Effects of Mixing and Temperature on Reaction Rates in Fume Incinerators

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With an increasing awareness of the adverse environmental effects of unreacted hydrocarbons, federal, state and local air pollution agencies have enacted legislation restricting hydrocarbon emissions. The first major legislation of this kind, known as L. A. Rule 66, was enacted in Los Angeles, California, on July 28, 1966. This initial legislation set the pattern for similar legislation in other geographical areas and different levels of government agencies.

The section of L.A. Rule 66, applicable to incineration, reads as follows:

> Rule 66
>
> f. Emissions of organic materials into the atmosphere required to be controlled by sections (a), (b), or (c), shall be reduced by:
>
> (1) Incineration, provided that 90% or more of the carbon in the organic material being incinerated is oxidized to carbon dioxide, or
>
> (2) Adsorption, or . . . . . .

Out of many physical and chemical methods of hydrocarbon removal, incineration is perhaps the most practical and economical method for fumes originating from many industrial operations. The National Fire Prevention Association (NFPA), requires that the fumes from such sources be diluted to 25% of the Lower Explosion Limit (LEL). The NFPA recommends 10,000 SCF of air for every gallon of solvent evaporated. Assuming an average heating value of 140,000 Btu per gallon, the heating value of fumes is 14 Btu per cu. ft. It is known that, as a rule of thumb, 1 cu. ft. air is required for every 100 Btu released by stoichiometric combustion of any type of fuel. Hence, the fumes contain approximately 7.15 times air than required for the stoichiometric combustion of their hydrocarbon content. The adiabatic flame temperature of this mixture is approximately 600°F, and sufficient heat must be supplied to the mixture to raise its temperature at levels where the reaction rate between the available oxygen and the hydrocarbons is significant.

In early attempts of oxidation of hydrocarbon from fumes, it was common to supply this heat by firing gas burners into the fume stream. The burners were located in a variety of configurations; tangential and opposed flow being the most common. This type of system had questionable mixing characteristics, and it was difficult to obtain uniform temperature for the whole stream. Many times, with improper burner designs, the flame quenching resulting from the relatively low temperature aggravated the problems of

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incineration. Such systems had a distinct disadvantage of high operating costs because of the additional heat load imposed by the introduction of combustion air through the burners.

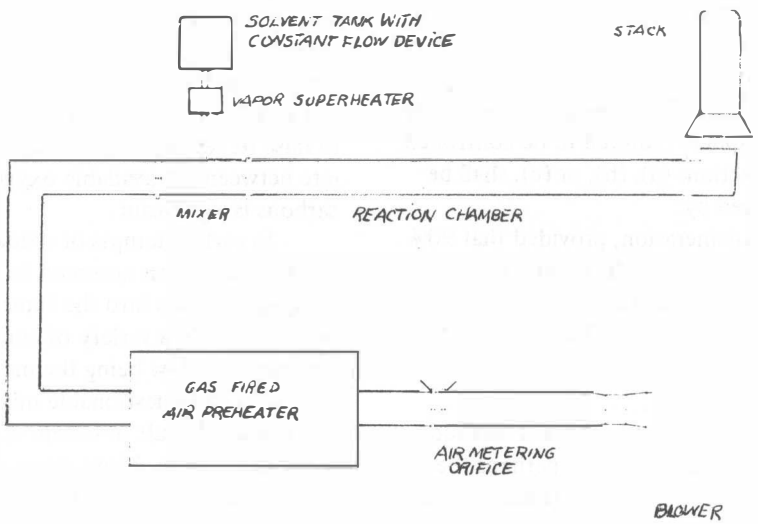
This led to the development of the "Raw Gas" burner, which utilizes the oxygen in the fume stream for the combustion of the fuel, which is normally natural gas. With this type of burner it is very important that the fuel distribution in the fume stream is very uniform; otherwise the unreacted fuel in the fumes would increase the hydrocarbon content, rather than decreasing it. At this time it was believed that the presence of the flame and free radicals associated with a flame were necessary for the combustion of dilute fume stream. Based on this theory, many "Raw Gas" burners took the shape of a grid of gas outlets, resulting in a grid of individual gas flames. The incinerator design was often based on a rule of thumb, of unknown origin, which stated that a residence time of 0.5 seconds at 1400°F. mixture temperature is necessary to incinerate the fumes. As will be shown later, this guide line was an estimation of the time required to hydrocarbon - oxygen reaction in poorly mixed system.

In early 1967, the Surface Combustion Division of Midland-Ross Corporation entered into a joint venture with Columbia Gas Systems Corporation to carry out a research program concerning fume incineration. Fume incineration research facilities were constructed to gather information on the reaction kinetics and its dependence on temperature for various typical hydrocarbons commonly found in fumes. Also, it was intended to study degree of mixing and its effect on incineration efficiency of various burner geometries. Using this information, the research group came out with several new designs of fume incinerators in which the fume incineration can be carried out with the minimum amount of auxiliary fuel over a wide variation of fume generating conditions, using a very efficient mixing system and a stable burner with a broad range of turndown.

Figure 1 shows a schematic of the research test facility. With this set up, the air flow could be measured through a calibrated orfice, the gas fired air preheater could indirectly heat the air stream to the desired temperature, the solvent tank with constant flow device and vapor superheat introduced vapors at the desired rate, the mixing chamber mixed the solvent vapor and preheated air stream, and the test ports along the axis of the reaction chamber provided a means for measuring reaction rates. By using preheated air, all radial thermal gradients were eliminated and the temperature uniformity required for accurate kinetic data was established. In addition to providing kinetic data, this test facility definitely established that the presence of a flame was not a requirement for the oxidation of hydrocarbons.

Figure 2 shows the actual construction of this facility.

Figure 3 shows a comparison of incineration rates for three hydrocarbons at a constant stream temperature of 1410°F. These hydrocarbons are cyclohexane, hexane and toluene. Note that for a well mixed system, a reaction time of 0.1 second will



RESEARCH TEST FACILITY

FIGURE 1

FIGURE 2

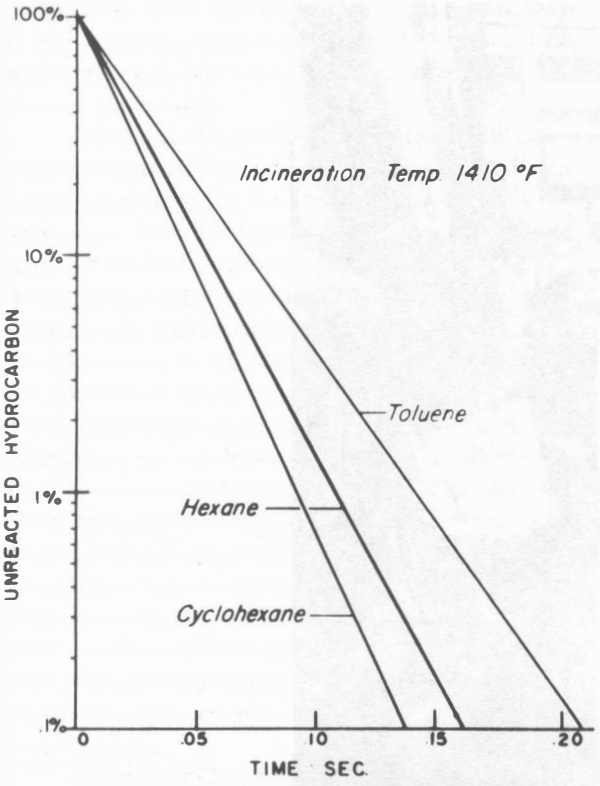
provide the 90% conversion required by L.A. Rule 66 at a temperature of approximately 1400°F. This time is considerably less than the normally used figure of 0.5 seconds. It must be emphasized, however, that complete mixing is necessary to achieve this value.

Figure 4 shows the decrease of Toluene concentration for different reaction times and temperatures. All initial concentrations were approximately 3,000 ppm and the differences on the abscissa at zero time indicate the experimental difficulties in establishing a zero time on a well mixed system with rapid reaction rates. In spite of these experimental difficulties, the exponential influence on reaction rate by temperature is clearly evident.

Figure 5 shows the duct incinerator facility which was used to develop a burner, mixing system and a reaction chamber. This facility has means for preheating the air and introduction of solvent vapor (fume spray) in the air to simulate fumes. A high temperature fan is used to handle the fumes. The fumes are mixed with hot gases from a specially designed gas burner. The mixing of hot gases and fumes takes place downstream and inside an annular orifice ring. This mixing device, as described in a later figure, produces very efficient mixing before the hot fume gas mixture goes to a reaction chamber.

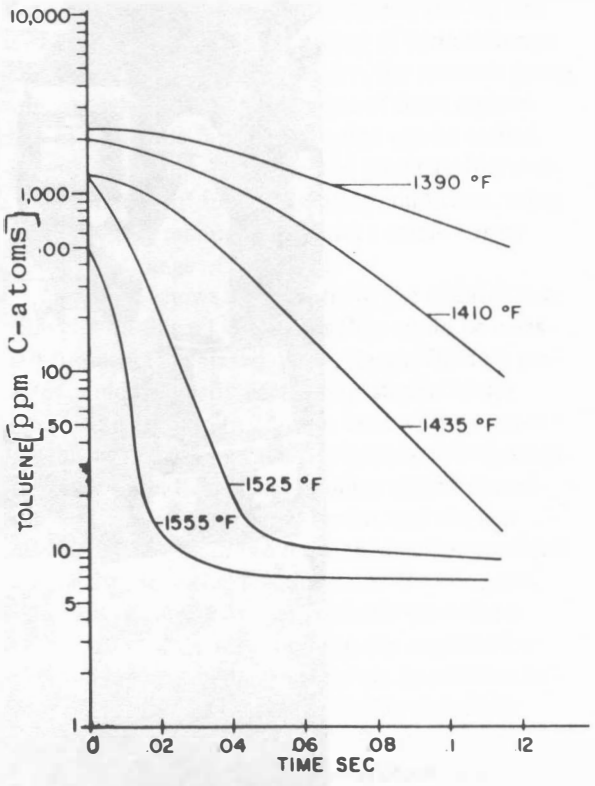
Figure 6 shows the gas burner which has a turndown of 10:1 on air rate and equally high turndown on gas rate. The flame length is very short and a very small volume of total fume flow passes through or from the vicinity of the flame. A high turndown on air is extremely important for batch or intermittent processes where it is desirable to maintain the unit at temperature during idle periods. By reducing the air flow through the unit to a minimum at low load conditions, approximately a 90% reduction in fuel costs can be achieved.

Figure 7 shows velocity profiles of the hot gas–fume mixture downstream of the annular orifice baffle. Note that initially there is a considerable recirculation of gases. This recirculation zone promotes a high degree of mixing between the hot gases and the relatively cold fumes. In spite of the initial nonuniform



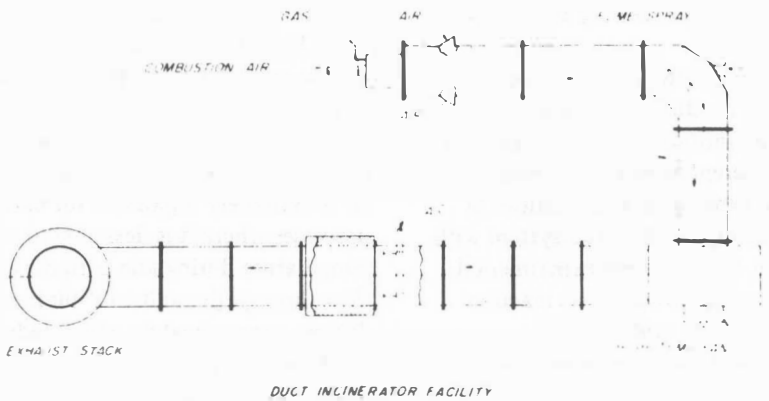
COMPARISON OF INCINERATION RATES FOR THREE HYDROCARBONS

FIGURE 3



DECREASE OF TOLUENE DEPENDENT ON TIME AND TEMPERATURE

FIGURE 4



DUCT INCINERATOR FACILITY

FIGURE 5

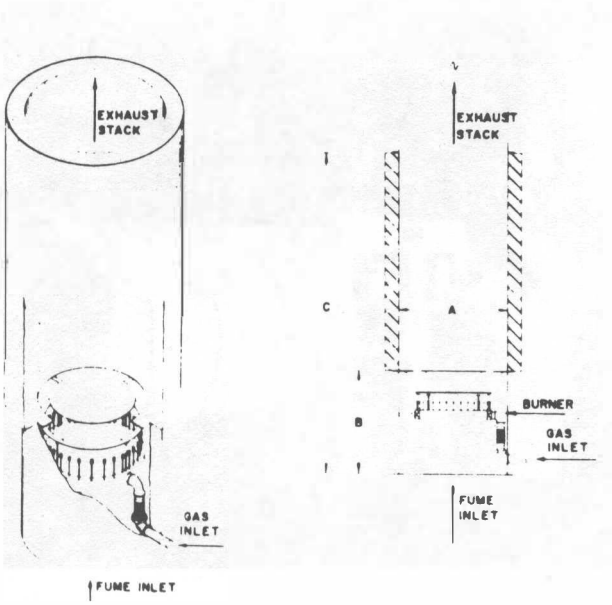
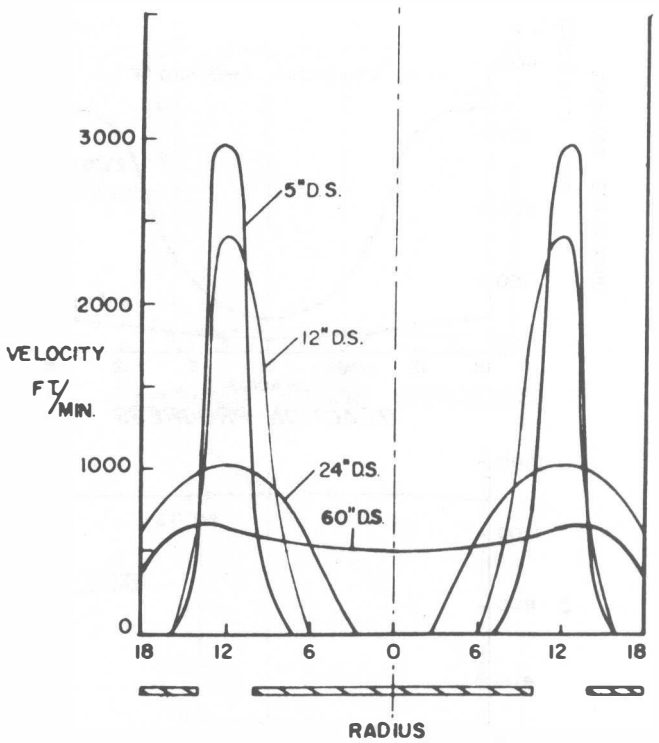
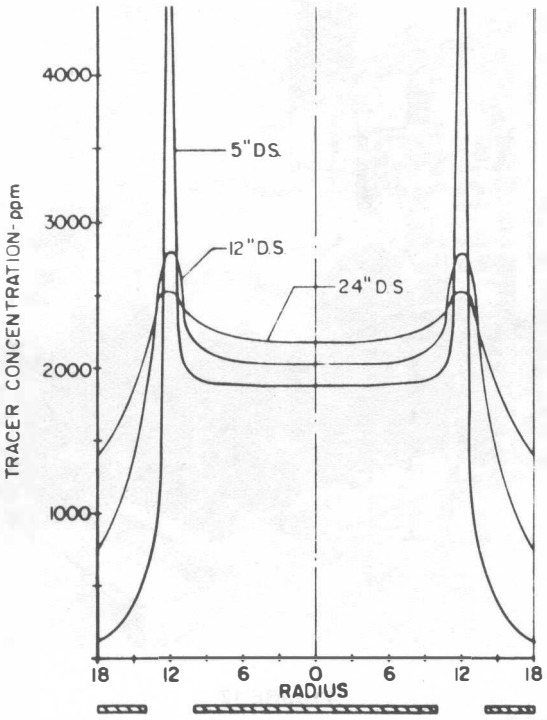


FIGURE 6



VELOCITY DEVELOPMENT DOWNSTREAM OF BAFFLE

FIGURE 7



TRACER CONCENTRATIONS INDICATING MIXING PERFORMANCE

FIGURE 8

velocity profile, the velocity becomes fairly uniform within a distance of 60 inches in a 36 inches diameter unit. This means that the uniformity is obtained within less than two diameters.

Figure 8 shows tracer concentrations for gases discharged from the burner. This indicates mixing performance.

Figure 9 shows reaction progress and temperature uniformity downstream of the burner baffle. Note the sharp decrease in unreacted toluene in the recirculation zone. The temperature and concentration of toluene are practically uniform in less than 2 diameters downstream.

Figure 10 shows the full sized laboratory burner. This particular size is rated for 5,000 SCFM.

Figure 11 is a view looking directly into the burner. In the color slide you can note the temperature uniformity of the two tests bars located 2 diameters downstream from the burner.

Figure 12 is a packaged stack fume incinerator, less refractory stack, pre-piped and wired for simple field installation.

Figure 13 shows a cross section of a Jet Incinerator, developed for applications where it is desirable

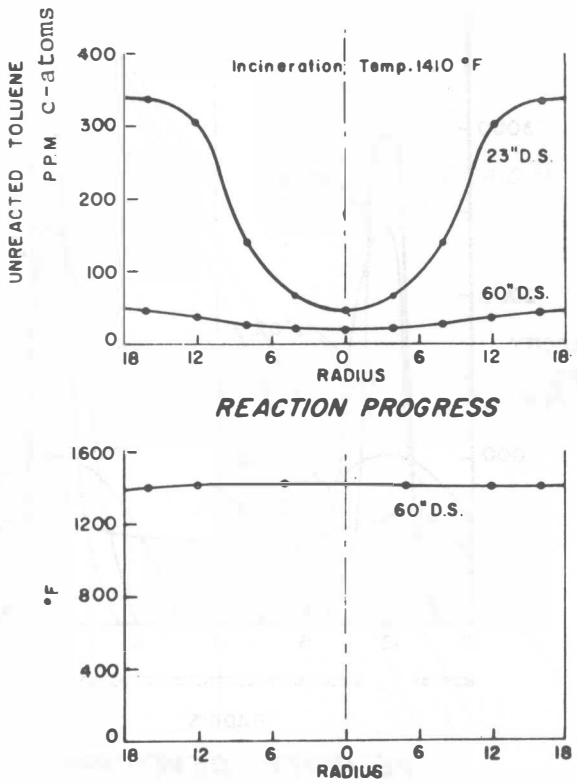


FIGURE 9

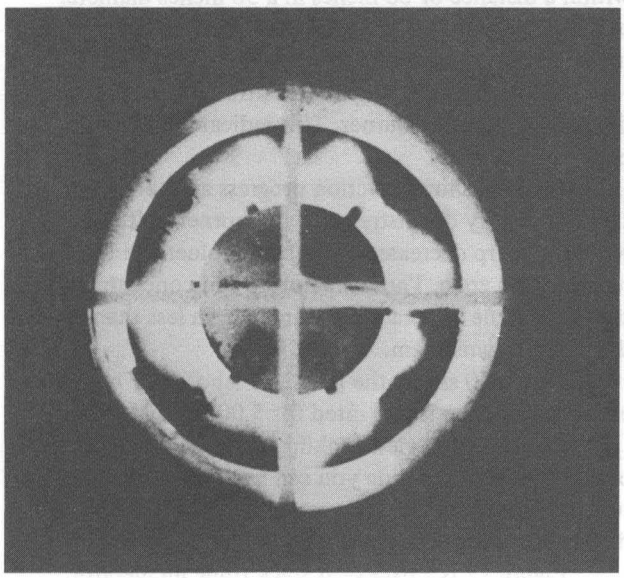


FIGURE 11

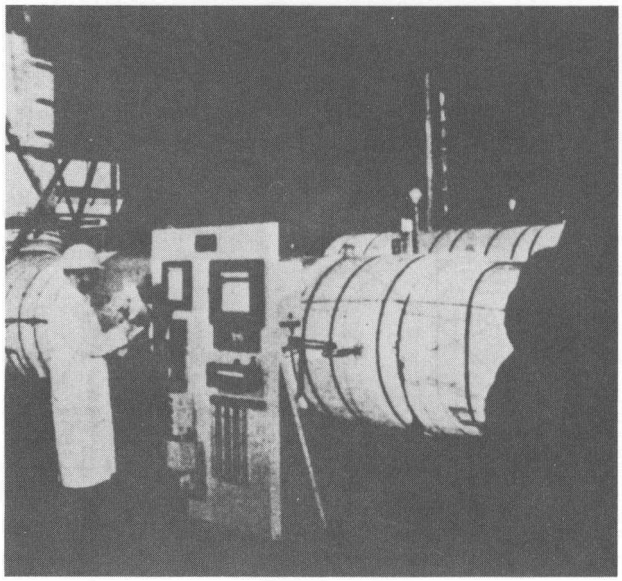


FIGURE 10

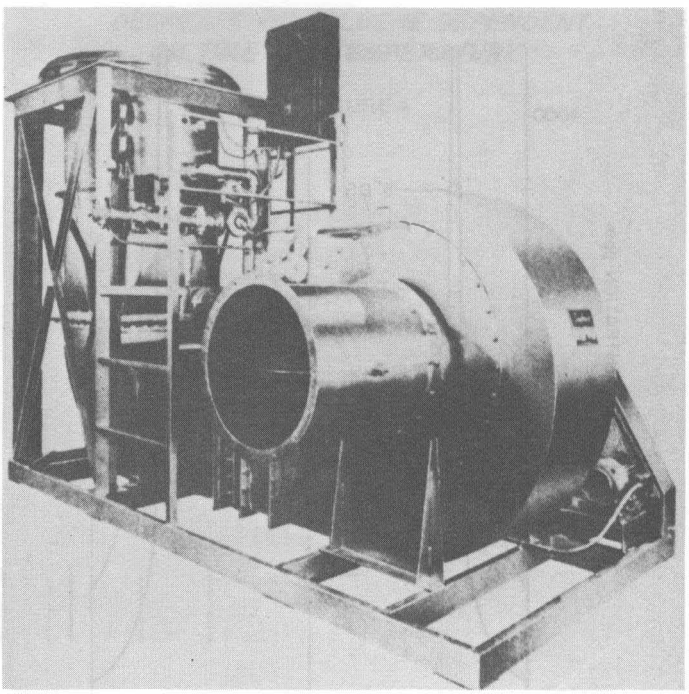


FIGURE 12

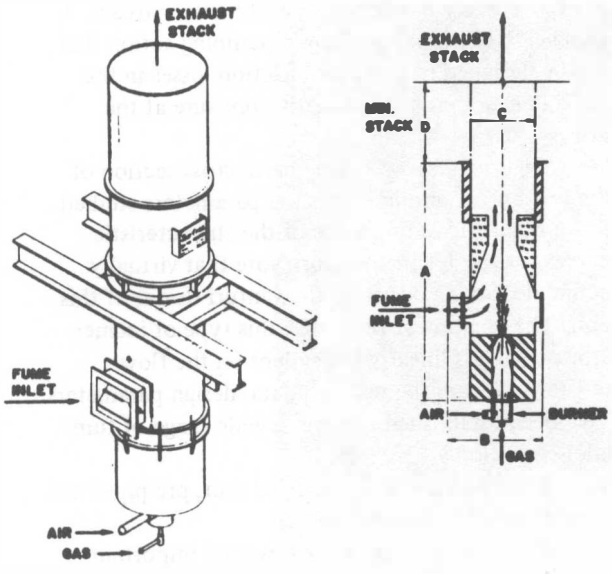


FIGURE 13

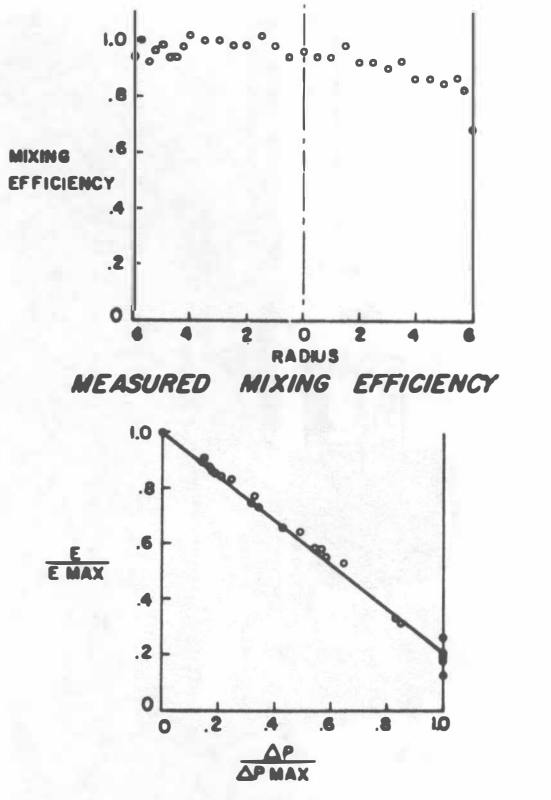


FIGURE 14

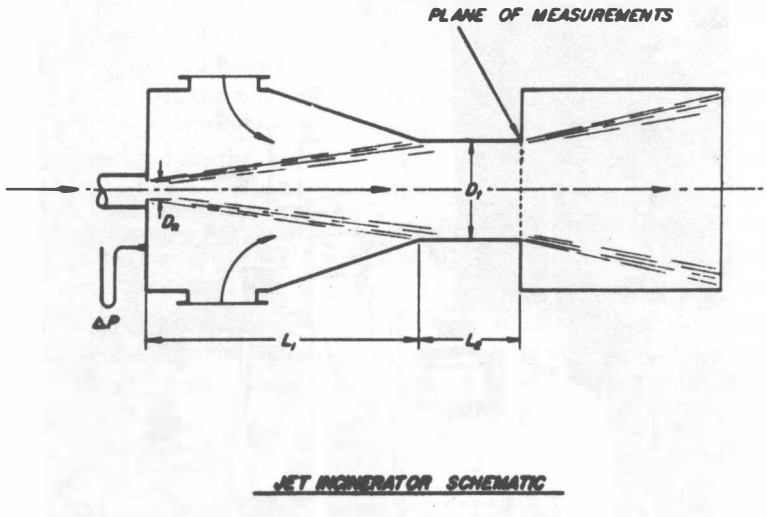


FIGURE 15

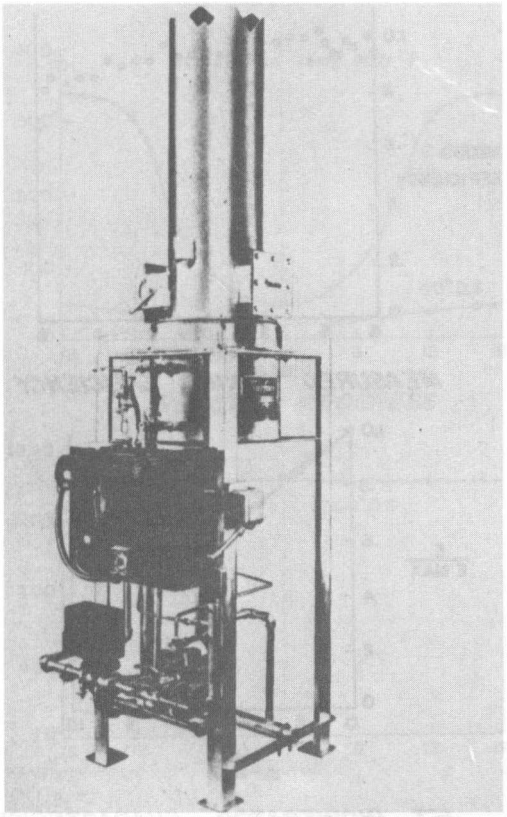


FIGURE 16

not to have any moving parts in the fume stream. A high velocity burner provides a pumping action that can be designed to overcome friction losses in the fume line and provide a negative pressure at the process.

Figure 14 shows a schematic cross section of the test burner and indicates the parameters studied.

Figure 15 shows some of the characteristic curves for the Jet Incinerator. Note that virtually complete mixing occurs at the venturi throat of this unit. The amount of fume that this type of incinerator can pull is linearly dependent on the flow resistance. From the research data, design parameters have been established to cover a wide range of fume inlet-conditions.

Figure 16 shows a packaged unit, pre-piped and wired, ready for installation.

From the data presented, several important conclusions can be drawn.

1) Oxidation of hydrocarbons is not dependent on the presence of a flame.

2) For a perfectly mixed system, reaction rates are much higher than previously anticipated.

3) Reaction rates are extremely temperature dependent.

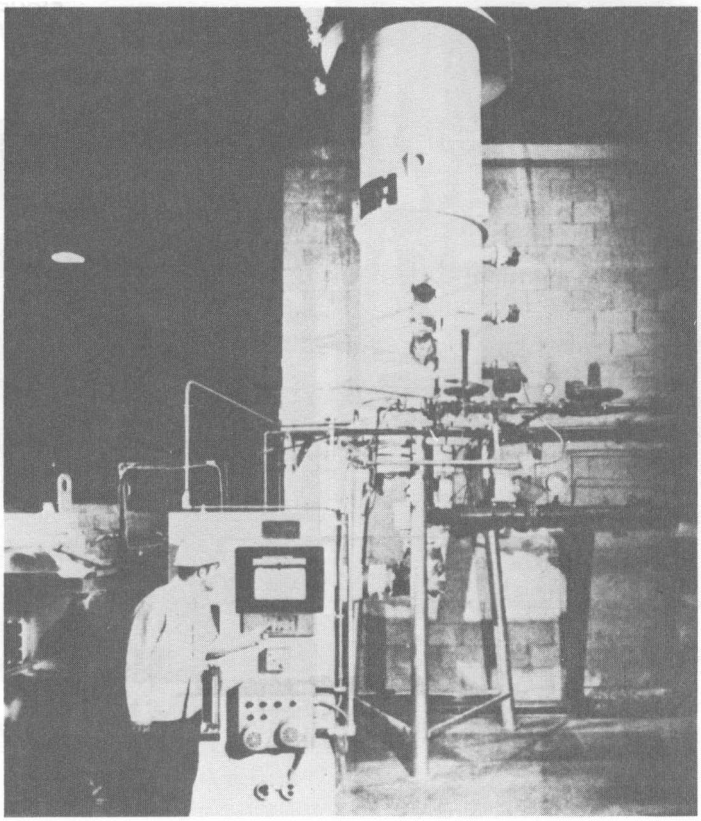


FIGURE 17

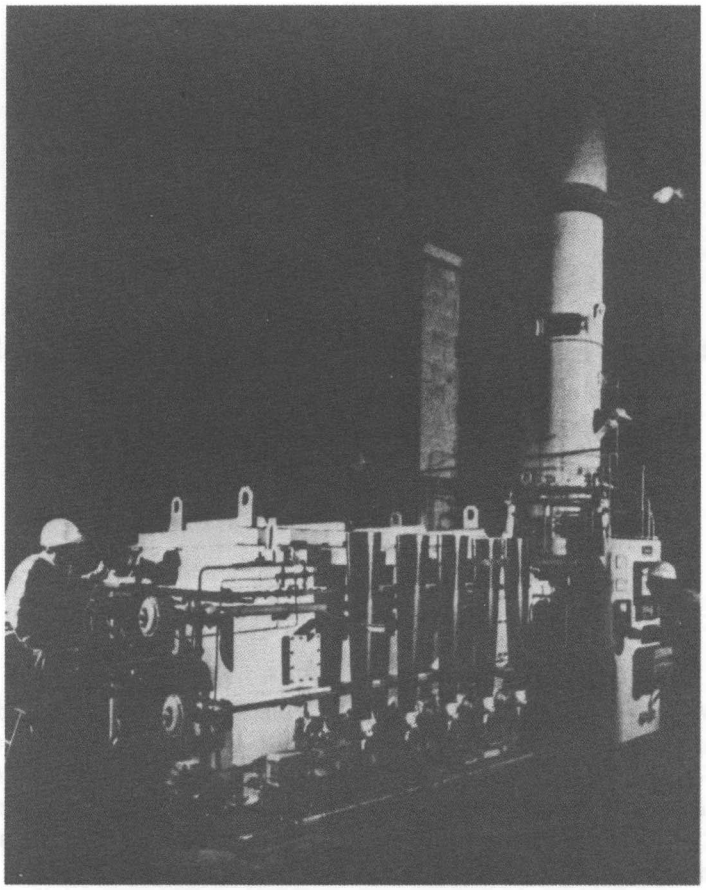


FIGURE 18

4) Incinerator designs are available that can effectively duplicate a perfectly mixed system.

The technical information about mixing and reaction rates of hydrocarbons, developed during this research has resulted into Fume and Jet Incinerators. Recently this knowledge is utilized in development and design of a unit which can be used for the incineration of fumes which have relatively high heating values due to high hydrocarbon content. This unit is known as "Rich Fume Incinerator". A laboratory unit was used to establish design parameters of the rich fume incinerator.

Figure 17 shows the photograph of the laboratory unit. Two rich fume incinerators have been operated successfully in the field for a year for incineration of volatiles generated during carbon baking process.

The rich fume incinerator uses air for pumping and combustion of hydrocarbon vapors and unburned carbon particles such as encountered in carbon baking, wax melting or pyrolysis process. Theoretical equations for predicting the pump characteristics have been derived and optimum design parameters have been established so that the unit needs minimum of auxiliary fuel.

Figure 18 shows the complete system with a pyrolyser to generate rich fumes and the rich fume incinerator. The writers are hopeful that full details of this incinerator can be presented at a future meeting.