

Experimental Investigation on the Effect of Double-Burner Configurations on the Incineration of Fumes - A Natural Gas Case Study

دراسة تجريبية لأثر وضع الحواريق المزدوجة في المعالج الحراري

للغازات الطيارة (دراسة لحالة الغاز الطبيعي)

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Abstract: Burner configuration in a double burner system affects its performance. Generally, interference between burners degrades their performance and hence increases air pollution from incinerators or industrial burners. However, it has been found that there is a preferred interference that improves the performance of the burners. The selection of a burner configuration that gives the best performance has been found to depend on the equivalent ratio of the feed (Φ). A configuration of parallel burners is preferred in a premixed fuel lean case ($\Phi < 1$). However, a configuration of perpendicular burners is preferred for non-premixed diffusion flames. In the premixed fuel lean case, the difference of CO concentration in the flue gas between the worst and the best configurations has been found to be 34%. In the premixed fuel rich case, the difference of CO concentration reached 88%. For laminar diffusion flames, where no premixed air is used, the difference has been found to be 167% for CO and 116% for CH₄.

Keywords: Boilers emission, burners configuration, diffusion flames, double-burner, equivalence ratio, fumes incineration, premixed flames.

المستخلص: إن وضع الحواريق في الأجهزة ذات الحواريق المزدوجة مثل المعالجات الحرارية والمراجل الصناعية، يؤثر على أداء تلك الأجهزة. وبشكل عام، فإن التداخل في تلك الحواريق يؤثر سلباً على أداء تلك الأجهزة، ويزيد من تلوث الجو بسبب عدم الاحتراق الفعال. لكن وجد أن هناك نوعاً من التداخل المحيد، الذي يزيد من كفاءة تلك المحارق في بعض الأحيان. تشير النتائج إلى أن اختيار كيفية تركيب المحارق يعتمد على نسبة التكافؤ لخليط الغازات الداخلة للحواريق (Φ). لقد وُجد أن المحارق المتوازية في الخليط الغازي الذي يحتوي على كمية قليلة من المواد المحترقة ($\Phi < 1$) هو الأفضل. ولكن وجد أن المحارق المتعامدة، هي الأفضل في حالة اللهب ذي الانسياب الطبقي الناتج عن حرق الغازات غير المخلوطة مسبقاً بالهواء. أما في حالة الغازات التي تحتوي على كمية قليلة من المواد المحترقة بالنسبة للهواء، كان هناك فرق 35% في تركيز غاز أول أكسيد الكربون الناتج عن الحرق بين أفضل وأساء وضع للمحارق. وفي حالة الغازات التي تحتوي على كمية كبيرة من المواد المحترقة بالنسبة للهواء ($\Phi > 1$)، كان هناك فرق 88% في تركيز غاز أول أكسيد الكربون الناتج عن الحرق بين أفضل وأساء وضع للمحارق. بينما في حالة اللهب ذي الانسياب الطبقي الناتج عن حرق الغازات غير المخلوطة مسبقاً بالهواء كان هناك فرق 167% في تركيز غاز أول أكسيد الكربون و 116% فرق في تركيز الميثان في الغاز الناتج عن الحرق بين أفضل وأساء وضع للمحارق.

كلمات مدخلية: المراجل الصناعية، تركيب المحارق، اللهب المنتشر، المحارق المزدوجة، نسبة التكافؤ، حرق الغازات، اللهب.

Introduction

Different technologies have been used for chemical waste treatment. Incineration is believed to be the most effective way to dispose of hazardous chemical waste (Kiang and Metry, 1982; Theodore and Reynolds, 1987; Brunner, 1993; Oppelt and Dempsey, 1993; Song, *et al.* 1993). The main challenge in incineration is to maintain combustion conditions that give the required destruction and removal efficiency (DRE) and meet other stack emission criteria. Much research has been directed toward the conditions that affect the incineration either in the post-flame region or in the pre-flame region, e.g. blending of the waste. Much work is dedicated to studies of the incineration process focusing on incineration parameters, such as temperature, residence time, excess air and mixing.

Several research groups studied the effect of additives (methanol, CO, H₂O₂, O₃) on DRE (Cooper, 1980; *et al.* 1992; Song, *et al.* 1993; Lee, 1994; Geiger, 1994). Other groups studied the correlation of the DRE of specific principal organic hazardous constituents (POHCs) with the incineration parameters (Miller, *et al.* 1989; Takeshita, *et al.* 1992; Song, *et al.* 1993). Cooper used time-temperature design parameters to study the destruction in a hydrocarbon vapor incinerator. The correlation between the conditions of incineration and the composition of the incinerator exhaust gas has been of special importance (Miller, *et al.* 1989; Takeshita, 1992; Song, *et al.* 1993; Wagner and Green, 1993; Martinez, *et al.* 1993; Rao and Saxen, 1993; Fangmark, *et al.* 1994; Thompson, *et al.* 1996).

In the case of liquid injection incinerators, which could also be used as fume incinerators, more than one burner is generally required. One burner is used to introduce the combustible waste, while an auxiliary burner is operated by natural gas or fuel oil. Since most of the destruction of the waste occurs in the flame, the configuration of burners, with respect to the incinerators and with respect to each other, is expected to play an important role in the destruction of the waste. Burners, as well as separate nozzles, may be oriented for axial, radial and tangential firing (Kiang and Metry, 1982; Oppelt and Dempsy, 1993; Brunner, 1993). It has been found that if liquid waste injectors or burners are located within a single air register, performance suffers (Kiang and Metry, 1982). As far as the authors know, no work has been done to study the effect of the configuration of burners on the destruction of fume waste.

In this paper we investigate the effect of burner configuration on systems using double burners in incineration or heating processes. Results could have direct application on fume incinerators or boilers and industrial furnaces that use natural gas as a fuel. The idea could be extended to different incinerator types that use multi-burners. However, tests are needed to quantify each specific case.

Experimental Setup

A schematic diagram of the experimental setup is shown in Fig. 1. The feed consists of natural gas and air. The composition of natural gas is found using a Chrompack gas chromatograph equipped with a flame ionizing detector and a 50m PLOT fused silica (CP-AL₂O₃/KCl stationary phase) capillary column. The combustion air is connected to a pressure regulator. A silica gel-calcium sulfate filter removes H₂O from the air stream. Then the air passes through 0.64cm (1/4 inch) rotameter from Fisher & Porter. Natural gas is passed through another 0.32cm (1/8 inch) rotameter from Fisher & Porter. The outlets of the rotameters and the pressure gauge (1400 electronic manometer from Datametrics) are connected together by a cross union. Mixing of gas and air occurs in a 25cm long, 0.64cm outside diameter (1/4 inch) stainless steel tube that ends with a T union. The gas mixture is then fed into identical burners through two 60cm long, 0.32cm outside diameter (1/8 inch) copper tubes. The burners' heads are made of stainless steel. As shown in Fig. 2, each burner has a rim that is 1.5cm wide and 1.5cm deep surrounding a 0.35cm orifice. Each burner head is connected through a 0.32cm (1/8 inch) union to the feed.

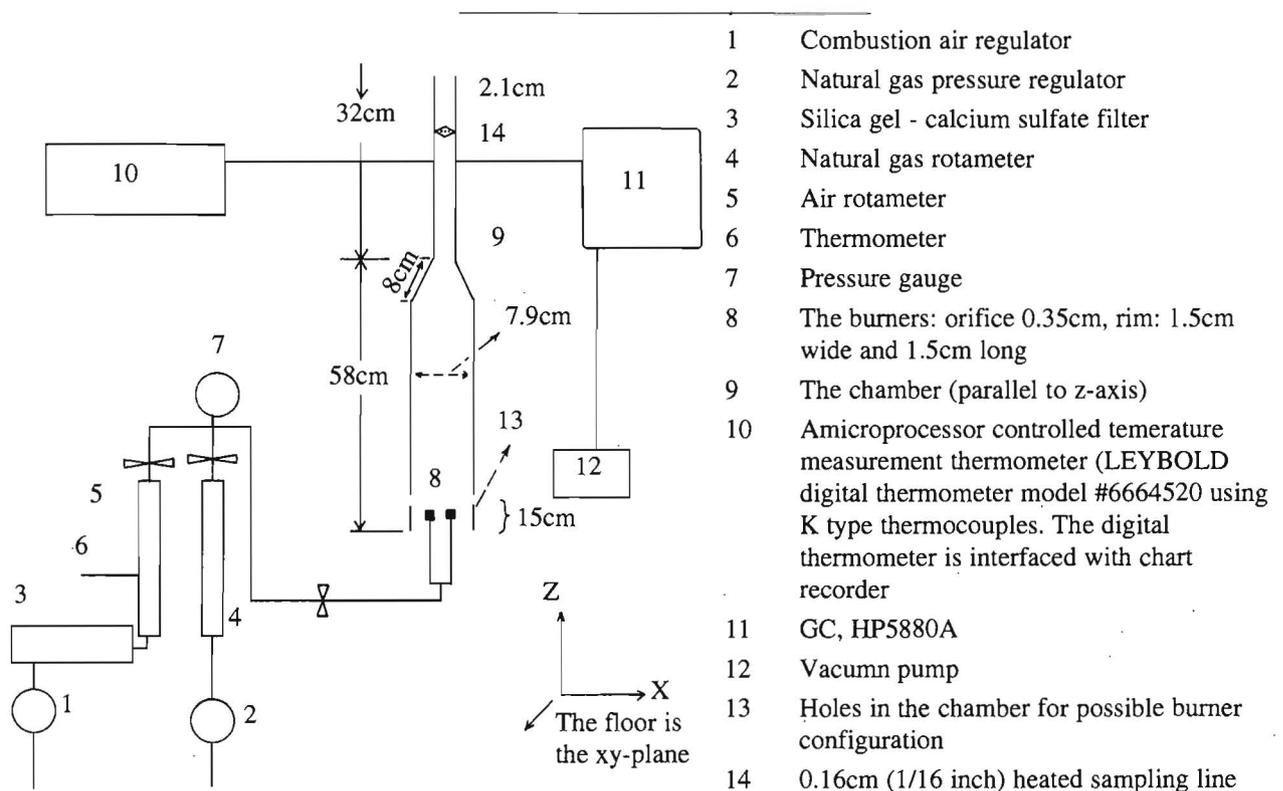


Fig. 1: The experimental setup

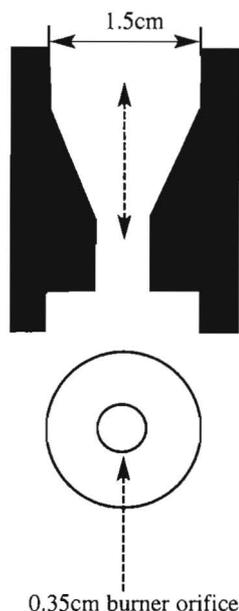


Fig. 2: The burner head

The chamber consists of two glass tubes welded as shown in Fig. 1. The lower part is 7.9cm inner diameter and 58cm long while the upper part is 2.1cm inner diameter and 32cm long. The holes in the chamber (#13 in Fig. 1) are used to obtain different configurations and are closed by aluminum foil after each configuration is set. The chamber is opened from both sides, which allows the ambient air to diffuse into the outer cone of the premixed flames and provides air in the case of diffusion flames.

For exhaust gas analysis, the sample is withdrawn from the chamber through a 0.16cm outside diameter (1/16 inch) stainless steel heated line that is connected to the 5.0ml loop-6-port gas sampling valve in a HP5880A gas chromatograph. A vacuum pump is interfaced with GC to allow continuous flushing of the sample loop. The GC is equipped with a thermal conductivity detector (TCD), flame ionization detector (FID) and a nickel catalyst methanator for CO detection by FID. The carrier gas is helium. A 13x molecular sieve column (4'x1/8") has been used for CO and methane separation at a He flow rate of 20ml/min. A pre-column 13x molecular sieve is used to trap H₂O and CO₂ from the sample to lengthen the lifetime of the column and the catalyst. The GC oven temperature is 50°C. The FID and TCD are at 250°C. The pressure of H₂ and air for the FID are 70 and 40psi, respectively. The pre-column and the column are conditioned at 300°C overnight before analysis the next day. The nickel catalyst also is activated under hydrogen gas at 350°C after each working day.

Temperature of the chamber is monitored (#10 in Fig. 1) using a microprocessor controlled temperature measurement thermometer (LEYBOLD digital thermometers, model #666452) using K type thermocouples. The digital thermometer is interfaced with a chart recorder.

The results of successive analysis of the exhaust gas and the temperature monitoring system (#10 in Fig. 1), measured near the sampling port, could indicate a steady state at given conditions.

Using a vacuum pump (#12 in Fig. 1), the sampling loop is first flushed by withdrawing the sample from the chamber (#14 in Fig. 1) at a flow rate of about 230ml/min for four minutes. The vacuum pump is then stopped, and after three minutes the sample is injected into the GC. Three to five samples are analyzed and averaged for each steady state studied. The concentrations of the species detected are normalized and given as $\bar{a} \pm \sigma$, where \bar{a} is the average of the measurements for each steady state and σ is the standard deviation.

Results and Discussion

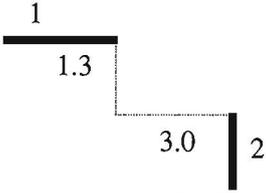
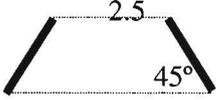
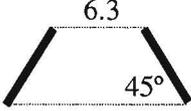
Different configurations of the burners at different equivalence ratios (Φ) have been studied. Carbon monoxide (CO) and methane were analyzed in each experiment using the FID of the GC.

Case 1: Fuel Lean Premixed Flames

The feed consists of air and natural gas. Natural gas consists of mainly methane, ethane, propane, butanes and ~1mass% of aromatics. The formula of the natural gas is calculated to be C_{1.16}H_{4.33}. The atmospheric flow of rates of air = 11430ml/min and of natural gas = 1020ml/min at 26°C, giving an equivalent ratio Φ of 0.97. The inner cone of each flame developed is about 2.5cm long. The outer cone extends up to 7cm, while the diameter near the rim is about 0.7cm. In this case, only CO has been detected.

Table 1 shows the CO normalized concentrations for different configurations of the burners. The distance shown between the burners is the distance from the center of the rim of each burner. The configurations A through G are arranged in decreasing order of the CO concentration in the exhaust gas. As may be seen, the performance of the burners depends on their configuration. In this aspect, the lower the CO concentration in the exhaust gas, the better the performance of the incinerator is. As could be seen from Table 1, the percent difference, [(maximum concentration - minimum concentration)/minimum concentration] x 100, of CO emission between the worst and best configurations is 34%.

Table 1: Normalized CO concentrations in the exhaust gas for different burner configurations. $\Phi = 0.97$

Burner configuration*	Normalized CO Concentration ($\bar{a} \pm \Phi$)	Comments
A) 	100±1.9	Burner 2 is parallel to z-axis, and burner 1 is parallel to x-axis, Fig. 1 more disturbance occurred and the conical shape of the upward flame flattened and bent away from the horizontal burner
B) 	96±1.2	About 1cm of the inner cones merged in each other at the top. The burners are in xz-plane, Fig.1.
C) 	92±1.6	The tips of the outer cones are touching each other. The burners are parallel to xz-plane.
D) 	91±1.5	The tips of the outer cones are merged in each other. The burners are parallel to x-axis.
E) 	90±0.9	The inner cone of each flame is about 2.5cm in length, the outer cone extends up to 7cm and 5cm and the diameter near the rim is 0.7cm.
F) 	84±0.6	The flame shape as in configuration E. The burners are parallel to z-axis
G) 	73±2.2	The flame shape as in configuration E. The burners are parallel to z-axis.

*Distances shown are in cm and they represent the separation from the center of burner heads (—). The inner cone of each flame is about 2.5cm long, the outer cone extends up to 7cm and the diameter near the rim is 0.7cm.

Considering configurations A to E in Table 1, configuration E causes the least interference between the flames. Interference is defined as the physical mixing, or flow overlap, between the reactants or products from both burners (King and Metry, 1982). Also configuration C causes less interference compared to B. As can be seen from CO concentrations, configuration A gives the worst performance and configuration E gives the best performance. This indicates that the more the interference between the flames the worse the performance of the burners. This conclusion is also in agreement with the behavior in liquid injection multi-burner systems. It has been found that if multiple injectors are located within a single air register, performance suffers (Kiang and Metry, 1982). As could be shown from the analysis in Table 1, configurations C-E give nearly the same performance. Here, the inner cones (2.5cm long) of the flames are far from each other; so the interference is less pronounced compared to A or B configurations, where the inner cones are touching each other.

Considering configurations E-G, it is clear that configuration G causes the highest interference due to the shorter separation between the burners. However, configuration G produces the least concentration of CO. It may be concluded that interference between the burners is not always undesired.

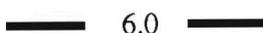
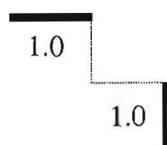
Case II: Fuel Rich Premixed Flames

Here, a fuel rich $\Phi = 6.01$ system is investigated. The atmospheric flow rates of air = 440ml/min and of natural gas = 378ml/min at 25°C. As can be seen in Table 2, the percent difference between the worst and the best configurations is 88% CO. While methane and carbon monoxide have been detected in some configurations, only carbon monoxide is detected in others. The concentrations of CO and/or CH₄ in the exhaust gas indicate how well the burners are performing.

The inner and outer cones of the flames are not well defined. The length of the flame extends up to 4.0-4.5cm with diameter of about 0.7cm. Methane and CO concentrations are normalized together (as if they are the same component) in Table 2. Since the GC used in these experiments detects CO after methanation, the response factor of the detector is the same for both CO and CH₄.

The opposite flames in configuration A (Table 2) give the worst performance. Again as in Case I, parallel burners that are 2.0cm apart give the best performance. Methane has been detected in configurations A and B, but it is not detected in configurations C and D, using the threshold of zero at attenuation 4 of the integrator. This shows that configurations C and D give better destruction of methane compared to configurations A and B.

Table 2: Normalized CO and methane concentrations in the exhaust gas for different burner configurations. $\Phi = 6.01$

Burner configuration*	Methane ($\bar{a} \pm \Phi$)	CO ($\bar{a} \pm \Phi$)	CO+CH ₄	Comments
A) 	25±1.0	100±0.3	125	The flames merged in each other
B) 	24±0.8	59±1.9	83	More disturbance occurred and the net flame has a length of 7-8cm
C) 	Not detected	59±3.3	59	The inner and outer cones are not well defined. The length of the flame from 4-4.5cm with diameter of 0.7cm
D) 	Not detected	55±0.3	55	The flame shape as in configuration C.

*Distances shown are in cm and they represent the separation from the center of burner heads (—). The flame developed in each burner is cylindrical. It is 7-8cm long and 1.0cm wide.

Case III: Laminar Diffusion Flames

Here, a diffusion flame is developed. No premixed air is used. The atmospheric flow rate of natural gas = 587ml/min. The length of the flame extends up to 7-8cm with a diameter of 1.0cm near the rim of the burner. In this case methane and CO have been detected. Methane and CO concentrations have been normalized as shown in Table 3. The overall $(CO+CH_4)\%$ difference concentration between configuration A and C is 22%.

As shown in Table 3, the total sum of CO and CH_4 concentrations in configurations C and B is lower than that of configuration of A. Therefore, in the case of a non-premixed diffusion flame studied here, the worst performance has been observed when the flames had least interference.

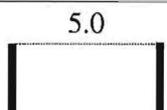
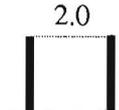
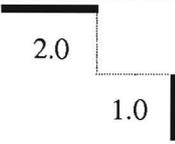
Different ways of interference gave different products distribution in the flue gas. While configuration B gave more methane than configuration C, i.e. less destruction of methane, configuration B gave less CO than configuration C, i.e. products of incomplete combustion were more

in configuration C. In configuration C the resultant flame is 13-15cm long which provides a larger trap for escaping CH_4 molecules. However, because of oxygen deficiency, partial oxidation occurs and this may explain a higher CO concentration than that of configuration B in Table 3. For non-premixed diffusion flames, mixing and interference between the burners is more preferred than non-interfered flames.

As could be seen from Table 1-3 the preferred configuration depends on the equivalence ratio. While perpendicular flames (configuration A, Table 1) are the worst in fuel lean flames, the opposite is observed in complete diffusion flames where no premixed air is used.

Comparing the parallel configurations (E & F in Table 1, C & D in Table 2, A & B in Table 3) which are separated by 5.0cm (or 5.3cm) and those separated by 2.0cm in the three cases studied, it could be seen that the performance of the burners is better in the 2.0cm separation. In all of these couples, the interference is preferred and gives better performance of the burners.

Table 3: Normalized CO and methane concentrations in the exhaust gas for different burner configurations. No premixed air is used.

Burner configuration	Methane ($\bar{a} \pm \Phi$)	CO ($\bar{a} \pm \Phi$)	CO+CH ₄	Comments
A) 	63±3.4	100±1.6	163	The flames is cylindrical. It is 7-8cm long and 1.0 thick
B) 	93±4.3	43±2.1	136	The flame is as case A.
C) 	43±2.3	91±0.68	134	More disturbance occurred and the net flame has distorted cylindrical shape (flattened) of length 13-15cm and 2cm in diameter.

Conclusion

The configuration of burners in a double burner system affects its performance. The selection of a certain configuration to achieve the best performance has been found to depend on the equivalence ratio of the feed (Φ). The configuration of parallel burners is found to be preferred in a premixed fuel lean case ($\Phi < 1$). However, a configuration of perpendicular burners is preferred for non-premixed diffusion flame. The parallel burner configuration is also found to be preferred in the premixed fuel rich case. However, the improvement in the performance of the burners is much less pronounced compared to the corresponding premixed fuel lean case.

The present study could have direct application on fume incinerators, where fumes are fed directly through the burners, or boilers and industrial furnaces (BIFs) that use natural gas as a fuel. The idea could be extended to different types of BIFs or incinerators that use multi-burners and other types of fuel.

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