



**THE SAFE USE OF THERMAL OXIDISER (INCINERATION)
SYSTEMS FOR POTENTIALLY FLAMMABLE MIXTURES**

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INTRODUCTION

The manufacture of many articles includes the application of a coating such as ink, paint, varnish or enamel to their surface. This coating often contains a large amount of solvent which usually has to be evaporated off to leave the print or decorative surface behind. The solvents used in these operations and the reactants and products in many chemical processes are frequently volatile organic compounds (VOCs). These materials are known to cause unwanted air pollution where their release is not properly controlled.

Increasing public awareness and pressure over recent years has led to the introduction of many pieces of UK legislation, including the Environmental Pollution Act (EPA) 1990¹, aimed at reducing the pollution caused by industrial processes. Many process and manufacturing industries have installed thermal oxidiser systems (incinerators) to remove VOCs and other polluting substances from their gaseous waste streams before discharging them into the atmosphere.

A thermal oxidiser system is an assembly of linked fans, heat exchangers and burners that remove pollutants from gaseous process waste streams by burning or oxidising them. In recent years there have been a number of serious fires and explosions involving them. These have often resulted from a failure to appreciate the hazards or effectively manage the risks associated with the use of this technology on potentially flammable mixtures.

This guidance should assist operators to identify and control the fire and explosion hazards associated of thermal oxidisers (incinerators). It should also help employers and designers to appreciate and comply with the Dangerous Substances and Explosive Atmospheres Regulations 2002, (DSEAR), and other relevant safety legislation.^{2,9}

BACKGROUND

Many manufacturing processes generate of gaseous waste streams containing hydrocarbons, halogenated hydrocarbons, other volatile organic compounds (VOCs) or gases. These substances are often used when a coating is applied to the surface of paper, metal or ceramics. There is now a duty on the operators of such processes to minimise the amount of pollutants released from their factories and thermal oxidisers are frequently used to reduce VOC and gaseous emissions.

A European Standard - EN 12753:1999; “**Thermal cleaning systems for exhaust gas from surface treatment equipment Safety requirements**”, will soon be published. This is a type C standard, as stated in EN 1070, giving detailed safety requirements for a particular machine or group of machines, in this case thermal oxidisers.

The scope of EN 12753 is limited to a consideration of the fire and explosion hazards in thermal cleaning systems and this HSE Guidance booklet provides practical help in understanding and controlling these hazards and the requirements of EN 12753:1999. The requirements necessary to address the other hazards that may be associated with thermal oxidisers are covered in European Standards EN 292-1 and EN 746-2.

Experience has repeatedly demonstrated how important it is that operators have a good understanding of the hazards of their plant. This knowledge is particularly helpful in appreciating how changes to approved acceptable procedures can greatly increase the risk from fire and explosion. Serious incidents continue to occur in appropriately designed equipment due to poor installation, inadequate maintenance or from a failure to fully understand the hazards or to **properly consider the effect of changes to the process or plant upstream or downstream of the thermal oxidiser.**

SCOPE

This booklet covers only the fire and explosion hazards arising when thermal oxidisers are used to destroy volatile flammable substances. Although the guidance is particularly appropriate where the flammable emissions arise from surface treatment equipment, the principles described should be regarded as general examples of good practice for the operation of thermal oxidisers.

Typical examples of upstream equipment whose polluted waste gas streams may be fed to a thermal oxidiser system for cleaning may include:

- Dryers
- Printing machines ³
- Coating equipment
- Press roller washing equipment
- Chemical reactors, storage tanks etc.

The scope of this guidance does **not** include other abatement systems or equipment associated with the destruction of domestic, communal, agricultural or hospital waste.

THERMAL OXIDATION (INCINERATION)

A thermal oxidiser is an item of plant that removes pollutants from a waste gas stream by burning the pollutants in a controlled manner. Consequently, another name for a thermal oxidiser is an incinerator. Typical pollutants that can be treated by thermal oxidisers are hydrocarbons, other solvents and waste gases; often collectively known as VOCs.

The treatment carried out by the thermal oxidiser is simply a controlled form of burning (combustion). The polluted gaseous waste stream requiring treatment is preheated and then fed into the process space (combustion chamber) of the plant. Here there is a powerful naked flame running on the supplementary fuel, usually natural gas or fuel oil, which incinerates the pollutants in the gas stream.

Burning or incineration involves the chemical process of oxidation. The incineration of pollutants in a thermal oxidiser usually requires high temperatures in the presence of excess oxygen (air) to achieve complete oxidation. When hydrocarbon

VOC pollutants are completely oxidised the only products formed are carbon dioxide and water.

A thermal oxidiser is designed to burn, as completely as possible, all the combustible components within the gaseous waste stream being treated. For this to be effective the pollutants in the waste stream need be intimately and uniformly mixed with oxygen/air at a sufficiently high temperature and for a sufficient length of time. Effective distribution is difficult to achieve and additional air is often added to the combustion chamber to ensure that complete combustion of the pollutants takes place.

In some thermal oxidisers the oxidation process takes place on the surface of a catalyst rather than in a flame. These catalysts are often expensive and their effectiveness may be adversely affected by contaminants in the waste stream such as sulphur or nitrogen compounds or heavy metals.

Combustion efficiency

The **combustion efficiency** of the process is the extent to which pollutants are removed from the waste stream by the thermal oxidiser. The higher it is the more effective the removal of pollutants has been. High combustion efficiency predominantly depends on effectively controlling three main process variables; the “Three Ts” of efficient thermal oxidation:

Temperature

The minimum temperature necessary to achieve effective combustion depends on the nature of the VOCs requiring treatment. To ensure that complete oxidation takes place the operating temperature of the thermal oxidiser is usually controlled at 200°C to 400°C above the auto-ignition temperature of the most stable pollutant present in the waste stream.

Residence Time

The minimum time that each pollutant molecule must remain within the combustion zone at the selected operating temperature to ensure complete combustion varies for different pollutants. Some VOCs are quickly destroyed whereas others require a much longer residence time in the furnace before combustion is complete.

Turbulence

Turbulence within the combustion chamber is necessary to ensure good mixing and effective heat transfer between the pollutants, oxygen and the hot combustion products. Baffles are often incorporated into the combustion chamber in order to ensure that a suitably high level of turbulence is achieved.

Types of Thermal Oxidiser

Recuperative and Regenerative are the most common types of thermal oxidiser. A catalytic version of each of these types is also available; see [Appendix 1, Fig 4](#). Until recently, the recuperative type system was probably been the most frequently used form but now the regenerative system is becoming more popular.

Recuperative

The recuperative system constantly recovers (recoups) a significant proportion of the thermal energy present in the hot gases leaving the thermal oxidiser furnace; see [Appendix 1, Fig 2](#). This heat energy, which would otherwise be lost with the exhaust stream, is captured by a heat exchanger and is usually used to preheat the incoming polluted gas stream. The technique is costly to engineers but may result in a significant reduction in the use of supplementary fuel.

Recuperative thermal oxidisers can either be forced or induced draft systems. In the former type the system incorporates a fan that forces the process waste stream through a heat exchanger, whereas in the latter case the waste stream requiring combustion is drawn into the combustion chamber.

Regenerative

This type of thermal oxidiser is used when the expense and complexity of flexible heat recovery cannot be justified due to either a low external heat demand or the low calorific value of the polluted gas stream. The regenerative type of plant is ideally suited for processes with an inlet waste solvent stream that has a high volume but a low concentration of VOCs.

The arrangement of a typical regenerative thermal oxidiser is shown in [Appendix 1, Fig 3](#). The system frequently consists of 2 towers containing ceramic packing. The towers are used sequentially to capture and store heat from the hot exhaust gases and then to preheat the polluted gas stream.

FIRE & EXPLOSION HAZARDS

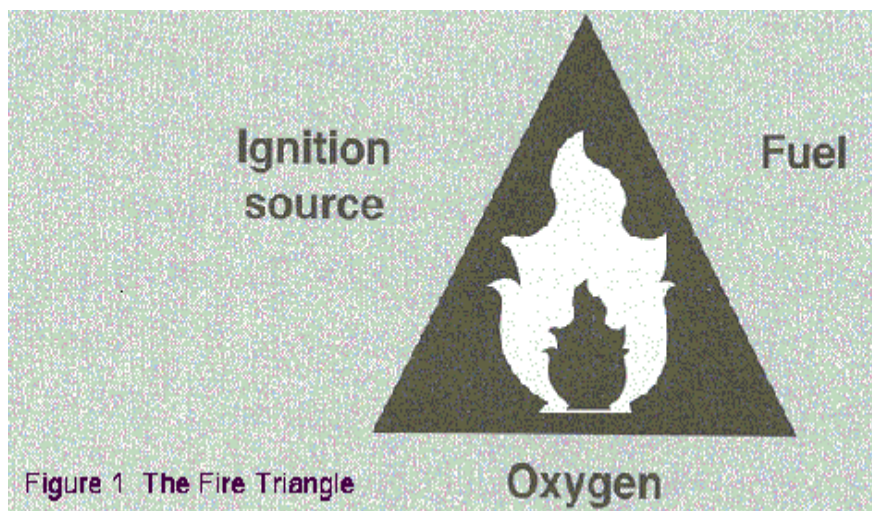
Risks to safety are created when flammable mixtures and ignition sources are not kept apart. These hazards can occur within the thermal oxidiser and in the upstream or down stream equipment. It should be a fundamental principle of the appropriate design and operation of thermal oxidiser systems that these hazards are not allowed to be present together inappropriately.

The thermal oxidiser and the upstream/downstream plants and processes should be considered as an integrated system when assessing the risks from fire and explosion hazards, not the thermal oxidiser in isolation.

A thermal oxidiser system can be loosely divided into four main areas where risks from fire and explosion hazards are foreseeable and where appropriate measures should be employed to reduce those risks to acceptable levels. Typically, these areas include:

- Upstream plant; presses, dryers, coating plants, washing units
- Vent lines, pipe work, ducts, emergency bypass arrangements
- Thermal oxidiser
- Downstream plant e.g. heat exchanges

The fire triangle (Fig. 1) provides a useful starting point when considering fire and explosion hazards.⁴ In order for burning (**combustion**) to occur the fire triangle must be complete; fuel and oxygen or an oxidising agent must be present in the correct amounts together with an effective ignition source. If any one of these conditions is missing or removed then a fire will not start or it will go out.



The safe operation of thermal oxidiser plant relies heavily on preventing the requirements for combustion; fuel, oxygen and ignition source, from occurring together at inappropriate times or places within the equipment. A sound understanding of the principles of combustion is important when assessing the risks from the operation of thermal oxidisers and associated plant. The important features of the three essentials necessary for fire and the different forms that it can take are discussed below.

Fuel

Many substances can be made to catch fire, some more easily than others. The easier it is to set a substance alight the more **flammable** it is.

Temperature has a great effect on how easily substances, especially liquids, catch fire. This is because it is usually the vapour above the liquid that ignites first and carries the flame to the liquid. The warmer the liquid, the more vapour is given off at the surface and the more likely the vapour is to catch fire.

If a source of ignition is held close to the surface of a flammable liquid that is being heated, a temperature will be reached at which the vapour being given off catches fire. The lowest temperature at which this occurs, when a combustible mixture forms near the surface of the liquid, is called the liquid's **flashpoint**. When a liquid is at a temperature above its flashpoint it will give off a flammable vapour that will readily ignite. Flammable mixtures can also be formed when combustible dusts or a mist or spray of fine droplets of high flashpoint liquids are mixed with air.

Substances with a flashpoint below 55 °C are classified as flammable under The Chemicals (Hazard Information and Packaging for Supply) Regulations 2002.⁵ These materials are also called **dangerous substances** under The Dangerous Substances and Explosive Atmospheres Regulations 2002².

Substances with a flashpoint below 21 °C are more hazardous and are classified as **highly flammable**. A liquid with a flashpoint greater than the ambient temperature is less likely to give off flammable concentrations of vapour when released or spilled than one with a flashpoint lower than the ambient temperature.

Not all possible mixtures of a flammable substance with air will ignite or explode. The range of concentrations in air that will ignite and burn varies greatly between different flammable substances. Some have very narrow ranges while others have a wide range of concentrations that will ignite. The lowest concentration of a substance in air that will ignite is called the lower explosion limit (LEL); the highest concentration is the upper explosion limit (UEL).

Mixtures with concentrations below the LEL or above the UEL will not ignite and support (propagate) a flame. This principle is frequently used as the basis for the design and safe operation of thermal oxidiser plant. The manner in which this principle may be used to ensure safe operation is described later.

Temperature dependency of the lower explosion limit (LEL)

The lower explosion limit (LEL) of a flammable substance varies significantly with temperature. In most cases, as the temperature of the mixture increases, the lower explosion limit reduces.⁶ In other words, at higher temperatures a lower concentration of the flammable substance in air can cause an explosion.

This effect is particularly important in the design of thermal oxidiser systems as the polluted air stream is often at a temperature significantly higher than ambient. The contaminated air stream may be subject to considerable preheating before being fed into the combustion chamber of the thermal oxidiser. It is important to remember that the LEL quoted in material safety data sheets (MSDSs) was usually determined at 20 °C. The LEL at the operating temperature of the plant will usually be much lower than this value.

Ignition sources

A thermal oxidiser usually uses a flame to destroy pollutants and so an ignition source is always likely to be present. A number of other potential ignition sources may also be present in the pipework and ductwork upstream of the thermal oxidiser and the risks that these may present should be fully considered. The more important of these are listed below and a more detailed discussion and additional guidance on controlling the risks associated with ignition sources can be found in HSG140.⁴

- Electrostatic sparks
- Hot work
- Electrical equipment
- Hot surfaces
- Mechanical friction
- Auto-ignition

- Thermal decomposition
- Chemical reaction

Oxygen or oxidising agents

Oxygen or an oxidising agent is the third essential part of the fire triangle. It is the chemical reaction between the fuel and oxygen, usually from the air, which produces the heat and the flames that we associate with fire. If there is too little oxygen present then a fire or an explosion will not occur. The minimum amount of oxygen necessary to enable combustion of a particular fuel to take place is called the **minimum oxygen concentration**.

Oxygen from the air is by far the most common oxidising agent involved in fires and explosions. Other substances, however, including chlorine, ozone, the oxides of nitrogen and oxygen-rich salts such as nitrates, peroxides and chlorates etc can also promote fire and explosion. If other oxidising agents are likely to be present or produced in the upstream processes then the risks associated with their presence should be adequately assessed.

Deflagration and Detonation

The combustion of a fuel/air mixture in a confined space is very different to the process that takes place when fuel burns in the open air. When a flammable mixture contained within a duct or vessel is ignited, combustion takes place rapidly and the pressure rises sharply; an explosion has occurred.

Explosions can be divided into two main categories, **deflagrations** and **detonations**, according to their properties. The more common of these is **deflagrations**. A **deflagration** is defined as a flame, a **combustion wave**, moving into the unburned gas at a velocity less than the speed of sound.⁷

Deflagrations often result from the ignition of a flammable mixture in a duct or pipework. Pressures up to 10 times greater than the initial pressure in the system may be generated by deflagrations. The flame front may move through the system with a velocity between 10 - 300 metres per second.

Detonations are rarely experienced in everyday life. A detonation is defined as a combustion wave propagating at supersonic velocity (as measured at the flame front), which propagates by shock compression heating⁷.

Deflagration to Detonation Transition

Most explosions in ducts or pipework systems start as deflagrations and remain as such. In some cases, however, the deflagration develops into a detonation. This is known as **deflagration to detonation transition**. It results from the acceleration of the flame front as it travels through the flammable mixture in the confined space. If the rate of acceleration is sufficient for the velocity of the flame front to become supersonic then the deflagration will become a detonation. In appropriate situations the use of a suitable flame arrester can prevent the transition to detonation.⁷

The more congested the space or the higher the number of bends in the duct, the greater the turbulence and the faster the flame will accelerate. The acceleration of the flame front during deflagration to detonation transition can produce peak pressures, **overdriven detonation pressure**, in the system that are up to 100 times greater than the starting pressure.

The pressures resulting from deflagration to detonation transition (DDT) cannot easily be estimated. They are dependent on many factors such as pipe layout, surface roughness etc. The pressures are, however, only very short-lived pulses, applying momentary stress on the walls and so may not always lead to the failure of the vessel or pipe.⁸

Once the **deflagration to detonation transition** has occurred the detonation is likely to stabilise and sustained pressures of 20 – 50 bar can be expected from flammable mixtures that were originally at atmospheric pressure. Events of this type are likely to have devastating effects on unprotected systems.

The consequences of a detonation occurring in a system should be considered very carefully with particular emphasis paid to possible injury or plant damage from missiles. Domino effects by missile impact into other pieces of plant and equipment, e.g. tanks holding toxic or flammable materials, should also be taken into account.

SAFETY REQUIREMENTS AND MEASURES

Thermal oxidiser plant should comply with the specific requirements of EN 12753 and the general requirements of the Provision and Use of Workplace Equipment Regulations 1998 (PUWER). Under PUWER employers are required to ensure that work equipment is suitable for purpose, is only used under conditions for which it is suitable and is appropriately maintained⁹.

You should ensure that the full range of operating scenarios that may arise are identified and process information gathered on them. Scenarios that you should consider may include:

- Start-up from cold
- Re-start after trip
- Routine shut-down
- Emergency shut-down
- Stand-by
- Normal operation
- Low rate operation
- VOC/fuel excess
- Air/oxygen/oxidant excess or generation

- Maintenance
- Purging

Other significant and foreseeable events that could produce a hazard should also be identified. A structured Hazard and Operability Study (HAZOP) may be an appropriate approach by which to detail the full envelope of operating conditions of the system. Those scenarios that would arise through the failure of trips or controls should be included in the study. An in-depth knowledge of the plant and its associated control systems and safety trips will be required to identify and assess all the foreseeable scenarios.

A team of experienced personnel should be used for this task rather than a single individual. The maintenance of records on the system, however, should be the responsibility of a named individual. An important outcome of this work is to identify any differences in the way in which the system performs under the different operating scenarios and to appreciate if these lead to changes in the flow rate or composition of the waste gas stream entering the thermal oxidiser.

Effective control over the concentration of the flammable mixtures being fed into thermal oxidiser plant is an essential requirement for safe operation. This is of paramount importance because a source of ignition is usually present in a thermal oxidiser due to the manner in which this type of plant operates.

Limitation of the inlet concentration of flammable substances

As discussed earlier, only when the concentration of flammable substances in air is within the flammable range will a mixture explode when presented with an ignition source. This principle should form the basis of safety for thermal oxidiser plant.

Mixtures with concentrations above or below the flammable range will not ignite and so in theory either of these situations could form the basis for safe operation. Reliance on maintaining a fuel-rich (above the UEL) mixture involves a much greater degree of risk than does fuel-lean (below LEL) operation. Any increase in the amount of air or reduction in the amount of flammable substance entering a fuel-rich system would be likely to reduce the concentration of flammable substances and bring the mixture into the flammable region. There would then be a high probability of an explosion occurring. Consequently, fuel-rich operation would not normally be considered to be an acceptable basis of safety for thermal oxidiser plant.

The design and operation of the thermal oxidiser and the associated plant, such as dryers, printing equipment etc., should be such that the concentration of flammable substances in the thermal oxidiser system always remains well below the lower explosion limit. It is particularly important that the design and operation of systems with more than one source of flammable substance is appropriate to ensure that this is always the case.

The equipment and operating arrangements in place should be designed to take into account the hazards that may arise from all foreseeable operating conditions. All intermittent operations that may cause an increase in the quantity of solvents entering the system, such as blanket washing procedures, should be identified.

These operations should be effectively controlled to prevent the formation of flammable concentrations of dangerous substances.

In the majority of thermal oxidisers the temperature of the polluted air stream is increased before it enters the combustion chamber. During this preheating some of the flammable pollutants may begin to react with the oxygen in the air and may lower the concentration of the flammable substances entering the combustion chamber. A guide to the temperature at which prereactions become significant can often be gained from the substance's auto-ignition temperature. The lower the temperature at which prereactions begin and the greater the extent to which they proceed, the more the concentration of the flammable pollutant is reduced.

Aromatic hydrocarbons, such as toluene and xylene, have high auto-ignition temperatures and their concentration is reduced by prereactions to a much lesser extent compared to non-aromatic hydrocarbons such as hexane. This difference in the onset temperature and the extent of prereactions for aromatic substances is the basis for the different maximum admissible concentrations quoted in [Table 1](#). A wider margin of safety is needed when significant concentrations of aromatic hydrocarbons are present.

The reduction in concentration of flammable substances as a result of prereactions has to be considered alongside the general reduction in LEL that occurs at higher temperatures. The nett effect of these two opposing effects depends on the structure of the flammable substance and the temperature involved.

The concentration of flammable substances shown in [Table 1](#) and summarized below are the **maximum admissible concentration of flammable substances** that should be present at the inlet of the thermal oxidiser system. These experimentally established values take account of the reduction in the concentration of flammables and the lowering of their LEL as a result of preheating and also provide a suitable margin of safety.

Table 1. Maximum admissible concentration of flammable substances

Maximum preheat temperature	Concentration of aromatic hydrocarbons in waste stream	Maximum acceptable concentration of flammables	Measurement temperature for LEL
°C	% w/w total flammables	% LEL	°C
Independent	<25	25	20
Independent	>25	20	20
450	independent	50%	Maximum temp & pressure in the heat exchanger

Where the mass of aromatic hydrocarbons, such as toluene or xylene, is less than 25% w/w of the total concentration of flammable substances at the inlet to the thermal oxidiser system, then the maximum concentration of those flammable substances should be 25% LEL (at 20°C and 1 atmospheric pressure). This limit is irrespective of the preheating temperature.

or

Where the mass of aromatic hydrocarbon is greater than 25% w/w of the total concentration of flammable substances at the inlet to the thermal oxidiser system, then the maximum concentration of those flammable substances should be 20% LEL (at 20°C and 1 atmospheric pressure). This limit is irrespective of the preheating temperature.

or

In systems where the maximum surface temperature of the heat exchanger used to preheat the gas stream does not exceed 450 °C, the maximum concentration of flammable substances at the inlet to the thermal oxidiser system should be 50% of the LEL appropriate for the maximum temperature and pressure on the polluted gas stream side of the heat exchanger. This limit is Independent of the aromatic hydrocarbon content of the gas stream requiring treatment.

You should not operate a thermal oxidiser outside the conditions summarized in [Table 1](#) unless there is documented and well-established scientific or experimental data to show that this is safe **and** the following have also been completed:

- A suitable and sufficient assessment of the risks associated with use etc. of the thermal oxidiser, flammable source(s), pipework, ducts and equipment has been carried out and documented in accordance with EN 1050:1997 and the Dangerous Substances and Explosive Atmospheres Regulations 2002.²
- The design, installation and operation of the thermal oxidiser system embody the measures required by the risk assessment described above.
- Appropriate documented operating instructions, maintenance information and training are provided. These should include defined permitted operating conditions, especially the maximum concentration of flammable substances, specific instructions and information to maintain safe operation and actions and responsibilities in the event of an emergency.

Thermal oxidisers often incorporate arrangements to divert the polluted gas stream around the incinerator and directly to the discharge point (stack). This may be necessary during start up or when the vent stream composition approaches the flammable range. The hazards associated with the discharge of untreated potentially flammable mixtures should be fully identified. The risk from fire and explosion should be suitably assessed and appropriate arrangements made to ensure safe operation.

Avoiding hazards from condensates and deposits

Condensation of material and the accumulation of dust etc in the pipework, ductwork and heat exchanger(s) of the thermal oxidiser system can be a significant hazard and should be avoided. The system should be designed and operated so as to ensure that the gas flow and temperatures etc within the system are appropriate to prevent condensation or the formation of deposits.

Condensed flammable material may quickly vaporise when the system warms up leading to a sudden enrichment of the gas stream and the formation of an explosive atmosphere. You should take care to ensure that the temperature of the pipework and ducting is always above the dewpoint of the mixtures likely to be present in the gas stream. This may be very difficult to achieve during start-up or in cold weather and appropriate procedures should be in place to deal with the hazard from any deposits that may occur at these times.

Disturbances in the airflow or physical impacts to the ducts etc. can lead to accumulated dust forming an explosive atmosphere. Deposits of flammable material in the system increase the likelihood and potential consequences of a fire. Due consideration should be given to minimising the length of ducts and to avoiding abrupt changes in their direction and cross-section. This will help to reduce the likelihood of material being deposited in the duct/pipework.

If, in spite of the above, there is still a possibility that deposits may occur then you should make appropriate provisions to ensure that the pipework, ducts and heat exchangers can be inspected and cleaned safely and easily. The system should incorporate a suitable number of inspection and cleaning/draining points and the “fall” in the various parts of the system should be consistent with the location of these.

Following the shutdown of the VOC emitting process the thermal oxidiser system and the relevant ductwork should be drained and purged to ensure that all residual flammable substances are removed before the furnace is shut down. If this is not done then a flammable atmosphere may be produced within the system as the deposits of material evaporate over time.

At least five complete air changes of the pipework/ductwork and the thermal oxidiser plant will usually be required to be drawn through the system to ensure that all residual flammable substances have been removed and incinerated. The airflow through the plant used during the purge should be at least 25% of the maximum flow for the plant. You should take care to ensure that **all** sections of the plant are effectively purged and that no “dead-legs” containing flammable substances remain.

Avoiding hazards from insufficient forced ventilation

A reduction in the flow of air through the system can result in an unacceptable increase in the concentration of flammable material in the gas stream. Ventilation and flow rates within the system may be impaired and a hazardous situation created by the following:

- Insufficient purge before starting the system

- Choked ducts/pipework or fan housings due to deposits or condensate
- Failure of fan speed controls
- Mechanical failure e.g. motor, fan, transmission or drive belts
- Inappropriate adjustment/control of flaps or dampers

You should take the following measures to ensure that insufficient forced ventilation does not lead to concentrations of flammable substances above the admissible level entering the thermal oxidiser system:

- The VOC producing plant is not started up until the thermal oxidiser plant is operating steadily and in accordance with the manufacturer's operating instructions.
- The system has been drained of any accumulated flammable liquids and there are no blockages or obstructions present.
- The concentration of flammable substances in the gas stream entering the combustion chamber is less than 25% of the LEL of the flammable substances present prior to ignition of the thermal oxidiser.
- The design and operation of the system ensures that the forced ventilation continuously and effectively scavenges all parts of the thermal oxidiser and pipework/ducts at all times to avoid inadmissible concentrations of flammable substances.
- Ducts and pipework etc. that are currently not in service are isolated as close as possible to the main header.
- Suitable flow control devices, such as differential pressure gauges and pitot tubes, should be used to ensure an adequate airflow rate exists at all times.
- Where the system incorporates adjustable airflow dampers it should not be possible for these to restrict the airflow to less than the appropriate minimum volume flow.
- Electrically operated dampers should have their controls designed in accordance with category 3 of EN 954-1; Safety of machinery – Safety related parts of control systems – Part 1 General principles for design.
- Where variable speed fans are used to adjust the airflow through the system their controls should be designed in accordance with category 3 of EN 954-1 to ensure that an appropriate minimum volume flow is always maintained.

Avoiding hazards from insufficient oxidation in plants with recirculation

In plants where the treated gas is recycled back into the system upstream of the thermal oxidiser it is particularly important that you ensure there is effective destruction of all pollutants before recycle. This will prevent the return of additional flammable materials into the system upstream of the thermal oxidiser. If effective oxidation of pollutants is not ensured then the concentration of flammable substances in the gas stream may rapidly increase until a flammable mixture is produced. The likelihood of a serious explosion occurring would be high should this situation were allowed to develop.

The design and operation of plants, particularly those with recirculation of cleaned gases, should recognize the need to ensure high combustion efficiency. You should address the following issues to ensure that the pollutants in the gas stream are effectively destroyed:

- The oxygen content within the combustion chamber is always sufficient for complete oxidation to take place.
- The temperature in the combustion chamber is always appropriate for the polluted gas stream that it is treating.
- The combustion chamber includes suitable arrangements such as baffles etc to ensure that the temperature is sufficiently uniform to enable the effective oxidation of all the flammable substances present.
- The residence time of the polluted gases within the combustion chamber is sufficient to ensure the complete oxidation of the flammable substances present at all foreseeable throughput rates.
- In catalytic oxidation systems, suitable arrangements should be made to ensure that catalyst activity is always adequate to ensure effective oxidation of the flammable materials in the gas stream. Regular checks should take place to assess the catalyst for ageing, poisoning and other effects that could result in a loss of oxidation efficiency.
- The temperature of the polluted gas stream entering the catalytic process space is monitored and maintained above the minimum temperature necessary for effective oxidation. The minimum temperature necessary for effective oxidation is dependant on the pollutant and the activity of the catalyst. Suitable arrangements should be made to ensure that the operating temperature is appropriate.
- Appropriate filters are fitted at the inlet to catalytic combustion systems to protect the catalyst. Suitable arrangements should be in place to identify when the filters require cleaning or replacement.

Avoiding hazards from adsorption/absorption of flammable substances

Hazardous conditions may develop if flammable substances adsorb onto the surface of the catalyst or absorb into the refractory lining of a thermal oxidiser plant.

These situations are often the result of operating the plant at a temperature that is too low.

You should not use the thermal oxidiser system, **whilst shutdown**, as a vent for process streams. This is a common example of dangerous bad practice that can produce hazardous conditions. When the system is next started up flammable materials may desorb from the refractory lining or catalyst and produce a flammable atmosphere inside the plant. In these circumstances an explosion is likely to occur.

You may avoid the hazards that result from the adsorption/absorption of flammable substances through the following measures:

- Ensure that the minimum inlet temperature for effective catalytic oxidation is identified and the actual temperature of the polluted gas stream entering the catalytic reactor is monitored and controlled during operation. Arrangements should be in place to prevent the system from being used when the inlet temperature is too low.
- Ensure that the gas being fed through the catalyst is free of flammable substances during the start-up phase. Adequate interlocks with the processes producing the flammable substances should be installed to ensure this.
- Ensure that process waste streams containing dangerous substances are not permitted to enter any type of thermal oxidiser that is not operating, or is below its specified minimum operating temperature.

Avoiding the hazards of additional ignition sources

The destruction of flammable materials in a thermal oxidiser takes place at high temperature and usually involves the use of a flame, a potent ignition source. Provided that the concentration of flammable substances is kept within the limits defined by [Table 1](#) then this arrangement does not represent a hazard. In installations where the thermal oxidiser is integrated into other upstream process plant in which dangerous substances are used or generated a risk assessment should be carried out on the whole system to establish the significance of other ignition hazards.

You should classify all parts of the workplace where a flammable mixture may occur as either hazardous or non-hazardous according to the extent and frequency with which a potentially explosive atmosphere may be present. DSEAR requires you to classify the hazardous areas into hazardous zones.^{2, 10, 11} Only suitable equipment should be used in hazardous areas.

Measures to avoid overheating and fires

You should ensure that the measures identified earlier to prevent condensation and the accumulation of deposits are used to minimise the risk from a fire within the pipework or ducting. The system should also include appropriate fire-resistant thermal insulation in order to reduce the likelihood of condensation, ensure safe operation and conserve fuel.

You should ensure that the heaters and heating system are designed to an appropriate standard. Heating systems involving burners should fulfil the requirements of EN 746-2, for electrical heating systems an appropriate standard is IEC60519-1. The heating system should include suitable monitoring instruments and interlocks. High temperature shutdown devices and/or heat reduction systems should be fitted to avoid an unsafe condition arising through the failure of the temperature control system.

You should ensure that if overheating occurs, due to loss of temperature control within the combustion chamber, the heating system is shut down and the supply of flammable substances into the thermal oxidiser system is isolated. You should also consider incorporating purging/cooling arrangements that are initiated as part of the high temperature shutdown procedure.

Process control requirements

Safe operation of thermal oxidiser plant is based upon effective control of certain key parameters such as the concentration of flammable material in the gas stream. The basis of safety and the risk assessment for the plant rely heavily upon the accuracy and reliability with which these are monitored and controlled. Table 2 below shows examples of parameters that should be continuously monitored, the application and examples of typical measurement techniques.

Table 2. Monitoring of operating parameters

Parameter	Application	Measurement technique
Conc. of flammable substances	All	F.I. detector Flame temp. detector I.R. analyser
Temp. at inlet to combustion chamber	All non catalytic	Thermocouple Resistance thermometer
Temp. at inlet to catalytic reactor	All catalytic systems	Thermocouple Resistance thermometer
Temp. within combustion chamber	All systems	Thermocouple Resistance thermometer
Temp. within catalytic reactor	All catalytic systems	Thermocouple Resistance thermometer
Volume flow through plant	All systems	d.p. switch, venturi nozzle anemometer, pitot tube
Preheat temperature	All systems	Thermocouple Resistance thermometer

You should ensure that the monitoring and control system installed is suitable and covers the whole plant; flammable generating plant(s), pipework/ducting and thermal oxidiser. It should ensure that emergency measures, such as isolation of the thermal oxidiser from the source of flammables, occur quickly and reliably as soon

as hazardous conditions, such as inadmissible concentrations of flammable materials, are detected.

You should ensure that all electrical control, monitoring and measurement systems that are used in safety critical functions, such as to prevent or detect the occurrence of explosive mixtures, fulfil the requirements of category 3 of EN 954-1. Where one or more of the safety-related systems incorporates electrical/electronic/programmable electronic devices then the system should be designed and constructed to comply with the requirements of IEC 61508-1.

Protection from the effects of explosion

You should take measures to limit or mitigate the effects of fires or explosion where the risk from these hazards cannot be reduced to an acceptable level by the avoidance of flammable mixtures and ignition sources. Suitable measures may include explosion resistant design, explosion relief and the prevention of flame and explosion propagation. In most systems the addition of explosion protection will lead to a reduction in risk and is usually reasonably practicable. Consequently, in most situations there should be an expectation that suitable explosion protection or mitigation measures are installed.

You must ensure that the use of explosion protection or mitigation techniques must not give rise to a new hazard. Explosion relief systems must discharge to a safe place and not into a workroom. The design and implementation of protection or mitigation measures should be consistent with the likely operating conditions within the system. In particular, the risks resulting from the use of flame arrestors, such as backpressure and blockages, should be fully assessed before they are used in systems handling materials that may accumulate, form deposits, polymerise, condense or congeal.

LEGAL REQUIREMENTS

Employers are required under the Health and Safety at Work etc. Act 1974 to secure the health, safety and welfare of people at work and to protect those not at work from risks to their health and safety arising from work activities.

The Management of Health and Safety at Work Regulations 1999, often referred to simply as “The Management Regulations”, require all employers and the self-employed to assess the risks to workers and others so that they can decide what measures need to be taken to fulfil their statutory duty.

The general principles of an appropriate risk assessment are identified in EN 1050 “Safety of machinery - Principles of Risk Assessment” and in “The Management Regulations”. In the risk assessment process employers should identify the potential hazards and determine their significance. They should then take appropriate precautionary measures to reduce the risk from the hazards to an acceptable level that is as low as is reasonably practicable.

The Provision and Use of Work Equipment Regulations 1998 (PUWER 98) applies to thermal oxidisers in most work situations and imposes duties to ensure that the equipment provided is suitable and appropriate.

Risk assessment

Employers must assess the risks in the workplace and take all reasonably practicable precautions to ensure the safety of their employees and others who could be affected.^{2, 12, 13} The general principles of an appropriate risk assessment are identified in EN 1050 “Safety of machinery - Principles of Risk Assessment” and in The Management of Health and Safety at Work Regulations 1999 (Management Regulations). Through the risk assessment process employers should identify the potential hazards and determine their significance. They should then take appropriate precautionary measures to reduce the risk from the hazards to an acceptable level that is as low as reasonably practicable.

The Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) place a specific duty on employers to use risk assessment to ensure that the risk from fire and explosion is as low as reasonably practicable. If you are in control of thermal oxidiser systems you should ensure that you understand the implications of these Regulations on the design, installation, operation and maintenance of your equipment.

DSEAR is specifically concerned with protecting people against the risk from fire and explosion arising from **dangerous substances** in the workplace. Dangerous substances include flammable materials, such as solvents and VOCs, which can produce an explosive mixture with air. Substances of this type are often treated using thermal oxidisers.

DSEAR requires you to assess the risks from fire and explosion in detail. An appropriate risk assessment is an identification and careful examination of the dangerous substances present or likely to be present in the workplace; the activities involving them and how these might fail and cause harm to employees or the public. Its purpose is to help determine what needs to be done to eliminate or reduce the risks to safety arising from the use of dangerous substances in the thermal oxidiser system. In the risk assessment you should take account of the hazards of the dangerous substances likely to be present and the other hazards discussed earlier associated with the operation of a thermal oxidiser, e.g.:

- The possibility of hazardous explosive atmospheres occurring.
- All potential ignition sources.
- All foreseeable factors that could upset conditions in the plant.
- Control of non-routine operations.
- Maintenance and repair activities.
- Human factors.

The results of the risk assessment should indicate whether the safety of the thermal oxidiser system is acceptable or not. If the level of risk is not acceptable then opportunities for further risk reduction measures must be explored. Should a point be reached when the risk is still unacceptable and no further control measures are

practicable then measures to mitigate the effects of a fire or explosion should be applied. Suitable mitigation and risk reduction measures for thermal oxidiser systems may include:

- Explosion relief.
- Explosion suppression.
- Flame arrestors.
- Access control to hazardous areas.
- Training.
- Emergency procedures.

When the risk assessment has been completed and an acceptable risk determined the assessment should be documented (for enterprises with 5 or more employees) and an appropriate review date set.

A new risk assessment should be carried out:

- Before adding any new plant or equipment to the system.
- Before using any new substances in the system.
- Before making significant modifications to the system or surrounding area.

GLOSSARY

Auto-ignition temperature: The minimum temperature at which a material will ignite spontaneously under specified test conditions. Also referred to as minimum ignition temperature.

Catalyst: A substance that speeds up or lowers the temperature at which a chemical reaction takes place but is not used up in the reaction.

Combustible: Capable of burning in air when ignited.

Combustion chamber: The region of the thermal oxidiser where the flammable substances are burned, also known as the process space.

Deflagration: An explosion in which the flame front is moving through the unburnt flammable mixture at a velocity less than the speed of sound.

Detonation: An explosion in which the flame front is moving through the unburnt flammable mixture at a velocity greater than the speed of sound.

Direct combustion: Combustion of flammable substances using a flame or high temperature.

Flame arrester: A device consisting of an element, a housing and associated fittings which is constructed and used to prevent the passage of a flame front.

Flammable: Capable of burning with a flame. **Flammable range:** The concentration of a flammable vapour in air falling between the upper and lower explosion limits.

Flashpoint: The minimum temperature at which a liquid, under specific test conditions, gives off sufficient flammable vapour to ignite momentarily on the application of an ignition source.

Forced ventilation: The use of fans or other mechanical means to direct the waste streams of upstream plants towards the thermal oxidiser.

Hazard: Anything with the potential for causing harm. The harm may be to people, property or the environment, and may result from substances, machines, and methods of work or work organisation.

Incendive: Having sufficient energy to ignite a flammable mixture.

Inert: Incapable of supporting combustion; to render incapable of supporting combustion.

Lower explosion limit (LEL): The minimum concentration of vapour in air below which the propagation of a flame will not occur in the presence of an ignition source. Also referred to as the lower flammable limit or the lower explosive limit.

Maximum admissible concentration of flammable substances: The concentration of flammable substances within the thermal oxidiser system that must not be exceeded.

Overdriven detonation: A detonation resulting from the acceleration of a deflagration flame front to supersonic velocity.

Process space: The region within the thermal oxidiser in which the flammable substances are oxidised. This is frequently referred to as the combustion chamber.

Recirculation: A portion of the cleaned exhaust stream from the thermal oxidiser is reintroduced into the polluted gas stream to save energy etc.

Risk: A measure of the likelihood and potential severity of harm arising from a particular hazard. It reflects the likelihood that harm will occur, its severity in relation to the numbers of people who might be affected, and the consequences to them.

Risk assessment: The process of identifying the hazards present in any undertaking, the extent of those likely to be affected by them and likelihood of harm occurring and of evaluating the extent of the risks involved, bearing in mind whatever precautions are already being taken.

Thermal cleaning system: An assembly of linked components and machines such as fan(s), heat exchanger and heating device (burner) etc. joined together for the destruction of flammable substances, predominantly VOCs, by oxidation.

Upper explosion limit (UEL): The maximum concentration of vapour in air above which the propagation of a flame will not occur. Also referred to as the upper flammable limit or the upper explosive limit.

Vapour: The gaseous phase released by evaporation from a material that is a liquid at normal temperatures and pressure.

Vent collection system: An arrangement of pipework, ducts and other equipment, e.g. instruments, fans etc, used to prevent the uncontrolled escape of gaseous waste streams at the point of their generation by containing and directing them to a suitable location for their release or destruction.

VOC: volatile organic compound.

Volatile organic compound: A carbon based substance with a relatively low boiling point, i.e. less than 200 °C.

APPENDIX 1

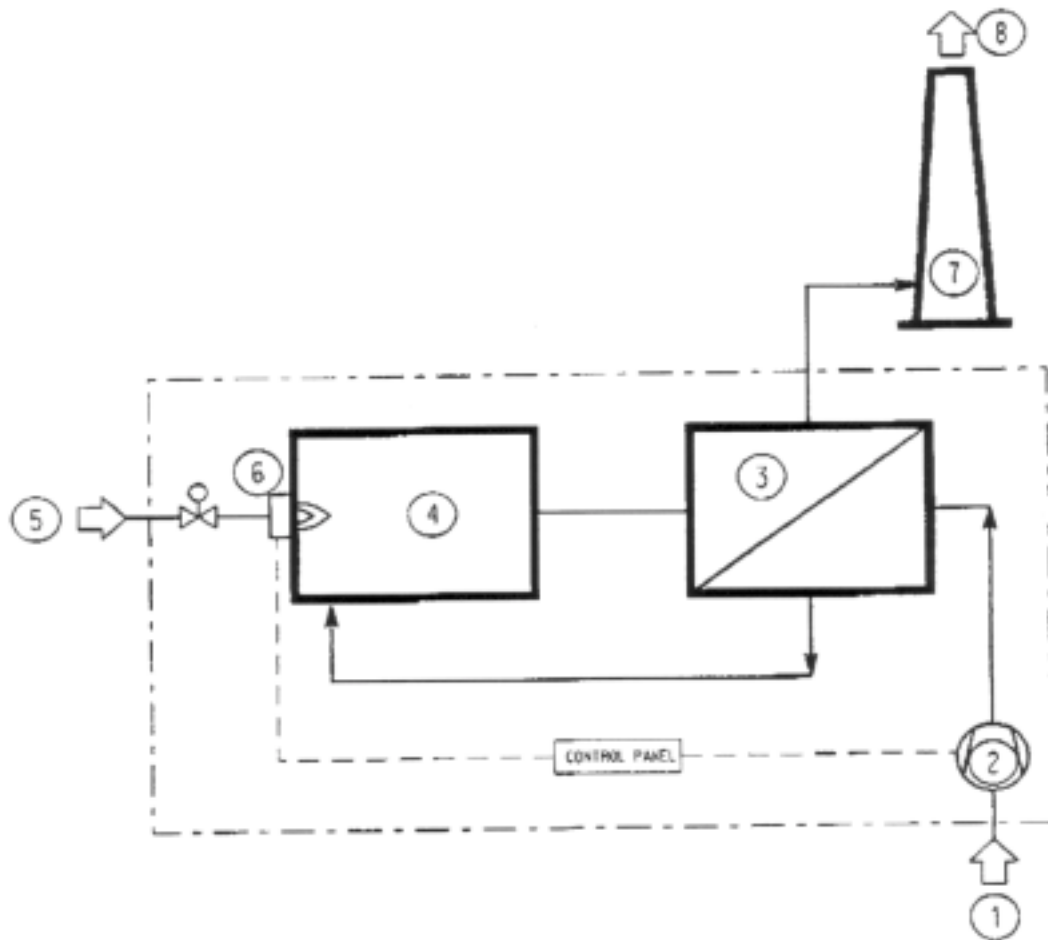


Figure 2. Direct recuperative thermal oxidiser

Legend:

- | | | | |
|---|-----------------------------|---|--------------------|
| 1 | polluted gas stream | 5 | supplementary fuel |
| 2 | polluted gas stream fan | 6 | burner |
| 3 | recuperative heat exchanger | 7 | stack |
| 4 | combustion chamber | 8 | clean gas |

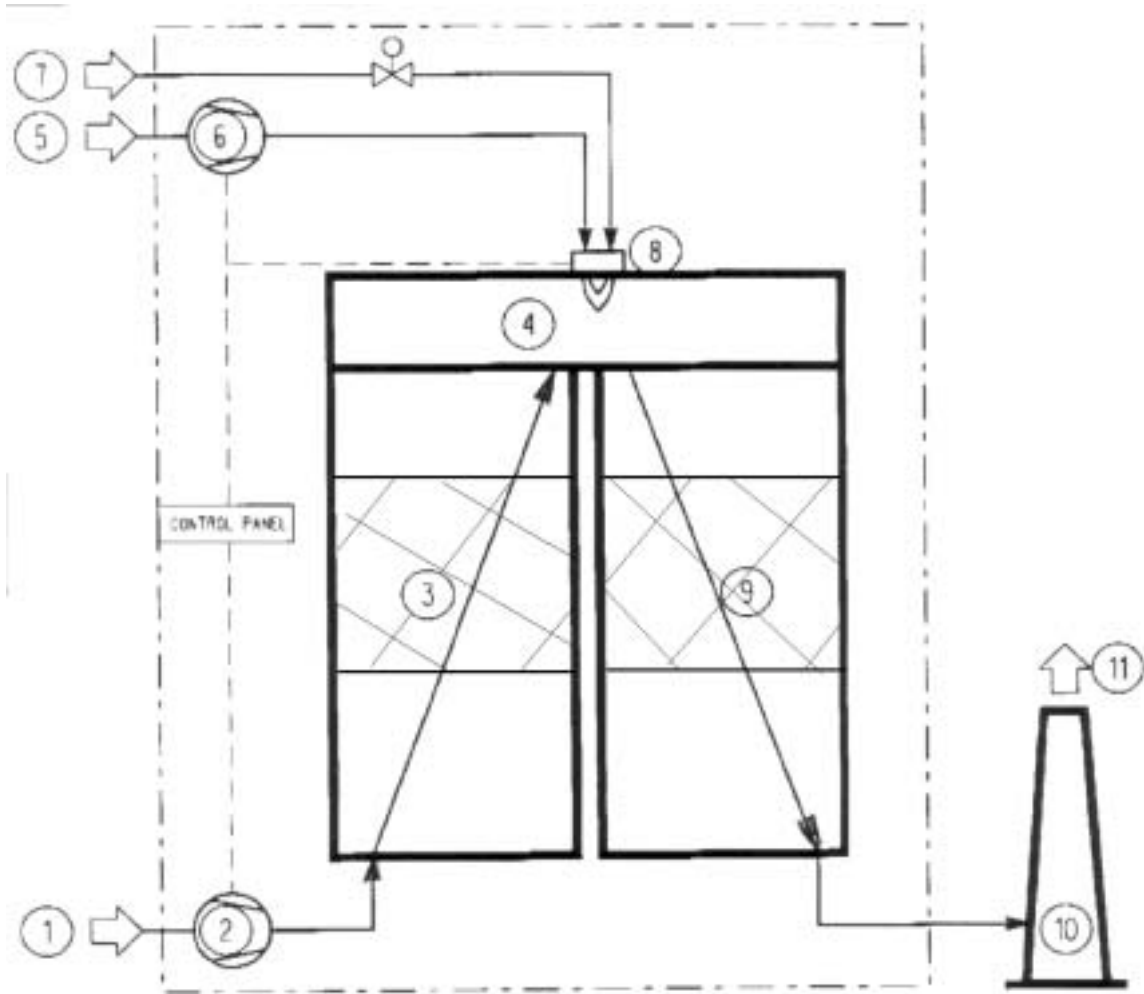


Figure 3. Direct regenerative thermal oxidiser

Legend:

- | | | | |
|---|-------------------------|----|-------------------------|
| 1 | polluted gas stream | 6 | combustion air fan |
| 2 | polluted gas stream fan | 7 | supplementary fuel |
| 3 | heat exchange packing A | 8 | burner |
| 4 | combustion chamber | 9 | heat exchange packing B |
| 5 | combustion air | 10 | stack |
| | | 11 | cleaned gas |

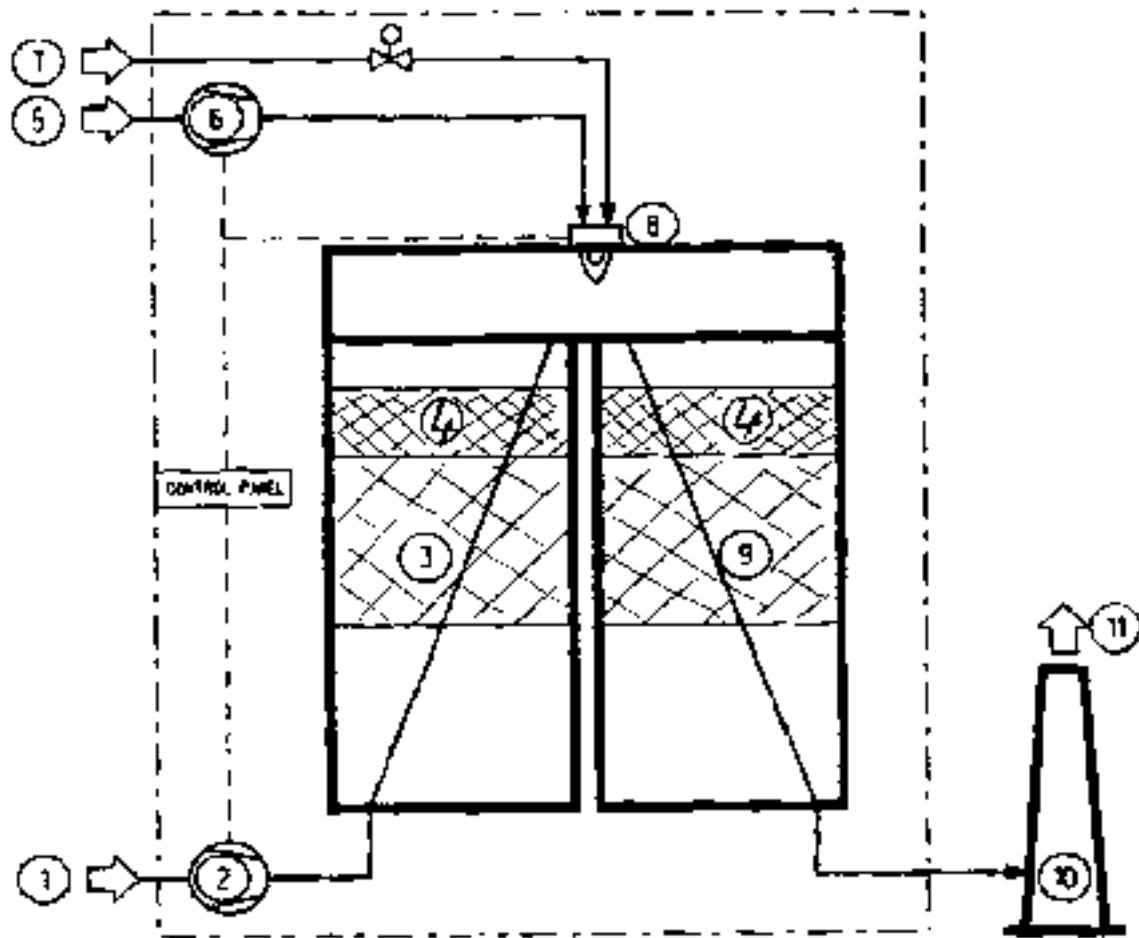


Figure 4. Catalytic Regenerative Thermal Oxidiser

Legend:

- | | | | |
|---|-------------------------|----|-------------------------|
| 1 | polluted gas stream | 7 | supplementary fuel |
| 2 | polluted gas stream fan | 8 | burner |
| 3 | heat exchange packing A | 9 | heat exchange packing B |
| 4 | catalyst | 10 | stack |
| 5 | combustion air | 11 | cleaned gas |
| 6 | combustion air fan | | |

REFERENCES

1. **The Environmental Protection Act** - 1990 HMSO 1990 ISBN 0 10 544390 5
2. HSE DSEAR Guidance document
3. **The Printer's Guide to Health and Safety** - HSE Books 2002, ISBN 0 7176 2267 3.
4. **The Safe Use and Handling of Flammable Liquids** - HSG 140 HSE Books 1996 ISBN 0 7176 0967 7
5. **Chip for Everyone** - HSG 228, HSE Books 2002, 07176 2370.
6. **Thermal Cleaning Systems for Exhaust Gas from Surface Treatment Equipment – Safety Equipment** - CEN prEN 12753:1999
7. **Flame Arresters** - HSG 158, HSE Books 1997, 0 7176 1191 4.
8. Reidewald. F. **“Explosive mixture”** - The Chemical Engineer, 9 November 1995.
9. **Safe Use of Work Equipment, Provision and Use of Workplace Equipment Regulations 1998** - L22 1998 HSE Books ISBN 0 7176 1626 6
10. **Area Classification Code for Installations Handling Flammable Fluids** Model Code of Safe Practice in the Petroleum Industry; part 15, The Institute of Petroleum ISBN 0 85293 223 5.
11. **Electrical Equipment for Explosive Gas Atmospheres – Part 10: Classification of Hazardous Areas** - BS EN 60079 and PD 14. **A guide to the application of BS EN 60079-14** - BSI London.
12. **Management of Health and Safety at Work** - L21 2000 HSE Books ISBN 0 7176 2488 9
13. **HSE Five Steps to Risk Assessment** - HSG183, HSE Books 1998 0 7176 1580 4