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OPERATION OF THE SUCTION SYSTEM DURING THE PRODUCTION OF A MIXTURE OF POLYPROPYLENE AND POLYETHENE GRANULATE FROM THE POINT OF VIEW OF THE RISK OF POSSIBLE FIRE AND EXPLOSION OF COMBUSTIBLE DUST

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Review article

Abstract: This article deals with the operation of the suction system with the risk of fire and subsequent explosion of combustible dust during the operation of screw extruders and their equipment. Machines process a mixture of polyethylene and polypropylene to a granular form. It describes the suction device from the suction attachments to the separator at the selected workplace and points out specific technological problems of the device, together with measures for its solution.

Keywords: Explosion, Fire, Combustible Dust, Polymers, Suction Systems.

Introduction

Several preparatory operations produce a specific product from polymeric materials, including plasticization, mixing, granulation, tabletting, agglomeration, gelatinization, and vulcanization. After these operations, the polymers undergo various technological processes of forming, pressing, rolling, extruding, injection, and blow moulding. For all these operations, it is necessary to have the machinery and technological equipment arranged primarily in larger units (Fig. 1). Operations create dangerous substances to human health, including flammable dust particles with the risk of fire and subsequent explosion (or vice versa) on the premises with these devices. To eliminate the risks mentioned above, suction devices remove pollutants in separate workplaces for accumulation and removal. Large technological units should also install ventilation systems to equalise the atmospheric pressure of the space and ensure air quality.

The topic of this article selects operations and technological procedures to produce polymers by extruding the polymer mixture with screw extruders and their accessories, followed by granulation for further processing. The workplace is an industrial plant that processes a mixture of polypropylene and polyethylene. Both polyethylene and polypropylene belong to the group of thermoplastics that, at higher temperatures, change into the form of a highly viscous liquid.

This viscous liquid can shape and stabilise after it has cooled. The process is repeatable so that after further heating, the thermoplastic can re-plasticise and reshape. The blend of polyethylene and polypropylene also contains other organic and inorganic additives to modify their properties according to the customer's requirements. For the final shape of the product, the mixture is produced in granular form.

The input material for production is especially polypropylene and polyethylene, materials whose dust particles were the cause of several serious accidents (Seonggyu, 2019). Polypropylene can produce flammable dust with explosive properties, so the precautionary explosive measure is necessary to consider during processing (Jie et al., 2019). This is similar to polyethylene. Polypropylene dust has a high risk of fire and explosion during transport by pipelines or conveyors and accumulation in silos or

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Tab. 1 Fire characteristics of polyethylene and polypropylene (Low density polyethylene Bralen, 2015; Polypropylene Tatren, 2016)

Fire characteristics	Polyethene	Polypropylene
Degree of flammability	C3	C3
Lower explosion limit LEL (dust) (g.m^{-3})	100	30
Melting point (granules)	105 ÷ 115 °C	158 ÷ 165 °C
Flashpoint (granules)	350 ÷ 370 °C	370 ÷ 390 °C
Ignition temperature of granules	380 ÷ 390 °C	380 ÷ 390 °C
Ignition temperature of deposited dust	350 °C	
Ignition temperature of swirled dust	445 °C	
Minimum ignition initiation energy (J)	1,6	
Combustion heat (MJ.kg^{-1})	46 ÷ 47	

other similar equipment (Kai et al., 2021). The fire characteristics of polyethylene and polypropylene used during production show in Tab. 1.

For the technological process of screw extruders, there is the possibility of transmission of fire by suction nozzles, especially after the initiation of the flame, the formation of hot combustion products, hot surfaces and electrostatic charge, or in the case of failure of electrical equipment because there is a probability of the formation of a layer of combustible dust and its swirling during production. Therefore, the suction nozzles connect the suction system piping with a fan that discharges dust particles to the technological rooms to clean and accumulate dust with a separator (fabric filter).

The formation of swirled flammable dust is possible in all areas of activity with organic products (Glor, 2003). Therefore, dust explosion is possible in almost every industry and has been the cause of many accidents. Dust particles are created as the main product, mainly in the chemical industry. Still, they can also cause accidents in other areas of the industry during the production of by-products (Kuracina et al., 2021). The danger of a combustible dust fire occurs in places where the dust settles in a continuous layer. At the same time, a layer of dust of 1 mm considers being a continuous layer capable of spreading fire. A swirling dust cloud is usually not homogeneous, so the concentration can fluctuate according to the swirling of the settled dust.

Clouds of 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 cause a fire with a subsequent explosion, it is necessary to initiate the combustible substance. 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 1127-1 defines initiation sources capable of igniting a dust-air mixture. Possible sources of ignition of combustible dust of polymeric substances related to this article include hot surfaces, flames, sparks, and electrical equipment. The electrostatic charge is also an essential source of initiation. During the handling of organic dust, the so-called triboelectric phenomenon occurs, which means an increase in the charge of the dust itself and the equipment for handling the dust. Most organic products, and thus also dust, are very quickly charged and can initiate combustible dust by discharge. In the process, the initiation of electrostatic charge has been the cause of many fires and explosions (Glor, 2003).

Fig. 1 Production line for polymer processing
(1 extruder, 2 cooling bath, 3 pelletiser)

Extruders

Twin-screw extruders operate in the plastic industry in various applications, including mixing, blending, and reactive extrusions of polymeric materials. They have a perfect balance between the mixing efficiency of the mixture and the ability to generate the required pressure. However, it is necessary to know the values of the main input parameters such as temperature, pressure, residence time, shear rate, specific energy, etc., in a different position along with the screw profile and as a way of affecting variable factors such as screw geometry, speed phase, or screw speed (Carneiro et al., 2000). Extruders essentially consist of a hollow cylinder kept under a stable internal temperature with an Archimedean screw-type screw with an engine, gearbox, heaters, sensors, and a control system.

In general, solid polymer materials (granules, flakes, dust) pour into the working space of the screw either by gravity from the hoopers or by a feeding device at the prescribed speed. Subsequently, they move along the screw and melt by heat conduction into a highly viscous melt. First, the homogenisation of the melt runs through dispersion processes and distribution mixing. Subsequently, the melt continues through an extrusion head with the given number of holes with a given diameter (approx. 0.5 cm). From the extrusion head, the melt continues to the cooling bath to return to a solid state. After this operation, there is the possibility of other processes, for example, granulation.

The entire plasticisation process in the inner part of the extruder and consists of the following individual operations known as a functional zone:

1. The input of feed material from the hoppers.
2. The step of drawing material is by rotating the screw.
3. The formation of a thin layer of melt separates the solid component of the material from the melt.
4. Gradual melt formation.
5. Transfer the melt by a screw to the extrusion head.
6. Melt outlet from the extrusion head (Covas and Gaspar-Cunha, 2011).

During the transport of the polymeric solids from the hopper to the extruder, it may occur that part of the dust particles does not enter the inner part of the extruder but disperses to the surroundings of the extruder, where it settles. Some solid polymer materials are powder form, but even polymer granules abrasion to form dust particles. Suppose that the granular polymer material is fed into the hoppers through a pipe from a more considerable distance pneumatically. In that case, there is the possibility of generating a substantially more significant amount of dust from the granules colliding with each other. Moreover, since the polymeric substances dust is suspended, there is a risk that the dust will ignite. After that, it is the possible explosion in case of swirling of the dust.

Suction system and the principle of its operation

The suction system captures harmful substances (gases, vapours, solid particles) or excessive heat directly at their origin, thus preventing their spread into the open space. A local suction is always more economical than general ventilation because of lower suction airflow. If a pollutant with a mass flow M_s (kg.s^{-1}) leaks into the room, the airflow for the removal of the pollutant in general and local ventilation define according to the relation (1):

$$V = \frac{M_{\check{s}}}{C_o - C_p} \tag{1}$$

where:

C_o pollutant concentration in suction air (kg.m^3),

C_p pollutants in the supply air (usually $C_p = 0$) (kg.m^3).

For total ventilation, the concentration of the pollutant in suction air C_0 shall not exceed the permissible exposure limit C_{PEL} for the given pollutant, which means $C_o \leq C_{PEL}$ in case of local suction with designed the suction nozzle, no pollutants enter the room C_o » C_{PEL} may be present. This shows that the higher the concentration of pollutant in the suction air, the lower the required suction airflow. Therefore, the basic requirements for suction equipment are the following:

1. Pollutants shall capture directly at the source with a purposefully designed suction attachment suitable for operation and possible handling of products.
2. Air blown from the suction system into the outdoor environment must meet the legal emission requirements, and, if necessary, installation of a separator (filter) must be in front of the air exhaust into the atmosphere.
3. The suction system must meet all fire and explosion protection requirements, so that the hazardous concentration in the suction air must be less than 10% of the lower explosive limit LEL of pollutants. In addition, it shall meet the safety and operational reliability requirements.

Sorting of suction systems:

1. Central suction systems with multiple the same or similar sources of suction.
2. Group suction systems are used to suction one technological process, forming substances that cannot mix due to their danger (Fig. 2).

3. Divided suction systems that use several fans connected to one technological process; are primarily used on large production lines.
4. Unit suction systems contain a fan and a highly efficient filter to meet hygienic requirements.

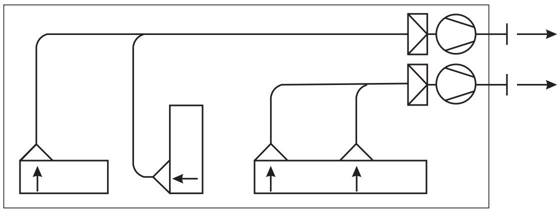

Fig. 2 Group suction scheme (Drkal and Zmrhal, 2020)

The group suction system uses a given technological process of polymer production. The system consists of two independent ducts with separate fans. Each system links to a separate fabric filter (Drkal and Zmrhal, 2020). Suction systems consist of the following main components:

1. Suction nozzles to capture dust particles from the dust source.
2. Piping system transporting dust to the dust filter.
3. Dust filter that removes dust from the air.
4. Fan with sufficient power and energy (Bhuiyan, 2020).

Suction nozzles

Suction nozzles immediately capture pollutants at the source site and operate as part of the technical equipment that produces pollutants. They design in such a way to be if it is possible to surround the source of the pollutant. The cross-section through which air flows into the suction attachment should be minimal but shall allow airflow at an acceptable speed which ranges from 0.5 to 2.5 m.s^{-1} according to the harmfulness of the suction substance. If suction nozzles are impossible to use for technological or handling reasons, the simple suction attachment must be placed as close as possible to the source so that the flow of pollutants is directed to the attachment (Drkal and Zmrhal, 2020).

The screw extruder includes two simple suction nozzles to remove dust particles from a fabric filter to clean and accumulate dust through a piping system; it is the first branch of the group suction system.

The suction slit in Fig. 3 on the right removes the fumes formed during the cooling of the polymer fibres that emerge from the extrusion head and is part of the second branch of the group suction system. These fumes do not risk fire and subsequent explosion as there are no flammable dust particles.

Fig. 3 Suction nozzles for screw extruder

Air ducts

Air ducts remove air with pollutants from work areas or supply air for ventilation to work areas. The operation of suitable air ducts depends on the proper design and construction.

Most air ducts are made from galvanised steel sheets the thickness grade according to the dimensions of the piping and group characterising the operation conditions. The air duct cross section is square or circular. The advantage of round pipes is that there is less dust accumulation.

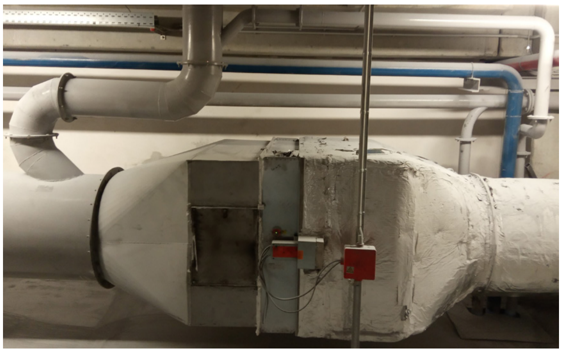

Fig. 4 Fire damper

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The fittings change direction and speed, connect or divide airflow, and have a shape for small pressure losses. Although simpler to manufacture, sharp elbows usually do not design due to significant pressure losses. Bends used for dust suction the radius $R = 3\ d$ where d is pipe diameter (Chyský and Hemzal, 1993).

Circular air ducts connect with plug-in couplings, and square ducts connect with flanges via rubber seal. The flanges connect fixed or so-called loosed flanges fixed in place after measuring the required length of the air duct. The air ducts produced are textile, plastic, aluminium (flexible hoses) or ALP material, a foam panel covered with aluminium foil (Drkal and Zmrhal, 2020). In addition, air ducts include control dampers, constant flow regulators, and fire dampers (Fig. 4).

Fabric filter

Fabric filters operate in the industry for cleaning discharged gaseous particles. They represent some of the most important devices used for environmental protection. They employ to effectively remove industrial dust, especially fine particles. Fabric filters work as follows. The flowing air with dust particles passes through the filter. The dust particles are captured on the filter's surface to form a so-called filter cake. The formation of a dust cake on commonly used filters is divided into three stages: deep, intermediate, and surface filtration. Cleaning the filter from the filter cake is usually done with compressed air inside the filter (regeneration) (Arymbayeva and Van Hess, 2020).

Fig. 5 Air ducts in the workplaces

The central piping system leads from the fabric filter to the screw extruders. Another branch connects this pipeline to ensure suction of dust from other workplaces without screw extruders and accessories. Both branches have fire dumpers in their pipelines, but between these two branches, there is another independent branch for sucking other workplaces without a fire damper.

Fig. 5 shows the different air duct network systems that led from the suction devices to the fabric filter.

Fabric filters are usually part of a system that removes dust particles from the production line. This system usually does not guarantee the complete removal of dust particles. However, a well-designed dust removal system can prevent or reduce the likelihood of a fire hazard resulting in a combustible dust explosion. Most dust removal systems use ducted ventilation to remove dust particles from the dust generation point to the fabric filter. The choice of control system depends on

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the quality of the discharged air according to the legal regulations given.

A dust removal system can provide the required and effective control and is known as a local exhaust system. The safety requirements are stated in the European technical standard EN 12779.

Various methods work for regeneration, such as backflow of cleaned gas, air pressure shock or shaking. The different constructions of filters and fabrics used also correspond to individual types of regeneration; used filter cloths used are made of particularly natural or synthetic fibers.

The fabric filter used in operation for dust suction (Fig. 6) is a hose filter with automatic time-dependent flushing with compressed air (regeneration of the pulse method). The filter cakes remove high pressure air from the hose filters 5 to 7 times per second. Separated dust was collected in the lower part of the filter unit and discharged through a rotary screw feeder into a large bag located under the filter.

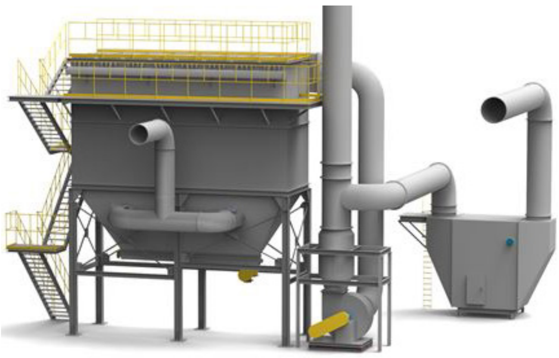

Fig. 6 Fabric filter connected to HEPA filter

The dust filter is the essence of the fabric filter. The performance of the filter affects the operational energy consumption and the performance of the fabric filter (Xingcheng et al., 2019). In the past, dust filters were mostly made of nonwoven fabric whose objective was to create an effective porous barrier against pollutants. They were mostly materials of natural origin, e.g., felt.

A second stage in the dust suction system is the HEPA type fabric filter connected with the fabric filter. HEPA means high-efficiency particulate air filter. It consists of a continuous strip of filter medium placed between the sheets of the aluminium separator like an 'organ'. This type of filter can capture dust particles below 0.1 µm with an efficiency of 99.7 %. The cleaned air is discharged into the main production areas of the production hall to improve the hygiene of the working environment.

Fans

Fans operate to move the intake air from the intake nozzles of the machinery through the piping to the separator. A fan is part of every suction system. It is a rotary blade machine that is widely used in air conditioning. The most used radial fans are low-pressure fans with forward-curved blades. The impeller has a constant width and is structurally simple, even with many blades (approximately 40 to 50). This type of radial fan achieves an efficiency of 0.55 to 0.65 (Drkal and Zmrhal, 2020).

Description of the technology

The input material of the polyethylene and polypropylene mixture feeds from the storage silos through the distribution pipe to the mixer for pulverisation to approximately the same size, and the overall homogeneous mixing of the individual components of the mixture takes place. The raw material is most often in the form of pellets and less often in the form of powder and flakes.

Fig. 7 Dosing device to feed the mass into the extruder

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After mixing, the mass feeds into operating silos equipment with a dosing device that controls the mass supply to the screw extruder. These are three operating silos (Fig. 7). The silo on the right feeds a basic mixture of mixed material consisting of polyethylene and polypropylene. Additional mixtures (talc, calcium carbonate, crushed glass, pigments, and additives) feed into the extruder from the other two silos. The material is poured to form dust particles sucked out of the suction nozzles, but a certain amount of dust particles is not sucked off and creates a layer of dust a few millimetres on the floor.

In a screw extruder (Fig. 8), the mixture heats to a temperature of 220 °C to 280 °C. The melting point is from 158 °C to 168 °C, which is substantially below the flashpoint from 350 °C to 370 °C. If this temperature is higher, it is a risk of the material burning.

Heating performs the heaters (14 pieces for each screw extruder). The machines include equipment for conducting heat from which waste heat with dust particles suctions out suction nozzles. However, a certain amount of dust particles from the mixture settles on the surface of the extruder heaters. In some cases, the surface temperature can reach more than 350 °C, for example during a temperature sensor failure. In the event of a fire, there is a control mechanism above the screw extruders. These are smoke and flame detectors.

Fig. 8 Screw extruder

The output of the screw extruder is an endless stream of material, which is a fibre with a diameter of about 0.5 cm. Cooling of the fibre takes place in a two-stage closed cooling water cycle with a temperature of about 50 °C. At the outlet of the cooling bath, the fibre already has a sufficiently low temperature for subsequent processing.

After cooling and removing adhering water, the fibre enters the pelletizer and sieves to adjust to the required size. The pellets are then transported to another production silo by a compressed air piping system. The lower part of the production silo contains a weighing mechanism that releases the required amount of material in batches. Subsequently, the produced material pours into big bags.

Fig. 9 Pouring of material into big bags

The hopper of the production silo includes a branch for sucking dust into the fabric filter. It is a galvanised pipe system, but the last part of the pipe is a flexible plastic hose.

Discussion

These results can achieve after analysing the suction system used in the workplace for suctioning dust particles from screw extruders and their equipment.

In terms of the possibility of fire and subsequent explosion of combustible dust, the most significant risk of ignition of combustible dust in screw extruder heaters is where there is a possibility of ignition of combustible dust from hot surfaces. The heaters do not have any protection, for example, a protective cover or insulation. However, a certain amount of dust particles settles directly on the surface of the heaters, which can reach a critical temperature of more than 350 °C. This temperature can already ignite combustible dust with the possibility of flame transfer to the suction piping system. Another fire

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risk occurs during an exceeding temperature of the material inside the screw extruder and its ignition. The suction system is not very professional; used at 90 ° elbows are not suitable for suction; the best way is to use bends that prevent pressure loss.

Regarding the screw extruder attachment, Fig. 5 shows a piping system made from two branches of operating silos connected, the so-called T piece which increases turbulent flow so that the efficiency of the suction nozzles decreases, and some the amount of dust forms a dust layer on the floor in a layer of a few millimetres. During production, two of the three operating silos produce non-flammable inorganic admixtures (talc, crushed glass), but the main operating silo feeds a mixed mixture of polymers to the screw extruders. The dust particles in this mixture already pose a risk of potential fire and subsequent explosion during the transfer of flames to the suction piping system. It would be more appropriate to use manifolds instead of a T-piece to change the turbulent flow and thus to increase the efficiency of the suction system. However, it would be appropriate to redesign a substantial part of the piping system, mainly the 90° elbow exchange for bends as described above, and then dust particles would not settle in layers on the ground or the surfaces of screw extruder heaters.

With regard to the operational silos for material packaging, the pneumatic material transport system can generate a powerful electrostatic charge. The most efficient way to eliminate the risk is to ground all conductors to the earth, including flanges and flexible plastic hoses (CSN CLC/TR 60079-32-1). Another risk of fire may be a failure of the electrical equipment of the fan, which ensures the movement of air and the transmission of flames to the piping system, mainly during overload or short circuit.

The Czech standard CSN 12 7040 approved in 1986 is still valid, and it explicitly 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 equipment by the suitable protecting device. Therefore, if the assessed workplace does not have a flammable dust explosion device system, it violates the above standard (missing fire dumpers).

Conclusions

The plastics processing industry has had a growing trend in recent decades, and although it operates with flammable processing material, and thus its dust particles can be explosive, explosions in the plastic industry are not prevalent. However, since this is never zero, there is always a potential risk of fire and subsequent explosion (or vice versa).

The paper deals with the risks of explosion and fire related to the suction system while producing a mixture of polymer granules. After analysing the workplace, glaring nonconformities were found, for example, in installing the suction pipe and its low performance, missing fire dampers, unresolved explosion protection of the separator or inappropriately designed covers of the heating elements. Therefore, it would be advisable to eliminate these nonconformities as soon as possible to reduce the risk of fire, explosion, and related work safety to the lowest possible level. It primarily means equipping secondary branches with fire dampers and solving the risk of the possibility of an explosion in the inner spaces of the fabric filter by using flaps to separate the explosion or by using inertization.

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