ASSESSING THE POTENTIAL FOR IGNITION FROM MECHANICAL EQUIPMENT

S Hawksworth[1], R Rogers[2], M Beyer[3], C Proust[4] D Lakic[3], J Gummer[1] & D Raveau[4]
[1]Health and Safety Laboratory, Buxton, SK17 9JN, UK
[2]INBUREX GmbH, D-59067 HAMM, Germany
[3]Physikalisch-Technische Bundesanstalt (PTB), 38116 Braunschweig, Germany
[4]Institut National de l'Environnement Industriel et des Risques (INERIS), Verneuil-en-Halatte, France

The EU funded MECHEX project (EU contract G6RD-CT-2001-00553) investigated the ignition of explosive gas atmospheres by mechanical equipment. This paper briefly summarises the main findings of this work in relation to the ignition of explosive gas atmospheres by mechanical equipment that has rotating or sliding parts and which can produce heat through rubbing, grinding and sparks. The paper then describes two possible approaches to determine the likelihood of ignition based on the parameters power, load, speed and coefficient of friction.

INTRODUCTION

Prevention of ignition is identified as one of the Essential Health and Safety Requirements in the ATEX Directives (European Directives 94/9/EC[(1)]) for use in areas where potentially explosive atmospheres cannot be avoided. General guidance on this approach can be found in standard EN1127-1[(2)], which describes the general principles and the different types of potential ignition source that need to be considered.

Mechanical equipment that contains potential ignition sources is widely used, but generally does not benefit from the high levels of ignition control associated with electrical equipment, which are based on many years of investigation into the conditions and mechanisms of ignition from electrical equipment. This paper describes the current thinking from the MECHEX project on a possible approach to the assessment of ignition from mechanical equipment.

Intuitively, it is clear that ignition by mechanical equipment is due to the high temperatures produced and testing confirms that this is the case. However, this does not mean that understanding when and why ignition is likely to occur is trivial as ignition by a hot surface is also a complex process which has been studied for many years and is still not well documented. In addition to the complexity associated with hot surface ignition, the problem of heating by friction is not trivial also.

SUMMARY OF TYPES OF IGNITION SOURCES PRODUCED IN MECHANICAL/ROTATING EQUIPMENT

Friction processes involving rotating machinery can be divided into rubbing, grinding and impact. Rubbing produces long duration hot surfaces and generally no or only a few sparks. Grinding also produces long duration hot surfaces, generally with large numbers of sparks depending on the material. Evidence from the MECHEX project indicates that, for gas or vapour explosive atmospheres, hot material around the frictional hot surface (e.g. trailing edge burr) is a much more potent ignition source than sparks. The efficacy of the ignition source produced depends on the power, load, speed, size and coefficient of friction associated with the friction process and the confinement of the equipment in which the hot surface is produced. In relation to the latter, there is the possibility of a pseudo auto ignition whereby a contained volume of the explosive atmosphere is heated to the auto ignition temperature. This is discussed further by Proust[3]. However, for the experiments observed, in most situations ignition occurred at the hot spot.

For grinding (steel on steel), at contact temperatures greater than 450°C sparks begin to be produced in large numbers for contact velocities greater than 2 m/s. At low rubbing speeds (<1 m/s) generally no sparks are produced, with only a small number produced at moderate speeds (1 to 2 m/s), although pieces of metal may become detached. In terms of the potential for ignition, large "continuous" showers of sparks are more likely to cause ignition than a few individual sparks. However, based on work carried out at HSL, a shower of sparks is a less effective ignition source than a hot surface, such as a trailing edge burr, that is produced close to the hot spot from which the sparks originate.

Work carried at PTB, as part of MECHEX which involved igniting explosive atmospheres by simulated sparks (laser heating of particles under controlled conditions) has shown that temperatures far in excess of the auto ignition temperature and, in general, greater than the temperatures in the contact zone are required to cause ignition, confirming that the contact hot spot is a more effective ignition source than single sparks. From the work of MECHEX what is clear is that although the ignition may not occur directly from the hot contact zone (inaccessible to explosive atmosphere), it is the temperatures produced in this zone, which introduce the risk of ignition and so the approach has to be to limit the temperatures in the contact zone.

Figure 1 is a contour plot that summarises the temperatures measured in the contact zone as a function of contact load or pressure, and contact speed for duplex stainless steel. For more information on how and why this data was obtained see Hawksworth et al.[4] This plot is for contact areas of roughly 25 mm square cross section. Other results have also been obtained which show that these temperatures based on a normalised force (contact pressure) also apply or are conservative for smaller areas. Figure 2 shows a plot of the temperatures measured as a function of power density for the same tests. Again for more information see Ref. 6. Both of these plots are discussed further later in this paper in relation to incendive conditions occurring during friction.

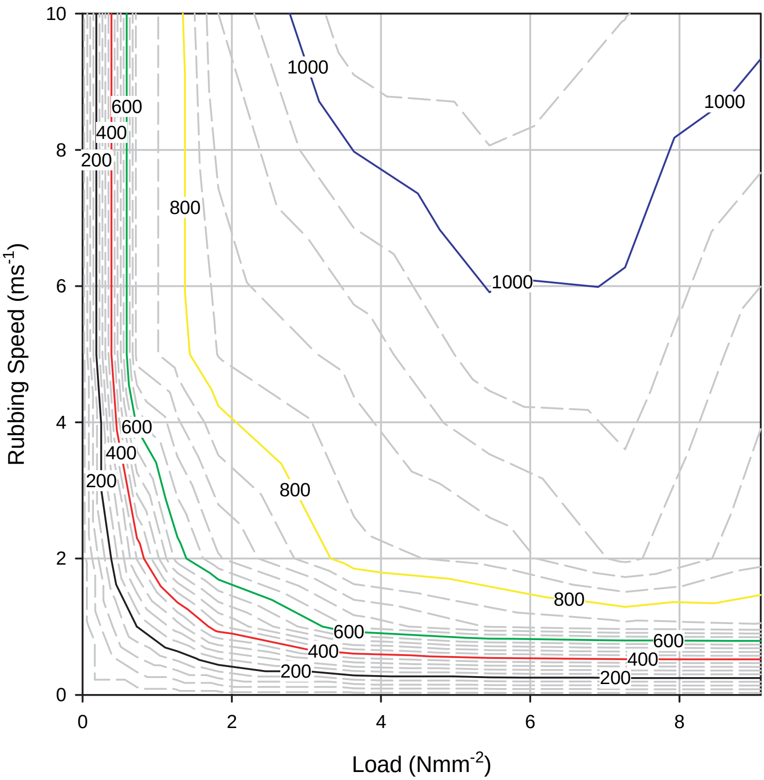

Figure 1. Plot showing temperature contours (°C) as a function of rubbing speed and load (pressure)

CLASSIFICATION OF MECHANICAL EQUIPMENT FOR USE IN EXPLOSIVE GASES

Table 1 shows the relationship between categories of equipment, protection levels and zones as prescribed in EN1127[2]. It is a well-known approach (in principle if not word) that has been used for many years to match the ignition protection levels of electrical equipment to the likelihood of an explosive atmosphere occurring.

CATEGORY 3 – NO IGNITION SOURCES UNDER NORMAL OPERATION

With mechanical equipment for use in Zone 2 (Category 3), as long as under normal operation the equipment does present any ignition sources then it should be suitable for use in

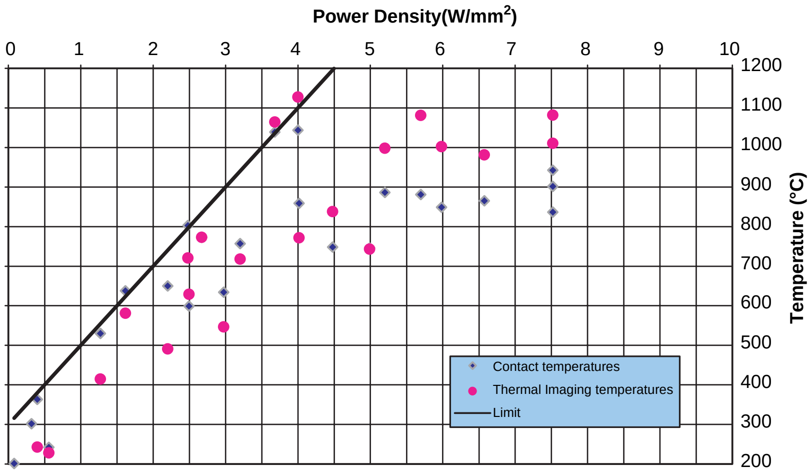

Figure 2. Plot of measured temperatures as a function of power density in contact zone

areas where explosive atmospheres occur infrequently or for short periods. Suitable types of equipment may be rotating machinery containing bearings, which are lubricated so that little heating is produced. In such a case, although the load (F) and speed (v) may be high, the coefficient of friction (μ) is very small. In terms of Joule–Coulomb law,

$$\text{Dissipated Power} = \mu.v.F \tag{1}$$

Table 1.

Equipment category	Avoidance of effective ignition sources	Level of protection	Applicable in zone	Occurrence of explosive atmosphere
3	During normal operation	Normal	2	Infrequently or for short periods
2	During foreseeable malfunctions	High	1 & 2	Likely to occur
1	During rare malfunctions	Very high	0, 1 & 2	Continuously or for long periods

the heat dissipated in the bearing will be small. Provided that such equipment is correctly maintained, then the risk of ignition should be low. In reality, this is in effect the situation at present for mechanical equipment in Zone 2.

CATEGORY 2 – AVOIDANCE OF IGNITION SOURCES DURING FORESEEABLE MALFUNCTIONS

For category 2 equipment, additional precautions to prevent ignition sources produced as a result of foreseeable faults are also required. This raises the question as to what are foreseeable or expected malfunctions. Discussions with a certifying test house[9] indicated that all instances of fault conditions which can result in mechanical contact must be considered as foreseeable, unless there is other strong supporting evidence to the contrary e.g. long history of operation without failure.

The protection against foreseeable faults for mechanical equipment could be achieved by detection of changes in power consumed, operating speed changes, changes in temperature or other method. For such methods to be effective, it is essential to know what power or speed change is indicative of a fault condition developing without a dangerous situation occurring. This approach can use independent methods as discussed, or could use the approach described in below for Category 1 equipment.

CATEGORY 1 – AVOIDANCE OF IGNITION SOURCES EVEN UNDER RARE MALFUNCTIONS

Category 1 equipment is by far the most problematic, as very high level of protection are required; drawing the analogy with electrical equipment, intrinsically safe equipment which cannot under any circumstances produce an ignition source is required. For electrical equipment this requires very low power or energy levels, implying that the same will be required for mechanical equipment. By referral to further data and an example from the MECHEX project we can begin to get an appreciation of what this might mean.

Ignition of propane–air mixture

A series of tests was carried out to ignite the most sensitive propane-air mixture at low rubbing speeds. Under such conditions the ignition occurred from around the hot spot and the maximum contact zone temperature measured was 750°C, compared to the auto ignition temperature of 470°C. To achieve this required a power of 1.75 kW (speed was 1 m/s and a load of 5 kN, or approximately 9 N/mm^2). Figure 1 is consistent with this measured data, the 750°C contour passing off the right hand edge of the graph half way up the first grid block. Points to note about these results are:

i. Ignition temperature was 750°C compared to auto ignition temperature of 470°C. This is a well-known problem of hot surface ignition and has been previously documented for a range of fuels. It is a result of the size and orientation of the hot surface, and of the ability of strong convection currents to pass over it. There is information in the literature to suggest that similar behaviour would be observed for other Group IIA vapours (see Ref. 6) regardless of auto-ignition temperature, although the actual ignition temperatures may not be as high.

ii. The coefficient of friction was approximately 0.35 based the power, load and speed fed into equation 1 from section 3.1. If the coefficient of friction had been higher, for example the maximum value of 1, then the power dissipated would have been 5 kW.

iii. In agreement with Figure 2 the power density for ignition is 3 W/mm^2, which is to the right of the solid line.

This example is used referred to further in Section 4 where possible approaches to assessing equipment for ignition are discussed. Note also that other tests were also carried out with ethylene and hydrogen atmospheres which were equally consistent with the data of Figures 1 and 2 (see Ref. 4).

USING MECHEX INFORMATION TO ASSESS EQUIPMENT FOR ITS POTENTIAL TO CAUSE IGNITION

This is only a provisional approach for discussion, which does not have any approval or standing at this stage. It is presented for consideration and assumes that the test data was obtained using a worst-case situation based on the materials and conditions used, and noting that there may be exceptions where this does not apply. The approach is to establish conditions under which equipment will be "intrinsically safe". Two approaches are presented which treat the situation from slightly different perspectives, i.e. power density and pressure (normalised load) and speed. Both of these approaches require an understanding of the fault conditions that are likely to occur, and particularly the contact areas and forces that will result.

Approach 1: This approach assumes that all of the power available to the system can be used to produce heat in the contact zone. The approach is to follow the three steps below:

i. What is the input power to the equipment? Obtain the power density by dividing the input power by the contact area in mm^2 that will occur under fault conditions.

ii. Based on the ignition temperature appropriate to the situation, cross-reference to Figure 2 and if the point lies close to or to the right of the solid line for the ignition temperature of interest then ignition is likely to occur. The conservative approach would be to use the auto-ignition temperature although the method could be applied to other less conservative temperature limits.

iii. If the predicted temperatures are greater than 450°C then sparks may be produced depending on the contact speed. This is particularly important for Group IIB and IIC atmospheres, which are more likely to ignite from sparks. Further consideration may be required – see Approach 2 below for more information.

iv. If ignition is predicted in ii above then consideration of Approach 2 below should be made if possible.

Approach 2: This approach looks at the speed and fault pressures (normalised loads in N/mm^2) that are involved in an ignition event. It assumes that the speed of the equipment is limited to a maximum value by some infallible means.

i. What is the maximum operating speed of the equipment? If it is greater than 1 m/s then in addition to the hot spot, sparks are possible. If it is greater than 2 m/s then large numbers of sparks could be produced which increases the possibility of ignition still further. Sparks are more likely to be incendive for Group IIB and IIC atmospheres, but should also be considered for IIA.
ii. What are the forces per unit area in the contact zone under failure (in N/mm^2)?
iii. Use the speed and contact pressure information and refer to Figure 1. Establish the point on the contour plot based on the speed and pressure (load per unit area) and read off the temperature contour. If the temperature contour value is close to or higher than the ignition temperature of the explosive atmosphere, then ignition is predicted.

NOTES ON ABOVE METHODS

1. For small contact areas both approaches will predict a high probability of ignition for comparatively low powers. From the knowledge of small hot surfaces, the method is likely to be more conservative than required. However, this is an area that has not yet been investigated because of the financial constraints of the MECHEX project.
2. If the loads are sufficiently high then deformation of the contact zone could rapidly increase its size under certain situations. Again this is an area that it has not been possible to address within the MECHEX project.
3. Clearly to maximise the safety of equipment under failure, it should be designed such that the contact areas that will be produced between moving parts are as large as possible. These large areas of contact should occur immediately after failure to minimise the potential for high temperatures and ignition.
4. The tests were carried out using duplex stainless steel as a worst case. Tests were also carried out using mild steel, which behaved in a similar manner. The coefficient of friction was typically of the order of 0.3 to 0.5. For materials where the coefficient of friction is likely to be higher, then caution is required particularly for the second approach, as higher temperatures may be produced. Possible situations include ceramic materials or friction involving concrete etc.
5. Figure 3 compares the theory (equation in Figure 3) to measured powers (P_{crit}) and temperatures for (T_{crit}). In this equation T_{amb} is the ambient temperature, λ is the thermal conductivity of the most insulating component, R_f the size (largest linear dimension) of the hot contact zone, and S the total surface area which can lose heat by convection. This method has been proposed by Proust et al.[3] (and is conservative as shown in Figure 3).
6. It is recognised that the ignitability of a hot spot is related more to the so-called critical ignition temperature of an explosive gas or vapour/air atmosphere rather than its Auto-Ignition Temperature (AIT). However the characteristic Critical Ignition

$$P_{crit} = \frac{2\times(T_{crit} - T_{amb})}{\left[\dfrac{1}{4\times\lambda\times R_f} + \dfrac{1}{1.3\times(T_{crit} - T_{amb})^{1/4}\times S}\right]}$$

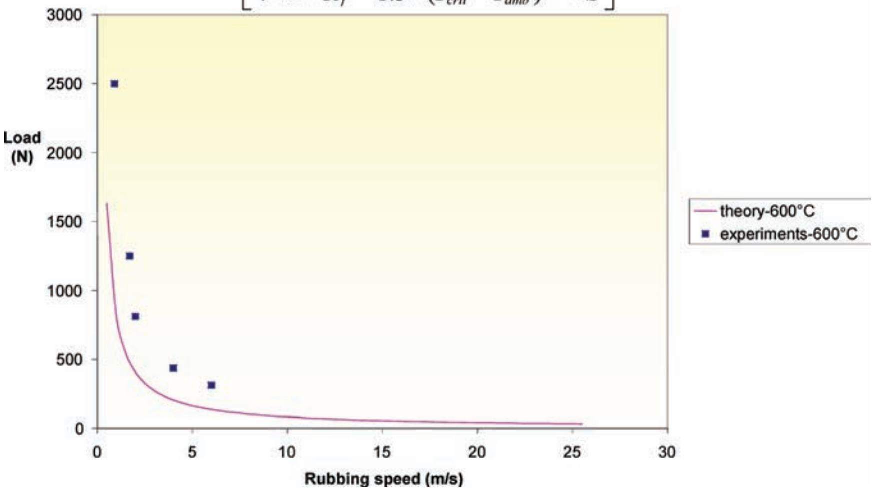

Figure 3. Sample of practical results obtained from HSL experiments at 600°C plotted against theoretical predictions

Temperature (CIT) is not currently used in standard safety assessments nor is there a standard for its determination. Similarly, tabulated values for the common gases and vapours are not available as they are for the AIT. Previous research (see Refs. 5, 6 and 7)) has shown that the CIT could be approximated as a constant for most gases, being much higher that the AIT (notable exceptions being Hydrogen with a CIT similar to its AIT and carbon disulphide which has a low CIT). This behaviour for Group IIA atmospheres has been recognised in standard API2216 (8).

7. This approach could also be used for equipment handling dusts and could find direct application to dust clouds. However, caution is required particularly in the case of layers as the friction coefficient and temperatures (due to insulating properties of dust) will be different.

SUMMARY

This paper has described two provisional approaches developed as part of the MECHEX project to attempt to obtain the temperatures produced during friction events, and so the possibility of ignition, from parameters such as equipment power, load speed and coefficient of friction. The methods are provisional at this stage, and are presented as such for discussion and possible assessment.

REFERENCES

1. Directive 94/9/EC of the European Parliament and the Council of 23 March 1994, on the approximation of the laws of the member states concerning equipment and protective systems intended for use in potentially explosive atmospheres, O.J. L100 of 19/04/1994, page 1.
2. BSEN1127-1:1998 “Explosive atmospheres – Explosion prevention and protection: Part 1. Basic concepts and methodology.”
3. Proust C, Raveau D, Hawksworth S, Beyer M, Rogers R, Hervé P, Pina V, Petitfrère C, Lefebvre X (2005) “MECHEX un programme européen consacré à l’examen des mécanismes d’inflammation des atmosphères explosives par un frottement mécanique”, Preventique 2005, 13 October 2005.
4. Hawksworth S et al. (2004), “Ignition of Explosive Atmospheres by Mechanical Equipment”, Hazards XVIII, 23-25 November 2005, page 337.
5. Powell F (1986), “Can non sparking tools and materials prevent gas explosions”, Gas-Wasser-Abwasser 66, Jahrang 1986, Nr 6.
6. Ritter K (1984), “Incendivity of mechanically produced sparks with regard to gas/air and dust/air mixtures”, PhD Thesis, Faculty of Chemical Engineering, Fredericiana University, Karlsruhe, HSE Translation Number 11518, 1988.
7. Carleton F, Bothe H, Proust C & Hawksworth S (2000),“Prenormative research on the use of optics in potentially explosive atmospheres” European Commission BCR Information Project Report EUR 19617 EN.
8. “Ignition Risk of Hydrocarbon Liquids and Vapours by Hot Surfaces in the Open Air”, American Petroleum Institute Recommended Practice 2216, Third Edition, December 2003.
9. Private correspondence with D Brearley, BASEEFA, UK, November 2005.