© 2001 IChemE

THE FIRE AND EXPLOSION HAZARDS OF DRIED SEWAGE SLUDGE

S.J. Manchester BSc CChem MRSC
Fire and Risk Sciences Division, BRE Ltd, Bucknalls Lane, Garston, Watford, WD25 9XX.

This paper describes the fire and explosion tests that have been undertaken on dried sewage sludge samples from plants throughout the UK, elsewhere in Europe and from around the world. As a result of legislation banning the dumping of sewage sludge at sea, it has become necessary for waste water treatment companies to find alternative means of disposing of sewage sludge. One process used extensively is to dry the sewage sludge to produce a solid granular or pellet product that can be used as fertiliser. During the operation of producing the final dried material fine dust is produced. This dust is combustible and a number of explosion and fire incidents have occurred in drying plants. These incidents have occurred mainly through a general lack of understanding of the hazards posed by the generation of fine dust and the long term storage of large quantities of combustible final product. Dust explosibility tests and self-heating tests on the sewage sludge provide quantitative data, which is used to enable preventative and protective systems to be designed and implemented.

Keywords: dust explosion, self-heating, spontaneous combustion, explosion prevention, explosion protection.

BACKGROUND

The total amount of sewage sludge produced in the UK is currently about 1.1 million tonnes and is expected to grow to 1.5 million tonnes of dry solids by 2005. As a result of legislation banning the dumping of sewage sludge at sea, it has become necessary for the waste water treatment companies to find other means of disposing of sewage sludge. One technique currently used is to dry the sludge to form granules or pellets and then sell this material to use as fertiliser or fuel. There are currently approximately 110 drying plants in Europe, using a number of different processes to dry the sewage sludge. All have the following in common: the production of a combustible solid as granules/pellets and dust. In the presence of sufficient oxygen and with numerous potential sources of ignition present in the process, there is a considerable risk of an explosion or fire occurring.

Since 1997 at least six significant fire and explosion incidents have occurred at sites in the UK and throughout Europe resulting in damage to process equipment. These incidents could have been prevented if the risks had been understood and adequate preventative and protective measures been taken.

The Fire and Risk Sciences Division of BRE has undertaken a number of on-site assessments of sewage sludge drying operations. This has resulted in a large amount of dust explosion, and self-heating tests being conducted on many samples of dried sewage sludge from various stages of the drying process and from many different drying plants. As a result of test work on samples of material from processing plants and site visits, recommendations on the most appropriate safety measures can be given.

INTRODUCTION

In de-watering and drying sewage sludge a large quantity of dust and final dried product is produced, both of which are readily combustible. They will form the fuel in what is known as the "fire triangle". This refers to the necessary requirements for a fire or explosion to occur in

 © 2001 IChemE

any system. The first requirement is the presence of a **fuel,** and in order for the fuel to burn a sufficient quantity of **oxygen** is required. Finally, there must be an **ignition source** present of sufficient energy to ignite the fuel air mixture.

Although dust explosions have been known for over two centuries in industries such as flour milling and coal mining, they were a new phenomenon to the water industry when they started producing large amounts of dust as a consequence of their drying operations on sewage sludge. The fire hazards arising from layers of dust and bulk storage of the final product were also relatively unknown to the water industry. Many drying plants were supplied, installed and commissioned without sufficient thought to the possible fire and explosion risks posed by the production of fine dry dust and final granular/pellet product. As a result a number of fires and explosion incidents occurred, as the conditions required for an ignition of dried sewage sludge material are present during the drying operations of a de-watering plant.

DUST EXPLOSIONS

In order for a dust explosion to occur there must be a dust cloud suspended in the atmosphere. Dusts are generally regarded as having particle sizes less than 500 microns. Sizes larger than this will not be able to be suspended in the atmosphere and hence ignited. Once the dust cloud is created it needs to be of a sufficiently high concentration to be able to be ignited.

Physical and chemical variations can have significant effects on the initiation and progress of a dust explosion. As will be seen later, a general understanding of these effects can be incorporated in explosion prevention and protection techniques. For a dust explosion to propagate, a number of conditions must be satisfied:

- The dust must be combustible.
- The dust must be capable of becoming airborne.
- The dust must have a particle size distribution capable of propagating flame.
- The concentration of the dust suspension must fall within the explosible range.
- An ignition source of sufficient energy capable of initiating flame propagation must be in contact with the dust suspension.
- The atmosphere into which the dust is suspended must contain sufficient oxygen to support and sustain combustion.

Other factors will also have an effect on the sensitivity to ignition and the severity of the explosion, these are:

- The turbulence of the dust cloud.
- The chemical composition of the dust.
- The moisture content of the dust.
- The initial temperature and pressure.

Generally, the severity of an explosion will increase with dry and fine dusts that form a highly turbulent dust cloud. The types of materials that are explosible cover a very diverse range of different materials such as food stuffs (e.g. flour, sugar, coffee, maize), chemicals, pharmaceuticals, dyes/pigments, metals, carbon/coal, rubber, bone meal, paper/wood products and of course, sewage sludge.

 © 2001 IChemE

The typical characteristics of a dust explosion are: flames, a rapid expansion of combustion gases producing pressures up to about 10 bar, and the possible production of toxic gases such as carbon monoxide and oxides of nitrogen. Many explosion incidents start with a relatively small primary explosion from a localised dust cloud ignition, which then disturbs other dust deposits creating a much larger cloud and a more severe secondary explosion. It is this secondary explosion that usually causes the most damage and risk of injury to personnel.

The types of equipment involved in dust explosions include: mills/grinders, filters, dryers, silos/hoppers, ducts, conveyors, cyclones, and bucket elevators. Many, if not all, of these plant items can be found in a sewage sludge drying process plant.

LEGISLATION

In the UK the Health & Safety at Work Act (1974) is the main legislative framework. It places duties on each of the main parties to industrial activity - employers, self-employed, employees and owners of premises - to ensure the safety of those at work and people who may be affected by a work activity. The Act should ensure that equipment at work is safe to use, but this requirement is extended by the Provision & Use of Work Equipment Regulations 1992. However, the European Union is now the main engine for legislative change.

There are two EU Directives relating to explosion prevention and protection:

- The ATEX-100A-Directive (94/9/EC) requires that measures to prevent ignition of potentially explosive atmospheres by equipment and applies to electrical and mechanical equipment and protective systems.

- The ATEX-137-Directive (1999/92/EC) sets out minimum requirements for improving the safety and health of workers potentially at risk from explosive atmospheres, e.g. undertaking a risk assessment.

The ATEX Directives become mandatory throughout the European Union on 1st July 2003. The approach taken by the Directive is to lay down some essential health and safety requirements which must be met, but gives the task of developing practical means for compliance to the European Standards bodies. Standards bodies such as CEN are mandated to produce standards in support of the Directive. CEN is writing new standards covering risks from non-electrical equipment, explosion protection systems and dust explosibility test methods, including minimum explosible concentration, minimum ignition energy, limiting oxygen concentration, maximum explosion pressure and rate of pressure rise.

DUST EXPLOSION TESTS

In order to comply with ATEX it will be necessary to demonstrate that the requirements of the Directive have been met. This will place an onus on equipment manufacturers to ensure that their products can operate safely in the environment for which they are intended, and on plant operators to provide a safe operating environment. In both these instances, the nature of the dust that is present in the plant will need to be assessed for its explosibility.

The risk of a dust explosion is removed if a dust cloud is never allowed to form, all the potential ignition sources are removed and the concentration of oxidant is reduced to a level that cannot support combustion.

In a sewage sludge drying process the formation of a dust cloud results from the drying and conveying processes that are necessary in order for the final product to be formed and

 © 2001 IChemE

collected. Hence, guaranteeing the non-formation of a dust cloud is not a practical method of dust explosion prevention, except possibly in some plant items in the early stages of the process, before the material enters the dryer where it still contains enough moisture to prohibit dust cloud formation.

This leaves preventative methods relying on the elimination of ignition sources and the reduction of oxygen levels. However, before these two techniques can be applied it is necessary to obtain some data on the ignition properties/behaviour of the dust present in the plant. A number of standard tests are available to provide information of the ignition sensitivity and behaviour of dusts.

DUST LAYER IGNITION

This test, which follows IEC 1241-2-1 : 1994[1], determines the minimum temperature of a hot surface, which will result in the decomposition and/or ignition of a dust layer placed on it. The results are used to define the safe surface temperatures of equipment, exposed to the atmosphere, that may be susceptible to layers of combustible dusts forming on them.

Surfaces in a sewage sludge drying plant that may become hot enough to ignite layers of dusts include the surface of the dryer, motor surfaces, electrical and light fittings. Dust layers that ignite may act as ignition sources for dust explosions and fires in bulk material. Accumulations of dust layers within the plant building, such as on girders and ledges, should be avoided as in the case of an explosion they may be disturbed and act as the fuel for a secondary explosion. This occurs when a small localised explosion disturbs accumulations of dust, thus generating a much larger dust cloud which is then ignited by the first explosion, resulting in a much bigger overall explosion. Noxious fumes will also be produced which could affect the health of personnel in the plant.

Tests undertaken on numerous sewage sludge samples have shown quite a large variation in the results, which fall within the range 150 - 280°C for a 5mm layer. For layers of increased thickness, lower ignition temperatures may be expected. The results of this test are used to specify safe operating surface temperatures for equipment being used in areas where dust is present. Dust hazardous area zoning guidance[2] should be used to ensure all equipment within areas where dust may occur is rated correctly. As the results show large variations from sample to sample it is important that the dust present in a particular process is tested. The results of the test are very dependent of the physical and chemical nature of the material, e.g. particle size, moisture content, composition of the sewage sludge.

MINIMUM IGNITION TEMPERATURE (MIT) OF A DUST CLOUD.

The minimum ignition temperature of a dust suspension is the lowest temperature at which it will ignite spontaneously and propagate flame, the value being particularly relevant to problems involving relatively large heated areas of plant, e.g. the surface of a drier.

The test equipment and method used follows IEC 1241-2-1 : 1994[1]. It involves placing a small amount of dust, typically 0.2g, in a dust holder at the top of a thermostatically controlled "Godbert-Greenwald" furnace (Figure 1). The dust is then dispersed by an air blast forcing the dust vertically downwards through the furnace tube. The criterion for an ignition is that flames should be observed at the bottom end of the tube. If no ignition occurs the temperature of the furnace is increased until an ignition is observed. The temperature of the furnace is then reduced incrementally until flame propagation is no longer observed from the bottom of the furnace for ten consecutive tests.

For the sewage sludge samples tested dust cloud ignition temperatures were found to fall within the range 350 - 550°C, again the values are very dependent on the nature of the sample

 © 2001 IChemE

tested. In the sewage drying plant, dust clouds generated internally within a plant item or externally within the process building, may be ignited if the dust cloud comes into contact with any areas of the plant that may have heated surfaces within this range of temperatures. For example, the inlet to the dryer, the dryer surface or other items of machinery where the surface temperature may exceed the minimum ignition temperature of the dust cloud. A risk assessment will be required in all areas of the plant where dust clouds are present and the classification zoning system for dusts[2] used to ensure all equipment within the zones are rated accordingly.

MINIMUM EXPLOSIBLE CONCENTRATION (MEC)

The minimum explosible concentration is the lowest concentration of powder dispersed as a cloud in air that will, on contact with an ignition source, allow the propagation of flame through the cloud. In situations where the concentration of dust in the atmosphere can be reliably controlled, as might be possible in electrostatic spraying booths, some dust extraction units and lean phase pneumatic conveying equipment, it may be used as a parameter on which explosion protection could be based.

The equipment used for the test is either the vertical tube (Figure 2) or the 20-litre sphere (Figure 3). The vertical tube consists of a perspex tube, volume 1.2 dm^3, mounted on a dispersion cup and fitted with a filter paper bursting disc and two ports for electrodes. The gap between the electrode points is set to 6 mm and the continuous spark of energy 8 - 10 J, generated from a 240V supply through a nominal 14.4 kV transformer. The 20-litre sphere apparatus consists of a spherical chamber with a volume of 20 litres and surrounded by a water jacket. Dust enters the sphere from a 0.6 litre pressurised storage chamber via a pneumatically operated outlet valve. The sample is injected by compressed air and a perforated deflector plate inside the chamber ensures uniform dispersion. The ignition source comprised of two pyrotechnic igniters with a total energy of 10 kJ located in the centre of the explosion chamber.

A weighed sample of the powder is dispersed into the apparatus using a single blast of compressed air form a pre-filled reservoir. A dust cloud forms around the ignition source and ignition is recorded. If the dust ignites the test is repeated at successively lower concentrations until no ignition occurs in ten consecutive tests (three if the sphere is used), using a fresh sample for each test. More details on this test are given in reference 3.

The Minimum Explosible Concentration (MEC) of sewage sludge has been found to fall with the range 50 - 200g/m^3. Most, if not all sewage sludge drying plants will be likely to exceed these values in some parts of the plant and hence reliance on the MEC as a basis of safety is not recommended. However, the information may be required by designers of explosion protection systems.

MINIMUM IGNITION ENERGY (MIE)

Any powder handling operation involving the transportation (e.g. pneumatic conveying or pouring) or agitation (e.g. grinding, micronising, mixing or sieving) of a powder can lead to the build up of electrostatic charge. If rapidly discharged a spark of sufficient energy to ignite a dust cloud may result.

The minimum ignition energy of a dust cloud gives an indication of the sensitivity of the sample to ignition by electric and electrostatic sparks. If a material is found to be sensitive to ignition by this means, then suitable precautions must be taken. Guidance is given in BS5958 Parts 1 & 2[4,5].

 © 2001 IChemE

The vertical tube apparatus (Figure 2) used for this test consists of a perspex tube placed over a dispersion cup and fitted with a filter paper bursting disc and two electrodes. The electrodes are connected to a circuit which produces a spark of known energy. The spark is generated using a small inductive trickle-charge circuit following IEC 1241-2-3 : 1994[6].

The ignition energy of the sample can be calculated using:

$$E = \tfrac{1}{2} CV^2 \qquad (1)$$

where, E = Spark Energy in Joules
C = Capacitance of the system is set in Farads
V = Voltage is measured in Volts

The weighed sample is placed in the dispersion cup and the vertical tube fitted to it. The sample is then dispersed using a single blast of compressed air from a pre-filled reservoir. The dust cloud forms around the spark gap as the spark discharges and an observation is made of any flame propagation away from the ignition source. If flame propagation is observed the energy of the spark is reduced incrementally until a spark energy is reached in which no flame propagation is seen. The quantity of powder used in the tests is varied to cover the most readily ignitable mixture in air.

The majority of the sewage sludge samples tested showed a low sensitivity to ignition from low energy static discharges. Many samples could not be ignited at 500mJ. However, there were some that could be ignited at spark energies of 250mJ, indicating some sewage sludge dust clouds are capable of being ignited at relatively low energy ignition sources. As a minimum requirement all plant items should be earth bonded.

LIMITING OXYGEN CONCENTRATION (LOC) OF A DUST CLOUD

The minimum concentration of oxygen that is necessary for a dust suspension to ignite and propagate flame needs to be known in cases where explosion prevention measures include the use of inert gas. The test apparatus used may be the vertical tube (Figure 2) or 20-litre sphere (Figure 3), and operate at ambient temperatures.

The weighed dust sample is dispersed within the apparatus around the ignition source in known concentrations of oxygen in nitrogen (or carbon dioxide). Once ignition is achieved at a known oxygen concentration, the level of oxygen is reduced until a point is reached where no ignition occurs. The source of ignition is a continuous electric spark of nominal energy 8 – 10 Joules (vertical tube) or two chemical igniters of 1000 J. A full description of the test is given in reference 3.

Values of the LOC obtained for sewage sludge samples tested varied from 9.0 - 12.0 %, using nitrogen and carbon dioxide as the inert gas. Most drying plants use inerting as a basis of safety, the inert gas used is the steam from the water entrained within the sewage sludge. However, it has not yet been determined what effect the use of steam as the inerting agent has on the results of the LOC. No tests are currently available to determine the LOC using steam. This will be the subject of a forthcoming research project funded by the HSE. Until the research project has been completed, the LOC results using nitrogen or carbon dioxide should be viewed with some caution. Large safety margins of at least 4% below the LOC for a particular sample should be used as the safe operating oxygen limit in the plant.

 © 2001 IChemE

EXPLOSION INDICES (MAXIMUM PRESSURE, RATE OF PRESSURE RISE AND KST)
The determination of the explosion indices is essential quantitative information for explosion protection, based on relief venting[7][8], suppression[8] and containment[8] The severity is characterised by two parameters, the maximum pressure P_{max} and the maximum rate of pressure rise $(dP/dt)_{max}$.

P_{max} is essentially independent of volume, but $(dP/dt)_{max}$ is volume dependent and is therefore related to a volume independent parameter the K_{st} which is defined by an equation known as the Cube Root Law:

$$K_{st} = V^{1/3}.(dP/dt)_{max} \qquad (2)$$

where V is vessel volume in m^3, $(dP/dt)_{max}$ is the maximum rate of pressure rise in bar s^{-1} and K_{st} is a constant in bar m s^{-1}.

The values of K_{st} and P_{max} for a powder are determined under defined conditions in a laboratory test apparatus either $1m^3$ or 20-litre volume. Values of K_{st} are also related to a broader explosion hazard classification, which is used to rank groups of powder according to their K_{st} value. This is the St. classification and Table 1 shows the relationship between K_{st} and St. classification.

Extensive work has been undertaken to relate the K_{st} value to the sizing of the explosion reliefs and suppression systems.

All the test work on sewage sludge samples was undertaken in the 20-litre sphere. The apparatus consists of a spherical chamber with a volume of 20 litres and surrounded by a water jacket (Figure 3). Dust enters the sphere from a 0.6 litre pressurised storage chamber via a pneumatically operated outlet valve. The sample is injected by compressed air and a perforated deflector plate inside the chamber ensures uniform dispersion. The ignition source comprises of two pyrotechnic igniters with a total energy of 10 kJ located in the centre of the explosion chamber.

Explosion pressures are measured for a range of dust concentrations using piezo-electric pressure transducers. The maximum explosion pressure (P_{max}) and the K_{st} of the dust sample tested is defined as the mean values of the maximum values of each test series (total 3 series) over the concentration range close to the observed maxima.

Table 1. St. Classification

K_{st} Bar m s^{-1}	**Explosion Classification**
0	St. 0
0 – 200	St. 1
200 – 300	St. 2
300	St. 3

Sewage sludge samples tested have shown quite large variations in the values of the maximum pressures and Kst determined in the 20-litre sphere, see Table 2. However, they all fall within the St.1 classification (Table 1) category. St.1 dusts typically include natural products such as flour, grain, wood products and coal. Specific values of pressure and Kst are

 © 2001 IChemE

required for the dust within the process to enable explosion protection systems to be accurately designed.

Table 2 Explosion test data for sewage sludge samples tested at BRE

Explosion test	**Results**
Layer ignition	150 - 280°C
Minimum ignition temperature	350 - 550°C
Minimum explosible concentration	50 - 200g/m^3
Minimum ignition energy	> 250mJ
Limiting oxygen concentration	9 - 12 %
Maximum pressure	7 - 9 bar g
Kst	80 - 200 bar m/s

DUST EXPLOSION PROTECTION

Once all the required data has been accumulated on the driest and finest sample of sewage sludge dust present in the plant, then a risk assessment can be made as to likelihood of an ignition. In the first instance this will be avoiding the formation of dust clouds wherever possible and eliminating all the identified potential ignition sources. If the plant is being run under an inert atmosphere of steam or other inert gas then protocols and procedures should be in-place to ensure that the oxygen levels do not exceed the maximum permissible oxygen concentration. This is typically set at 2 - 4% below the LOC value.

If the above measures cannot be guaranteed or the risk is not sufficiently reduced, then explosion protection measures will be required. The most suitable systems will depend on the nature and position of the plant item, and may include use of one or a combination of the following: relief venting, suppression, containment and isolation

FIRE HAZARDS

Dried sewage sludge is combustible. There are two potential sources of ignition that may lead to a fire hazard, from an external source and from self-heating.

EXTERNAL IGNITION

The high temperatures involved in drying and processing the sewage sludge to form the final product can cause the sewage sludge to smoulder and burn. If deposits of dust are allowed to build-up in areas of the plant where hot dry conditions exist then the temperature may be high enough to ignite the deposit. The level of oxygen required to initiate a smouldering combustion is not known at present, but values considerably less than atmospheric concentration could be sufficient. Hence, either deposits are not allowed to form and remain in the system for long time periods, or the oxygen concentration is kept to a such a low level that combustion cannot be initiated. The HSE research programme of work mentioned earlier is to include work on initiation of smouldering deposits under low oxygen concentrations.

SELF-HEATING

Self-heating can occur in either small volumes of material in warm environments or in bulk deposits held at relatively low ambient temperatures. Self-heating occurs when heat is generated within a material either due to chemical oxidation or biological reactions[9]. If the

 © 2001 IChemE

rate of heat generated within the sample is greater than that lost from the sample to the surroundings, then the heat will gradually increase within the sample. If this continues, then eventually the temperature of the material may reach its auto-ignition temperature leading to ignition.

Smouldering deposits of sewage sludge dust have been found to occur in warm areas of drying plants, where deposits have built-up over a period of time. It is essential that there are no areas within the processing plant where deposits can accumulate. If such areas exist then measures need to be undertaken to ensure these areas are removed or cleaned regularly to remove the deposits.

Bulk storage of the final product, either in silos or storage areas after being bagged, can lead to self-heating and eventual spontaneous combustion. Advice on safe storage volumes, temperatures and times to ignition of sewage sludge products has been given following investigations into the self-heating behaviour. Isothermal self-heating tests[10] have been undertaken on a number of different samples of sewage sludge and the results used to give specific fire safety advice.

Isothermal self-heating tests

Isothermal self-heating tests[9,10] determine the critical ignition temperature of the dried sewage sludge. Thermal ignition theory[9] can then be used to enable the behaviour of the dried sewage sludge to be predicted under specific practical conditions of storage, plant operation and transport.

The tests involve placing the dried sewage sludge material in a cubic wire mesh basket inside an oven set at a particular temperature. The sizes of basket usually chosen are of size 75mm, 100mm, 125mm, 150mm and 200mm. The temperature inside the oven and the temperature of the sample are monitored using thermocouples and continuously logged until ignition has occurred or exothermic reaction takes place. If ignition occurs the test is repeated at a lower oven temperature until no ignition is observed. The procedure is then repeated using three different sizes of basket. In this way the critical ignition temperature for each basket size is determined.

This information can then be used to calculate the critical ignition temperature of any system if the volume and ambient temperature is known. Further calculations can also be performed to assess the time to reach ignition and the hazards arising from placing warm material into a cool store.

From the variety of sewage sludge samples tested the critical ignition temperature values obtained with the basket sizes tested, indicate that the results are very dependent on the form in which the product is tested, i.e. pellets will give different results to granules, which will be different to powders.

Packing Group

It has been determined in the isothermal basket tests that sewage sludge is liable to self-heat. If the sewage sludge is to be transported it needs to meet the requirements of the UN Orange Book Test N.4[11]. This test is similar to the isothermal basket test.

The ability of a substance to undergo oxidative self-heating is determined by exposure of it to air at temperatures of 100°C, 120°C or 140°C in a 25mm or 100mm wire mesh cube. Each sample container is housed in a cubic container cover of stainless steel, slightly larger than the sample container. In order to restrict the effect of air-circulation, this cover is installed in a second stainless steel cage 150 x 150 x 250mm in size.

 © 2001 IChemE

The sample/container is housed in the cover and hung at the centre of the oven. The oven temperature is raised to 140°C and kept there for 24 hours. The temperature of the sample and oven is recorded continuously.

A positive result is obtained if spontaneous ignition occurs, or if the temperature of the sample exceeds the oven temperature by 60°C. The results of these tests will initially determine whether the substance being tested is classified in Division 4.2, i.e. the substance is regarded as being a hazardous substance for transportation. If the material does come into this category then it will be assigned a packing group, depending on the results of the tests and the quantities of material being transported.

TOXICITY ASSESSMENTS OF COMBUSTION PRODUCTS

A number of assessments have been made by BRE on the toxic products produced when different samples of dried sewage sludge are decomposed under various fire conditions. The test apparatus used in these investigations was the BRE "Purser" Tube Furnace. Details of the test method and the procedure used to estimate the lethal toxic potency of the fire effluent is described in reference 12. The conditions chosen for these studies included non-flaming decomposition (350°C), vitiated flaming conditions (650°C) and vitiated high temperature flaming conditions (900°C). The yields of carbon monoxide, carbon dioxide, smoke density and particulates were measured and estimates were made as to the quantity of acid gases and total organic products.

It was found that the main hazardous products evolved under the fire conditions studied were carbon monoxide and smoke. Some organic products would also be emitted, but these were judged to be unlikely to present a serious health hazard unless they were to occur frequently. The extent of the hazard would then depend on the mass of material decomposed, the individual composition of the sewage sludge, the volume into which the products were dispersed and the ventilation system.

The data obtained from the tube furnace tests enable fire hazard assessments to be made in specific facilities from sewage sludge fires during processing and storage.

CONCLUSIONS

Dried sewage sludge dust is an explosible powder. Measures need to be taken to ensure that the risk of this hazard is reduced as much as possible. The first stage is to undertake a risk assessment of the plant and instigate dust explosion preventative measures. These measures include: trying to minimise dust cloud formation, elimination of potential ignition sources, hazardous zoning of the area within the process building and maintenance of an inert atmosphere with the plant. In addition, explosion protection systems, such as relief venting, suppression, and isolation will also be required as a back-up to these measures.

Fire hazards also exist with dried sewage sludge when present as a dust and also with the final granular/pellet product. Layers or accumulations of dust in warm/hot areas of the plant can lead to smouldering combustion, which can then act as an ignition source for a dust explosion or lead on to larger fires. Procedures need to be in place to ensure dust does not accumulate in areas of the plant where temperature/oxygen conditions could lead to an ignition. The final product is liable to self-heat when stored for long periods of time in bulk containers such as silos or after being bagged and placed in storage areas. Information on safe storage volumes. temperatures and times will be required for the product. If the material is to be transported, then tests need to be undertaken to ensure compliance with regulations concerning the transport of substances liable to self-heat and to enable correct packaging/marking.

Combustion of dried sewage sludge also produces the toxic gas carbon monoxide, as well as smoke. Depending on the quantity of material burning and the building volume/ventilation, this could pose a hazard to workers within the process building. This potential hazard should be included in any risk assessment on the process.

RECOMMENDATIONS FOR FUTURE WORK

- The limiting oxygen concentration data for sewage sludge dust clouds needs to be assessed at high temperature and using steam as the inerting agent. HSE sponsored research work on developing a test method to undertake these assessments should be commissioned this year. The results of this project should then be used to implement additional safety procedures.

- Layer and deposits of dust inside the drying plants may also self-heat to ignition over a period of time, even under low oxygen conditions. The concentration of oxygen and the temperature necessary for this to occur is not known at present. This information is important as it is known that smouldering deposits have been the cause of past incidents. This work also forms part of the HSE sponsored research project.

- Sewage sludge plants need to have a rigorous safety review of their operations to ensure that dust explosion and fire prevention and protection measures are adequate.

REFERENCES

1. IEC 1241-2-1 Part 2, Section 1, Method B "Methods for Determining the Minimum Ignition Temperature of a Dust" 1994.
2. IEC 61241-3. Electrical apparatus for use in the presence of combustible dust - Part 3: Classification of areas where combustible dust are or may be present. 1997.

3. Field, P. Dust explosions. Handbook of Powder Technology Vol. 4, Elsevier, Amsterdam 1982.

4. BS5958 Part 1. Code of Practice for the control of undesirable static electricity. General considerations. British Standards Institution, 1991.

5. BS5958 Part 2. Code of Practice for the control of undesirable static electricity. Recommendations for particular industrial situations. British Standards Institution, 1991.

6. IEC 1241-2-3 Electrical apparatus for the use in the presence of combustible dust - Part 2: Test methods - Section 3: Method for determining the minimum ignition energy of dust/air mixtures. 1994.

7. Lunn, G.A. Guide to Dust Explosion Prevention and Protection. Part 1 - Venting. 2nd Edition. The Institution of Chemical Engineers, Rugby, 1992.

8. Schofield, C., Abbot, J.A. Guide to Dust Explosion Prevention and Protection. Part 2 - Ignition Prevention, Containment, Inerting, Suppression and Isolation. The Institution of Chemical Engineers, Rugby, 1988.

9. Bowes, P.C. Self-heating: Evaluating and Controlling the Hazards. HMSO. 1984

10. Beever, P. F., Spontaneous Combustion - Isothermal Test Methods, Building Research Establishment Information Paper IP23/82 (1982).

11. United Nations. Recommendations on the Transportation of Dangerous Goods. Manual of tests and criteria. Third revised edition 1999.

12. Purser, D.A. Fardell, P.J. Rowley, J. Vollam, S.J. An improved tube furnace method for the generation and measurement of toxic combustion products under a wide range of fire conditions. Flame Retardant '94 Conference, London 26-27 January 1994. Proceedings pp 179-200.

Figure 1 Godbert-Greenwald furnace

Figure 2 Hartmann (Vertical) Tube

 © 2001 IChemE

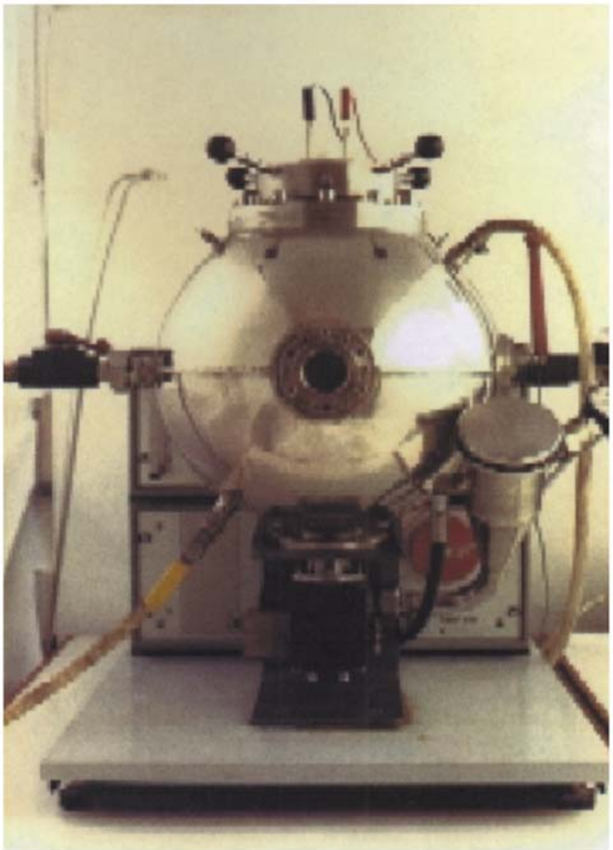

Figure 3 20-litre sphere

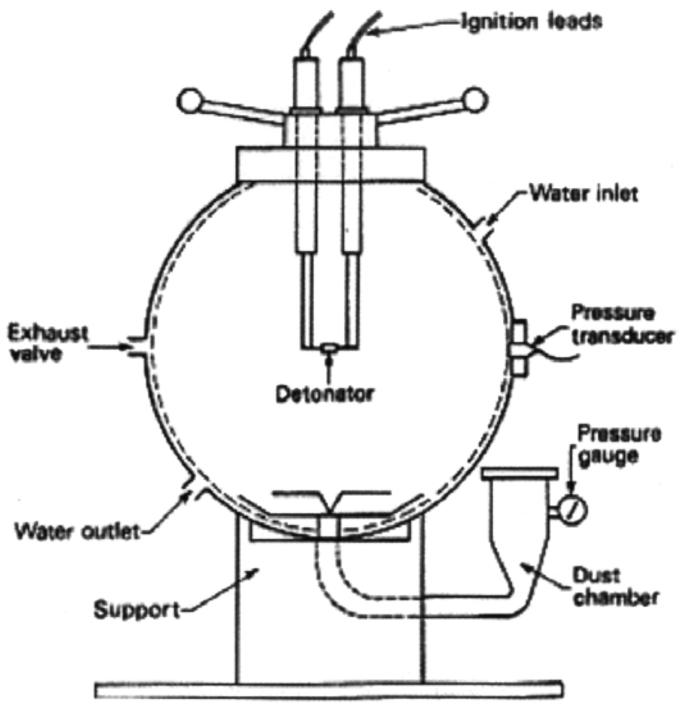

Figure 4 20-litre sphere (schematic)