Health and Safety Executive

Carbon Bed Adsorbers – Fire and Explosion Safety Issues

DIN SI5/62

Target Audience:
Process Safety Specialist Inspectors

Date issued: 2007-04-02	**OG Status:** Fully open
Review date: 2009-05-31	**Author Unit/Section:** HID CID

Contents

Introduction

1. Carbon bed adsorbers are widely used to control emissions of solvents and other volatile organic compounds (VOC's) from process streams, off-gases and tank ventings in the chemical and petrochemicals industries. They are also used to remove VOC's and other chemicals in land remediation, waste water, offshore, nuclear, military and specialist extraction applications.

2. The VOC is adsorbed onto active sites in the carbon. The process is referred to as "adsorption", which means capture on the surface of a material, as opposed to absorption which involves the incorporation of one material into another (for example using a miscible liquid). Heat is evolved when adsorption occurs. Heat can also be generated if the adsorbed material is oxidised by air or reacts with the carbon. Usually, the initial rate of heat generation is slow for most solvents. However, if the heat evolved exceeds the heat losses via conduction and convection, a hot spot can be formed.

3. Carbon is a very good thermal insulator, so heat losses in an adsorber bed can be low enough to approach adiabatic conditions, and the temperature can rise quickly if a hot spot is formed. If the air flow is suitable, and remedial action is not taken sufficiently quickly, a

hot spot can be fanned into a fire. Fires have occurred in beds in service, in beds that have been taken offline, during regeneration and during the handling of spent carbon.

4. There have been relatively few major incidents worldwide, but nevertheless there is a clear potential for fire and explosion, and for potentially severe domino effects where these units are located on sites handling dangerous substances.

5. Carbon bed adsorbers have been the subject of safety alerts issued by the US Environmental Protection Agency, US Occupational Safety and Health Administration and the Canadian Petroleum Safety Council, and a special issue of Loss Prevention Bulletin (Ref 1).

6. This document contains information and guidance on previous incidents, design and operation (including types of carbon used), the formation of hot spots and occurrence of bed fires, the use of small scale testing to predict the onset of exothermic activity, hot spot detection and mitigation and the handling of spent carbon. Paras 65 to 68 contain a summary of key points and a list of basic questions to assist Inspectors.

Incident History

7. Examples of incidents involving carbon bed adsorbers are given in Appendix 1. A literature search has indicated that approximately one serious incident per year has occurred over the past twenty years. There is also significant anecdotal evidence of fires that have not been reported to HSE.

8. The RIDDOR Regulations 1995 require any explosion or fire causing stoppage of the plant or suspension of normal work for over 24 hours to be reported to the enforcing authority. Some units no doubt become operational within the 24 hour time limit. If the 24 hour period is exceeded, some companies may not report their incidents because the main plant is still capable of operation (the carbon bed adsorber is seen as a “bolt-on extra”, rather than part of the process itself. This is not a correct interpretation of the legislation).

9. Typical factors involved in incidents include:

- The adsorber becomes overloaded with effluent vapour, leading to the formation of hot spots; or
- The grade or source of the carbon (see para 10) is changed, and the new grade has a lower thermal stability; or
- Introduction of air into the adsorber fans a hot spot into a fire; or
- Hot particles from a carbon bed adsorber are carried downstream or down-wind and ignite flammable vapours in other vessels, leading to further fires and/or explosions.

Types of Carbon

10. Carbon is typically sourced from natural materials such as wood, coconut shell or peat. It can be activated by gas phase oxidation, for example using steam, or liquid phase treatment, for example using phosphoric acid. Its vast microporous structure (typically 800

to 1200 m^2 per gramme) makes activated carbon an effective adsorbent. It is usually supplied in the form of granules or pellets.

11. UK suppliers of **activated carbons** include CPL Carbon Link (Wigan), Chemviron (Essex), Norit (Glasgow) and MEGTEC Environmental (Standish, Lancashire).

12. Activated carbon can be chemically impregnated to adsorb specific materials, such as SO_x, NO_x, chlorine, formaldehyde, ammonia, mercury and various radioactive isotopes. Some of these treatments can significantly reduce the carbon's thermal stability and increase its chemical activity. Other factors which affect thermal stability and hot spot formation are discussed in paras 26 to 37.

Design and Operation

13. Carbon bed adsorbers vary in size from small cartridges and skid-mounted disposable drums up to large units with capacities in excess of 100,000 m^3/hr. Smaller disposable units are usually used for odour control, and can only handle relatively low VOC concentrations. Large units can remove VOC's from ppm concentrations up to approximately 100 g/m^3. Beds either operate as a once-through disposable system, or are regenerated by desorbing the solvent once the carbon becomes saturated.

14. In regenerative systems, VOC's are recovered from the carbon by desorbing using either high temperature (usually with steam) or vacuum. The regenerated carbon can then be re-used for adsorption. It is common to have three or four beds, with the operational beds being used for secondary, then primary adsorption (i.e. used for the lighter adsorption load first, when the bed's adsorption capacity is at its most efficient), whilst another bed is regenerated.

15. Suppliers of **carbon bed adsorbers** include MEGTEC Environmental (based in Standish, Lancashire and in the US) and John Zink (based in the US). The latter is a major supplier of pressure swing adsorption systems (see Appendix 2) to the petrochemicals industry.

16. Before start-up, it is common to establish a small amount of solvent (called a "heel") on the carbon. This is known as "pre-conditioning". Applying a heel has an important safety benefit because it reduces the adsorption exotherm (which can result in temperatures of up to 120^0C on new or "virgin" carbon) to between 5 and 30^0 C (there is a corresponding endotherm during desorption).

17. A few users start up with the bed wet in order to:

- Prevent dust cloud formation when charging the carbon to the bed, in order to minimise any flammability and/or occupational hygiene hazard arising from the dust; and
- Prevent exothermic activity during start-up.
- However, this not generally recommended by suppliers because VOC's will not be adsorbed until the relative humidity falls below 50-60%. Also, wetting the carbon can significantly reduce its life.

18. To ensure that a flammable atmosphere is not formed in the ductwork, the usual method is to limit the solvent concentration in the incoming airstream (and, if necessary, also in the outlet airstream) to a maximum of 25% of the lower flammable limit, for example by dilution with air. If the vent stream is at elevated temperature, account should be taken of this when calculating the lower flammable limit used, as it can often decrease the lower flammable limit (see Ref 2). The need for air flow rate monitoring should be carefully assessed. Further guidance on vent collection systems is given in Ref 3.

19. Where flammable vapours are adsorbed in the bed, carbon bed specialists consider that the risk of explosion inside the bed is minimal under normal conditions [where vapour cloud explosions have been reported, they are usually preceded by the formation of significant hot spots, which develop into a fire]. There are a number of (sometimes conflicting) theories on the effect of factors such as air flow rate put forward to explain this (and these theories sometimes give rise to conflicting precautions). The reasons appear to be not well understood, and further research in this area would be useful. It is likely that factors such as quenching effects of the carbon bed [quenching effects in this context are the cooling of the flame by the heat sink of the carbon and the disruption to the flame front by travelling through narrow apertures in the bed] and weak (Van der Waals) bonding between solvent molecules and the surface of the carbon work together to prevent flame propagation.

20. The likelihood of potential ignition sources, such as hot carbon particles, being formed in the carbon bed adsorber and the risks associated with the propagation of these ignition sources both upstream and downstream of the carbon bed adsorber should be considered carefully in the risk assessment (see paras 65 to 68). This is relevant to small disposable units as well as larger adsorber systems. The most appropriate measures to prevent the propagation of such an ignition will depend on the specific case. Flame arresters fitted as close as possible to the bed inlet and/or outlet (as appropriate) are typically used. Guidance on the use of flame arresters is given in Ref 4.

21. Consideration should also be given to the need to prevent air being drawn into the adsorber, for example via the outlet line. One way to achieve this is to use a suitable pressure/vacuum (breather) valve.

22. Although no dust explosions are known to have occurred in carbon bed adsorbers, this aspect may need further consideration. Flammable dust cloud formation needs to be considered as part of the risk assessment.

Desorption

The effectiveness of the adsorption process is usually monitored by measuring solvent breakthrough into the outlet airstream using a gas analyser. Once solvent breakthrough reaches the maximum acceptable level, the maximum working capacity of the carbon has been reached and the unit should be made safe, for example by desorption [beds can also be switched over using a timer if demands on the system are relatively consistent].

24. Desorption is the release of solvent from the carbon surface so that the carbon can be re-used. One of two desorption methods can be used:

- Temperature swing desorption - heating the carbon with steam or (less commonly) with hot nitrogen or hot air [the use of hot air for desorption should be subject to very careful risk assessment, because it can initiate combustion in the bed even if solvent has been desorbed successfully. In very large beds, the onset temperature for thermal runaway may be lower than the temperature required to desorb the solvent] (the usual basis of safety in this case is to prevent the formation of flammable atmospheres by limiting the solvent concentration to a maximum of 25% of the lower flammable limit); or
- Pressure swing desorption - using vacuum (commonly used in petrochemicals applications).

Further information on these desorption methods is given in Appendix 2. More detailed guidance on pressure swing adsorption systems in the petroleum industry is available in Refs 5 and 6.

Formation of Hot Spots – User Issues

25. Users may have a lack of experience of handling solids with a potential for self-heating, so they can be heavily reliant on information from manufacturers and suppliers. Some carbon suppliers (particularly non-specialist companies) can have a lack of understanding of thermal stability issues relating to the use of activated carbon, and provide poor quality information on this subject. **Users may be unaware that hot spots and fires can occur in carbon bed adsorbers**. Consequently, they may be unaware that changing the carbon grade or the VOC adsorbed can lead to a change in thermal stability. Inspectors may wish to consider the need for enforcement action with the PI (supplier) where suppliers have not provided suitable information on these issues.

Factors Affecting the Formation of Hot Spots

Air Supply and Effect on Location of Hot Spot

26. If a hot spot forms, it is likely to be located near the air inlet (usually at the bottom of the bed). Unattended hot spots can smoulder for a considerable length of time. As the combustion progresses, they may also move within the bed. For example, if the air flow is fluctuating, a hot spot will tend to “follow” the airstream that has the optimum flow rate for hot spot development (the effect of air flow rate is discussed further in paras 32 to 34).

Carbon Pre-conditioning

27. Inadequate or inappropriate pre-conditioning (defined in para 16) of new carbon can contribute to hot spot formation. Some types of virgin activated carbon have very high adsorption capacities. If the heel is not properly applied the adsorption capacity will not be reduced sufficiently and more heat will be generated than expected. The Energy Institute guidance (Ref 5) states that, in general, a nitrogen-rich atmosphere is used for conditioning and recommends that:

- The manufacturer should have well documented procedures in place for the conditioning procedure, including an emergency response plan;

- The procedure should be carefully followed and supervised;
- Careful records should be kept, including the temperature-time profiles for each bed, in order to demonstrate that the conditioning process has been undertaken fully and successfully.

28. Too much desorption can cause the heel to be partially removed, for example if excessively hot steam is used.

Materials Issues

29. Carbons that are chemically activated or impregnated with metal salts tend to be less thermally stable than steam activated ones. The thermal stability of the carbon bed can be affected by physical characteristics of the carbon such as its origin (for example fruit-based, wood-based) and particle size.

30. Certain adsorbed materials such as aldehydes, ketones, amines, sulphides, some monomers and some organic acids can oxidise in the bed and generate substantial amounts of heat. Also, any material being adsorbed which has relatively low thermal stability could produce similar effects. The onset temperature for exothermic activity in a saturated carbon bed can be as low as 25^0C for some chemical species (Ref 7).

Solvent Vapour Loading

31. Prolonged exposure of carbon to solvent vapour without proper regeneration can contribute to hot spot formation. This can arise from overloading the unit with solvent, incorrect operation of the adsorber system or shutting the system down in an emergency, such that the bed does not complete its desorption cycle.

Air Flow Rate

32. During normal operation, the flow of air and vapour through the carbon helps to remove heat by convection (see also para 18). Very low air flow rates can result in a build-up of flammable vapour in the bed, which may increase the likelihood of hot spots. This may occur if there is a "dead spot" in the bed caused by a blockage (for example, attrition of the carbon can result in powdered carbon blocking the support mesh). Inadequate air flow can also occur if the system remains idle for an excessive period of time with solvent adsorbed on the carbon.

33. Increasing the air flow rate, once a hot spot has been formed, can fan it into a fire, for example during start-up (hence the "Monday morning incident").

34. Although very high air flow rates sometimes lead to a hot spot being controlled by cooling, this is not recommended as a mitigation method.

Size of Adsorber Beds

35. Hot spots are more likely in larger beds, due to the reduced specific surface area available for cooling. Also, it can be more difficult to distribute the air flow evenly in a large bed.

Temperature

36. Hot spots are more likely at high ambient and/or vapour temperatures.

37. Hot spots are more likely at night. This is because, when the ambient temperature drops, a slight vacuum is created, which can draw air into the system.

Bed Fires

38. Temperatures of several thousand degrees are possible if the system is allowed to burn for some time, and melting of steelwork has been reported. A burning adsorber bed is a potentially powerful ignition source for any flammable or combustible materials in the vicinity and for some distance downwind. Even small disposable drum units have been known to catch fire.

39. It is important to take the fire risk into account when positioning new units. **Carbon beds should preferably be located outdoors, in an easily accessible position to facilitate temperature monitoring and hot spot/fire mitigation. The area should be kept free of combustible materials (such as packaging and wooden pallets), flammable and other dangerous substances.** Further guidance on risk assessment of carbon bed adsorbers is given in paras 65 to 68.

Use of Small-Scale Testing to Predict Onset Temperature of Exothermic Activity

40. Various small-scale tests have been used to attempt to quantify the onset temperature for exothermic activity. Although not necessarily essential for safe operation, provided suitable precautions are in place to prevent ignition, this information can help to reduce the likelihood of hot spot formation and bed fires by specifying maximum safe operating temperatures. Tests that have been used include:

- Powder thermal stability tests such as the Bowes-Cameron cage tests (commonly known as “UN basket tests”) and the ICI Aerated Powder Test (Ref 8);
- Calorimeters such as the Adiabatic Reaction Calorimeter™ and Adiabatic Dewar; and
- Individually designed systems, such as the Aerobic Adiabatic Dewar described in Ref 7.

41. Small-scale tests must be carried out by suitably competent personnel, taking care to ensure that the tests accurately model plant conditions including likely air flows. Great care and expertise is needed to analyse the results and apply suitable scale-up factors, in order to meaningfully apply the results to plant conditions.

42. Carbon suppliers sometimes quote the ignition temperature as measured in the ASTM test (Ref 9). These test results do not indicate the temperature at which ignition will occur under operating conditions. The test results are only to be used for comparative purposes. This is because the test is highly non-adiabatic (the sample size is only 35 ml). This is stated in the standard, but is often overlooked.

Hot Spot Detection

43. In practice, carbon bed adsorbers are often not provided with any means for hot spot detection. Suppliers may consider that the risk of hot spot formation is sufficiently low, based on a risk assessment of the specific application and in particular the type of VOC adsorbed. For example, hydrocarbons and alcohols tend to be regarded as low risk, because their adsorption exotherms are relatively low and they do not tend to oxidise on the bed. The need for hot spot detection should form part of the detailed risk assessment for the carbon bed adsorber.

44. Differential temperature monitoring using probes **on the inlet and outlet** can provide an indication of hot spot formation, although CO monitoring (see below) is much more sensitive. Temperature probes **in the bed** only provide information on bed conditions in the immediate vicinity of the probe and are not a reliable means of detecting hot spots early on, or even in advanced stages in larger beds. A hot spot may not be initially apparent because the adsorption process usually results in a small temperature rise, but any deviations from normal should be investigated immediately.

45. Hot spots can be detected by carbon monoxide (CO) monitoring. This can detect the onset of combustion during its very early stages. However, CO monitoring is more expensive than differential temperature monitoring and is rarely used in practice. If the CO monitor measures the CO concentration at the sampling point (so-called “point detection”), readings during the early stages of hot spot growth may be too low to be detected accurately. In these cases, CO monitoring on the outlet or differential measurement between the inlet and outlet will be needed. CO monitoring is more effective when the adsorber is “off-line”, because when the adsorber is “on-line” the CO is diluted by the carrier gas (Ref 10).

46. Infra-red type CO monitors are more likely to be suitable than pellister types, which may be poisoned by materials such as silicones, organo-lead compounds, halogenated hydrocarbons and materials containing sulphur. Some substances such as formic acid can give false readings because they decompose to give carbon monoxide. Also, there may be a background level of carbon monoxide if the bed has been exposed to air, and then closed up. Other techniques such as oxygen monitoring, smoke or ionisation detection may be suitable, but they are susceptible to interference from particulates and organics.

47. In addition to CO or temperature monitoring, **the exterior of the adsorber unit should be checked at least daily for signs of overheating.** A thermal imaging camera and/or temperature-sensitive paint could also be useful to assist in detecting hot spots.

Mitigation

48. Suppliers may not provide carbon bed adsorbers with hot spot mitigation systems, although a connection for a water flooding system may be fitted. This should be justified as part of the risk assessment.

49. Manufacturers operating instructions should contain information on hot spot mitigation procedures and the temperatures at which the various actions are needed. Operating personnel should be provided with suitable training and written instructions. Advice on dealing with hot spots is given in guidance (Ref 5) from the Energy Institute (formerly the Institute of Petroleum). This strictly applies only to vacuum swing desorption units handling gasoline, however it contains a lot of generally useful advice. Dutyholders will need to determine its relevance to their particular case. In particular, the Energy Institute guidance suggests action temperatures for:

- Increased frequency of temperature monitoring;
- Isolating the inlet from the process; and
- The use of nitrogen inerting and water flooding.

50. If a hot spot or fire is detected, suitable procedures may include removing any lagging around the carbon bed if it is safe and practicable to do so. This will help the bed to cool down faster. The bed should not be opened up, as this can introduce oxygen, which will fuel the combustion.

51. Flooding with water or nitrogen are the usual methods for dealing with a bed fire. **Flooding with water is preferable** because it can effectively stop combustion and remove the heat.

52. Nitrogen can be used if the bed is at a relatively low temperature (100^0C is suggested in the Energy Institute guidance). It can effectively stop the combustion reaction but will not significantly remove the heat.

53. Water flooding can be used either alone or if nitrogen flooding fails to halt the temperature rise. An action temperature of 150^0C is suggested in the Energy Institute guidance. To minimise pressure build-up, water should preferably be introduced at the base of the bed with a velocity of 1 to 2 cm/min (Ref 11). Care should be taken to ensure that the vessel and its supports can withstand the extra imposed load due to the weight of the water.

54. It is important that there is adequate venting capacity for the large volumes of steam produced during water flooding, to avoid potentially damaging pressure build-up in the system. It should be ensured that the outlet valve is fully opened, for example by suitable interlocking. The vent outlet should be in a safe position, such that the hot steam/VOC mixture cannot be vented into areas where personnel could be present. Suppliers recommend that the adsorber should be left for some time after flooding with water (one supplier recommends at least 24 hours) before any further remedial action is taken.

55. Flooding with steam can also stop the combustion, but the bed will remain hot and in some cases fires have restarted after prolonged steaming. It could also increase the likelihood of the water gas reaction (see below).

56. Hydrogen and carbon monoxide can be formed by the “water gas” reaction between steam and carbon at temperature that may occur during a fire. However, to date it appears that no incidents have been attributed to this mechanism.

Control and Instrumentation Issues

57. Any instrumented system with an effect on safety should have a suitable integrity, so that risks arising from the operation and maintenance of carbon bed adsorbers are adequately controlled. Examples of safety instrumented system functions are:

- Control of sequencing and flow to ensure correct and complete conditioning of adsorbers, and subsequent start up;
- Measurement of critical operating parameters, the selection of safety actions, alarm triggering, and the provision of operator information;
- Selection of input stream source(s), which adsorber is on line, and output stream(s);
- Control of desorption sequences and parameters;
- Detection of the onset of dangerous conditions and correct operating configuration, including air fans and dampers, inerting and water deluge systems;
- Co-ordination with other safety systems.

58. Safety Instrumented Systems (SIS) should be designed by competent persons according to a suitable standard, such as the functional safety standard BS EN 61511 (Ref 12), and be correctly installed, operated and maintained. General information on safety issues associated with control systems is given in Ref 13.

Oxygen Depletion in Carbon Bed Adsorber Vessels

59. The 1994 incident in Appendix 1 illustrates the dangers of oxygen deficiency that can occur in sealed carbon bed adsorber vessels.

Handling Spent Carbon

60. Adsorbed solvent can significantly reduce the carbon's thermal stability. Some types of spent carbon can smoulder and even catch fire if hot spots are present.

61. Where the carbon has been used to adsorb particularly reactive chemicals such as ketones, consideration should be given to preventing exothermic activity during storage and transportation, for example by thoroughly wetting the carbon. However, the dutyholder will need to ensure that hot spots are not present so that the water gas reaction does not occur. Alternatively, the containers can be purged with nitrogen (usually at least three volume changes are needed). If carbon is wetted whilst in the adsorber bed, the adsorber should be thoroughly dried before fresh carbon is introduced, for example using hot nitrogen.

62. Where dry carbon is removed from the adsorber, a supply of water should be on hand to douse the carbon if a hot spot is discovered.

63. Spent carbon should preferably be sent promptly for disposal. If spent carbon needs to be stored on site for a significant period, then the spent carbon should be stored well away from other fire hazards, combustible materials, flammable and other dangerous substances. Further guidance on the storage of dangerous substances is given in Ref 14.

64. Spent carbon should be suitably packaged and labelled before transportation, taking account of both the potentially reduced thermal stability and the effect of adsorbed solvent on flammability. Spent carbon may be spontaneously combustible (i.e. a UN Class 4.2 material), and may need to be classified as such for transport. However, in practice the classification depends on the grade of carbon, size of package in which it is stored and the type of adsorbent, so assessment of a representative sample may be needed. If test data specific to the spent material is not available, then a realistic worst case should be assumed. Further information on the carriage of dangerous goods by road is given in Ref 15.

Summary

65. A carbon bed adsorber should be the subject of a suitably detailed risk assessment. This usually needs to be specific to the plant and process. All foreseeable operating conditions should be assessed, including start-up, regeneration, drying of a wet bed (if appropriate) and shut-down as well as normal operation. Care should be taken to include the effects of nearby plant and operations, particularly where combustible, flammable or toxic materials are involved. The scope should include consideration of the measures needed to minimise the formation of hot spots and fires, and measures to mitigate the consequences should a hot spot or fire occur. The need for these measures, and their nature and extent, will depend on the fire risk for the specific application. Further information on this type of risk assessment is given in Ref 16.

66. The following list contains some basic questions that can be used to provide information for input to the risk assessment:

- If the solvent is flammable, how is the percentage of solvent in the incoming airstream controlled to a suitable level below the lower flammable limit? Bear in mind that flammable limits tend to widen as the ambient temperature increases. Further information on vent collection systems is given in Ref 3.
- What VOC's are adsorbed, and how do they affect the thermal stability of the carbon?
- How critical is the grade of carbon used in preventing the formation of hot spots? If a new grade or supplier is used, what is the effect on thermal stability? This should be subject to the usual plant change procedures.
- Have there been any previous incidents involving hot spots or fires in this type of application?
- Is the exterior of the unit visually checked at least daily?
- Is the unit located outdoors, in an easily accessible area and well away from combustible materials and flammable or other dangerous substances?
- What systems are provided for the detection of hot spots? How were they designed in order to be adequate for duty? Are the inspection and maintenance regimes appropriate, such that the required availability is achieved?
- What mitigation systems (for example water deluge, nitrogen flooding) are provided, and what criteria are used for their initiation?
- What information and training have operators received on how to deal with a hot spot or bed fire?
- Has the potential for a dust cloud explosion been considered?
- Has consideration been given to the likelihood of potential ignition sources, such as

hot carbon particles, being formed in the carbon bed adsorber? Have the risks associated with the propagation of these ignition sources both upstream and downstream of the carbon bed adsorber and the need for preventive and/or protective measures such as flame arresters been considered?
- Have the effects on safety of control and instrumentation issues been adequately addressed?
- If the vessel can be sealed, has the potential for oxygen depletion been considered?
- What systems are in place for the handling, storage and transportation of spent carbon?

67. A detailed risk assessment, for example including a HAZOP study, is likely to be needed where flammable atmospheres could foreseeably exist downstream or downwind of the carbon bed adsorber, or where domino effects could foreseeably occur if there is a fire in the carbon bed adsorber.

68. Consideration should be given to the classification of hazardous areas and the selection of suitable electrical equipment for use in these areas. Further information is given in Ref 16.

Acknowledgements

The author would like to thank Andrew Fowler and Ralph Rowlands of HSE, who carried out earlier work on carbon bed adsorbers, Andrew White of HSE, Mark Hoyle of AstraZeneca (Macclesfield), Jim McMullon of MEGTEC Environmental, Aidan Foley of Macfarlan Smith (Edinburgh), Adrienne Goodwin of Mitchell Cotts Chemicals (Mirfield), Michelle Pullen of Trelleborg (Leicester), Graham Astbury formerly of the Health and Safety Laboratory (Buxton) and staff at Syngenta (Huddersfield) for their help and advice.

References

1. Loss Prevention Bulletin, issue 184, August 2005, Institution of Chemical Engineers.

2. “Dryers and ovens, in which flammable substances are released – safety requirements”, BS EN 1539, 2000.

3. “Safe design and use of vent collection systems for potentially flammable mixtures”, G Newsholme, 16/9/04.

4. “Flame arresters – preventing the spread of fires and explosions in equipment that contains flammable gases and vapours”, HSG 158, HSE Books, 1997.

5. “Vapour recovery units – guidance on preventing and controlling temperature excursions in carbon beds”, Energy Institute (formerly the Institute of Petroleum), January 2001.

6. “Marine vapour control system”, US Coastguard Federal Register.

7. “Thermal stability of activated carbon in an adsorber bed”, Hoyle, Astbury and Chen, I Chem E Symposium Series No.141, pp.247-260, 1997.

8. Gibson, Harper and Rogers, Plant/Operations Progress, Vol 4, No.3, pp.181-189, 1985.

9. “Standard test method for ignition temperature of granular activated carbon”, ASTM D 3466-76, 1998.

10. “The safe application of activated carbon adsorbers to abate VOC emissions from vents”, Jim McMullon, Chemviron Carbon, presentation at Institution of Chemical Engineers meeting “Vent VOC abatement – environmental protection without creating new hazards”, 22/11/05.

11. “Gas Phase Handbook”, Chemviron Carbon, p.4.5.

12. “Functional safety. Safety instrumented systems for the process industry sector”, BS EN 61511 Parts 1 to 3, BSI, 2004.

13. “Out of control – why control systems go wrong and how to prevent failure”, HSG 238, 2nd edition, HSE, 2003.

14. “Chemical warehousing – the storage of packaged dangerous substances”, HSG 71, HSE, 1998.

15. “Working with ADR – an introduction to the carriage of dangerous goods by road”, Department for Transport, 2004.

16. “Dangerous Substances and Explosive Atmospheres Regulations 2002 – Approved Code of Practice and Guidance”, L138, HSE, 2003.

17. “Fires and explosions in vapour control systems: a lessons learned anthology”, TJ Meyers, HK Kytomaa and RJ Martin, Process Safety Progress, Vol 22 No 4, Dec 2003, pp.195-199.

18. “Safety hazards associated with air-emission controls”, H Ozg and WJ Erny, Process Safety Progress, Vol 19 No 1, Spring 2000, pp.25-31.

19. “Lessons learned from fires and explosions involving air pollution control systems”, RA Ogle, AR Carpenter and DT Morrison, Process Safety Progress, Vol 24 No 2, June 2005, pp.120-125.

20. “Fatal accident on a hydrocarbon recovery plant”, Loss Prevention Bulletin 069, pp.25-28.

21. Lloyds Register.

22. “Activated charcoal filter fire”, Loss Prevention Bulletin 105, p.15.

23. Australian SafetyLine Institute website.

24. “OSHA Information Bulletins: Fire hazard from carbon adsorption deodorising systems”, SW Witt, 30/7/97.

25. “Carbon bed adsorber fire”, GR Astbury, Loss Prevention Bulletin 134, pp.7-9.

Appendix 1: Examples of Carbon Bed Adsorber Incidents

Further information on incidents involving carbon bed adsorbers (including summaries of more recent incidents than the ones described below) is given in a special issue of Loss Prevention Bulletin (Ref 1), and in Refs 17 to 19.

1983 (Ref 20)

An operator was killed by an explosion in a five bed carbon adsorber unit. The explosion occurred during the annual maintenance shutdown. In order to desorb, dry and cool each bed, it was standard practice to introduce air into the recirculatory fan system, to prepare vessels for entry purposes. Air was introduced via an opening in the inlet ductwork, flow being adjusted manually using a blanking plate. The operator was standing in front of the blanking plate when there was an explosion within the fan system. He sustained fatal injuries from flying debris. The source of ignition was probably hot spots in the carbon bed.

1987, Sydney, Australia (Ref 21)

A fire occurred in a nuclear research laboratory in an area used to process medical isotopes. The fire started in a carbon filter and resulted in the release of a small amount of radioactive material into the atmosphere.

1991 (Ref 22)

A fire occurred in a carbon bed adsorber located on a loading dock. The fire was limited to some PVC pipes above the unit, and no-one was injured. The fire started shortly after the fan was turned on. Ignition was caused by hot spots in the carbon bed.

1993, California, USA (Ref 18)

A tank in a refinery effluent treatment plant over pressurised. The tank roof separated from the shell and travelled approximately 60 m. No injuries occurred. The most probable source of ignition was hot particles in the carbon vent adsorber.

1994(?), Australia (Ref 23)

Newly constructed water filtration tanks had been partly filled with a slurry of activated carbon and water. The water was drained off and the tanks were sealed. The following morning two workers entered one of the tanks. Later, they were both found dead on top of the carbon bed. Subsequent tests showed that, 24 hours after sealing the tanks, the oxygen level had dropped to 12%. Other tanks in the area were checked and some that had been closed for several days had oxygen levels of only 2%.

1995, US (Ref 24)

Drums of activated carbon were used for deodorising emissions from tanks of crude sulphate turpentine. The system design permitted the backflow of air through the drums. Exothermic activity in the bed led to a fire, which ignited flammable vapours in the headspaces of the tanks. The fire and explosion burned for three days and damaged other storage tanks, resulting in the release of toxic gases. Over 2,000 residents were evacuated.

1995 (Refs 7, 25)

A carbon bed adsorber on a fine chemicals intermediates plant was severely damaged by fire. This was caused by using wood-based carbon with a lower thermal stability than the coal-based carbon used previously, and prolonged steaming due to plant problems. The fire occurred when cooling air was introduced. Solvent was not present on the bed at this time – the exotherm was entirely due to the fresh carbon.

Appendix 2: Summary of Desorption Methods

Temperature Swing Desorption Using Steam

Steam is the most common desorbant for recovery of materials that are immiscible with water. The mixture of steam and solvent is condensed by cooling and then separated. The bed must be cooled and dried before returning to adsorption duty, usually using clean warm air.

Temperature Swing Desorption Using Hot Nitrogen

This is particularly suitable for use with water-soluble solvents. Oxygen levels in the desorption system are first reduced by purging with nitrogen, then hot nitrogen at typically 200-300^{0}C is circulated. The hot gas preferentially desorbs the moisture captured from the air by the adsorbent. This water is usually removed by drying the gas with a molecular sieve (in which the water is adsorbed by the pores of an aluminosilicate compound called a zeolite). Once the water has been desorbed, hot dry nitrogen is used to desorb the solvent. The desorbed solvent is condensed from the carrier gas, ready for direct re-use. The bed must be cooled before returning to adsorption duty.

Pressure Swing Desorption Using Vacuum

The reduced pressure causes the adsorbed solvent to vaporise from the adsorbent pores. The solvents desorbed from the bed are removed by purging with a small amount of the clean vent stream. In the petroleum industry, it is common to use a stream of gasoline to condense the solvent vapours.