# Hydrocarbon destruction in incinerators

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# HYDROCARBON DESTRUCTION IN INCINERATORS

by

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## FOREWORD

This incinerator report was made for Väst Gas in order to assist them with the needed technology to provide clients with technical advices regarding the use of natural gas for incinerators.

The report covers mainly the part of incinerator technology which deals with hydrocarbon destruction and the formation of nitrogen oxides. Also some burner types are discussed in this report.
In the report are not incorporated incineration design detail such as heat exchanger, reaction chamber and other equipment design.

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## SUMMARY

Thermal incinerators destroy combustible pollutants trough oxidation for which temperatures are needed between 750 and 800°C to obtain complete conversion to $CO_2$ and $H_2O$ of most substances in 0,1 to 0,3 seconds residence time. Oxidation rates of hydrocarbons are very strongly temperature dempendent. The cleaning efficiency may highly increase with just little higher incineration temperature.
Beyond 650°C reaction temperature almost all hydrocarbons are oxidized. For a proper removal of CO a higher oxidation temperature is required. In the report an attemp was made to calculate the expected $NO_x$-production. From this attempt it could be concluded that the $NO_x$-production inside an incinerator is influenced by some variables such as burner type, solvent load and the preheated temperature level of the fume stream. The calculation results could not yet be confirmed with practical measurements.

## 1 FUME INCINERATION - GENERAL

Fume incinerators or afterburners can be used to control the emission of gaseous or small particulate air pollutants which are combustible at high temperatures. Hydrocarbons are oxidized to the products carbondioxide and water. This oxidation proces may be carried out in thermal or catalytic incinerators.
The list below gives a number of processes from which emissions have been controlled using incinerators.

Adhesive tape curing
Coated paper drying
Coil and strip coating lines
Deep fat frying
Fiber glass curing
Lithographing ovens
Metal coating ovens
Paint and varnish process equipment
Paint baking ovens
Printing presses
Roofing papermachine hoods
Textile dryers
Wire enameling

In many coating processes some kind of solvent or solvent water mixture must be applied to serve as a vehicle for the solids (ink or paint). In the dryer these solvents (moisture) are extracted from the substance by evaporation.

The dryer should be ventilated in such a way that any chance of explosion due to high solvent or hydrocarbon concentration is prevented. In practice this means that solvent concentration inside the dryer usually does not exceed 25% of the lower explosion limit (L.E.L.).
It will be clear that a manufacturer will try to work on minimum ventilation rates of his dryer, since any extra $m^3$ of fresh air supplied must also be heated.

Some dryers equiped with hydrocarbon monetoring devices are working on 40% L.E.L. levels to minimize make-up air supply.

The above will explain why pollutant concentrations in exhausts of dryers are always far below explosion limits.

For this reason exhaust gases from dryers can never be seen as a sort of low calorific gas which can be utilised in a burner.

The thermal oxidation process is based on oxidation of hydrocarbons on a temperature level high enough to accomplish the process within a second. More precise, the thermal incinerator process comprises a system in which exhaust gases with hydrocarbon pollutants are heated to a temperature beyond the self ignition temperature of the hydrocarbons in a surrounding with enough oxygen.
Auto ignition temperature is the temperature above which a combustible mixture of hydrocarbons with air must be raised to initiate combustion in the absence of a spark or flame.

Above several expressions were used for incineration, like:

- fume incineration;
- after burner;
- thermal incineration;
- thermal after burner.

Further in this paper I will prefer to use the word thermal incineration.

Thermal incinerators destroy combustible pollutants through oxidation for which temperatures are needed between 750 and 800 °C to obtain nearly complete conversion to $CO_2$ and $H_2O$ of most substances in 0.1 to 0.3 seconds residence time.
Destruction of most hydrocarbons occurs rapidly at 550 - 650 °C but oxidation of CO to $CO_2$ requires a higher temperature and residence time. Dense carbon smoke may require temperatures of up to 1100 °C and longer residence times.

Since hydrocarbon concentrations are always below the lower explosion limits the fume itself is not combustible. Fuel must be burned to supply heat to attain mentioned 750 to 800 °C. This fuel cannot be premixed with the entire fume stream since such mixture is below the flammable limit. The fuel must be burned separately using a part of the fume (maximum about 50%) for combustion air (if the fume has a high enough oxygen content and is non-fouling).

Mixing of bypassed fume and hot combustion gases is very important to attain good incineration performance.

The mixing itself will often require about 0.5 second and since most incinerators are designed for 0.5 second total residence time some of the fumes may escape without being raised to a sufficiently high temperature.

To meet in such a case the cleaning specification more fuel must be burned than would be needed if mixing were complete.

Distributed line burners are placed directly in the fume stream and divide the flame into many individual jets surrounded by fume. This system speeds the mixing process and these burners are well suited to use oxygen from the fume for combustion. The use of outside air requires an additional 30 - 50% of the fuel to be burned to heat to 750 °C. Distributed burners are somewhat sensitive for fouling and are not available for use with fuel oil. For these reasons some manufacturers employ discrete burners which give either long or short pointsources of flame. With these discrete burners the mixing is much more difficult since there is no and with modern burners less subdivision at the burner. Sometimes even baffles are required in the relatively short after burner chamber.

## 2 THERMAL INCINERATION PERFORMANCE

Fume incineration requires contacting pollutant molecules with sufficient oxygen at a high enough temperature for the oxidation reaction.
Every writing about incinerator design starts with the story of the 3T'S, being time, temperature and turbulence. All these elements will be discussed in this study.
Most fumes treated by incinerators are dilute which means, they do not contain sufficient combustible to support combustions.
Therefore supplementary fuel must be burned to generate heat, and the resulting hot combustion products must be mixed with the contaminated fume stream in order to raise the entire stream to a sufficiently high temperature.
If the fume stream is not dilute and can give combustion without supplement fuel it can be burned with combustion air in a normal waste burner.
In most incinerator applications the fume stream is in fact contaminated air and has adequate oxygen (15-20%) both for burning the needed fuel and for oxidizing the contaminents.
Some publications are stating that in the incinerator effluent at least 4% oxygen should be present.

Once the supplemental fuel has been burned, the cold fume and hot combustion products must be mixed to give a nearly uniform temperature of all the fume flowing through the incinerator. This should be done as rapidly as possible without causing flame quenching. After this mixing sufficient residence time must be available at the required temperature.

As discussed temperatures between 750 and 800 °C are normally required whereby the stream is held for 0.5 second on this temperature.

The relation of incineration temperature and residence time will be discussed later in this study.

Further will be discussed:

- Calculation of residence time
- Hydrocarbon destruction
- Carbon monoxide cleanup
- Nitrogen Oxides formation
- The role of flame contact and benefits of flame contact
- Burners for fume incinerators.

## 3 THE RELATION OF INCINERATION TEMPERATURE AND RESIDENCE TIME - IGNITION TEMPERATURE

Temperature and residence time requirements are discussed together since they are interchangeable to some degree - a higher temperature allows use of a shorter residence time and vice versa. Additional residence time involves a bigger combustion chamber and therefore a higher capital cost. However, additional volume is relatively cheap and the residence time could be doubled for a 20 - 30% increase in capital. Operating temperature on the other hand has a direct relationship to fuel consumption, which is the major operating cost. Depending on specific considerations (fuel cost, hours/year operation, available space, etc.) it would often appear that temperature should be reduced and residence time increased. However this interchangeability of temperature and time is not of great practical importance since oxidation rates are very strongly temperature dependent which is shown in figure 1. This figure shows the general relationship between residence time on oxidation rates and the temperature effect.

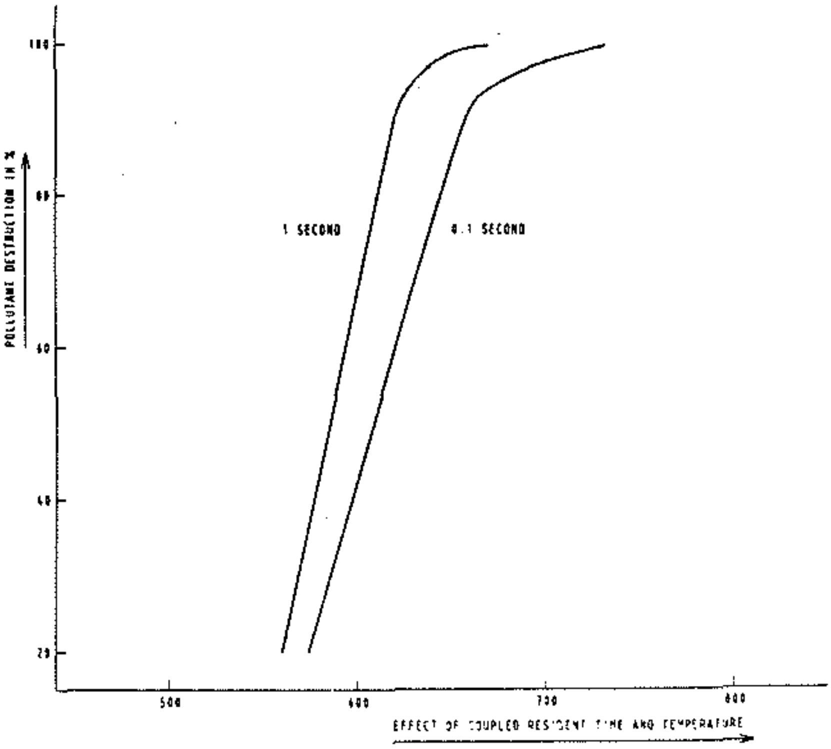

Figure 1 Effect of coupled residence time and temperature

From figure 1 can be seen that over a narrow temperature range the destruction efficiency increases from low to high efficiencies and the small influence of the residence time.

The ignition temperature also called auto ignition temperature is the temperature above which a combustible mixture and air must be raised to initiate combustion in the absence of a spark or flame.
Many hydrocarbons have a large range.
Among the widest ranges and highest temperatures are toluene (between 520 °C and 800 °C) and methane (between 535 °C and 700 °C).
Auto ignition temperatures given in handbooks do not apply to hydrocarbon - air mixtures below the lower explosion limit.
For above reasons most incinerators are designed to reach at least 70 °C more than the highest ignition temperature of the solvent mixture.

## 4 CALCULATION OF RESIDENCE TIME

The total incinerator residence time is simply the total combustion chamber volume in $m^3$ divided by the temperature corrected fume and supplemental fuel volume flow per second.

As stated the volume flow must be temperature corrected.
At 750 °C this flow is $\frac{273 + 750}{273} = 3.75$ times the $Nm^3$ ($m_o^3$) flow.

When outside air is not used, the methane or natural gas will contribute less than 3% to the volume. If however supplemental fuel is burned using only outside air the volume may be increased by 50% or more.

As stated incinerators should have a residence time of 0.5 second. Whith above calculation this will be the total residence time. This time is not equivalent to the time during which the fumes are held at the required temperature. A significant amount of time is required to bring the cold fume up to the designed temperature. Also, all elements or parts of the fume do not spend an equal amount of time in the comubustion chamber. This variation in time is a function of flow patterns and can very much effect the performance of the unit.

## 5 HYDROCARBON DESTRUCTION

Destruction of most hydrocarbons occurs very rapidly at temperatures between 550 °C and 650 °C). (Possible) exceptions are methane, toluene which are stable molecules and require higher temperatures (750 °C) for oxidation in a few tenths of a second.
The oxidation process in general can be explained with the graph from figure 2.
In this graph the remaining hydrocarbon and carbon monoxide exhaust concentration is given as a function of the reaction temperature which is the temperature inside the reaction chamber. The residence time in the reaction chamber is 0.6 second.
Line B shows mentioned function for white spirit which is a solvent with a very low auto ignition temperature (250 °C). Line A shows the line for toluene which has a rather high auto ignition temperature (535 °C). Line C gives the CO remaining in the exhaust as a function of the reaction temperature. The Lines A and B are applicable for inlet concentrations between 2 and 12 grams per $m_o^3$.
The graph is a result of many measurements.

The following conclusions can be made:

- Beyond 650 °C reaction temperature almost all hydrocarbons are oxidized.
- For a proper removal of CO, a higher oxidation temperature is required.
- At 750 °C the remaining CO concentration will be about 100 ppm.
- Comparision of lines A and B shows that hydrocarbon with lower ignition temperatures allow lower incineration temperatures to oxidize the hydrocarbons. The CO formed during any incineration or oxidation process requires a higher temperature.
- The most important conclusion, however, is that if CO begins to drop (lower than 1000 ppm) all hydrocarbons have already been oxidized.

If we compare the results of many measurements with the requirements of the German T.A. Luft then we may conclude that a 750 °C incineration temperature will give results to meet the German pollution law.

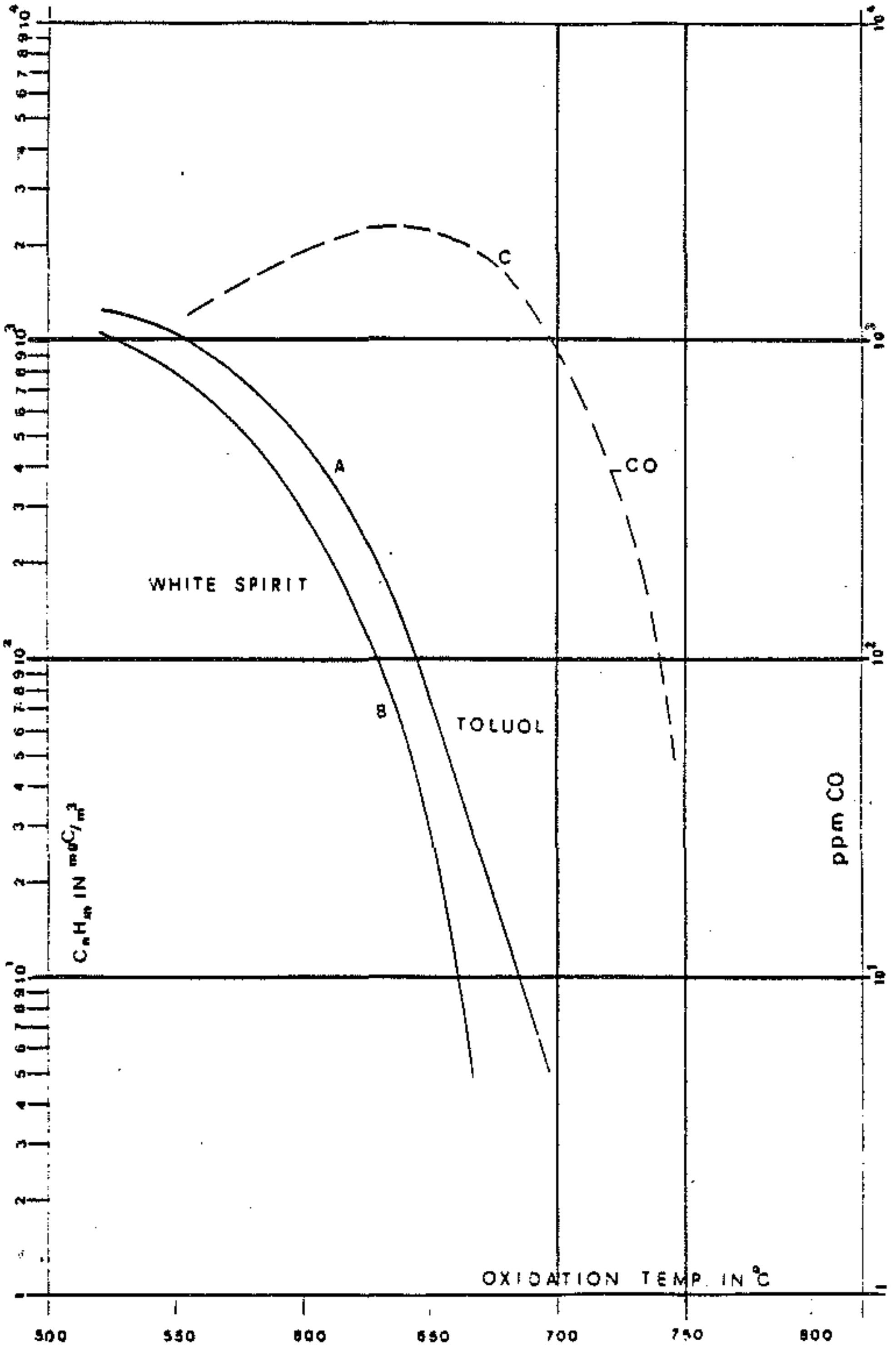

Figure 2 Hydrocarbon oxidation curve

In addition to above general conclusions some more detailed remarks can be made about the destruction of hydrocarbons.
As stated methane is difficult to destroy at temperatures below 750 °C, however in most cases where methane is present in the exhaust this is in most cases due to inefficient combustion in the burner in the drying oven. Adjustment of these burners normally directly reduce inlet methane concentration to the incinerator.

The curves shown in figures 3 and 4 are experimental data taken by Surface Combustion Division of Midland Ross Corporation. Measurements were made in the absence of a flame and at temperatures and concentrations of interest. Prevaporized solvent was added to air heated to the desired operating temperature. Mixing was designed to be nearly instantaneous, and plug flow was maintained in the reactor. As can be seen, the rate of hydrocarbon disappearance was taken to be first order in solvent concentration and somewhat dependent on solvent type. Toluene, which is often reported to have a very high ignition temperature, disappeared more slowly than cyclohexane or hexane.

Figure 4 shows the rate at which toluene is oxidized as a function of after burner temperature. Rates are slow below 750 °C but increase rapidly above this temperature. (The asymptote shown for concentrations < 10 ppm may be real, but more likely is a sampling and analysis problem.)

As can be seen from figures 3 and 4, the rate of toluene destruction is very fast at temperatures greater than 750 °C. Conversion greater than 95% can be obtained with residence times of 1 second or less without any need for flame contact.

## 6 CARBON MONOXIDE DESTRUCTION

As described under hydrocarbon general explanation about the oxidation process it was concluded that for proper removal of CO, a higher oxidation temperature is required than for hydrocarbons.
It has been reported that the time required for the oxidation of CO is about 10 x the time needed for oxidation of hydrocarbons to CO. Destruction of CO is required since most pollutant laws include CO in the cleanup rules.

Incinerator experience shows that temperatures in excess of 750 °C and 0,5 second residence time are required. Figure 2 compares the estimated rate of CO oxidation with that of hydrocarbons. As described it is obvious that longer times and higher temperatures are needed when CO cleanup desired more than destructing hydrocarbons only.

In the absence of water CO is extremely difficult to burn. Afterburners fume stream however always contain water vapor since the combustion of natural gas and the oxidation of hydrocarbons generates water.
All studies report a significant dependence of the oxidation rate on the oxygen content of the stream. In normal incinerators the oxygen content is 15 to 20% even after passing the burner.

Some equipment manufacturers have specified 4 - 5% $O_2$ as a minimum in the incinerator effluent.

Incinerator experience shows that temperatures of 750 - 800 °C are required with an actual residence time at this temperature of 0,2 - 0,4 seconds and above mentioned enough oxygen to achieve nearly complete oxidation of CO to $CO_2$. At these conditions less than 200 ppm CO in the flue gas can be expected.

Units with poor mixing patterns exhibit outlet CO concentrations higher than 1000 ppm though temperatures are at 750 - 800 °C level.

## 7 NITROGEN OXIDES FORMATION

In incinerators, as in any combustion burner where fuel is burned with air in a flame, some reaction of nitrogen and oxygen from the air will occur, forming nitrogen oxide (NO) and nitrogen dioxide ($NO_2$). These oxides are often mentioned together as $NO_x$ ($NO + NO_2 = NO_x$).

The NOx formation is depending on the combustion conditions.
As with all chemicals processes, the rate of formation of $NO_x$ is, among other things, a function of temperature and residence time.
$NO_x$ formation is reduced both by lowering the flame temperature and shortening the residence time of the combustion gases.
A low flame temperature can be obtained by mixing the gas with a large excess of combustion air before burning it. Here, the excess air serves to cool the flame and the combustion products. The greater the proportion of excess air, the lower will be the flame temperature. Figure 5 shows the relationship between the $NO_x$-concentration in the combustion gases, referred to stoichiometric conditions (air factor n = 1), flame temperature and air factor. This graph shows that every increase of 10 °C in the flame temperature raises the $NO_x$ concentration by a factor of 1.3. In other words, hot spots in the flame have a disastrous effect on the ultimate $NO_x$-concentration. In order to avoid hot spots and hence a locally high rate of $NO_x$-formation, perfect premixing of the combustion air and the gas is essential. However, there is a limit to the level to which the flame temperature can reduced by increasing the excess air in order to reduce the $NO_x$-concentration. There comes a point at which the flame becomes so cold that combustion is incomplete, a condition characterised by the presence of unburnt or incompletely burned hydrocarbons in the flue gases.

$NO_x$-concentration in flue gases as a function of air factor and theoretical flame temperature with complete gas/air premixing

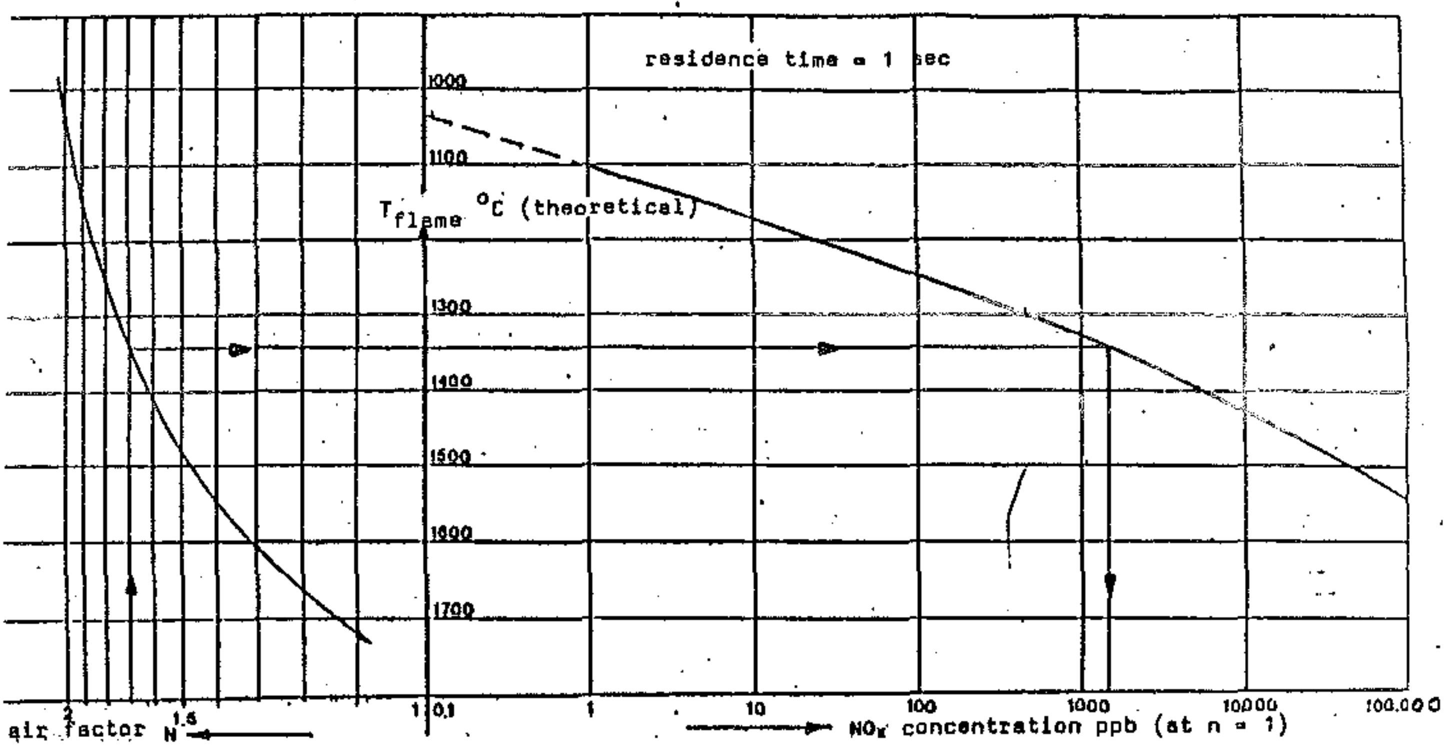

Figure 5

From figure 5 can be seen that all $NO_x$ is formed in the high temperature region and this is in the burner flame it self. In the reaction chamber almost no $NO_x$ will be formed.
In some incinerator applications where nitrogen containing compounds like $NH_3$, amines, etc. are present in the fume contaminants additional $NO_x$ may be formed during oxidation.

When using the normal type of burners for incineration mixing of fume with combustion products will result in relatively small flame size with rapid quenching of the flame products from 1500 to 800 °C.

In comparison with larger combustion equipment like boilers and furnaces, incinerators will have relatively low $NO_x$-emissions.

The use of preheated combustion air leads to higher flame temperatures and more rapid $NO_x$-formation. Similarly preheated or heat exchanged fume (as in an incinerator) may lead to slower flame quenching and higher flame temperatures and higher $NO_x$-formation.

As can be seen from many installations in practise discrete burners are applied. The discrete burner is viewed as a point source of flame. In all cases they are raw gas (oil) burners which are placed in the fume stream and obtain oxygen for combustion directly from the preheated fume. These discrete burners can be seen as boiler burners with adaptations to make the burner applicable for incineration. These adaptations are needed because the flame yet only will not be able to provide complete mixing which is especially a problem when firing on low rate.
In most cases the basic boiler burner design is provided with a conical mixingplate through which most of the fume is transported (figure 7). A small part of the fume (5 - 20%) is used to supply combustion oxygen to burn the needed supplementary fuelgas.

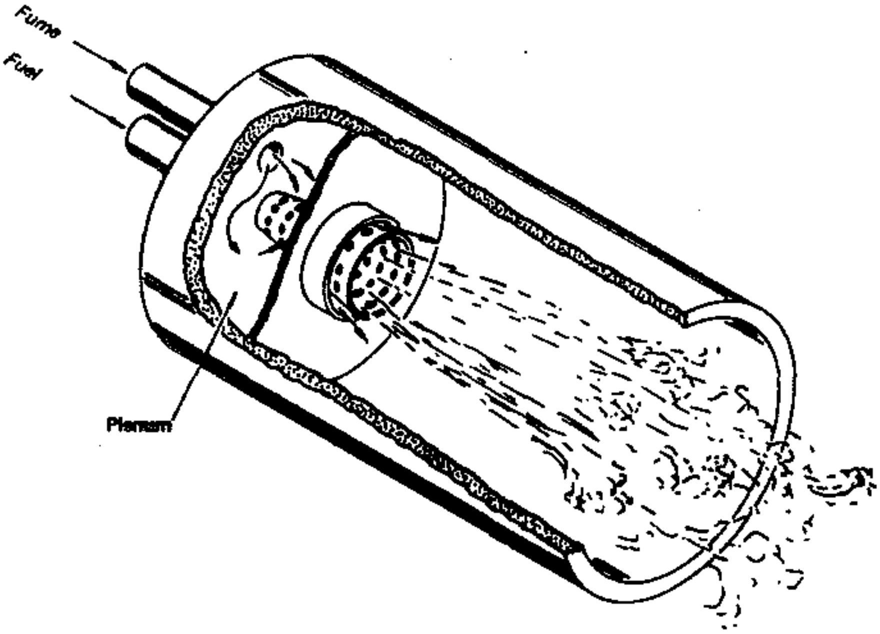

Figure 7

Based on above and taking into consideration the known $NO_x$-production figures from boiler burners the expected $NO_x$-production figures can be calculated.

In most incinerators the fume is preheated to about 450 °C from where it is further heated to 750 °C with the help of a burner or with the help of the combination of burner and the available hydrocarbons in the fume stream.

In both cases oxygen for combustion of the fuel is taken out of the fume stream. During normal working the fume stream is polluted with hydrocarbons. Due to this the burner will work on a little higher capacity than will be indicated by the gasmeters due to the fact that any gram of solvent load in the fume stream will carry energy.

Solovent data

| | Formula | Molecular weight | L.E.L. | | Auto ignition temperature | Temperature rise if 1 gr is oxidized in 1 $m^3o$ |
|---|---|---|---|---|---|---|
| | | | vol.% | gr/$m^3$o | | |
| Methane | $CH_4$ | 16,04 | 5 | 33 | 595 | 33 |
| Propane | $C_3H_8$ | 44,09 | 2,1 | 39 | 470 | 30,6 |
| n-Hexane | $C_6H_{14}$ | 86,17 | 1,2 | 42 | 240 | 30 |
| Ethylene | $C_2H_4$ | 28,05 | 2,7 | 31 | 425 | 34,7 |
| Acethylene | $C_2H_2$ | 26,04 | 1,5 | 16 | 305 | 32 |
| Benzene | $C_6H_6$ | 78,11 | 1,2 | 39 | 555 | 27 |
| Toluene | $C_6H_5CH_3$ | 92,13 | 1,2 | 46 | 535 | 27 |
| Xylene | $C_6H_4(CH_3)_2$ | 106,16 | 1 | 44 | 465 | 27 |
| Styrene | $C_6H_5.CH: CH_2$ | 104,14 | 1,1 | | 490 | 27 |
| Petrol | Mixed | - | | | | |
| Turpentine | $C_{10}H_{16}$ | 136,23 | 0,8 | | | |
| Methanol | $CH_3OH$ | 32,04 | 5,5 | 73 | 455 | |
| Ethyl Alcohol | $C_2H_5OH$ | 46,07 | 3,5 | 67 | 425 | |
| Iso-Propanol | $(CH_3)_2$ CHOH | 60,09 | 2 | 50 | 425 | |
| Phenol | $C_6H_5OH$ | 94,11 | 1,4 | 63 | 605 | 21 |
| Cresol | $CH_3C_6H_4OH$ | 108,13 | 1,3 | 58 | 555 | 22 |
| Formaldehyde | HCHO | 30,03 | 7 | - | - | 11,4 |
| Acetaldehyde | $CH_3CHO$ | 44,05 | 4 | 73 | 140 | 16,6 |
| Acetone | $CH_3.CO.CH_3$ | 58,08 | 2,5 | 60 | 540 | 19,4 |
| M.E.K. | $CH_3.CO.C_2.H_5$ | 72,1 | 1,8 | 54 | 505 | 21 |
| Cyclohexanone | $C_6H_{10}O$ | 98,14 | - | - | 430 | - |
| Diëthyl ether | $(C_2H_5)_2O$ | 74,12 | 1,7 | 50 | 170 | 22,7 |
| Ethyl Acetate | $CH_3CO.OC_2H_5$ | 88,10 | 2,1 | 75 | 460 | 15,8 |
| M.I.B.K. | $CH_3COC_4H_9$ | 100,16 | | | | 27,8 |
| Vinyl Acetate | | 86,09 | 2,6 | 90 | 427 | |

Figure 8

The temperature rises per gram/$m^3_o$ for a number of hydrocarbons are given in figure 8. Note that the given temperature rises are corrected for the higher specific heat of the fume stream between 450 and 750 °C.

For the heating of 1 $m_o^3$ of fume from 450 to 750 °C (Δt 300 °C) is needed 300 x 1,484 = 445,2 kJ. If methane is burned in a burner the methane consumption will be (if no hydrocarbons are available in the fume stream)

$$\frac{445,2}{35882} = 0,0124 \ m_0^3 \ CH_4$$

35882 is the net calorific value of $CH_4$ in KJ.

Per $m^3$ methane $\frac{35882}{445,2} = 80,6 \ m_o^3$ fume can be heated.

A boiler burner working on 10% excess air will need 1,1 x 9,675 $m_o^3$ of combustion air with 20,8% oxygen. Assuming that the fume stream contains 19% oxygen the burner will need

$$1,1 \times \frac{20,8}{19} \times 9,675 = 11,65 \ m_o^3$$

This means that 80,6 - 11,65 = 68,95 $m_o^3$ will bypass the flame and 11,65 $m_0^3$ is applied as combustion air.
As stated above we can assume that a for an incinerator applied and modefied discrete burner works similary as a boiler burner, due to which we can state that the production will be at 10% excess air, 65 ppm.
Since the combustion air forms a part of the preheated fume stream we have to include a correction for preheated air as shown in figure 6.
The produced $NO_x$ per $m_o^3$ will than be 4 x 65 = 260 ppm/$m_o^3$

The average $NO_x$ load over the total fume stream will be

$$\frac{(11,65 + 1) \ 260 + 68,95 \times 0}{80,6 + 1} = 40,3 \text{ ppm } NO_x$$

This figure will be somewhat high because providing the burner with combustion air with 19% oxygen can be compared with fume recirculation in a normal burner which will result in a lower $NO_x$ production as shown in figure 9.

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Since a part of the fume stream is utilize as preheated combustion air for the burner, a part of the solvents are burned in the burner flame giving a bit larger flame than would we expected from the gasmeter (as stated above). The solvents in the fume stream bypassing the burner will oxidize in the incinerator reaction chamber without showing a flame and without producing $NO_x$. As explained 750 °C is far to low to produce any NO (see figure 5).
Assuming again 19% oxygen in the fume stream the combustion air volume needed for combustion is 11,65 $m_o^3$ (see above) (conditions as stated above).

This is $\frac{11,65}{80,6}$ x 100 = 14,45% of the total fume stream
This part of the solvents will also be burned in the burner which is $\frac{14,45}{100}$ x 162 = 23,4 °C temperature rise.
The rest of the solvents 85,5% will oxidize in the reaction chamber which will result in a 138,59 °C temperature rise in this chamber.
The total temperature rise produced by the burner is 300 - 162 + 23,4 = 161,4 °C. Based on this temperature rise the $NO_x$-load can be calculated.

The calculated $NO_x$-load will thus be

$$\frac{161,4}{300} \times 40,3 \times 0,45 = 9,75 \text{ ppm } NO_x$$

- 40,3 ppm has been calculated above;
- 0,45 is the factor of 55% $NO_x$-reduction due to recalculation giving lower oxygen %, (see above).

It should be noted that all above figures are purely based on calculations bases on what can be expected.

With the help of above developed calculation methode we can conclude that there are many variables influencing the $NO_x$-load in the exhaust from an incinerator.

These variables and conclusions are:
- Type of burner applied (will be discussed under burners).

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The calculated $NO_x$-load will thus be

$$\frac{161,4}{300} \times 40,3 \times 0,45 = 9,75 \text{ ppm } NO_x$$

- 40,3 ppm has been calculated above;
- 0,45 is the factor of 55% $NO_x$-reduction due to recalculation giving lower oxygen %, (see above).

It should be noted that all above figures are purely based on calculations bases on what can be expected.

With the help of above developed calculation methode we can conclude that there are many variables influencing the $NO_x$-load in the exhaust from an incinerator.

These variables and conclusions are:
- Type of burner applied (will be discussed under burners).

Since a part of the fume stream is utilize as preheated combustion air for the burner, a part of the solvents are burned in the burner flame giving a bit larger flame than would we expected from the gasmeter (as stated above). The solvents in the fume stream bypassing the burner will oxidize in the incinerator reaction chamber without showing a flame and without producing $NO_x$. As explained 750 °C is far to low to produce any NO (see figure 5).
Assuming again 19% oxygen in the fume stream the combustion air volume needed for combustion is 11,65 $m_o^3$ (see above) (conditions as stated above).

This is $\frac{11,65}{80,6} \times 100 = 14,45\%$ of the total fume stream
This part of the solvents will also be burned in the burner which is
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With the help of above developed calculation methode we can conclude that there are many variables influencing the $NO_x$-load in the exhaust from an incinerator.

These variables and conclusions are:
- Type of burner applied (will be discussed under burners).

- The solvent load in the exhaust. A higher solvent load will result to lower $NO_x$-load due to the fact that more temperature rise will produced in the reaction chamber where due to too a low temperature no $NO_x$ will be produced. The solvent load works proportional.
- The preheated temperature level of the fume stream. The higher this temperature level is the higher the produced $NO_x$-level will be (seek figure 6).
  Figure 6 shows an exponential rise.

Of course a higher preheat temperature will result to a lower temperature rise over the burner and a proportional lower $NO_x$-load. As can be seen the influence from the preheated temperature is larger (see figure 10).

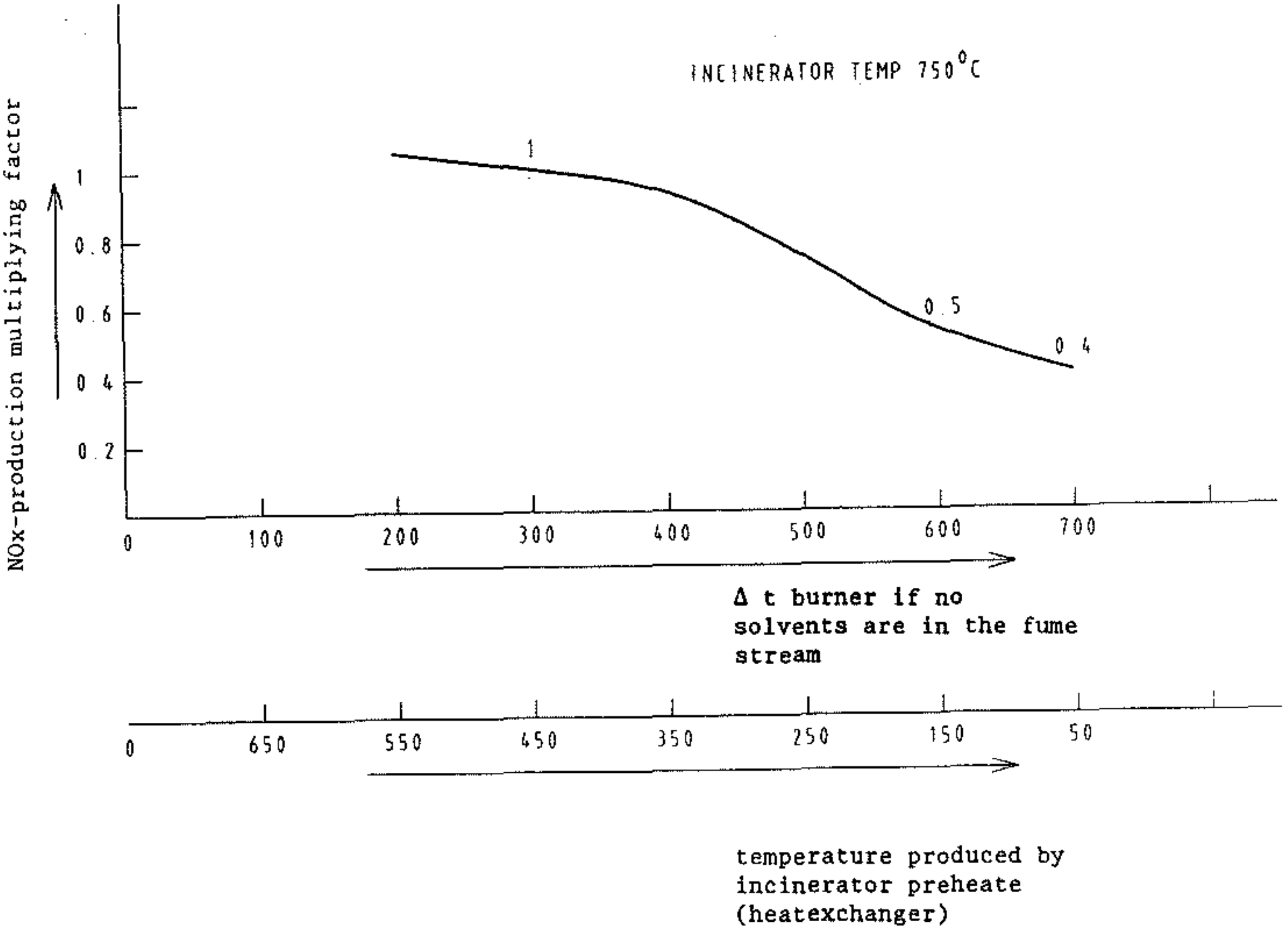

Figure 10 $NO_x$-load production multiplying factor as a function from fume preheat temperature based on a preheat temperature of 450 °C being 1.

- The oxygen percentage in the fume stream. Less oxygen means more combustion air is needed which will result in a lower combustion air temperature and a lower $NO_x$-load, see figure 9.

General conclusion

From above it can be concluded that the $NO_x$-load or $NO_x$-ppm rate in the incinerator exhaust depends upon a number of variables.

After above more or less calculative approach method we have studied a number of test reports made in the past on practical installations.

Installation 1

| | | |
|---|---|---|
| Incinerator temperature | 775 °C | 761 |
| Hydrocarbons | Cresol Phenol | same |
| Inlet temperature to burner | 165 °C | 163 |
| Amount of fume stream per $m_o^3$ gas | 45 $m_o^3$ | 83 $m_o^3$ |
| $O_2$ in the exhaust after incinerator | 15.6% | 15.6% |
| $CO_2$ in exhaust | 3.3% | 3.7 |
| CO in exhaust | 80 ppm | 940 ppm |
| $NO_x$ in exhaust | 34 ppm | 28 ppm |

This installation was equiped with a distributed burner (line burner).

Installation 2

| | |
|---|---|
| Incinerator temperature | 750 °C |
| Hydrocarbons | not known |
| Inlet temperature to burner | 166 °C |
| CO | 584 ppm |
| $NO_x$ | 26 ppm |

This installation was equiped with a distributed burner (line burner).

## Installation 3

| | | |
|---|---|---|
| Incinerator temperature | 605 °C | 651 °C |
| Hydrocarbons | oils | oils |
| Inlet temperature to burner | 150 °C | 150 °C |
| $O_2$ in exhaust | 15.6% | 14.7% |
| $CO_2$ in exhaust | 3% | 3.5% |
| CO in exhaust | 550 ppm | 500 ppm |
| $NO_x$ | 25 ppm | 20 ppm |

This installation was equiped with a distributed burner.

## Installation 4

| | | |
|---|---|---|
| Incinerator temperature | 740 °C | 770 °C |
| Hydrocarbons | Phenol + cresol | |
| Inlet temperature to burner | 450 °C | 450 °C |
| $O_2$ in exhaust | 17.6% | 17.42% |
| CO in exhaust | 1000 ppm | 40 ppm |
| $NO_x$ | not measured | |

This installation was equiped with a distributed burner.

With these measurements conclusions can not be made in relation to the given theory.

Literature study shows that $NO_x$ concentrations in effluents are between 20 - 35 ppm for incinerators working on temperatures between 720 and 780 °C.

## 8 THE ROLE OF FLAME CONTACT AND BENEFITS OF FLAME CONTACT

Often has been reported that contact between the supplemental fuel flame and the fume is needed for satisfactory pollution destruction. The reason seems to be that it may lead to improved mixing between cold fume and hot combustion products and excess free radicals from the flame which will improve oxidation rates.
Oxidation rates are proportional to the concentration of these radicals.

In general can be said that the concept of "flame contact" is a good one. Al the fume however cannot be put through the flame since a non combustible mixture would result.

## 9 BURNERS

It has been noted that large fuel savings up to 50% are gained by using the oxygen from the fume stream for combustion of the supplemental fuel rather than bringing in outside air which must also be heated to 750 °C. It was also shown that most of the fume stream must bypass the burner.
The most important point for good incineration was to get good mixing between the bypassed fume and the hot combustion gases from the burner. For this reason the distributed raw gas burner is well suited for use in thermal incinerators. However never deep investigations have been carried out to find if there are differences in performance between the distributed burners on the market and the modern discrete burners.
Both the distributed and discrete are directly placed in the fume stream in order to utilize oxygen in the fume. With the distributed burners the required mixing distance can be made short which means that less time is needed to bring all fume to the required temperature.

Figures 11, 12 and 13 are showing the graxon type distributed line burner. Same type of burners are also made by Eclipse.

The Eclipse types are of similar concept. As indicated in most incinerator applications the fume is essentially contaminated air, and has adequate oxygen content (usually 15-20%) both for burning the necessary preheating fuel, and oxidizing the contaminants.

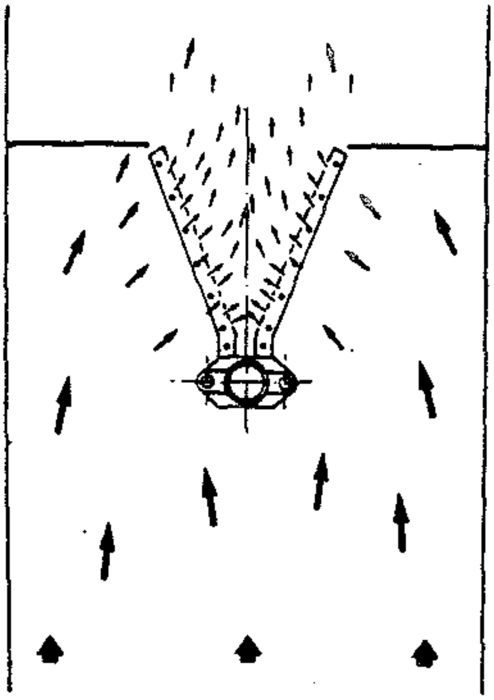

Figure 12  Flow patthern flue gases through line burner

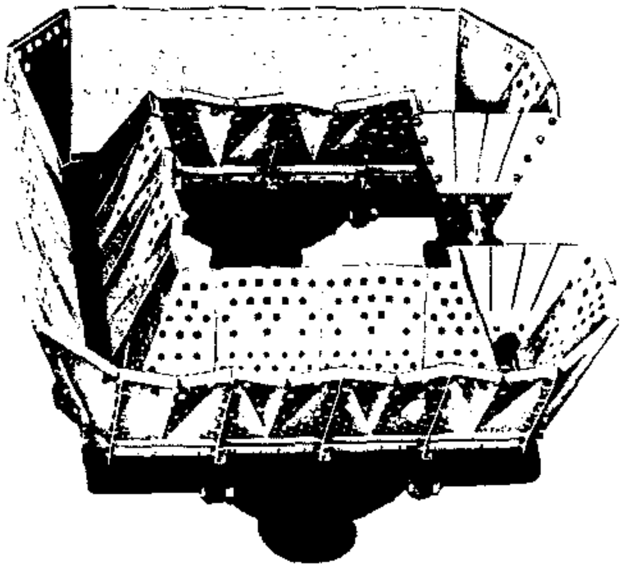

Figure 13  Maxon Combustifume Line burner

These burners are able to work on difficult to determine maximum capacity. Eclipse and lately also Maxon are stating higher heat inputs per foot of burner length.

The result is lower burner costs because at a given heat input less burner length is required. However burner spacing will be greater since less burner length is needed. So mixing of fume and flame must occur across somewhat greater distances. Also a long flame length means that several feet of combustion chamber are lost before all the heat from the supplemental fuel has been released.
With mentioned high heat releases per foot of line burner it will be clear that burner performance of distributed burners become the same of that of modern discrete burners designed for incinerators.

Burners can get fouled if liquid or solid particulates are entrained by the fume. This will result in buildup on the inside of the burner plates arround the fume inlet holes. Due to in general high mixing plate temperatures the fouling combustible material usually will burn off.
Distributed burners should not be used in fouling fume streams unless frequent cleaning is possible. Discrete burners are less sensitive for fouling.
Since very high mixing plates have been observed it is advisable to apply Hestelloy mixing plates for distributed and often also for discrete burners.

High preheat of the fume stream can also cause decomposition of the natural gas in the distributed manifold producing coke on the inside of these manifolds. This becomes a problem at preheat temperatures greater than about 500 °C. This high temperature can occur if fume is raised to a temperature where oxidation of the hydrocarbons in the fume begins upstream of the burner. The problem is also caused to the fact that at low capacity of the burner the natural gas flow through the manifold is low due to which the fuel gas flow will get heated to almost the fume stream temperature level.

Since discrete burners are not provided with manifolds above described problem does not apply to these burners.

The distinction between discrete and distributed burners is such that a discrete burner provides a discrete or a point source of flame whereas a distributed burner provides a distributed flame.
All of the major manufacturers make gas and oil discrete burners. There are so many variations among these burners that they will not described in this publication.

Figure 7 shows a discrete burner from UOP. This burner, as many other designs, is provided with a conical mixing plate. The fume is split between combustion air and bypass. Operation is in fact like described for distributed burners but a single flame results. This flame will extend about a meter into the combustion chamber. As in the line burners, high temperature alloys must be used for construction of the mixing plate cone.

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