THERMAL DRYING OF SEWAGE SLUDGE - HSE'S ROLE IN PROMOTING SAFER PLANT.

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UK waste water treatment companies, driven by the need to stop dumping of sewage sludge at sea and the uncertainty of the future of sludge disposal to land, have invested heavily in thermal drying equipment for sewage treatment. The dried sludge products are typically granular, are easy to handle and have a range of potential uses. The product can however give rise to a dust explosion hazard and under certain conditions may smoulder and self-ignite. There has been a rapid growth in the number of thermal drying plants in the UK over the last 3 years, bringing to the waste water treatment companies large-scale chemical engineering challenges outside their previous experience. Several of these, using different technologies, have suffered dust explosions, which, fortunately, despite causing significant damage to equipment, have not resulted in any injuries. This paper describes some of the incidents, which have occurred, highlights common features and outlines HSE's approach to risk reduction in terms of encouraging cooperation with manufacturers and users and producing appropriate guidance. It also describes areas where new work has been needed to establish safe operating conditions.

Keywords: thermal drying, sewage sludge, dust explosion

BACKGROUND

European Directives have caused the UK wastewater industry to change the way in which municipal sewage is handled. Dumping at sea was prohibited from the end of 1998 and the application of raw and treated sewage to agricultural land has been severely restricted. Only material which has undergone what is referred to as "advanced treatment" may now be used on the land. The wastewater treatment companies began to assess the options available to them. Those companies located close to the coast or those with a well-developed agricultural market needed to seek alternative methods of sewage sludge disposal. Many of the companies affected in this way have invested in plant for thermal drying of sewage sludge. The dried product is a granular material which is relatively easy to store and to transport. The thermal drying processes meet the criteria for advanced treatment and make the dried material suitable for agricultural application. The versatility of the product means that it can also be used for landfill, for building materials, for horticulture or as a medium calorific value fuel for heat and power generation.

The first modern UK sludge drying plant was commissioned at the Wessex Water site at Avonmouth in 1992. Of the 20 UK drying plants currently operating or being constructed, five were commissioned in 1998, three each in 1999 and 2000 and a further seven are due to be commissioned in 2001. Driven by impending legislation, the speed of installation of thermal drying technology in the UK wastewater treatment industry has been very rapid indeed. What is unclear is whether the current investment satisfies the immediate needs of the wastewater industry or whether further plants are required to do so. Equally, proven success of the first generation of plants or more demanding legislation may precipitate further development.

TYPES OF DRYING PLANT INSTALLED

The drying plants installed in the UK have encompassed a range of sizes, a number of different drying technologies and several drier manufacturers. The smallest plant is at a seaside location and only operates according to seasonal demand and then only on a day-shift basis. The largest plant which is located on the North East coast accepts municipal sludge both from local pipelines and also from satellite locations which deliver the sludge by ship. When the second phase of this development is complete it will be the largest sludge drying facility in the world, capable of treating 250,000 cubic metres of raw sewage per day and producing 90,000 tonnes per year of dried sludge pellets.

Although there are individual examples in the UK of a belt drier and a fluidised bed drier, the most common driers are drum driers including both rotary and paddle types; in a rotary drier the drum itself rotates whereas in a paddle drier the drum is stationary but an internal paddle rotates. Heat may be supplied directly or indirectly. In a directly heated drier the sewage sludge within the drier is in direct contact either with heated air or with combustion products from a burner system. In an indirect system the heating medium is usually a thermal oil or low-pressure steam, which is held in a jacket around the drier and inside the internal rotating vanes of a paddle drier. A directly heated drier is usually a high velocity system, with a low solids hold-up and the residence time of the sewage sludge in the drier may only be a few seconds. An indirect system is usually a slow moving system with residence times of around an hour and a solids hold-up of several tonnes.

None of the manufacturers of the principal drying equipment are British though they have all had experience in Europe of using their equipment with sewage sludge and other organic and inorganic species. For the water companies and their preferred contractors thermal drying represented a completely new technological challenge.

INCIDENTS OCCURRING

In 1998 and 1999 dust explosions occurred at four of the recently installed plants, which at the time represented up to 50% of the operating plants in the UK. Fortunately no one was injured although there was in each case significant damage caused to equipment and buildings. The explosions were not confined to a particular type of plant and occurred on rotary and paddle drying plants using both direct and indirect drying. All of the incidents occurred during start-up, shutdown or commissioning.

Although differing in detail, the incidents at each of the plants had a number of common features:

- The reactivity of the dried or partially dried sludge had not been fully appreciated.
- There was no effective method to control inertisation during shutdown as well as normal operation; indeed in some cases there were facilities to override oxygen level alarms.
- There was no tolerance to loss of sludge flow. Bearing in mind the variability of the material being handled, flow upsets are foreseeable.
- There was ineffective temperature monitoring and control particularly during shut down periods and in local dead spots.
- Temperature activated quenching systems did not operate or were ineffective.
- There was a lack of explosion protection measures on plant equipment both on the drier and also on the conventional solids handling equipment.

The incidents were not all investigated in detail by HSE. Instead, each of the waste water treatment companies instigated their own internal investigation supported by external consultants experienced in the field of dust explosions. In conjunction with this some of the consultants used their own or other recognised test houses for testing of the dried sludge properties. There was therefore an absence of a co-ordinated approach in investigating the incidents and the recommendations arising, whilst valid for individual cases, were inconsistent. Not all of the waste water treatment companies agreed to adopt their consultants' full recommendations.

About this time HSE, through its Utilities National Group, became aware of the incidents which had occurred, the similarities between them and the rapid growth of this new technology. The Group, with support from local and national specialists, began to look into the topic of thermal drying of sewage sludge.

SAFETY DESIGN

At the design stage of a plant handling a combustible dust, a decision should be made on the type of safety precautions to be adopted. This is often referred to as the "Basis of Safety" and may be embodied in a statement detailing the preventive and protective measures to be followed. Preventive measures include the avoidance of flammable atmospheres by inerting or by control over dust clouds, and the elimination of ignition sources. Protective measures include explosion containment, explosion relief venting and explosion suppression. The Basis of Safety need not be the same for all parts of the plant - in some areas prevention may not be possible - but all areas should be covered. It does not appear that such a formalised approach was taken to any of the first series of drying plants which were installed in the UK in 1998 and 1999. Despite that, for most of the plants it is clear that the basis of safety adopted for the drier itself was prevention based on self-inerting. Under normal operating conditions the water vapour driven off in the drier is sufficient to depress the oxygen concentration to a value below that which supports combustion of the dust, referred to as the limiting oxygen concentration (LOC). However, during times of reduced throughput of sewage sludge or during start-up and shutdown, the LOC may be exceeded. None of the early plants appear to have included systems to maintain inerting by injection of inert species such as nitrogen or steam during these periods; some plants even allowed overriding of oxygen alarms. In the light of earlier experiences some of the more recent plants have included positive inerting systems in their design.

Each of the plants also included conventional solids handling equipment to a greater or lesser degree downstream of the drier. Bucket elevators, screw conveyors, sieve classifiers, mills and pelletisers were all in evidence. With the exception of the product silos, which did generally incorporate some form of protection, the remainder of the solids handling equipment was unprotected. Some of the companies have argued that an inert atmosphere would be present throughout the product handling equipment as a result of being carried through from the drier, although there were no oxygen detectors to support this argument and no equipment for injection of inert species into those areas of plant. Solids handling equipment is notoriously prone to leakage and some plants operate under slight negative pressure, giving a driving force for air to enter the system. An inerting system is unlikely to be effective for this type of equipment unless detailed estimates of leakage rates are made in order to determine the required supply rate of inert gas. Because of the inherent tendency of dried sewage sludge to self-heat and auto-ignite, avoidance of ignition sources is unlikely to be a valid preventative method. Protection of equipment from the effects of a dust explosion, either by explosion venting or by suppression, is likely to be the most appropriate safety precaution for the dried solids handling equipment.

STANDARDS/REGULATIONS/GUIDANCE

Currently no industry standards exist for sewage sludge drying plants in the UK or the US. The most relevant guidance is contained in the 1990 I.Chem.E. publication, *Prevention of fires and explosions in dryers*[1] but few of the suppliers appear to have incorporated its recommendations and it does not cover all the issues. There is in existence a draft European standard[2] and also German publications by DIN[3] and VDMA[4] . Suppliers and users of thermal drying equipment must also comply with the relevant parts of the ATEX Equipment and User Directives in due course[5, 6]. The DIN standard states that the oxygen concentration in the drier must be limited to a value which is within a safe margin of the LOC. It also states that the oxygen concentration within the drier is to be measured continuously. The VDMA standard states that thermal drying plants should take account of fire and explosion risks and be designed in accordance with VDI Guidelines[7]. It does not make reference to the importance of maintaining a low oxygen concentration. Contrary to HSE's current position it accepts that solids processing areas operating below 110°C may use "avoidance of ignition sources" as a preventative measure.

Thermal drying plant is covered by the *Equipment and Protective Systems Intended for Use in Potentially Explosive atmospheres Regulations 1996* [8](which enacted the ATEX Equipment Directive in the UK). Depending on the age of the equipment there is or there will be a requirement for the supplier to show that equipment and any protective systems conform to relevant safety standards and provide documentation to demonstrate that conformity. Schedule 3 of the Regulations includes more detailed requirements including that the equipment must be designed after due consideration of operating faults and maintenance conditions (this could refer to start-up and shut-down conditions). It also goes into detail on the range of preventive and protective measures available.

The ATEX User Directive[6], which is due to enacted in the UK in conjunction with the Chemical Agents Directive[9], requires users of drying equipment to make an assessment of the specific risks arising from explosive atmospheres, including those arising from dusts, and to classify places where explosive atmospheres may occur into zones (specific zone definitions for combustible dusts are contained in Annex 1 of the Directive). The results of the risk assessment and the area classification will need to be documented and updated in accordance with plant modifications.

HSE UTILITIES NATIONAL GROUP ACTIVITIES

Although there is legislation in place on the supply and use of thermal drying equipment, none of it is industry-specific. There is general HSE guidance in place on the safe handling of combustible dusts[10] and I.Chem.E. publications on dust explosion prevention and protection[11,12]. There is also specific I.Chem.E. guidance on the prevention of fires and explosions in dryers[1]. However, none of these addresses all of the problems associated with sewage sludge drying plants and the HSE Utilities National Group felt that more focussed guidance would be beneficial to equipment suppliers, to waste water companies and also to HSE inspectors. The immediacy of the problem and the very rapid growth in installation of these plants in the UK meant that issue of formal HSE guidance, which may take one or more years would not be appropriate. Instead it was decided to issue interim guidance which would provide information based on the current awareness of the risks from such plant. As and when new information became available as a result of plant operation or from further independent testing it could be incorporated. Finally, it would be issued as formal HSE guidance. It was decided that the most appropriate format would be an internal Operational Circular for use by HSE inspectors, supported by a detailed Information Document (ID) which would also be available to interested parties outside HSE.

An information gathering exercise, including visits to plants already operating in the UK, began in October 1999. A discussion document was prepared in October 2000 and was used as the basis for consultation. In a series of open meetings the major issues were discussed with drying equipment suppliers, with waste water treatment companies and with consultants with experience of the hazards of dried sewage sludge or similar materials. Finally the Information Document, prefaced by the HSE Operational Circular, was issued in July 2001[13].

HSE INFORMATION DOCUMENT

The ID contains information on the principal hazards presented by the drying and ancillary processes. It outlines the need to specify the anticipated range of physical and chemical properties of the sewage sludge raw material and calls for systems to accommodate both longer-term changes and short-term contamination e.g. from petrol spills or from industrial effluent. The document outlines applicable legislation and guidance and gives specific advice on the need for risk assessment and the use appropriate assessment methodologies such as HAZOP and Hazardous Area Classification.

A range of properties may be used to characterise dried sludge. The ID refers to each of these and advises which of the parameters are critical to drier safety design and should be measured at the outset. It gives examples of the wide range of measured values that may be expected. Such variations are more likely to be attributable to real variations in sludge properties rather than unsatisfactory testing procedures and they clearly demonstrate the need for each plant to test its own product and, importantly, to retest it at regular intervals once the plant is running.

The ID contains descriptions of the types of drier which may be used with details of the different drying technologies. It then goes into considerable detail on the principles of drier safety. The need for a Basis of Safety to be established is highlighted and the preference for preventive over protective measures is stressed. The principles of inerting, the importance of maintaining an inert atmosphere at all times and the design and use of equipment to monitor oxygen concentration are considered in some depth. The document stresses the need for accurate and reliable temperature measurement and gives examples of how it may be used to activate water sprays for controlling oxygen concentration or for tackling fires inside drying equipment. The importance of the availability of emergency systems and ensuring that systems do not fail to danger is outlined.

A range of preventive and protective measures is applicable to the product handling plant, storage silos and offloading equipment. The ID refers to each of these and highlights the importance of preventing propagation of a dust explosion through connected plant. It discusses appropriate protective systems for bucket elevators and the selection of equipment for detection and control of fires in storage silos. Although information is not yet available it draws attention to the fact that there may be need to be restrictions on the dimensions of product material stacked on the ground or in bulk containers.

Finally the ID highlights important management issues such as the need for change control procedures for plant modifications and the need for permit to work systems when carrying out hot work or when access to the inside of equipment is sought. Adequate training of operators must include a full understanding of the properties and hazards of dried sludge and knowledge of the appropriate emergency response.

ISSUES ARISING

LIMITING OXYGEN CONCENTRATION

During the course of preparing the ID and especially after consultation with the suppliers and dust consultants, it became apparent that the information available on dried sludge properties, particularly on LOC, was varied and inconsistent. The result of this was that outwardly similar plants were being operated over a wide range of oxygen concentrations (e.g. between 5%v/v and 12%v/v) without adequate justification. In addition to this, doubt was expressed whether the laboratory test results used could be reliably extrapolated to operating plant conditions.

LOC is usually measured in a 20 litre sphere apparatus and the oxygen concentration is adjusted by mixing air with nitrogen or carbon dioxide. The test method, described in a European draft standard[14], calls for the oxygen concentration to be varied in increments of 1%v/v and the test to be carried out over a range of dust concentrations. There is advice in the standard on how to interpret any observed pressure rise.

The test is usually conducted at ambient temperature whereas all the driers operate at temperatures in excess of 100°C. Bartnecht[15] reviewed the information available on LOC measured at elevated temperatures and other non-standard conditions but none of the data relates to dried sludge. His work shows that the measured LOC is expected to fall as the temperature rises. It is also known that the scale of the experimental apparatus and the size of the ignition source do influence the results and that correction factors should be applied to convert the results measured in the 20-litre sphere to operating plant scale. The condition of the product may also influence the LOC result. Apart from expected differences in individual sludges from diverse sources, the experimentally measured LOC may also be affected by the water content of the dried sludge and the particle size of the sample.

Although the test apparatus measures the minimum oxygen concentration which may result in an explosion, it is also desirable to maintain an atmosphere within the drier which will prevent smouldering ignition. Guidance suggests that the LOC for smouldering ignition may be lower than that for a dust explosion and may be affected by the bulk of smouldering material and the time of exposure. Smouldering product is believed to have been the ignition source for several dust explosions centred in sludge driers. It should be remembered that even though the oxygen concentration within the drier may be below that which supports smouldering, depending on the temperature at which the product leaves the inert atmosphere and encounters increased oxygen levels, there may be the potential for smouldering to occur in downstream equipment.

HSE has commissioned a research programme to examine the issues outlined above in order that users will be able to determine safe operating conditions for driers where inerting is the basis of safety. The work will look at the effect of elevated temperature and the effectiveness of steam as an inerting agent for sewage sludge drying and examine whether laboratory testing should always be carried out under operating plant conditions or whether extrapolation may be used. It will also examine whether it is possible to determine the LOC to prevent smouldering ignition and whether it is affected by the bulk of material or exposure time.

To use LOC as a critical operating parameter for drying plant will require continuous and accurate monitoring of the conditions within the plant. Any detection systems used to monitor atmospheres within an operating plant must be reliable and be tolerant to the hot, dusty and water-laden atmosphere prevailing in the drier.

SELF-HEATING PROPERTIES

It is widely understood that dried sludge can react with air and self-heat to spontaneous combustion, particularly if stored for too long and in too great a bulk. This places restrictions on the maximum temperature of product material supplied to storage silos and current practice is for the product to be cooled to 40°C to 50°C prior to bulk storage. Laboratory tests have been used to set the temperature limits but in some cases the safety margin is small. Problems may arise if the product is stored for much longer than normal, particularly during a hot summer period. Also, although most operators will ensure that there is a regular turnover of product in the silos, it is possible that stored material may bridge or "rat-hole" and significant quantities of product may not be emptied from the silo. An additional complexity is that the temperature cycling which occurs in a freely venting silo can cause condensation and the entry of microorganisms. In at least one case this is thought to have contributed to self-heating of product by biological action at a temperature well below the usual limit. Temperature monitoring inside large silos is unlikely to be sufficiently reliable for early warning of smouldering and suppliers are moving towards the use of carbon monoxide detectors. It is possible that the gas detection system could be extended to monitor for the products of biological activity.

CARRIAGE OF DANGEROUS GOODS

Operating experience to date and the results of testing of many samples have suggested that the dried sludge product should be classified as "Dangerous Goods for Transport" under the *Carriage of Dangerous Goods (Classification, Packaging and Labelling) etc. Regulations 1996*[16]. These regulations require persons carrying dangerous goods by road and rail to protect those persons involved in handling and carrying the dangerous goods, members of the emergency services and the public from the potential dangers of such activities. The regulations require the consignor to classify the goods according to their hazards, to package the goods suitably, to provide information about the hazards and to provide information to the vehicle operator/carrier.

The most relevant description for the dried sludge product based on the UN Recommendations is "Self heating solid, organic, N.O.S., UN 3088" (also classified as UN Division 4.2 - "spontaneously combustible substance") [17]. The classification is determined by carrying out tests detailed in the *Approved Requirements and test methods for the classification and packaging of dangerous goods for carriage*[18]. The results of the tests not only determine the classification and appropriate hazard labelling but also the type of packaging which is required - either Packing Group III (minor danger) or Packing Group II (medium danger). Additionally the classification may place restrictions on the quantity of bulk material carried in a single load so that in some cases transport by bulk tanker may not be permissible.

At present the UN test method for a combustible substance, which involves heating various sample sizes at temperatures between 100°C and 140°C, has not been carried out on dried sludge samples. The results from similar isothermal basket tests suggest that it is likely that most samples should be classified as "spontaneously combustible" and that in some cases the more stringent Packing Group II should apply. Further work is needed in this area by the drying plant operators to ensure that the material is correctly classified.

PLANT ISOLATION

Many plants handling explosible dusts consist of a series of containers of various sizes linked together by conveying equipment. If an explosion starts in one location it can spread through the plant, causing damage remote from the initial site of the ignition. Dust clouds can be raised from deposited material by a pressure wave spreading through the system and an explosion can occur even where no dust cloud was initially present. A requirement to restrict the spread of a dust explosion by the use of chokes and baffles has been UK law for 40 years[19]. Two commonly used plant items which are effective in preventing explosion propagation are rotary valves and screw conveyors. However the use of these items can produce dust by attrition of the product, which is undesirable to the operator from a quality control viewpoint. If rotary valves and screw conveyors cannot be used, designers should look at alternatives such as suppressant barriers, rapid acting slam-shut valves and explosion diverting devices. To date, too little attention has been given to these aspects of plant design.

HAZARDOUS AREA CLASSIFICATION

It is a requirement of the ATEX User Directive[6] for the operator to carry out a classification of areas into zones where explosive atmospheres may occur. For plant handling a combustible dust, the zoning exercise must consider not only those areas where a cloud of combustible dust may occur but also layers, heaps and deposits of dust which could subsequently give rise to an explosive atmosphere. Selection of electric equipment designed to prevent dust cloud ignition and with a temperature rating low enough to prevent ignition of dust layers can then follow. In order to carry out this exercise, designers will need to make estimates on the likely cleanliness of drying plant. Newly built plant should be effectively dust-tight and the building should remain relatively clean. However, as plants get older they are likely to develop dust leaks, particularly from any areas which operate above atmospheric pressure. It is difficult to give advice until there is a feel for the housekeeping standards to be expected in a plant which has operated for some time.

CONCLUSION

The use of thermal drying processes for sewage sludge treatment has presented the waste water treatment companies with a new technological challenge which they have had to tackle for the first time on very large-scale plants. The equipment suppliers, despite having had previous experience of operating such plants outside the UK, have not systematically addressed all the fire and explosion risks. A lack of appreciation of the principal hazards together with an absence of adequate controls has resulted in serious incidents at a high proportion of the UK plants. HSE has consulted widely to produce timely guidance which may be used to assist in future plant design and ensure consistency in the enforcement of related health and safety issues. Further research work has been commissioned by HSE to establish critical material properties which may be used to define safe operating parameters.

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