

# Facing the Pentagon

Understanding the difference between inherent safety and engineered/procedural categories in combustible dust is fundamental, explains Paul Amyotte.



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It's a simple geometric shape – a pentagon – yet it affords us everything we need to know on a fundamental level about dust explosion causation. Because when the requirements of the explosion pentagon (figure 1) are satisfied, the risk of a dust explosion arises. These requirements include the familiar need for a fuel, an oxidant and an ignition source, augmented by mixing of the fuel and oxidant, as well as confinement of the resulting mixture. The first of these additional components illustrates a key difference between dust and gas explosions – a solid rather than a gaseous fuel. In a dust/air mixture, the dust particles are strongly influenced by gravity; an essential prerequisite for a dust explosion is therefore the formation of a dust/oxidant suspension. Once combustion of this mixture occurs, confinement (partial or complete) permits an overpressure to develop, thus enabling a fast-burning dust flame to transition to a dust explosion.

These considerations explain why dust explosions usually occur in industry inside process vessels and units such as mills, grinders, and dryers – ie inside equipment where all sides of the explosion pentagon have a higher probability of existing. Such occurrences are often called primary explosions, especially if they result in secondary explosions external to the process unit.

The reason for the majority of dust explosions being initiated in this manner is that the range of explosible concentrations is orders of magnitude greater than the concentrations permitted in areas inhabited by workers. In other words, airborne concentration thresholds set by occupational hygiene considerations are much lower than the minimum explosible concentrations of combustible dusts.

Notwithstanding the discussion in the previous paragraph, dust explosions do occur in work areas, not just inside process units. A secondary explosion can be initiated due to entrainment of dust layers by the blast waves arising from a primary explosion. The primary event might be a dust explosion originating in a process unit, or could be any disturbance energetic enough to disperse explosible dust layered on the floor and various work surfaces. An example of such an energetic disturbance (other than a primary

dust explosion) would be a gas explosion leading to a dust explosion. This is a well-documented phenomenon in the underground coal mining industry, where devastating effects can result from the overpressures and rates of pressure rise generated in a coal dust explosion that has been triggered by a methane explosion. The text by Eckhoff<sup>1</sup> and a recent paper by Amyotte and Eckhoff<sup>2</sup> provide further details from comprehensive and overview perspectives, respectively.

The explosion pentagon also provides valuable insight into dust explosion prevention and mitigation. For example – remove electrostatic ignition sources by grounding and bonding and an explosion might be prevented; remove the containment criterion by explosion relief venting and explosion consequences are mitigated. What is needed in addition to the general knowledge provided by the explosion pentagon, however, is guidance on which risk reduction techniques are most effective and in what order the various techniques should be considered. Prevention is obviously preferred to mitigation, but both are likely to be required in a given application. The question then is, which dust explosion control measures should receive priority?

*“Inherent safety works to lower the risk of dust explosions by addressing the issue at its source – the dust itself, the equipment in which it is processed, and the manner in which it is handled”*

The answer is given by the hierarchy of risk control strategies – or simply hierarchy of controls. As one progresses downward through the hierarchy, strategy reliability decreases and possible failure modes increase in number. From most to least effective, the hierarchy of controls consists of safety measures that are: (i) inherent, (ii) passive (engineered), (iii) active (engineered), and (iv) procedural in nature. Engineered or add-on safety involves the addition of safety devices which do not perform any fundamental operation, but are designed to act when an undesired event occurs. The division of engineered safety into passive and active measures indicates that the devices accomplish their intended aim either without active functioning (passive – eg a pressure relief vent), or only upon detection and initiation of action (active – eg explosion suppression systems). Procedural safety measures or administrative controls, utilise safe work practices and procedures (eg ignition control strategies such as hot-work permits) to reduce risk. On the other hand, inherent safety uses the properties of a material or features of a particular work activity to eliminate or reduce the hazard. The fundamental difference between inherent safety and the engineered and procedural categories is that inherent safety seeks to remove the hazard at the source as opposed to accepting the hazard and looking to mitigate the effects.

Inherent safety involves consideration of a number of principles, of which the four most general and widely applicable are given in Table 1. Trevor Kletz<sup>3</sup> has succinctly described inherent safety with the phrase: what you don't have, can't leak; in the context of dust explosions, an apt analogy would be: what you don't have, can't explode. The application of all inherent safety principles to dust explosion risk reduction is considered in detail in a recent paper by Amyotte et al<sup>4</sup> and also in a new chapter appearing in the

Table 1: Inherent Safety Principles.

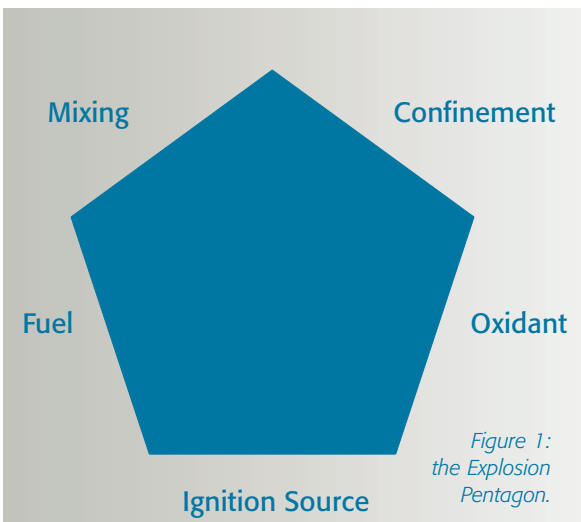
Principle	Description
Minimisation (Intensification)	Use smaller quantities of hazardous materials when the use of such materials cannot be avoided. Perform a hazardous procedure as few times as possible when the procedure is unavoidable.
Substitution	Replace a substance with a less hazardous material, or a work activity with one that does not involve hazardous material. Replace a hazardous procedure with one that is less hazardous.
Moderation (Attenuation & Limitation of Effects)	Use hazardous materials in their least hazardous forms or identify options that involve less severe working conditions.
Simplification	Design processes, equipment, and procedures to eliminate opportunities for errors by eliminating excessive use of add-on (engineered) safety features and protective devices.

upcoming second edition<sup>5</sup> of Kletz's original text on inherently safer design<sup>3</sup>. Here, we focus briefly on inherently safer ways to deal with the dust explosion problem through minimization (intensification) and moderation (attenuation).

Whether a combustible dust is the desired product or is an unwanted byproduct of the process being undertaken, it is critical to minimise, whenever possible, the amount of dust available to participate in an explosion arising from normal operating conditions or an upset event. Because of the large quantities of particulate material present in powder handling equipment (which as previously mentioned is where most primary or initial dust explosions occur), it can be difficult to achieve operation at dust concentrations below the minimum explosible concentration. It is, however, entirely possible – and absolutely essential – to minimise fuel loadings in the case of dust layers. The occurrence of secondary dust explosions can be avoided by the removal of dust deposits from the workplace in a manner that limits the formation of dust suspensions (eg, vacuuming with an explosion-proof device instead of sweeping). This point is well-illustrated by Frank<sup>6</sup> who makes a convincing argument for the critical importance of housekeeping in preventing dust explosions. Dust explosion investigation reports found on the web site of the US Chemical Safety Board ([www.csb.gov](http://www.csb.gov)) also illustrate the essential need for application of the inherent safety principle of minimisation in cleaning up combustible dust layers and deposits.


The risk of a dust explosion can be reduced, or in some cases eliminated, by handling the material in an alternate form (slurry, pellet, etc), or by using in solution if possible. These are examples of moderation in which a bulk material is processed in a form that would not be considered a dust by any definition. If a material must still be handled in powder form, perhaps its particle size can be increased to the extent where explosion consequences are mitigated. The effects of an increase in explosible dust particle size are numerous and are well-established. These include, for example, a decrease in explosion overpressure and rate of pressure rise, and an increase in the minimum explosible concentration. Thus, from the perspective of the inherent safety principle of moderation, larger-size particles of an explosible dust are inherently safer than finer sizes of the same dust.

Inherent safety works to lower the risk of dust explosions by addressing the issue at its source – the dust itself, the equipment in which it is processed, and the manner in which it is handled. The concept of inherent safety works in concert with engineered (passive and active) and procedural measures through the hierarchy of controls. The key to successful application of inherently safer design is early consideration when developing dust handling and processing facilities.



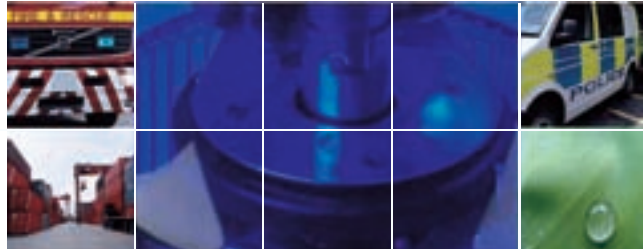
### References

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