AVOIDANCE OF IGNITION SOURCES AS A BASIS OF SAFETY – LIMITATIONS AND CHALLENGES

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When operating plants and processes it is important to establish a basis or principle of safe operation. With a clearly defined basis of safety then appropriate precautions can be implemented to maintain that basis. The link between what is done (precautions and procedures) and actually being safe is then explicit.

For fire and explosion hazard assessment flammable and potentially flammable atmospheres must be identified and compared with the potential ignition sources present. With knowledge of the possible flammable atmospheres, their sensitivity to ignition and the possible ignition sources present and the incendivity of these sources a robust basis of safety may be selected. Preventative bases of safety (absence of flammable atmosphere and avoidance of ignition sources) are the most economic and so there will always be a driver to chose them over protective bases of safety (venting, suppression and containment). It is not always possible to use absence of flammable atmosphere due to insufficient fuel. Inerting brings its own set of problems, as well as expense, and possible difficulty of implementation. Avoidance of ignition sources can then appear to be an attractive option, but it has limitations. There are also challenges for all involved in research: some 'rules' that exist are based on very limited data and as such may be conservative, but without further data to show where the ultimate limits are we cannot justify breaking these rules.

This paper will discuss the limitations to the applicability of '*avoidance of ignition sources*', and the challenges to extending the validity of existing safety rules.

WHAT IS BASIS OF SAFETY/BASIS OF SAFETY CONCEPT

The terminology of basis of safety is well used, but it is worth a digression to clarify and elucidate on its meaning before looking in detail at avoidance of ignition sources.

Each element of the plant or processing step should have a unique *Basis of Safety* (BoS), otherwise known as *Basis for Safe Operation*, to counteract each specific type of hazard (e.g. fire and explosion, chemical reaction or toxicity). This is the principle which protects people from harm and injury.

TYPES OF BASIS OF SAFETY

There are two general types of BoS: *Preventative*; and *Protective*. Preventative Bases of Safety work on avoiding incidents or events. Protective Bases of Safety work on limiting the magnitude of an event or controlling the consequences to prevent harm. It should be emphasised that this is an admission that an event cannot ultimately be ruled out, and therefore must be managed.

For fire and explosion hazards the preventative bases of safety deal with the elements of the fire triangle. They fall into three categories: absence of flammable atmospheres achieved by limited fuel quantities; Control/Avoidance of Ignition sources; and absence of flammable atmospheres by limiting the quantities of oxidant present. Safety measures are chosen to eliminate an element of the fire triangle whilst causing minimal interference to plant operation (Gibson & Lloyd, 1963).

Protective Bases of Safety (for fire and explosion hazards) yet again fall into three categories: venting the explosion (to a safe area) to prevent pressure in the equipment exceeding a given level; containing the explosion (and limiting its ability to propagate to other equipment); and explosion suppression – detecting and quenching the explosion before it exceeds a given pressure. Contrary to the opinion of some, it is not unreasonable to expect a protective basis of safety to be activated under process conditions at some stage, even if this is an infrequent event.

RELATIONSHIP BETWEEN BASIS OF SAFETY AND CONTROL MEASURES

A basis of safety is the principle or philosophy of operation that maintains safety rather than the specific measures required to implement it. The basis of safety must be clearly documented as such, this includes the limits to the scope and delineation of where it changes in the plant or process, and how the two elements are separated. The specific precautions to establish and maintain the basis of safety must also be clearly recorded. If the precautions are not clearly distinguished from the principle it is possible to lose sight of the intent.

It is this author's experience that often people are confused about what is keeping them safe, and can fixate on one control measure. For example basis of safety is often described as nitrogen; this is insufficient. Nitrogen is often supplied to process vessels for quality reasons (excluding atmospheric water vapour or eliminating minor oxidation), it is not necessarily supplied with sufficient reliability or rigour to constitute a protective measure. Inerting with nitrogen may not protect against some decompositions. And finally stating it as nitrogen does not sufficiently highlight the need to achieve a given oxygen level, and then maintain that. Whereas this should be avoidance of flammable atmospheres by restricting oxygen, then it will have an associated set of precautions aimed at establishing an inert atmosphere, and then maintaining it. This might sound pedantic, but clarifying this in documentation can facilitate understanding, and with that can come thought about changes to process and operations.

By keeping the basis of safety as a principle, the measures or precautions taken can be audited and examined to verify that they will actually achieve the desired end result, or even that they can be sustained with sufficient robustness. This is an important aspect of the iterative process of choosing an appropriate basis of safety.

Another reason for separating the basis of safety from the precautions is that on any chemical plant many precautions (in particular those associated with avoiding ignition sources) are taken as a matter of good practice, but do not necessarily implement the basis of safety. They may be there to reduce the frequency of events where a protective basis of safety is employed. Or may be there to support another preventative basis of safety which may not be infallible, and will have a given failure rate, e.g. absence of flammable atmospheres through insufficient oxygen achieved by inerting with nitrogen; any nitrogen supply system will have some frequency of non-availability or pressure failure during downtime. Another reason precautions may be implemented is to prevent *practice creep* or *creeping change*. Precautions such as excluding the use of non- conducting plastics are implemented everywhere on a plant to make sure plastics do not find their way from an area where it does not matter, into an area where they can pose an ignition hazard. This can be important where many units essentially look identical, even though they may be processing different materials with different hazards. Practice creep can be associated with several incidents where change control has failed for example Ackroyd & Newton (2002) where a plastic IBC had been used for aqueous waste, and was then used for a non-conducting and flammable waste, which led to an ignition.

LIMITATIONS OF BASIS OF SAFETY

The Basis of Safety will not necessarily protect the plant, or the materials being processed. It will also not necessarily address the economics of continued operation nor the risks of interruption to the business.

A basis of safety which protects against one type of hazard can lead to another hazard and violate a different type of basis of safety. For example protecting against toxicity an appropriate basis of safety might be containment, but for fire and explosion it could be explosion venting which would potentially violate the first basis of safety. The basis of safety against one hazard cannot be chosen independently and without reference to other hazards.

USING AVOIDANCE OF IGNITION SOURCES AS A BASIS OF SAFETY

TERMINOLOGY

Various workers use the terms avoidance, elimination, control or absence of ignition sources, and at least amongst the author's co-workers there is some debate as to the correct terminology. However, whatever word is preferred perhaps the full phrase ought to be avoidance of *viable or effective* ignition sources.

SETTING A BASIS OF SAFETY TO COUNTERACT FIRES AND EXPLOSIONS

Setting a basis of safety is always based on knowledge of the flammable or potentially flammable atmosphere characteristics. Different bases of safety require different data.

In preference order the preventative bases of safety are:

1. Avoidance of flammable atmospheres by limiting fuel concentrations
2. Avoidance of viable ignition sources
3. Avoidance of flammable atmospheres by limiting oxidant concentrations

If the fuel concentrations can be reliably kept below flammable ranges then avoidance of flammable atmospheres achieved by limited fuel concentrations is a viable basis of safety.

Failing this potential ignition sources can be identified and compared to the sensitivity of the atmosphere. If measures can be rigorously enforced to avoid viable ignition sources, without unduly affecting plant operation, then this could be a viable basis of safety.

Otherwise the minimum oxygen concentrations for combustion (MOC) must be determined. If levels of oxygen can reliably and economically be kept below this level then it could be a feasible basis of safety. However, inerting has its own drawbacks, and there are a large number of fatal incidents associated with nitrogen asphyxiation. Another problem can be emissions of volatiles in waste nitrogen. Inerting should not be regarded as an easy option compared with engineering appropriate control measures against ignition sources, particularly electrostatic sources which have many well defined control measures. Maintaining inert atmospheres can have its own engineering challenges.

Finally if these are not feasible or insufficiently reliable, then protective bases of safety must be considered, all of which require explosion violence characteristics.

Several publications deal with ignition sources, control measures and quantifying material properties and have a level of detail that will not be covered here (e.g. Barton, 2002; Dickens, 1996; Gibson *et al.*, 1985; Gibson & Rogers, 1980 and Walmsley, 1992). What should be particularly emphasised is Avoidance of Ignition sources requires intimate knowledge of the actual operations being carried out.

ILLUSTRATIONS OF THE LIMITATIONS OF AVOIDANCE OF IGNITION SOURCES

LEAKS

One particular example in Kletz (2001) illustrates several points about the avoidance of ignition as a basis of safety. In the particular plant concerned leaks of ethylene were tolerated because it was considered that all sources of ignition had been eliminated. There are two reasons why this is not a valid basis of safety.

a) Avoidance of ignition sources is only suitable for use within defined areas of process plant where ignition sources can be rigorously controlled; and to a more limited extent where materials are charged into and discharged from plant, yet again within well defined areas.
b) Ethylene has an MIE of 0.07 mJ (NFPA, 2000). This is more sensitive than normal solvent vapour and flammable gas atmospheres which tend to be 0.2 mJ and above. It is not usual to apply this basis of safety to atmospheres with a sensitivity below 0.1 mJ. Below this level electrostatic sources of ignition cannot be controlled with any degree of confidence.

The correct basis of safety in this case should be absence of flammable atmospheres by containment of fuel within pipework. This could then be supported by avoidance of ignition sources to reduce ignition frequency for the inevitable times when there is a loss of containment, but the fact that humans can be present in the area, and that they are potentially a very effective ignition source means that containment should be emphasised.

In the example the area was zoned. However, the existence of zoned areas is an acknowledgement that losses of containment with resultant flammable atmospheres occur; it is not a measure of the acceptability of losses of containment.

This also applies to powder layers which are dormant flammable atmospheres and should not be allowed to accumulate. Powder layers which have been disturbed have led to major secondary dust explosions.

CHARGE CHUTES

Charging solids down a charge chute into a flammable vapour atmosphere one can acceptably avoid ignition sources provided that the charge chute is less than 3 m long, and the vapour atmosphere has a sensitivity of 0.2 mJ or above. It is likely that the acceptable charge chute length may be longer but this has not been determined. However, if charging into more sensitive atmospheres that may contain hydrogen for example then an alternative basis of safety must be employed. This would apply to a solid such as Sodium borohydride which could emit hydrogen on addition to a solvent.

DRYERS

In spray dryers it is normal to control ignition sources as part of the operating regime such as by earthing and bonding, and keeping inlet temperatures below the Minimum Ignition Temperature (MIT) of the dust cloud, but this is not the basis of safety. There is sufficient uncertainty about the thermal stability of accumulated powder layers that thermal decomposition cannot be reliably excluded as a potential ignition source (Gibson & Schofield, 1977). Spray dryers should be operated with an alternative basis of safety – usually protective such as venting, or suppression. Absence of flammable atmospheres through inert gas blanketing can also be feasible, although this usually relies on recirculation of a portion of the spent gas (Gibson *et al*., 1985).

VENT HEADERS

Vent headers are another area where there is a huge temptation to try and employ avoidance of ignition sources as the basis of safety especially when one considers the potential cost of inerting or the necessary air flowrates and consequent fan sizes for dilution. However, vent headers are often shared with multiple vessels and there is potential for interactions between the vented materials. For example in Anonymous (1995) there are records of fires stemming from reactions of amines and NOx gases. Solids can and often do accumulate, leading to potential thermal stability issues, and vessels sometimes foam over into the vents. In fact this author has witnessed common vents which were effectively dug out, with many years of accumulated material. Although avoiding ignition sources where possible in these cases is a good idea, it is not suitable as a basis of safety (Iqbal Essa & Ennis, 2001).

SOLIDS ACCUMULATION

Solids near their melting point can stick and accumulate, even when being transported. In one case material formed a non-conductive layer on the inside of a metal pipe (Perbal, 2005). This layer became electrostatically charged, leading to incendive propagating brush discharges and hence explosion and fire.

In another case a powder which was known to be thermally unstable at relatively low temperatures was charged to a vessel using avoidance of ignition sources as the basis of safety. This assumed that the powder would not accumulate in layers greater than about 5 mm thick. The 5 mm layer ignition temperature was comfortably above operating temperatures. In practice the powder deliquesced with atmospheric water and formed layers up to 10 cm in thickness, these thicker layers would have an onset close to ambient temperature. Although the build up of material was discovered by operational staff who cleaned it out, the significance for safe operation was not appreciated. Eventually, after a failure in the normal processing sequence there was an overpressure event which blew a bursting disk and showed evidence of burning.

SOLVENTS IN POWDER

Some old guidance for avoidance of ignition sources discounted the incendivity of brush discharges with powders and simultaneously treated powders with up to 0.5% solvent present as only being as sensitive to ignition as the powder. An incident occurred when powder with less than 0.5% solvent was being milled. The milling released solvent from the powder, and a vapour atmosphere built up, which was in turn ignited by a brush discharge from the powder (SUVA, 2005). See also Puttick and Gibbon (2004) for more on this topic.

FUTURE CHALLENGES

Avoidance of ignition sources relies on well defined materials and ignition sources so that the sensitivity of the flammable atmosphere can be matched against the incendivity of the ignition source. There are still some large gaps in our knowledge, and filling these could allow us to apply avoidance of ignition sources to a greater range of situations.

DUSTS AND BRUSH DISCHARGES

Modern processes are creating finer dusts which are in turn increasingly sensitive to electrostatic spark ignition. Current standard dust testing equipment can only create sparks down to 1 mJ. There are a number of powders with MIEs below 1 mJ, but how far below? It is generally accepted now that brush discharges despite containing up to 3 mJ of discharge energy cannot ignite powders with MIEs above 1 mJ, unless there is solvent present. But it has also been seen that brush discharges can be made to ignite sensitive powders under extreme conditions (such as enhanced oxygen). However, the ability to measure MIEs below 1 mJ is a recent development, and there is not yet much data available. The missing part of this jigsaw is to then determine how sensitive a flammable dust would need to be to be ignited by a brush discharge.

FLAMMABLE MISTS

It has been known for a long time that mists of fuel can be flammable below the flash point (e.g. Burgogne & Richardson, 1949). Industrially mists can be created when formulating products; solvent borne materials are sprayed onto solid substrates, often in rotary mixers where electrostatic charges can be generated.

Some work has been undertaken on ignition energies, e.g. Singh (1986), but much of this work has been associated with automotive ignition and high altitude jet re-ignition, rather than hazards of handling within an industrial situation. The sensitivity to ignition will depend on the fuel and droplet size. In a spraying operation there will be a range of droplet sizes, and it is likely that the incendivity will be influenced strongly by the fraction at the lower end of the size range. Large scale spraying tests use very large volumes of fuel, which can be difficult to justify and expensive. However, useful worst case data might be obtained by characterising nozzles with water, then to use a small scale nozzle with a narrow distribution, and small drop size for ignition testing. This would be analogous with sieving dusts to less than 63 µm for MIE testing.

If a reliable MIE can be determined for a flammable mist, then it is possible to consider whether precautions against incendive electrostatic discharges can be implemented.

ELECTROSTATIC MISTS

There is a body of work associated with washing large tanks for crude oil and chemical transport (e.g. Hughes, 1972; van de Weerd, 1975; Jones & Bond, 1984 and Walmsley, 1987), and some work on much smaller vessels including spraying of solvents and two phase mixtures (Post et al., 1989). Much batch processing and formulation requires cleaning of vessels between products. The standards required can be extremely challenging to avoid cross contamination and product quality issues, and there is always a demand to clean with solvents.

Looking at vessel sizes and/or spray set-ups it is clear that much of this falls outside the existing guidance and experimental work from which the guidance was derived. The charge that will be generated by a nozzle and the consequent mist electric field are not clearly calculable *a priori.* Many of the proposed operations are probably safe, but we cannot prove this; inerting vessels ends up being the only justifiable safety measure, but this is unsatisfactory when many of these vessels are not routinely supplied with nitrogen systems.

MECHANICAL SPARKS AND FRICTION

What is required from an assessment perspective is to be able to characterise a flammable atmosphere with respect to its ignition sensitivity, and to identify potential ignition sources so the two can be compared. Although there are gaps in our knowledge of electrostatics discussed above, the gaps are more glaring in the case of mechanical ignition sources, in particular the issue of quantification.

MECHEX (Proust et al., 2007) has set about correcting this state of affairs, and has some tools now in place. Disconcertingly one the the *rules* previously used (friction between surfaces is acceptable at less than 1 m/s) has been shown to not be so absolute, and the situation is much more complex. If this work is continued hopefully it will yield quantifications for atmospheres and ignition sources.

CONCLUSIONS

Avoidance of Ignition sources can be a useful and reliable basis of safety in certain circumstances provided that it is restricted to the inside of chemical plants, and certain well defined charging and discharging areas. Its reliability depends on having relatively insensitive atmospheres and the main applicability will be counteracting electrostatic and some mechanical ignition sources. It is vital that potential ignition sources are identified, and there is feedback from operational experience back into the hazard assessment process to identify changes and deviations from original expectations. If avoidance of ignition sources is to be safely applied it is vital to be fully conversant with the details of plant and operations. It can also be important to be aware of material handling properties which are outside the scope of normal hazardous properties, but can affect what occurs on plant.

Future work should be around better defining of potential ignition sources, and better characterisation of the sensitivity of atmospheres.

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