ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XVIII [2020] | Fascicule 1 [February]

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584-2665 (printed version); ISSN 2601-2332 (online); ISSN-L 1584-2665

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FIRE AND EXPLOSIVE RISK ASSESSMENT FOR COMBUSTIBLE POWDER PNEUMATIC CONVEYOR SYSTEM

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Abstract: Failure to properly define operating hazards associated with pneumatic conveying system for combustible powder transportation has led to several incidences of fires and explosions. These hazards are mostly preventable if adequate safety measures are provided for the pneumatic conveying systems for dust and combustible materials during the system design, installation and operating stages. This paper presents assessment on risk of fire and explosive hazards associated with pneumatic conveying system for a combustible powder transportation and prescribe the best practice to prevent possible accident that might result from improper practice. The safety practice and relevant regulations for zoning of the operating area and guide for proper selection of suitable class of measuring instrumentation for safe system operation are enumerated.
Keywords: pneumatic conveyor, fire explosion, hazards, dust, risk assessment

1. INTRODUCTION

A pneumatic conveyor is transport system that uses air to transport materials from one location to another. It achieved material transportation by generating air pressure level either above or below the atmospheric pressure to move the materials through a pipe or tubes to the required destination usually storage tank (Ansell, 2009, Levy and Kalman, 2001a, Klinzing et al., 2011, Marcus, 2012). It is used for transporting different kind of particulate solids such as bulk solids and powder in a clean and efficient way. The high reliability and maintenance-free features make it an attractive choice when considering various conveying methods. The pneumatic conveyor system is generally a cost-effective, reliable and quick method for transporting materials such as powders, grains, soils, sands, pills, pellets, tablets, rocks, metals, coal, gravel, chemicals, textiles, food, plastics, powders, wood chips, toxic waste and asbestos. The main advantage of the pneumatic conveyor system in material handling is the low product leakage feature since the process takes place in enclosed setting. This remains particularly important in industrial applications involving the conveyance of hazardous materials like combustible powders where leakage can be dangerous and as well be a threat to the environment and operators. A single pneumatic conveyor system can handle varieties of material, so there is little need to have many conveyors specializing in specific product (Deng and Bradley, 2016, McGuire, 2009). Different types of air conveyors are available for handling various needs in industries, the basic types are the dilute phase and dense phase conveyors, and they differs by pressure and speed rate (Ostrowski et al., 1999). The dense phase conveyors are run by compression and mostly used for conveying heavier materials, therefore they convey at a slower speed than the dilute phase conveyors, which conveys by creating a vacuum (Kutz, 2013, Levy and Kalman, 2001b).

The other types of air conveyors named for their specific operations include the bulk handling conveyor, abrasive material conveyor and the food handling conveyor system. The selection of a conveyor system for an operation depends on several factors such as the conveying material specifications like the sizes, shape, weight and volume (Klinzing et al., 2011, Mills, 2003). Other factors are the process characteristic and the environment in which the conveyor system is to be operated.

In chemical industries, risk assessment of fire explosion and hazards is very important and fundamental to smooth and safe operation of conveyor systems. In the past, failure to properly define the operational hazards associated with transportation of explosive and combustible material has led to several reported incidents of fires and explosions (Crowl and Louvar, 2001, Garrison, 1988, Chang and Lin, 2006, Joseph and Team, 2007, Eckhoff, 2003). Depending on the severity, explosion has resulted in sustenance of injuries of various degree by the plant operators, loss of life and properties. Report have shown that some if not all but most of the hazards are preventable if adequate safety measures are provided during the design, installation and operating stages of conveyor system, especially when dealing with combustible powder (Amyotte and Eckhoff, 2010, Abbasi and Abbasi, 2007). To ensure the safety of plant and operator, design engineers are to properly analyse the presence of potential fire and explosive hazard in operating such system and incorporate modifications required to optimize safety, costs and productivity. The guideline to ensure that a system operation conforms to the standard for health and safety of plant and personnel include the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR), Atmosphères Explosibles (ATEX) and Health and Safety at Work Act (HASAWA) as applicable in the United Kingdom (DSEAR, 2002, DTI, 2016, HASAWA, 1974, ATEX). Proper risk assessment safeguards health and safety of workers and peoples around a working place and once it is well observed, plant operation can commence.

Given priority to health and safety provides the legal framework to promote, stimulate and encourage high standard practice in places of work. This paper presents overview of risk and explosion fire hazards assessment for a powder pneumatic conveyor using a typical laboratory scale system. The possible risk associated with the system during material transport that could lead to fire explosion during the operation were identified and classified in to place zoning such as where explosive atmospheres may and may not occur during material transport. The potential ignition source during the plant operation were also recognised and control measures were provided to guide against the occurrence of fire or explosion. Lastly, the criteria for selection of suitable and safe process instrument for variable measurement were enumerator to serve as guide in chosen the right equipment for proper protection and control against possible hazards during operation.

2. PNEUMATIC CONVEYOR SYSTEM

This section presents the specifications and operation of a typical laboratory scale pneumatic conveyor system considered in this study. The conveyor system was specially designed for testing mass flow rate of different materials in the instrumentation and control laboratory of Glasgow Caledonian University, UK. The Figure 1 shows the schematic diagram of the pneumatic conveyor test rig consisting of the compressor, the pipelines, the blow tank, the receiving vessel and the nozzle bank (Ansell, 2009). In this application, the pipeline pressure is rated at 15 bar g and the blow tank pressure is also rated to be above 15 bar g. The filter housing above the receiving vessel pressure rating is 0.3 bar g which is same as the receiving vessel of 0.3 bar g. The properties of Pharmex powder material transported round the conveyor system in this study are presented in Table 1.

Table 1: Explosive properties of Pharmex powder

Material	Min. ignition energy/mJ	Max. explosion pressure/ bar a	Max. pressure rise bar m s^{-1}	Min. explosible concentration/ g/m^3
Pharmex	15	10	156	80

The receiving vessel is positioned at the top of the blow tank to allow the powder Pharmex to be simply dropped into the blow tank during the test process. The compressor supplies the air used in conveying the Pharmex powder transport along the pipeline. It incorporates a dryer that removes moisture content presents in the compressed air preventing moisture getting into the powder which may cause pipeline blockage. The air flow rate from the compressor is controlled by the nozzle bank consisting of a series of critical flow orifices that allows a certain airflow depending on the number of nozzle valve opened. The blow tank right below the receiving vessel holds the Pharmex powder before transported through the pipeline to its destination. The Pharmex powder travels along the pipeline and collected into a receiving vessel located at the top of the blow tank. After the complete cycle of the powder transportation, it is discharged from the receiving vessel by opening the valve (SV2) below it to the blow tank for another process cycle. The receiving vessel is fitted with a filter to allow the air used in the conveying process to be separated from the powder that collects in the receiving vessel.

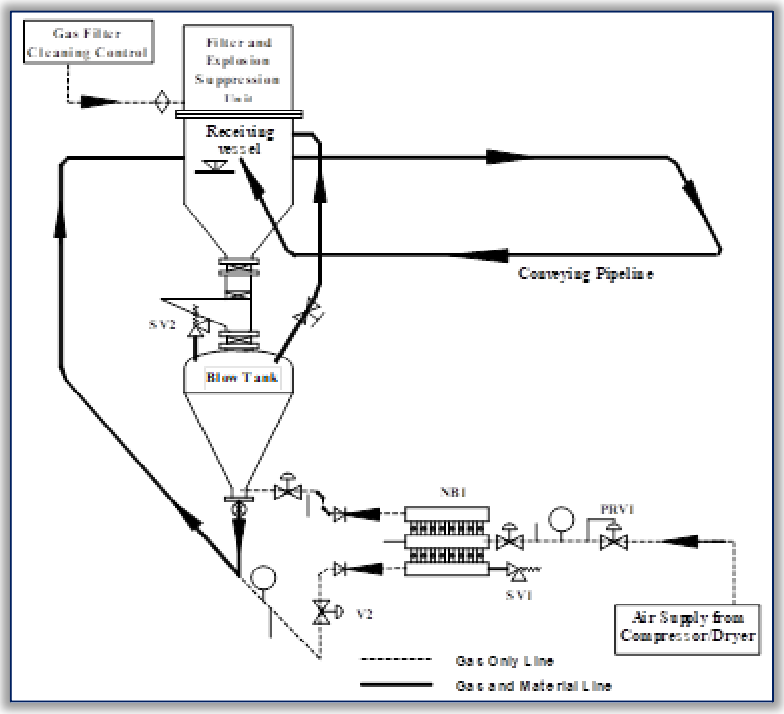

Figure1: Pneumatic conveyor system (Ansell, 2009)

3. FIRE AND EXPLOSIVE RISK ASSESSMENT

An explosive atmosphere is defined as a mixture of dangerous substances with air, under atmospheric conditions, in the form of gases, vapours, mist or dust in which, after ignition has occurred, combustion spreads to the entire unburned mixture. In order to carry out a risk assessment of fire and explosive hazards for the powder conveying system described in section 2, each part of the system including the Pharmex to be transported, pneumatic conveyor system components, operating process and the working environment were all considered. The risk assessment process identified the continuous presence of two out of the three factors necessary for fire and explosion to occur, the fuel (Pharmex powder), the oxidant (air) for moving Pharmex powder along the pipeline. The third factor which is ignition sources might arise from mechanical, electrical, electrostatic or thermal operation which is preventable if well managed. A general representation of the fire triangle is presented in Figure 2 showing the link between the factors responsible for fire and explosion in a process.

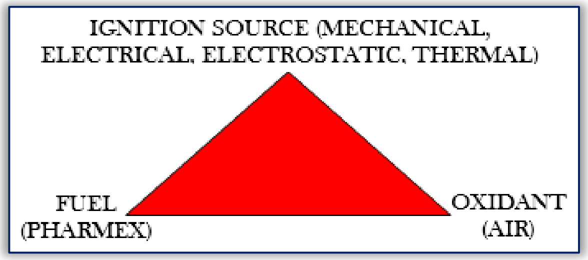

Figure 2. Fire triangle

In this process, an ignition source can be from mechanical, electrical, or thermal hazards particularly from the plant component parts or operation. By providing a measure for removing the ignition source and minimizing risk if there is an explosion, these guarantee safe working environment. To guard against any possibility of fire or explosion hazards in the application process, certain procedures needed to be followed by first identifying the risk associated with system parts, hazards involved in the process, and then provides the control measures that will eliminate or mitigate hazards. These procedural actions will guarantee the safety of equipment and operating personnel.

— Hazards Associated with Conveyor Parts

This section presents the first step in carrying out risk assessment on a powder conveyor system. The possible risk factors associated with the various parts of the pneumatic conveyor system which could lead to hazards during the system operation were identified based on the properties of the system parts. Identifying the risks will provide the ground for making provision for preventive measure and mitigation in case of accident.

1. Receiving Vessel and Filter Housing: The receiving vessel and the filter housing have a pressure rating of 0.3 bar g which is far lower compared to the maximum explosive pressure of the Pharmex powder of 10 bar g in Table 1. For safety operation to avoid vessel explosion which can come with severe risk, it is required that the vessel should be designed to be able to withstand at least 1.5 times the maximum explosion pressure. Since both receiving vessel and filter housing are not strong enough to withstand an explosion, therefore, a suppression system is to be incorporated for protection in the event of an explosion.
2. The Pipelines: The pipe is rated at a pressure of 15 bar g, this is safe for the operation since it has satisfied the condition of being able to withstand at least 1.5 times the maximum explosion pressure of the Pharmex in case there is an explosion. The operation of the system is at ambient temperature, therefore, there will only be a little temperature rise of the Pharmex powder during the transportation. It is expected that the temperature rise will but will not to reach the Pharmex ignition temperature and therefore this is considered safe and not presenting an ignition source.
3. Blow Tank: The blow tank can sustain an explosion determined by a factor of the pressure rating, it is rated above 15 bar g which has satisfied 1.5 times 10 bar g maximum explosion pressure presented by the Pharmex. The blow thank design is considered safe.
4. Compressor: The compressor supplies the air necessary to achieve Pharmex transfer along the conveying pipe. If there is an explosion, the supplied air will be pushed back towards the source and it is expected to contribute hazard on the compressor. Therefore, an isolation valve is provided in the system to stop blowback to the compressor in the event of an explosion.
5. Vent: The vent is the channel through which the separated air from the process is discharged. The vent is extended to the outside area of the working place so that it will not present any form of risk to the workers.

— Pneumatic Conveyor Hazard Place Zoning

The risk of fire and explosive hazard associated with the various part of the conveyor system and the potential explosive atmosphere (places) is very crucial when considering health and safety of equipment and personnel. The risk assessment enables special precautions to be put in place over sources of ignition in order to prevent fires and explosions.

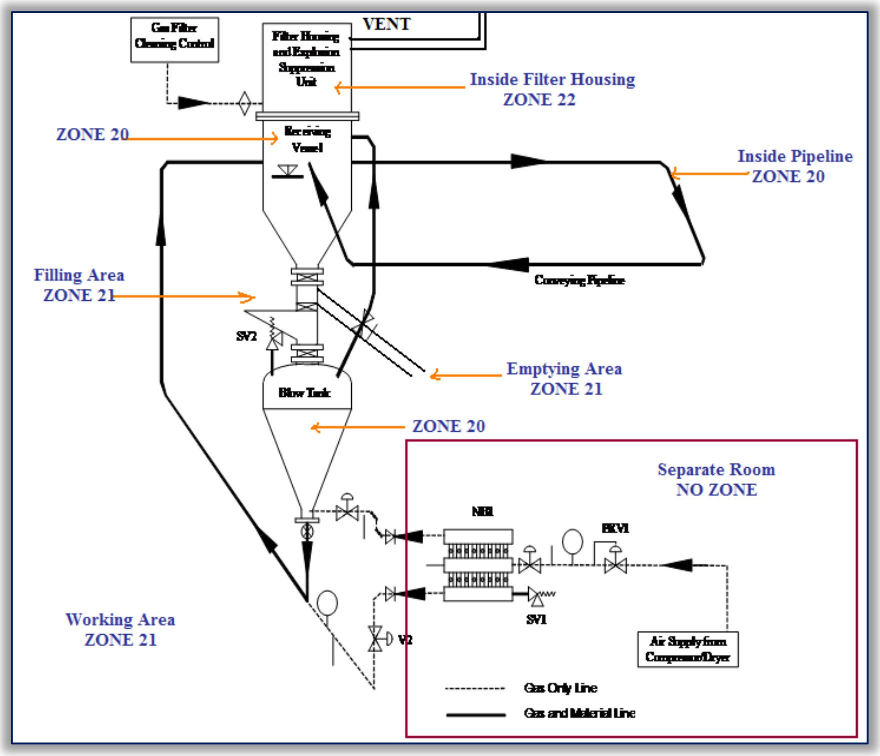

Figure 3: Conveyor place zoning

Place zoning is an integral part of the risk assessment, after identifying places (or areas) with risk level, control measure over ignition sources are then incorporated based on specified standards.

According to DSEAR, the places where explosive atmospheres may occur around the plant during the conveyance of explosive powder material such as Pharmex are classified into three zones; the Zone 20, Zone 21 and Zone 22 (HSE).

The Zone 20 are places in which an explosive atmosphere in the form of a cloud of combustible dust in the air is present continuously or for long periods of time. The Zone 21 is places in which an explosive atmosphere in the form of a cloud of combustible dust in air likely to occur in normal operation occasionally. The Zone 22 are the places in which an explosive atmosphere in the form of a cloud of combustible dust in the air is not likely to occur in normal operation but, if it does occur, will only persist for a short period of time . Considering the operating conditions of the conveyor system when Pharmex powder is being transported, the likelihood of the Pharmex substance being present and the time at which it will be present in an area is used in the classification of the areas into zones as indicated in Figure 3 conveyor zoning . The specific part of the conveyor system and areas zoning during the plant normal operation are presented in Table 2 indicating the level of risk of fire and explosive hazard associated with the various position.

Table 2: Place and area zoning

Place/Area	Zoning	Remark
Receiving vessel	ZONE 20	Pharmex moves from the blow tank into the receiving vessel during operation, so there is continues presence of an explosive atmosphere in the form of a cloud of combustible dust (Pharmex powder) for a long period of time.
Filter housing	ZONE 22	The filter housing is located above the receiving vessel and only the air used in the conveying process is expected to be present. An explosive atmosphere informs of a cloud of combustible dust in the air (Pharmex powder) is not likely to occur during normal operation but, if it does, will only persist for a short period.
Blow tank	ZONE 20	The Pharmex powder is to be fed into the blow tank at the beginning of the process, the powder will be blown gradually which means that during the process there will always be powder in the blown tank. It is an area where an explosive atmosphere in the form of a cloud of combustible dust (Pharmex powder) in the air will be present continuously or for long periods of time.
Pipeline	ZONE 20	During the process, the Pharmex powder will continuously move along the pipe indicating that the pipeline also can be classified as Zone 20, i.e. an area where explosive atmosphere inform of a cloud of combustible dust (Pharmex powder) in the air will be present continuously or for long periods of time.
Working (plant) area	ZONE 21	If the vent pipe is extended to the outside of the working room, inside of the working area is classified as zone 21, a place where an explosive atmosphere informs of a cloud of combustible dust in air (Pharmex powder) is not likely to occur during normal operation but, if it does occur, will only persist for a short period of time.
Filling and emptying of Pharmex powder	ZONE 21	Due to static charges, it is possible that there might likely be fired and explosion during the filling of the Pharmex powder into the blow tank, so this be avoided by taken special precautions. This is classified as zone 21, a place where an explosive atmosphere in the form of a cloud of combustible dust in air (Pharmex powder) is likely to occur in normal operation occasionally
Compressor	NO ZONE	The compressor is positioned in a separate room and there is an isolation valve incorporated to block flow back air in case of an explosion at the plant. It's not going to be exposed to an explosive atmosphere in the form of a cloud of combustible dust in the air during normal operation.

4. IGNITION SOURCES AND CONTROL

The ability to identify and isolate all potential ignition sources at the stages of design and installation of conveyor system is paramount to safety. The selection of material for body parts construction and instrumentation are to meet the minimum standard to avoid any form of hazard that might result in to fire and explosion. Once the possible ignition sources that might arise from the system units and operational parts are identified, these will make it possible to isolate them by putting measures in place. Some of the potential ignition sources wit the measure to isolate them during conveyance of combustible substances such as Pharmex powder are summarise in the following subsection.

— Potential Ignition Sources

The potential ignition sources during the conveyor system transportation of Pharmex powder are broadly classified as chemical, mechanical, electrical, static and thermal ignition sources. In this application, since the Pharmex powder is the single chemical substance to be transported around the closed pipe, it can be considered that there is no possibility of fire hazard resulting from any form of chemical reaction. During the Pharmex powder conveyance, some of the potential ignition sources that might result from other classified sources are summarised as follows.

≡ Mechanical ignition sources

» Tramp metal: - The presence of any tramp metal along the pipeline such as loose screw may bring about spark when in contact with isolated conductors depending on the capacitance.
» Overheating: The vessel or any rotating motor in the plant system can get overheated, during powder discharge, allowing the discharge pipe to be in contact with a metal collector can lead to ignition.

≡ Electrical ignition sources

» Electrical circuits can be ignition source, if electronic circuit or motors gets overheated. It is necessary to use heatsinks and special motors in a conveyor design stage.
» Switches can also constitute ignition source, so selection of the switch is an integral part of the electronically operated valve and requires special consideration.

≡ Static ignition sources

The major source of static energy is from personnel body charge and may be up to around 25 mJ which is greater than 15 mJ minimum ignition energy required by the Pharmex to explode. There is need for precautionary measure to control personnel contact with powder. Since most part of a pneumatic conveyor system is constructed from metal, the plant can build up static charges with higher ignition energy up to around 100 mJ.

≡ Thermal ignition sources

Thermal ignition can arise from mechanical or electrical overheating when in contact with the Pharmex powder during movement but it is expected that the powder temperate will only rise little above the room temperature so it will not necessarily constitute any danger.

≡ Naked Flame

Any source of naked flame can be an ignition source, so the working area of the plant must be designated as no smoking area and there should also be a prohibition of welding or cutting of metal during plant operation.

— Explosion Control and Mitigation for Pneumatic Conveyor

By providing the necessary control measures, the possibilities of occurrence of fire and explosion during pneumatic conveyor plant operation when transporting explosive powder is highly unlikely. As applicable in general situations, the control measures are the necessary actions put in place to ensure that the identified risk in any process is eliminated or reduced to an accepted practicable level. The preventive measures are required to be put in place to reduce the risk associated with the various parts of the powder (Pharmex) pneumatic conveyor and all the ignition source are to be eliminated. In this application, the recommended control measures are to be achieved by any of the three-basic procedure stated as follows.

≡ Prevention of formation of explosive atmospheres,
≡ The avoidance of ignition of explosive atmospheres, and
≡ Mitigation of the detrimental effects of an explosion for workers safety.

Taken the precautionary measures in the plant design, installation and operation based on the zoning recommendation would have prevented any formation of explosive atmosphere. Aside the air and powder to be transported, guiding against allowing the third element of the fire triangle (Figure 2) that is ignition sources to be present, then there will be no risk of fire and explosion. The safety measure is completed by ensuring that the operating personnel in the working place wears non-conductive shoes and movement is restrict. Tramp metal is continually removed by screening the Pharmex powder been fed into the system.

Proper selection of equipment for measuring variables will also go a long way in minimizing electrical, mechanical or thermal ignition sources. The electrical cables, circuit and switches should be of correct ratings, compatible with the environment and carrying out periodic test on the equipment are also essential. The motors should be of proper category compatible with the type of zoning where it will be used, and other frictional sources should be avoided.

5. PROCESS INSTRUMENTATION

The smooth operation and running of pneumatic conveyor largely depend on process monitoring, variable measurement and operational control using the sensors and control actuators. The measuring devices incorporated in to a conveyor system measure process variable including the pressure, the mass flow rate of air and temperature. The equipment selection require special precautionary measure because of the hazardous environment to prevent them from being a source of ignition. In situations where an explosive atmosphere has a high likelihood of occurring, it is important to use equipment with a low probability of creating a source of ignition. Where the likelihood of an explosive atmosphere occurrence is reduced, equipment constructed to a less rigorous standard may be used.

There are harmonized published standards that guides the ways of construction and selection of equipment to prevent ignition risks and additional requirements are set out in relation to installation and use of the equipment (DSEAR, 2002, DTI, 2016). In United Kingdom legislation document on health and safety, if the explosion protection document based on risk assessment does not state otherwise, equipment and protective systems for all places in which explosive atmospheres may occur are to be selected based on the categories set out in Directive 94/9/EC. The categories of equipment selected for different zones for pneumatic conveying system transporting explosive powder such as Pharmex powder is summarised in Table 3, provided they are suitable for dust and explosive atmosphere.

Table 3: Equipment categories and zones

Zone	Equipment	Conditions of operation
Zone 20	Category 1	The equipment remains energized and functioning in Zones 20, 21, 22
Zone 21	Category 1 or 2	The equipment remains energized and functioning in Zones 21, 22
Zone 22	Category 1, 2 or 3	The equipment remains energized and functioning in Zone 22

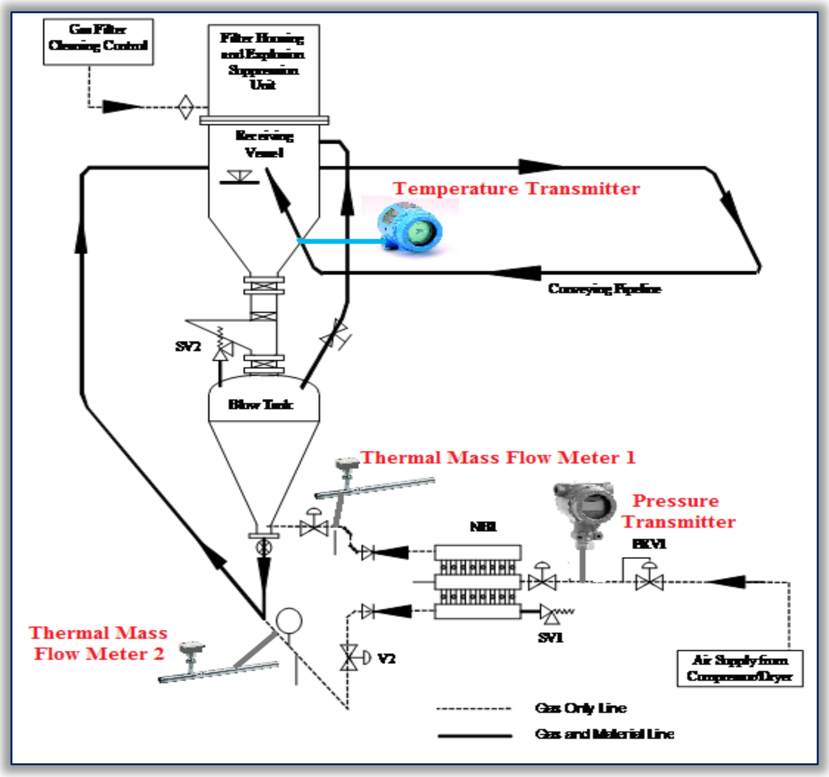

Figure 4. Equipment positioning for pneumatic conveyor

The DSEAR regulations are applicable to all equipment intended for use in explosive atmospheres, whether electrical or mechanical and protective systems. To achieve health and safety of workers , it is required that equipment used in zoned areas comply with the requirements in the DTI Regulations and that equipment of a higher or lower category would only be present in special circumstances. Some of which an alternative effective precaution is provided to control the risk during maintenance operations or workers are excluded from the hazardous area and will not be at risk from any ignition of an explosive atmosphere. A brief discussion on the selection criteria for the major equipment required for the pneumatic conveyor for Pharmex powder transport as indicated in Figure 4 are provided.

— **Pressure Gauge Transmitters**

The conveying process involve the use of air to transfer the Pharmex powder around the pipeline from the blow tank to the receiving vessel. The compressor pressure is monitored since different materials requires different pressure to generate airflow for moving the material around the conveying pipe. The pressure is monitored immediately after the pressure tank and before the nozzle bank as shown in Figure 4. In a worst case, the pressure gauge can be considered to fall in Zone 22 i.e. a place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does occur, will only persist for a short period of time. At this position, the three factors of the fire triangle are not complete, there is oxidized (air), but no fuel at normal operation (Pharmex powder) and with proper selection of the pressure transmitter there will be no ignition source. The category of the equipment is to be chosen based on Table 2 which indicates Zone 22, categories 1, 2 or 3 equipment.

— **Air Mass Flow Meter**

The air generated by the compressor passes through the nozzle bank from where it is divided into two parts; a part to the blow tank to discharge the Pharmex powder and the other part to the pipe to push the Pharmex powder around the conveying pipeline up to the receiving tank. The transfer process is multiphase involving Pharmex and air, which means it may be difficult to directly determine the mass flow rate of the powder. The two air mass flow meters incorporated on the pipeline closed to blow tank and the receiving tank collects data for improving air control from the compressor as depicted in Figure 4. Considering the position of the air mass flow meters prior to the blown tank and conveying pipeline, it is expected that there will no Pharmex powder presence. These areas are classified as Zone 22 categories 1, 2 or 3 equipment, a place in which an explosive atmosphere in the form of a cloud of combustible dust in the air is not likely to occur in normal operation but if it does occur, will only persist for a short period of time.

— **Temperature Transmitter**

The process temperature is expected to rise when Pharmex powder is being transferred around the conveying pipes depending on the properties and the mass flow rate of the material. As the powder moves from the blow tank through the conveying pipe, the process temperature increase is expected to be maximum at a point of entering the receiving vessel, so the temperature is monitored at this point as shown in Figure 4. This area is classified as Zone 20, a place in which an explosive atmosphere in the form of a cloud of combustible dust in the air is present continuously and for long periods of time. The fuel (Pharmex powder) and oxidant (air) are present during operation, so there is need to observe control measure and select proper measuring equipment to eliminate possibility of any form of an ignition source. The zone is classified to be Zone 20, it is only category-1 equipment that can be used in this area to guarantee safe operation.

6. CONCLUSION

The risk of fire and explosive hazards assessment for a laboratory scale pneumatic conveyor system for dust powder transportation has been carried out in this study following the standards stipulated by the health and safety executives and other relevant regulations. The risk associated with the plant part and environment were identified and necessary control measure was enumerated to prevent the occurrence of possible fire and explosion during operation. Also, there were recommendations to mitigate the injury severity if there is any. It is expected that the information will serve as guide during such plat design, installation and operation to ensure that incidence of any form of accident from fire or explosive is unlikely.

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ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665

Faculty of Engineering Hunedoara,
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