THERMAL OXIDISER FIRE & EXPLOSION HAZARDS

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Thermal Oxidisers by their very design operate on generating a flame or intense heat in their combustion chambers for the destruction of process waste or emissions containing VOCs. If process conditions upstream, where these emissions are generated, are not properly managed or controlled thermal oxidisers can pose a significant fire and explosion hazard.

This paper discusses the type of oxidiser available, fire and explosion hazards in the oxidiser and vent collection system, risk assessment and basis of safety. An overview of applicable legislation and guidance is attached and several case studies of incidents discussed. This paper includes an extensive bibliography.

INTRODUCTION

Ever increasing global public pressures have prompted many countries to introduce pollution control legislation to protect the environment. In the UK this has led to the introduction of the Environmental Pollution Act (EPA) 1990 (Ref 34).

In order to comply with EPA 90, many process and manufacturing industries are having to install "thermal oxidisers" (Incinerators or Afterburners) for the abatement of Volatile Organic Compounds (VOCs) and gases in their process waste streams before discharge to atmosphere. There are, of course, several other techniques besides thermal oxidation such as Substitution, Condensation, Adsorption, Liquid Scrubbing, Biological treatment and others. These are outside the scope of this paper. See reference 46 for advice on other treatment technologies.

Thermal Oxidisers by their very design operate on generating a flame or intense heat in their combustion chambers for the destruction of process waste or emissions containing VOCs. If process conditions upstream, where these emissions are generated, are not properly managed or controlled thermal oxidisers can pose a significant fire and explosion hazard.

Over the years, both in the UK and abroad, there have been a number of serious fire and explosion incidents involving thermal oxidisers because companies using them have failed to either properly manage or control their processes. A number of these incidents have resulted in fatalities and a significant loss to business. Some of incidents that have been investigated by the HSE are discussed later in this paper. In the USA, incidents have been reported which resulted in fatalities (Ref. 36). Other incident descriptions can be found in Refs 39, 40, 41, 42.

The aim of this paper is to ensure that those who operate thermal oxidiser plants and associated equipment manage and operate them safely and effectively to ensure that conditions leading to fire and explosion are prevented or at least minimised. This paper does not include other abatement systems associated with the destruction of domestic, communal, agricultural, and hospital waste, either as solids or volatile residue sludge.

In order to ensure uniformity in design, installation and operation of thermal oxidiser plant across Europe, a recent European standard has been published - EN 12753:1999 (Ref.28) entitled 'Thermal cleaning systems for exhaust gas from surface treatment equipment Safety requirements'.

DESIGN & SELECTION
Until the publication of EN 12753 there was no specific standard is available concerning thermal oxidiser design and associated safety. Reputable manufacturers of thermal oxidisers may, however, include recommendations contained in Refs. 9, 12, 13 and 14 into their design philosophy. The unit selected should be appropriate for the full range of foreseeable flows and compositions. Where more than one plant or process vent discharges into the vent header system extreme caution should be taken to ensure that the full range of potential operating conditions have been identified. The amount of time required for this exercise when retrofitting a thermal oxidiser to an existing plant should not be underestimated. Design of oxidisers and vent collection systems should be undertaken by suitably qualified persons.

Typical types of thermal oxidisers being used in the chemical and related industries are:
- "Simple" Thermal Oxidisers. These may be vertical (see figure 1) or horizontal units. Details of burners and fitments vary widely between manufacturers.
- Oxidisers for hazardous chemical waste streams. These are designed for a more complex mix of VOCs which require special treatment in order to ensure complete destruction. Typical features include staged air injection and chemical resistant refractories. (Figure 2)
- Regenerative thermal oxidisers consist of a number of beds filled with ceramic packing which are used in sequence with the bed that just come off line being used to pre-heat the incoming gases. Heat recovery of up to 90% is possible with this type of unit. Figure 4.
- Recuperative Catalytic Oxidisers operate at lower temperature and destroy VOCs by a catalytic reaction. Catalyst is carried on a ceramic matrix. It should be noted that the catalyst may be poisoned by certain chemicals hence application is limited. (Figure 5). Incoming gases are pre-heated in a separate exchanger and good heat recovery is possible.
- Regenerative Catalytic Oxidisers are similar to regenerative thermal oxidisers but using a catalyst. This type is particularly suitable for low VOC concentrations.
- Flameless Thermal Oxidisers may be used for streams containing halogenated or sulphonated materials which could poison catalysts. These may operate without support fuels at VOC concentrations ~50% - 60% of the LEL. Figure 3.
- Thermal Oxidiser with Integrated Rotor Concentration System may be used in situations where the VOC concentration is extremely low (<500ppm). The rotor section contains a Zeolite which acts as a molecular sieve to concentrate the VOCs up prior to the thermal oxidiser.
- Flares are often used in the petrochemical industry and are a very simple form of thermal oxidation generally used when the concentration of gases is above the LEL and not suitable where the by-products may be toxic or acidic.

HEAT RECOVERY
Heat recovery is not generally an economic option for smaller thermal oxidisers. Larger units can, however, successfully integrate heat recovery options which may significantly reduce operating costs and improve environmental benefits. It should be noted that heat recovery is more difficult for VOC streams containing halogens or sulphur since wet scrubbing is usually required to remove acidic combustion products. This entails cooling the gases to less than 70°C before wet scrubbing and then re-heating to prevent a visible plume.

FIRE & EXPLOSION HAZARDS

When considering fire and explosion hazards, thermal oxidisers should not be considered in isolation but as fully integrated system including upstream and downstream plants and equipment. There are three distinct areas where fire and explosion risks are foreseeable and demand appropriate measures to reduce these risks to acceptable levels. These are:
- Upstream process plant
- Vent collection system
- Thermal oxidiser

VENT COLLECTION SYSTEM
Vent pipes or ducts carrying the flammable waste stream to the thermal oxidiser for abatement are also susceptible to being involved in fire and explosion. This can occur if the solvent concentration conveyed via these vent pipes is not properly managed or monitored and there is an ignition source present.

There are many potential sources of ignition in a vent header system including:
- Flashback from thermal oxidiser
- Naked flames
- Electrostatic discharges
- Mechanical friction
- External hot work
- Impact sparks
- Pyrophoric materials
- Electrical apparatus
- External sources (e.g. lightning)

Appropriate measures should be taken to exclude all ignition sources wherever possible.

Control of VOC concentration in the vent header system is essential to prevent potential fires or explosions. Where the basis of safety is operation below the LEL then on no account should the solvent concentration in the vent collection system exceed 25% LEL unless a suitable concentration monitoring system is used, in which case the solvent concentration must not be allowed to exceed 50% LEL. Where solvent vapour concentration is kept above the UEL, the VOC should be delivered in an inert atmosphere (such as Nitrogen) whenever passing through the explosive range (UEL - LEL), as would be the case during start-up and shutdown.

THERMAL OXIDISER
Abnormal operating conditions in the thermal oxidiser can result in an explosion. These conditions can develop as a result of various deviations described below.

The consequences of an explosion occurring in the thermal oxidiser are potentially lethal due to explosion overpressure and missiles generated by failure of the casing. These may also lead to domino effects on adjacent plant. Small explosions may lead to damage either to the oxidiser shell or the ceramic lining or packing. It is also likely that after an explosion in an oxidiser a thorough HAZOP and re-design of the system would be needed to the satisfaction of the competent authority (HSE in the UK) prior to the system being allowed to re-start.

POTENTIAL MALFUNCTIONS
There are many potential malfunctions which may result in fire and explosion hazards in the thermal oxidiser and vent collection system. Typical of these are:
- Interruption to power supply
- Instrumentation problems
- Control system problems
- Mixing of vent streams
- Reduction in air flow rates
- Fluctuations in VOC flow rates
- Process deviations
- Bringing new vessels or processes on line

INTERRUPTION TO POWER SUPPLY

If power supply is interrupted either to one or more of the upstream plants, or to the thermal oxidiser itself, then a hazardous situation may result. VOCs could continue to be fed to the thermal oxidiser or the upstream process may become unstable, releasing increased amounts of VOCs into the vent headers. The thermal oxidiser system should be designed to fail safe in the event of a power failure occurring in all circumstances.

INSTRUMENTATION PROBLEMS

The absence or incorrect position of protection devices may lead to potentially hazardous concentrations being formed, for example due to:

- Over-temperature or under-temperature
- Failure of flow rate controls leading to excessive VOC loading
- Interruption in the exhaust system or recirculation system
- Maloperation of fans and / or dampers.

Instrumentation should be specified correctly for the duty and must be positioned correctly within the system to provide an accurate reading. It is essential to ensure that instruments continue to function correctly and that sensors are not blocked up or blinded by depositions.

CONTROL SYSTEM PROBLEMS

Failure or improper set up of the control system can result in the formation of a flammable mixture in the oxidiser. The control system must balance the combustion air and fuel gas requirements with the VOC. The supply of combustion air is normally controlled by monitoring the oxygen content in the flue gas. Temperature is controlled by altering the flow of fuel gas.

Control systems should conform to the requirements of Ref. 7 or one of the equivalent NFPA standards (See below). It should be noted that although many control systems supplied by oxidiser manufacturers are adequate for their duty, they may not meet the higher standards of integrity and reliability demanded by some sectors of the chemical industry. Further attention may, therefore, need to be paid to such items as trips and alarms at the design stage.

MIXING OF VENT STREAMS

For plants handling more than one vent stream, mixing of streams can present major hazards. All variations of flow and composition should be accounted for in the design of the thermal oxidiser and vent collection systems. Ref. 47.

It should also be noted that within the upstream and downstream plant all control systems should be fully and correctly integrated. If they are not, failure of any one or a combination could lead to rapid formation of a dangerous concentration of solvent vapours and thus an explosion. It is critical that a full HAZOP study is carried out on this aspect of operation. The amount of time required for this process should not be underestimated.

OTHER FACTORS CAUSING HIGH VOC CONCENTRATION TO THE OXIDISER

If condensates and combustible deposits are not removed regularly from the system they can evaporate or decompose to form a dangerous concentration leading to a fire or explosion. To avoid this, the upstream and downstream plant and equipment should be inspected and cleaned regularly. The frequency of inspections should be dependent on the severity of build-up and the risk this build-up could pose.

VENT HEADER SYSTEM

Hazardous mixtures could form in the vent collection system as a consequence of the following:

- Inadequate purging of the whole system including the upstream ductwork.
- Insufficient dilution and flow in the system.
- Blockages,
- Deposits causing imbalance in the ventilation fan and reducing efficiency
- Poor operation or failure of the exhaust ventilation system
- Vaporisation of condensates (particularly on start-up)

Any one of the following could create disturbances within the exhaust ventilation system:

- Changes in process pressure or temperature
- Bringing new vessels on line or taking vessels off-line
- Incorrect maintenance

POOR THERMAL OXIDATION

Conditions that could cause insufficient thermal oxidation may be attributed to one or a combination of the following:

- Insufficient oxygen content within the waste stream feed to the thermal oxidiser
- Too low a temperature within the combustion chamber of the thermal oxidiser
- Insufficient turbulence/mixing within the combustion chamber of the thermal oxidiser
- Reduced catalyst function due to ageing, poisoning or deposits
- Poor auxiliary fuel feed supply to the thermal oxidiser
- Poor selection and maintenance of the thermal oxidiser
- Poor circulation of the waste stream through the combustion chamber

HAZARDS CAUSED AS A CONSEQUENCE OF ADSORPTION

Hazardous conditions can develop if flammable substances adsorb unintentionally on to the surface of the catalyst due to the system being operated at a lower temperature than the desired temperature to secure efficient combustion. These can later desorb and could develop potentially hazardous conditions within the system. Rapid exothermic decomposition of the organic waste within the thermal oxidiser could also occur if undesirable conditions develop due to incorrect process conditions.

NOTE: If the thermal oxidiser is in its shutdown mode, it should not under any circumstances be used as a channel or duct for exhausting VOCs. Such a practice may cause the inner brickwork of the thermal oxidiser to absorb VOCs which be released upon start up and cause a serious fire or explosion with devastating effect on the thermal oxidiser and associated plant.

RISK ASSESSMENT

Employers are legally required to assess the risks in the workplace and take all reasonably practicable precautions to ensure the safety of workers and others who could be affected. In the risk assessment process employers should identify the potential hazards and determine the risks. Appropriate prevention or mitigation measures should then be taken to reduce the risk to an acceptable level.

The risk assessment process should include the impact on the whole system of all foreseeable fluctuations and maloperations in the upstream and downstream plant as well as the oxidiser. It should also include the operation of all instrumentation, controls and safety interlocks.

This risk assessment should be carried out in accordance with the guidance in Ref.16 by a suitably qualified leader and in the presence of key members of the design team and operations personnel.

It is essential that the personnel responsible for operating the thermal oxidiser and associated plants are fully aware of the potential risks and hazards involved in operating the system especially in terms of the fire and explosion hazards. Information from the risk assessment process should be cascaded down to operating personnel in order to raise their awareness and ensure that the plant is operated safely.

HAZOP (HAZARD & OPERABILITY STUDY)

Hazards may arise in a plant due to deviation from the normal operating parameters or conditions. Hence, a HAZOP Study approach, which is a structured and systematic technique for identifying hazards and operability problems throughout an entire facility, can be applied to determine critical parameters that could have a detrimental effect on the plant and the process.

The list of deviations should form part of the HAZOP study to determine and examine possible causes, possible consequences, with appropriate actions to minimise the risk of an incident. Typical aspects considered should include foreseeable changes in normal operation, equipment, and instrumentation, provision for failure of plant services, provision of maintenance, safety etc.. It is essential that HAZOP studies be led by a trained and experienced hazard study leader. The team should include the responsible process engineer, electrical and instrument engineer, mechanical engineer and plant representative. Other members may also be required at certain stages, in particular a representative or representatives of the thermal oxidiser manufacturer who should be fully conversant with the design, control, operation and limitations of the oxidiser.

A HAZOP or process hazard review should be carried out periodically (5 yearly intervals or sooner if required) to ensure that the safety and integrity of the system have not been compromised and that any changes in operating conditions have been taken into account. Again, this process should be carried out by an experienced hazard study leader.

MODIFICATION CONTROL

It is essential for the continued safe operation of the unit that some form of change control be exercised. This should include an element of HAZOP in order to ascertain that the proposed modification does not compromise the safety of the thermal oxidiser, the associated systems or the upstream plants.

Modification control should also extend to vent header systems and upstream plants and processes. These modifications should also be HAZOPed to ensure that no additional hazards or risks are introduced. Modifications should be fully detailed and traceable using a quality control system.

SAFETY DESIGN OF THERMAL OXIDISERS & VENT HEADERS

Many of the problems that occur with thermal oxidation systems are due to problems with, or maloperation of the upstream plant resulting in the formation of a flammable mixture in the vent headers. It is essential that the upstream plant, vent header system and thermal oxidiser are considered as a fully integrated system and not as isolated units.

A clear and tenable Basis of Safety for operation should be written for the system. For vent headers it is not generally sufficient to propose a basis of safety on the absence of ignition sources since there is always the chance of an external factor as discussed above. The Basis of Safety for vent header systems should, therefore, be operation outside the flammable region. The potential consequences of an ignition occurring in the header system mean that it is critical that a non-flammable mixture is maintained at all times. Design of the system should be carried out by a qualified and experienced engineering team.

THERMAL OXIDISER SAFETY

THERMAL OXIDISER OPERATION

Under no circumstance should the VOC concentration reaching the thermal oxidiser inlet be allowed to exceed 25% LEL unless continuous solvent vapour monitoring is provided upstream of the thermal oxidiser, where a maximum of 50% LEL is acceptable. Operation of the vent header system above these limits can result in flashback and severe explosion damage to the vent header system and connected equipment.

If, for any reason, the VOC concentration exceeds these limits then it is essential that appropriate emergency action is taken. In the first instance this should be to divert the waste stream to atmosphere. An interlock system should automatically shut down the process in this event. Only when the cause of the increased VOC concentration has been fully investigated and conditions rectified and made safe should the system be brought back into operation.

Due to their thermal inertia many oxidisers do not respond well to sudden changes in flows and compositions. The oxidiser should, therefore, be operated as far as possible under steady-state conditions. It should, however, be noted that flows and compositions can change rapidly, especially when vessels or processes are brought on line. Rapid changes in waste stream composition can lead to control system cycling or instability with consequent explosion hazard.

There are several codes and guidelines which are relevant to thermal oxidiser safety e.g. Refs 6, 7, 8, 9, 10, 11, 12, 13. Refs 27, 32 may also be useful. References 35, 37, 38 discuss the safety of vent collection and destruction systems.

FUEL TRAIN & THERMAL OXIDATION PROCESS CONTROLS

The thermal oxidiser fuel train and controls must be designed and constructed to recognised standards in terms of safety e.g. IM30 (Ref.7) and EN 954-1 (Ref. 15). Other codes such as NFPA 69 (Ref.26) also contain detailed recommendations which may be used by non-UK manufacturers. Most modern thermal oxidisers incorporate PLC control systems (known as Programmable Electronic Systems or PES) to control operation. Where necessary, hard-wired emergency shutdown systems should also be incorporated. Where such PES are used they should conform to the recommendations in Refs. 22, 23 and 24. Further guidance covering electrical equipment can be found in Refs 19, 20, 21.

EXPLOSION RELIEF & PROTECTION

It is possible to construct the oxidiser to withstand an explosion however this may be excessively expensive for larger units and hence is not usually the preferred method of protection.

Many thermal oxidisers are not fitted with explosion relief but rely instead on high integrity control and safety systems to reduce the risk of an explosion occurring to an acceptably low frequency. Some designs cannot be fitted with explosion relief for mechanical reasons. Often, this is due to the difficulty of maintaining a gas-tight seal on the explosion relief vent panel under the high temperatures within the unit. Explosion vents, where fitted, should be located such that they discharge to a safe location. Explosion relief should be considered for all thermal oxidisers if practicable. Guidance for the provision of explosion relief may be found in HS(G) 16 (Ref.32) and NFPA 68 (Ref.25). Further information is available concerning explosion relief in references 7, 31 and 32 with further information in Refs 17, 18.

VENT COLLECTION SYSTEM SAFETY

The consequences of an explosion in the vent collection system may include:

- Damage to, or destruction of the vent header
- Domino effects on adjacent plant and systems
- Injury / fatality to personnel

Many vent headers are relatively long and pass through areas where personnel or vulnerable plant are located thus giving a high risk of injury or domino effects in the event of a failure. Additional protection is, therefore, usually required such as:

- Flame Arresters
- Explosion Relief
- Explosion Suppression
- Fire Extinguishing system

EXPLOSION PROTECTION OF VENT HEADERS

Acceptable VOC concentrations in headers are discussed above. Even so, it is foreseeable for the VOC concentration to rise to dangerous level under upset or abnormal process conditions. It is at this time that the plant and its associated ductwork is most vulnerable to fire and explosion hazards with a high risk of ignition from the thermal oxidiser.

The most common form of secondary protection used is a flame arrester which should be placed in a position appropriate to the design. There are several designs of flame arrester available including flat plate, crimped metal and hydraulic. It is essential that the correct type and specification is used for any particular duty.

It should be noted that flame arresters are not 100% effective. Typical problems are:

- Blockage with particulates
- Polymerisation on arrester elements
- Burn back
- Overheating

Flame arresters are a complex subject and cannot be covered in detail within the scope of this paper but are covered in Refs 30, 31. Explosion relief is described in Ref 43. Tests of explosions in pipelines are discussed in Ref 44, 45.

VOC AND OXYGEN CONCENTRATION ANALYSERS

A total unburnt hydrocarbon (VOC) analyser should be provided where necessary as identified by the risk assessment. The analyser should be of a suitable design and provide continuous solvent vapour and VOC concentration monitoring. Analysers should meet the requirements set in Ref. 29.

A maximum safe concentration should be set for the system below the 50% LEL limit which should trigger a high alarm with a high level trip set above the alarm but below 50% LEL.

The monitor should initiate the shutdown and emergency diversion systems for the oxidiser. Shutdown valves and dampers should be of a fast-acting type since concentration can change very rapidly as a result of process deviations. An oxygen analyser should be used to establish that the oxygen concentration is less than 1% v/v and thus avert any possibility of forming an explosive atmosphere.

LEGAL REQUIREMENTS

There are several general legal requirements which cover the safety of the workplace and equipment e.g. Refs. 1, 2, 3, 4, 5. In particular the following are important:

- Health & Safety at Work Act 1974
- The Highly Flammable Liquids and Liquefied Petroleum Regulations 1972
- The Management of Health and Safety at Work Regulations 1992
- The Provision and Use of Work Equipment Regulations 1992

CASE HISTORIES

Over the years HSE has investigated a number of fire and explosion incidents involving thermal oxidiser plants. A few of these are given below.

CASE 1

A fire and explosion incident occurred at a chemical plant manufacturing and processing acrylic resin. Substantial damage was caused to the plant including the ethyl acrylate dump tank.

The company had installed a catalytic thermal oxidiser for the abatement of ethyl acrylate vapours (flash point 16°C) released in the process as waste. The temperature of the thermal oxidiser's catalyst outlet is temperature was between 350°C to 500°C. High temperature should have prompted an alarm and shutdown condition. The incident caused the temperature to rise to 640°C. A flame arrester, provided to prevent fire from propagating upstream, failed because it was not designed for flowing gas. No solvent vapour analyser was fitted..

Recommendations Included installation of VOC concentration monitoring, re-evaluation of the capacity of the thermal oxidiser against maximum VOC flows and regular inspection of flame arresters. Modifications to pipework connections were also required.

CASE 2

Two consecutive fire / explosion incidents occurred at a company engaged in recovering and cleaning oils for reuse in industry and the automotive trade. The first of the two incidents occurred inside the thermal oxidiser and the second occurred inside a room upstream where oil fumes were being generated by a process. Oil fumes were oxidised in a recuperative natural gas fired thermal oxidiser.

The oil fume feed was bifurcated. One line took fumes into the combustion chamber and the other was diverted to the base of the thermal oxidiser's exhaust stack in emergencies. The former of the two inlets was fitted with a flame arrester but the latter was not. It was this which caused the explosion to propagate back through the thermal oxidiser involving the upstream oil processing room. A number of other irregularities were noted and these included:

- Little or no knowledge of the hazards associated with the thermal oxidiser
- Absence of adequate temperature control in the oil processing room / storage
- Incorrect thermal oxidiser design

Recommendations included: reassessment of the design of the thermal oxidiser to meet process fluctuations and demands, provision of explosion relief to the thermal oxidiser and installation of effective monitoring and control of process oil storage temperatures etc.

CASE 3
A series of fires / explosions occurred, involving a large (approx. 21m x 5m x 9m high) three bed regenerative thermal oxidiser and its associated upstream duct, at a factory manufacturing aluminium cans for the soft drinks industry. The company had installed the oxidiser to abate hydrocarbon based solvent vapours generated during the curing of resin that had been applied to the aluminium sheets in preparation for the manufacture of cans.

There was a gas detection system with detectors at selected parts of the ductwork. The system had been set to alarm at 20% LEL with an arrangement to bypass to atmosphere via vent just upstream from the thermal oxidiser. The system was also arranged to afford an alarm and to shut down the curing ovens at 40% LEL.
The investigation revealed that a small fire occurred inside the feed duct leading to the thermal oxidiser and this caused other residual resinous waste that had settled inside the duct to vaporise and produce a dangerous concentration of VOCs. When this was introduced into the thermal oxidiser it caused an explosion. The duct had been provided with a water sprinkler system to quench fires. Explosion relief had been fitted to the inlet manifold connecting the duct to the thermal oxidiser and this worked but was inadequate to cope with the explosion pressure generated within the system.

Recommendations included: reduction of waste accumulation inside ducts, use of less volatile compounds in the process, provision of temperature activated sprinkler system.

CASE 4
An explosion occurred in a propane/air fired thermal oxidiser provided for the abatement of an effluent stream containing hydrogen, ammonia and pyridine. The oxidiser had an internal wet scrubber in its base. No definite cause of the explosion was established but it was postulated that blockages in the perforated plate on which the ceramic bed rested inside the thermal oxidiser may have caused sudden release of waste stream into the combustion chamber of the thermal oxidiser. It was also established that the company, following an initial HAZOP Study, had made a number of modifications to the thermal oxidiser system and the associated plant upstream without carrying through the implications to the rest of the system.

Recommendations included: a fresh HAZOP study on the whole system and measures to prevent blockages.

SUMMARY
Thermal oxidisers and vent collection systems can pose a significant fire and explosion hazard if not properly designed, operated and managed. This paper has highlighted some of the hazards and their potential solutions. A list of useful references is provided where valuable information on the applicable legislation, safety and design of thermal oxidisers and vent collection systems can be found. The latest standard EN 12753:1999 (Ref.28) provides valuable advice on these matters.

REFERENCES
1. Guide to the Health and Safety at Work etc. Act 1974. Guidance Booklet (L1) HSE 1990; ISBN 0 11 88555 7

2. Management of Health and Safety at Work Regulations 1992. Approved Code of Practice (L21) HSE 1992, ISBN 0 11 886330 4
3. Workplace (Health and Safety and Welfare Regulations) 1992 (L24) HSE Approved Code of Practice, ISBN 0 11 886333 9
4. Supply of Machinery (Safety) Regulations 1992, SI 1992/3073 HMSO 1992, ISBN 0110257197
5. Provision and Use of Work Equipment Regulations 1992, Guidance on Regulations (L22) HSE 1992, ISBN 0 11 886332 0
6. Industrial Thermoprocessing equipment EN 746
7. The use of gas in Industrial process plant, British Gas Code of Practice IM 30 1993
8. The Gas Safety Regulations 1972, SI 1972/1178 HMSO, ISBN 0 11 0211782
9. Automatic Gas Burners BS 5885 Parts 1 & 2
10. Automatic flue dampers for use with gas fired heating and water heating appliances British Gas Code of Practice IM 19 1983
11. Standards of training in safe gas installations, Approved Code of Practice (COP 20) HSE 1987, ISBN 0 11 883966 7
12. EN 746-1, Industrial Thermoprocessing equipment - Part 1: Common safety requirements for industrial Thermoprocessing equipment
13. EN 746-2, Industrial Thermoprocessing equipment - Part 2: Safety requirements for combustion and fuel handling systems
14. BS EN 292, Part 1 & 2, Safety of Machinery, basic concepts, general principles for design
15. EN 954-1, Safety of machinery - Safety related parts of control systems - Part 1: General principles and design
16. EN 1050 - Principles of Risk Assessment
17. EN 1127-1 (1998): Explosive atmospheres - Explosion Prevention and Protection - Part 1: Basic concepts and methodology
18. prEN 13478 : Safety of machinery - Fire prevention and Protection
19. prEN 50154 : Electrical Installations in potentially explosive atmospheres (other than mines)
20. EN 60079-10 : Electrical apparatus for explosive gas atmospheres - Part 10: Classification of hazardous areas
21. EN 60529-1 : Safety of machinery - Electrical equipment of machines - Part 1 : General Requirements
22. Programmable Electronic Systems (PES) in safety-related applications: Part 2 General technical guidelines HSE 1987, ISBN 883906 3
23. Use of Programmable Electronic Systems (PES) in safety-related applications in the gas industry IGE/SR/15, Institute of Gas Engineers, 1989, ISBN 1367 7850
24. ICE 61508-1 Functional safety of electrical/electronic/programmable electronic safety - related systems - Part 1 : General Requirements
25. NFPA 68 'Guide for Venting of Deflagrations 1998 Edition
26. NFPA 69 ' Standards on Explosion Prevention Systems 1997 Edition
27. HSC Publication: Safe operations of Ceramic Kilns, ISBN 0 7176 0630 9
28. prEN 12753:1999 (final draft) - 'Thermal Cleaning Systems for exhaust gas from surface treatment equipment Safety requirements
29. EN 1539: 2000 - 'Dryers and Ovens, in flammable substances are released - Safety requirements'
30. HS(G) 158, Flame Arresters - (Preventing the spread of fires and explosions in equipment that contains flammable gases and vapours, ISBN 0-7176-1191-4
31. HS(G)11 'Flame Arrestors and Explosion Reliefs'; HSE Publications

32. HS(G)16 “Evaporating and Other Ovens”; HSE Publications
33. HSE 5 Steps to Risk assessment IND(G) 163 L (also available in priced packs ISBN 0 11 025849 5)
34. Environmental Protection Act 1990 (EPA 90), HMSO Publications
35. Nichols FP; Design of Vent Collection and Destruction Systems; 2nd Int Symp Runaway Reactions, 11-13 March 1998, New Orleans, pp655-676
36. Ready DF, Schwab RF; Incinerator problems and how to prevent them; 14th Loss Prev Symp; Vol 14, pp66-72, 1981
37. Leite OC; Operating thermal incinerators safely; Chem Eng; June 98, pp131-136
38. Clark DG, Sylvester RW; Ensure Process Vent Collection System Safety; CEP; pp65-77, Jan 96
39. Thomas I, a)Coode Island- vapour recovery to blame? b) Blast rocks chemical store c)Coode riposte; TCE; 31 Oct pp17-18; 12 Sept pp14, 12 Dec; pp5 1991
40. Fishwick A; Three flare stack incidents; Loss Prev Bull No.142, 1998
41. Desai VM; Flare deflagration incident at Rohm & Haas; Process Safety Prog; Vol.15, No.3, pp166-167, 1996
42. Anon; Incinerator overheats; Loss Prev Bull; No.130, p7 1996
43. Senecal JA, Garzia HW; Explosion protection of pipe systems conveying dusts or flammable gases; Process Safety Prog; Vol.16, No.1, Spring 97, pp50-53
44. Henderson E; Combustible gas mixtures in pipe lines; Proc Pacific Coast Gas Association; Vol.32, pp98-111, 1941
45. Rogowski ZW, Rasbash DJ; Relief of explosions in propane-air mixtures moving in a straight unobstructed duct; 2nd Symp Chem Proc Haz (Hazards II), Manchester 2-4 April 1963, pp21-28
46. AIChE; Reducing and controlling volatile organic compounds; Center for Waste Reduction Technologies, AIChE
47. Hunt PJ; VOC abatement & vent collection systems; Hazards XIV “Cost Effective Safety”

FIGURES

Figure 1: Simple Vertical Thermal Oxidiser

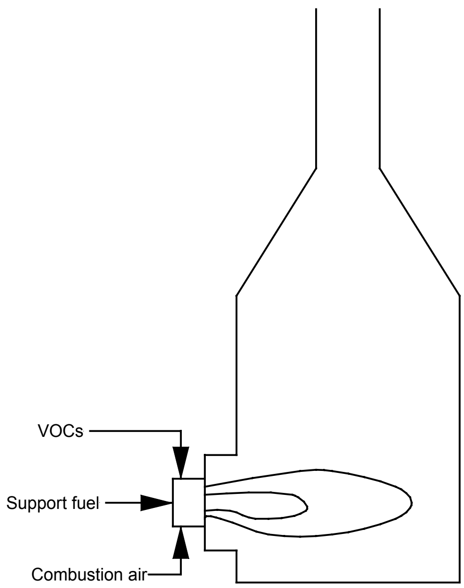

Figure 2: Thermal Oxidiser with Staged Air Injection

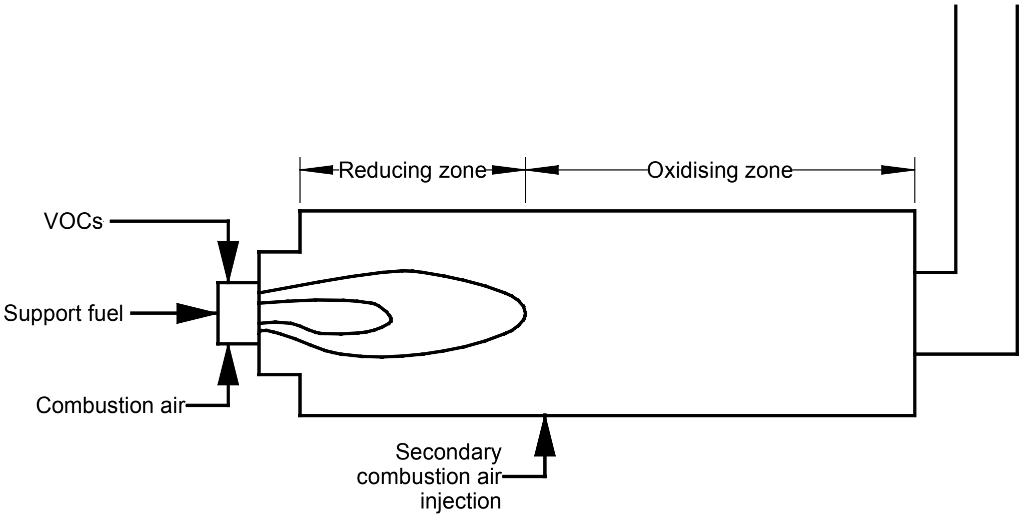

Figure 3: Flameless Thermal Oxidiser

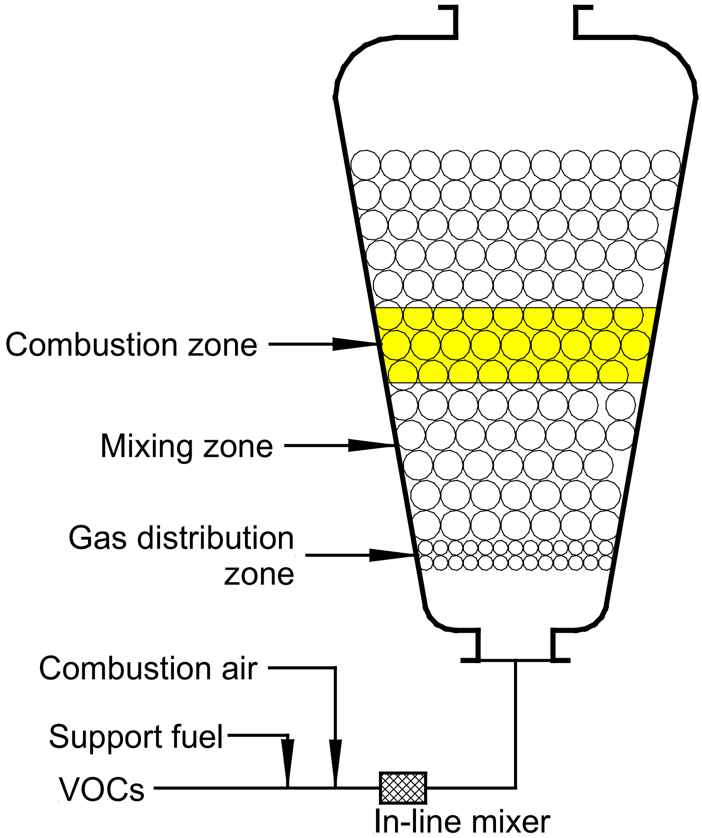

Figure 4: Regenerative Catalytic Oxidiser

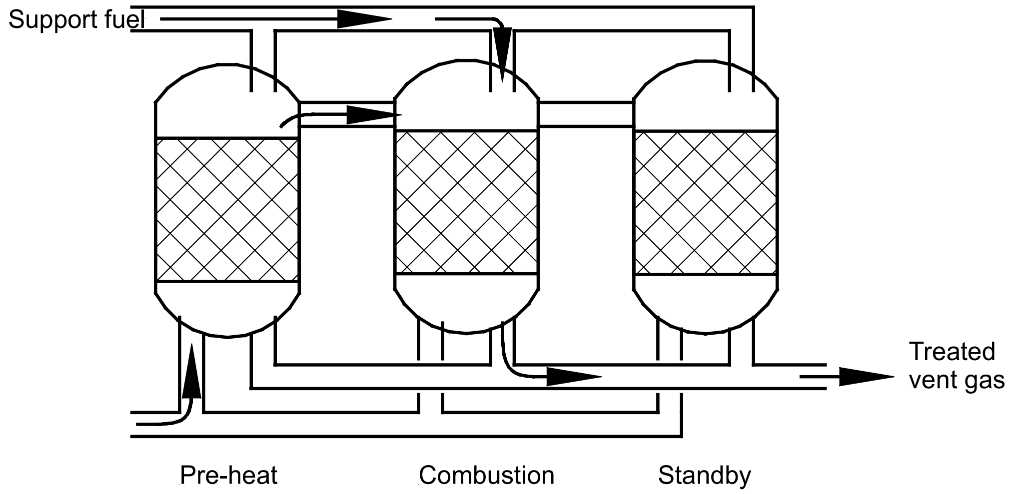

Figure 5: Recuperative Catalytic Oxidiser