2.3\} = 22\,m^3$$

Calculation of effective volume V_{eff}:

$$V_{eff} = V_p + \frac{V_k}{3} = 63.4 + \frac{22}{3} = 70.7m^3$$

Calculation of the effective cross-sectional area A_{eff}:

$$A_{eff} = \frac{V_{eff}}{L_{eff}} = \frac{70.7}{1.5} = 47{,}1\,m^2$$

Calculation of the effective average D_{eff}:

$$D_{eff} = \sqrt{\frac{4 \cdot A_{eff}}{\pi}} = \sqrt{\frac{4 \cdot 47.1}{\pi}} = 7.75\ m$$

Effective length/diameter ratio $\frac{L}{D}$

$$\frac{L}{D} = \frac{1.5}{7.75} = 0.19$$

C. Calculation of Relief Area

Calculation of relief holes *A*is computed according to equation:

$$A = B \cdot \left(1 + C \cdot \log \frac{L}{D}\right)$$

where pro-calculating*B*:

$$B = \left[3.264 \cdot 10^{-5} \cdot p_{max} \cdot K_{St} \cdot p_{red,max}^{-0.569} + 0.27 \cdot (p_{stat} - 0.1) \cdot p_{red,max}^{-0.5}\right] \cdot V^{0.753} =$$

$$B = [3.264 \cdot 10^{-5} \cdot 1.4 \cdot 30 \cdot 1^{-0.569} + 0.27 \cdot (0.1 - 0.1) \cdot 1^{-0.5}] \cdot 70{,}7^{0.753} = 0.032$$

and for C:

$$C = \left(-4.305 \cdot \log p_{red,max} + 0.758\right) = (-4.305 \cdot \log 1 + 0.758) = 0.758$$

After substituting *B* and C into the equation the result is:

$A = B \cdot \left(1 + C \cdot \log \frac{L}{D}\right) = 0.032 \cdot (1 + 0.758 \cdot \log 0.19) = 0.015\ m^2$(EN 14491, 2013).

The calculated relief area is 0.015 $m^2$for the given technological equipment of the fabric filter. Therefore, based on the above value, it is suitable to install a flat rectangular, for example, VMP SU relief membrane (Figure 4) with an escape area of 0.04 m^2so that it is sufficient to ensure the protection against the explosion of the fabric filter.

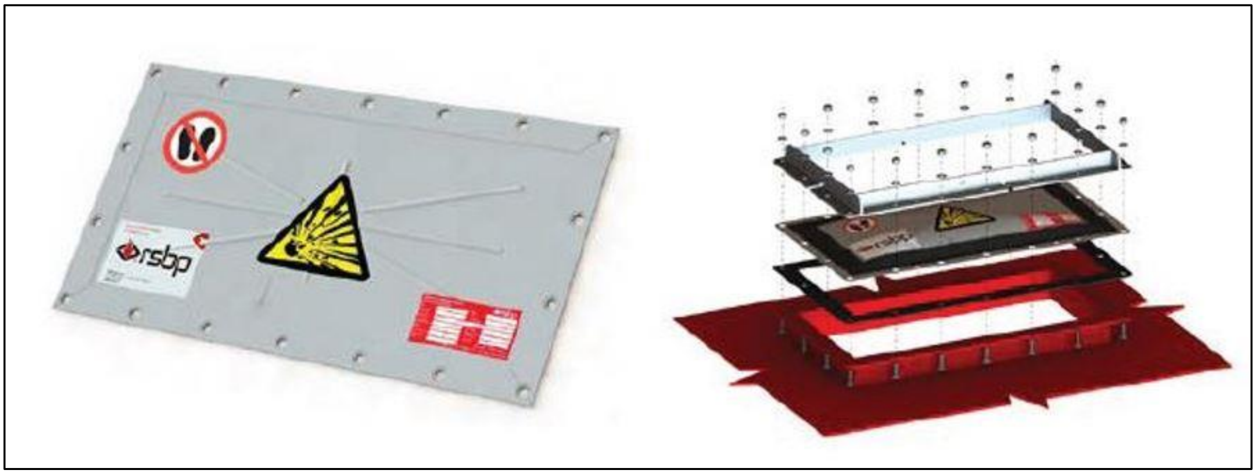

Figure 5: VMP SU flat rectangular membrane and its assembly (RSBP, 2019)

The relief membrane is appropriate for installation on the lower part of the fabric filter above the conical part of the fabric filter and the opposite side of the inlet pipe with dust particles. It is the rear part of the fabric filter that directs the outer wall of the workplace with the fabric filter located (Figure 5).

Figure 6: Space for placing the relief membrane

Given that employees, especially maintenance workers, move in the workplaces with the fabric filter, installing piping with explosion and flame exhaust outside the work area in front of the relief membrane would be appropriate. The length of the pipe from the relief membrane to the outer wall is 5 *m* above the floor and the diameter of thetube is 400 *mm*. The end of the line that leads to the outdoor area should be equipped with a hinged cover to prevent animals or other contaminants from entering the outdoor space. The emplacement outlet will be about 5 *m* above the ground to provide a sufficient zone for safety against the effects of flames in the horizontal and vertical planes. The movement of employees or other people is minimal in this zone.

4. Conclusion

Fabric filters used for dust cleaning and accumulation in the polymer industry are usually without tertiary explosion protection because of the unlikely risk of fire or explosion. However, underestimating the above risk is always probable and usually arises, especially in the safest place in terms of these risks. The paper can give a simple guide to one part of tertiary explosion protection, which is the analysis and calculation of relief areas if flammable; thus, explosive and combustible dust accumulates in the fabric filters. On the other hand, it is a fact that various types of software exist for measures. Still, there is a possibility to proceed from European standard EN 14491, which is undoubtedly available in companies faster than special software suitable for these purposes.

However, it is strange that the TOP management of companies is unaware of the risks of fire and explosion of combustible dust and possible damage to health and property. If the relief membrane to reduce the dust explosion were in the project documentation, the TOP management would probably not notice it. Increasing the price by tens of thousands of crowns would be mere money in terms of hundreds of millions of investments. In the case of additional installation, the problem is that the price already plays a significant role, and it is complicated to enforce it. Therefore, it would be appropriate for occupational health and safety to plan safety arrangements when designing technological devices in terms of fire and explosion risks and the entire area of occupational health and safety.

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