Smoke Emission from Burning Crude Oil

by

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ABSTRACT

Research has shown that burning can be an effective means to remove oil from the surface of the water after a spill. Previous research has focused on laboratory studies of combustion products from oil pool fires less than 1 meter in diameter. This paper describes instrument packages developed to determine the amount of various combustion products emitted from large (15 m x 15 m) crude oil pool fires. Based on samples drawn directly from the smoke plume immediately downstream of the flame, burning a mixture of Arabian light and Murban crude oils in a 2.7 m x 2.7 m pan produces a smoke yield of 0.15. Preliminary results from burning Louisiana crude in a 6 m x 6 m pan indicate a similar 0.14 of the crude oil is converted to smoke in the combustion process. The increase in burning rate and smoke production with increasing fire size is discussed. Progress is reported on new calculation methods for smoke dispersion and downwind deposition of particulate. Results of example calculations are presented.

INTRODUCTION

Response to oil spills includes consideration of oil containment, recovery, disposal and the logistics of delivering adequate response equipment quickly to the spill site. The use of burning as an oil spill response method is attractive, particularly in remote areas. Burning requires a minimum of equipment, and because the oil is gasified during combustion, the need for physical collection, storage, and transport of recovered product is reduced to the few percent of the original spill volume that remains as residue after burning.

Concerns regarding the safety of burning and the impact of the smoke on the public health have hampered the use of burning as an oil spill response method.

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Burning oil spills produces a visible smoke plume containing smoke particulate and other products of combustion. The public health concerns relate to the chemical content of the smoke plume and downwind deposition of particulate. Safety concerns have been raised regarding the effects of heat and thermal radiation from large fires on personnel and equipment. These concerns are being addressed both through measurements and predictions of effects of oil spill burning in a research program conducted by the U.S. National Institute of Standards and Technology (NIST) and sponsored by U.S. Minerals Management Service (MMS), U.S. Coast Guard (USCG) and the American Petroleum Institute (API).

BACKGROUND

In this six year research program, specialized large laboratory scale fire facilities at NIST have been used to investigate the fire dynamics and chemistry of the oil spill burning process. These studies have provided new quantitative information about the crude oil burning process including smoke particulate characteristics, polycyclic aromatic hydrocarbon (PAH) content, smoke plume trajectory and particulate settling. The results of this research have been presented previously [1-6].

The large accidental spill of crude oil from the tanker Exxon Valdez in Prince William Sound, Alaska focused national attention on oil spill response technology. In cooperation with a team of interested parties from industry and government, planning has begun for operational tests of burning on an experimental oil spill at sea in 1991. In preparation for these tests, the NIST research program is developing means to measure the burning characteristics of these large fires. To accomplish this task, NIST has developed methods and equipment for field measurement of many of the quantities used to evaluate crude oil combustion in the laboratory [5].

This paper contains results of measurements using the methods and equipment developed to evaluate the burning of crude oil. These measurements involved the use of fire testing facilities in both the United States and Japan. To assist in preparations for the offshore burns there has been an emphasis on understanding the effects of the area and quantity of fuel being burned (fire scale) on measured quantities. In this same regard, progress is reported on calculation methods capable of predicting the trajectory and settling of particulate from smoke plumes produced by burns of a size expected in an actual spill response which are larger than burns which can be reasonably conducted as experiments.

FACILITIES

The development and testing of new measurement equipment and techniques to evaluate crude oil combustion in offshore field tests of in-situ burning involved the use of four different facilities. Two of these facilities are large fire test laboratories and the other two are outdoor liquid fuel burn pans.

Initial laboratory measurements of crude oil burning characteristics were performed in the fire test facility at NIST. Basic measurements of the combustion process were performed by burning crude oil in 0.4 m and 0.6 m diameter pools and collecting the combustion products in a specially constructed and instrumented exhaust hood system shown in Figure 1. Samples drawn from the exhaust hood duct were used to quantify the amount of each major combustion product generated per kilogram of crude oil burned, the chemical composition of the smoke including polycyclic aromatic hydrocarbon (PAH) content, the size distribution of smoke particles, and the oxygen consumed in the combustion process. Oxygen consumption rate was used to calculate the heat release rate of the fire, which is the primary quantity used to characterize burning intensity. To further characterize the combustion process, additional instrumentation was used to measure radiant heat flux from the flame and mass loss rate of the burning fuel [5].

The relatively small, 0.6 m diameter, fires provide a good means of measuring fire characteristics under controlled conditions but are too small to provide a adequate test of measurement equipment being developed for field use. Through the cooperation of the Fire Research Institute (FRI) in Tokyo, Japan, joint studies of crude oil burning were conducted. FRI maintains a fire test facility in which crude oil pools up to 3 m in diameter are burned with all of the combustion products collected in a large hood system. Figure 2 shows a crude oil fire burning in the 24 m x 24 m x 20 m high test hall. This facility provided means to test the sampling equipment developed for field use under controlled laboratory conditions.

As part of the fire fighter training program at the U.S. Navy Fire fighter training facility in Norfolk, Virginia, 15 m diameter fuel oil fires are burned and extinguished. These fires were used as burns of opportunity to refine the techniques for instrument transport and positioning in an outdoor wind blown fire plume. Figure 3 shows a tethered blimp used to carry an instrument package into the plume from a test fire at the facility.

The final stage of preparation for the offshore burns involved the use of fully operational measurement methods in meso-scale crude oil burns up to 15 m square. In cooperation with the U. S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama, burns have been conducted in a new burn pan facility on Little Sand Island in Mobile Bay. The 15 m square and 0.6 m deep pan, shown in figure 4, was surrounded by a water filled channel designed to

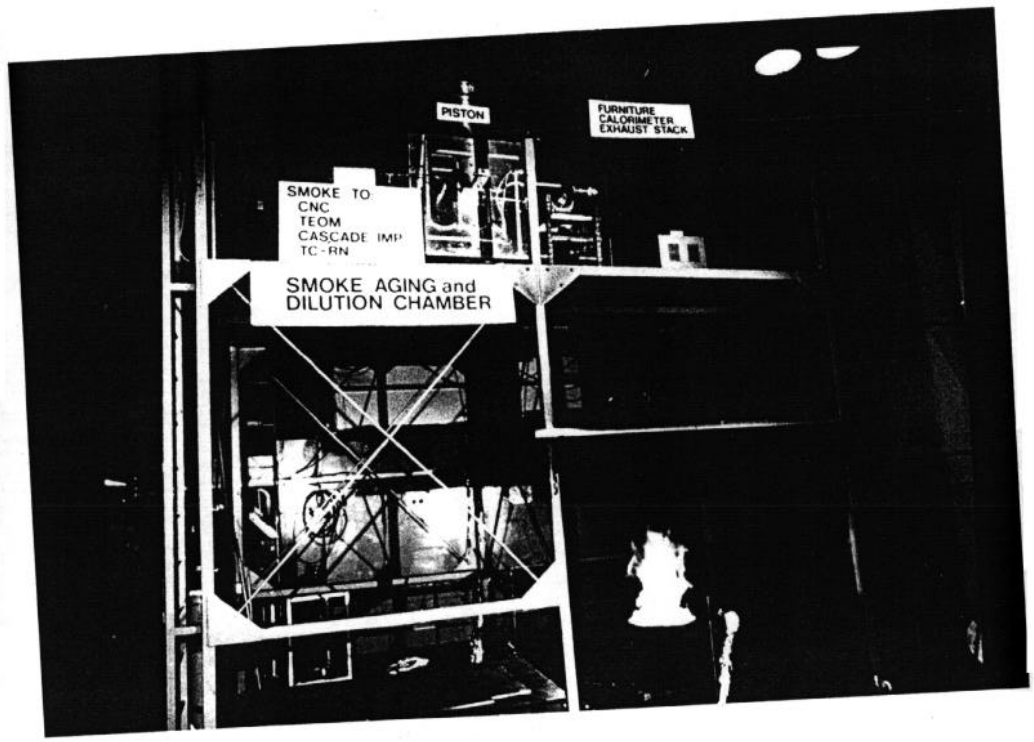

Figure 1 NIST Fire Test Laboratory, Gaithersburg, Maryland

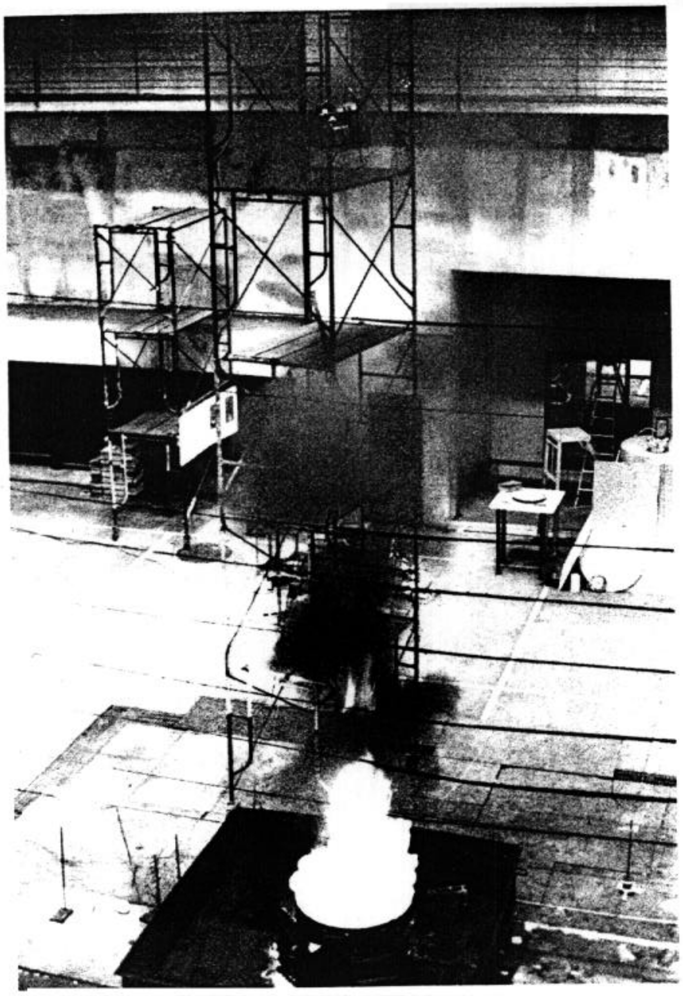

Figure 2 Fire Test Laboratory at Fire Research Institute, Tokyo, Japan

Figure 3 Navy's Farrier Firefighting Facility in Norfolk, Virginia

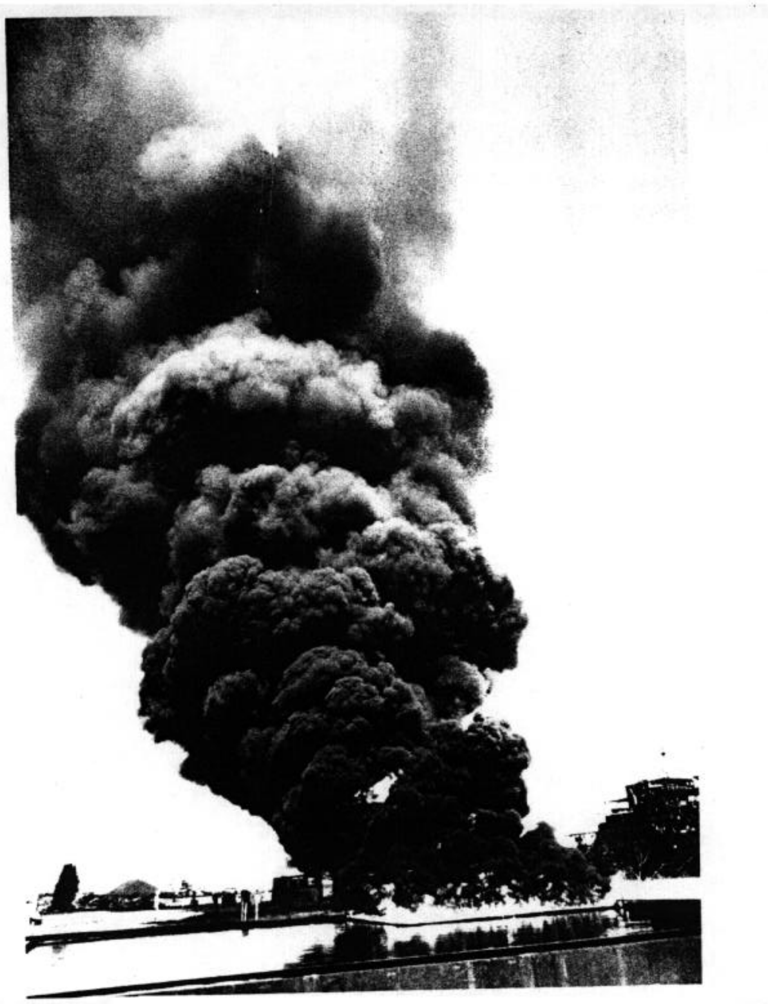

Figure 4 USCG Fire and Safety Test Detachment burn facility, Mobile, Alabama

protect the pan. In addition to the airborne measurements in the smoke plume, extensive ground measurement equipment was used to characterize the fire thermal radiation field, chemical and particulate species present, and local weather conditions.

BURNING RATE

The controlling mechanisms for the burning are presented in the often cited review of the Blinov and Khudyakov studies by Hottel [7]. Pool fire studies generally seek to understand the burning rate, flame height, and thermal radiation emitted as a function of pool diameter [8]. Normally single component liquid fuel pool fires are studied. After an initial ignition transient, these fires achieve nearly steady burning conditions. Over the range from normal laboratory experiments (order 0.1 m diameter) to field scale (order 10 m) there is a strong increase in burning rate per unit area. This reflects a change from convection dominated heating of the fuel at 0.1 m diameter to radiative dominated heating at the large fire diameters. The dominance of thermal radiation from the turbulent flames and the nearly equal heat of vaporization for the hydrocarbon fuels measured results in a nearly the same constant burning velocity (fuel surface regression rate) for all of the fuels in large diameter pools [7].

The study of crude oil combustion on water is complicated by two factors. One is that the oil is being burned in a layer floating on water. The other is that crude oil is a blend of many hydrocarbons with a wide range of boiling points the majority of which are at greater temperatures than the boiling point of water. For example, distillation measurements of South Louisiana crude oil show that 90 percent of the compounds in the oil have boiling points above 100°C [9]. During burning the surface of the crude oil maintains a temperature of around 300°C. As the fuel is consumed, heat transferred through the fuel to the water below can boil the water. This effect of "thin layer boilover" has been observed in laboratory crude oil pool fires with nominally 1 meter diameters [1]. The result of this boiling of the supporting water level is to agitate the fuel layer with both fuel and water droplets being sprayed into the flame, substantially increasing the burning rate of the fire [1,2]. Measurements of particulate formed during this intensive burning period have indicated that smoke production per kilogram of fuel consumed is reduced compared to burning prior to the "thin layer boilover [3]." The role of boilover in crude oil combustion at large scale is unclear at this time. It is being studied as part of this research through cooperative experiments with the Fire Research Institute in Japan [10] and through analysis [11].

Ignoring the complications of fuel distillation and boilover phenomena, the available data from burning of crude oil pool fires, figure 5 [12], suggest that burning velocities are nearly constant for pool diameters in the range of 5 m to 30 m. Based on these data, the pan built for the meso-scale crude oil fire tests to be conducted in Mobile, Alabama was designed to accommodate pool

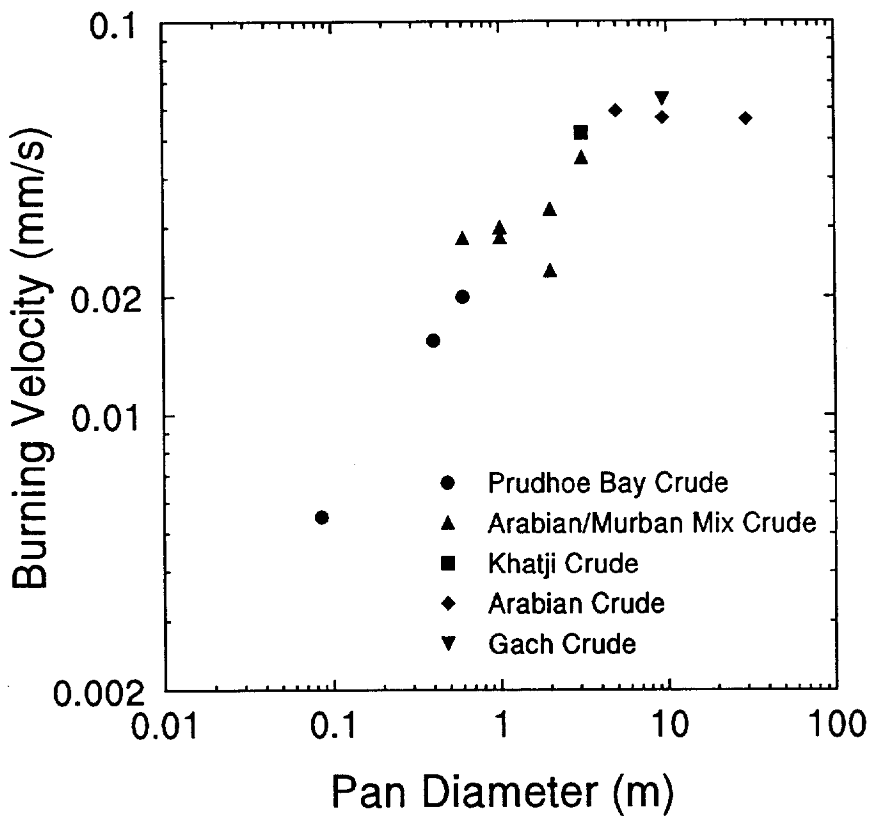

Figure 5 Crude oil fire burning velocity [10]

diameters up to 15 m. This was thought to be large enough to assure that the resulting fuel consumption per unit area would be the same as in the future larger burning area offshore tests.

In preliminary test burns in a 6 m x 6 m corner of the 15 m x 15 m pan on Little Sand Island in Mobile Bay, a 45 mm deep layer of Louisiana crude oil on bay water was consumed in 812 seconds. This equates to an average burning velocity of 0.055 mm/s. This datum agrees with other crude oil burning rates plotted in figure 5. Observations during the burn indicated that "thin layer boilover" occurred. The effect of boilover on the fuel consumption rate in large diameter pool fires has not been evaluated. Measurements to evaluate burning during "thin layer boilover" are being planned for future meso-scale experiments.

SMOKE YIELD MEASUREMENT

Methods to measure the smoke production from liquid pool fires have been evaluated in laboratory tests [1]. Smoke yield, the mass of smoke particulate produced from burning a unit mass of fuel, can be determined using the carbon balance method in both laboratory and field experiments . Smoke yield by the carbon balance method is the product of the measured fraction of carbon in the fuel and the ratio of the measured carbon in the form of smoke particulate to the measured total carbon in the combustion products including particulate, CO_2 and CO.

The carbon balance method is the only known method for determination of smoke yield in field tests because it does not require measurement or knowledge of the total combustion product flow. With regard to smoke yield measurements, field burns differ from laboratory experiments in that the combustion products are not collected into an exhaust stack, but are dispersed in a buoyant flow from the combustion zone. The application of the carbon balance method to smoke yield measurements in the field can be made with the assumption that in the region of the plume from which samples are drawn, both the smoke particulate and gaseous combustion products have been transported together from the combustion zone and their concentrations have been equally diluted by entrained air.

Smoke Sampling Package

A self-powered sampling package that is capable of being switched on and off by remote control was constructed to measure smoke yield in plumes from large crude oil fires. The package is shown in Figure 6 and components are diagrammed in Figure 7. At the heart of this system is the battery powered pump. This pump provides a constant volumetric air flow into the system by automatically compensating for the increase in pressure drop across the filter as it collects sample. Although the pump flow can be varied to adjust for different sampling durations and expected smoke particulate concentrations, the pump

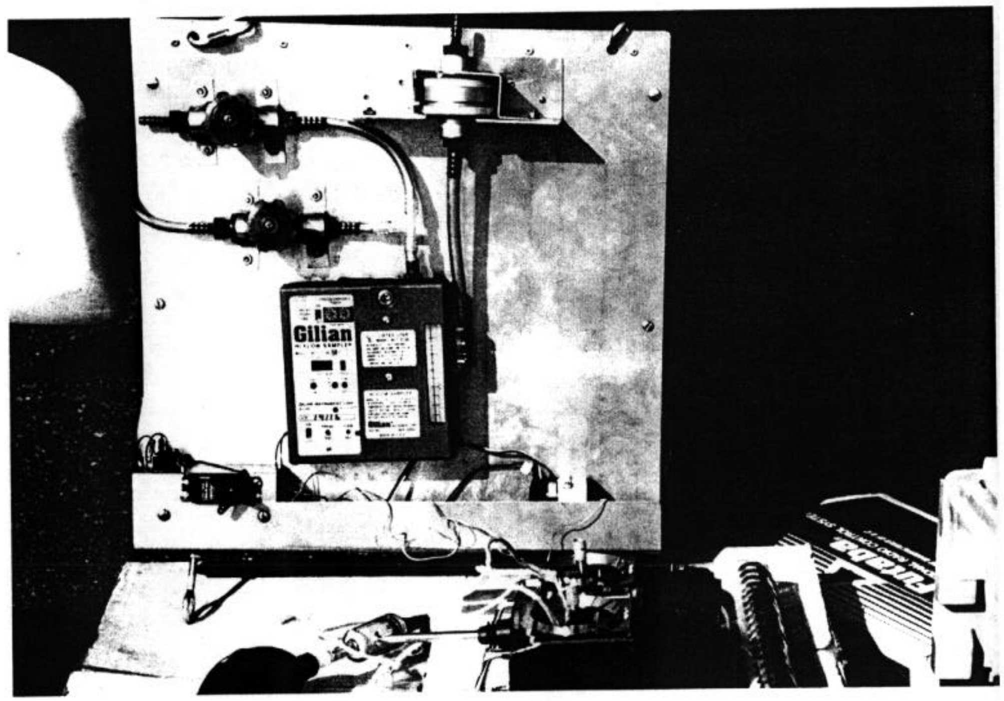

Figure 6 Assembled smoke sampling package

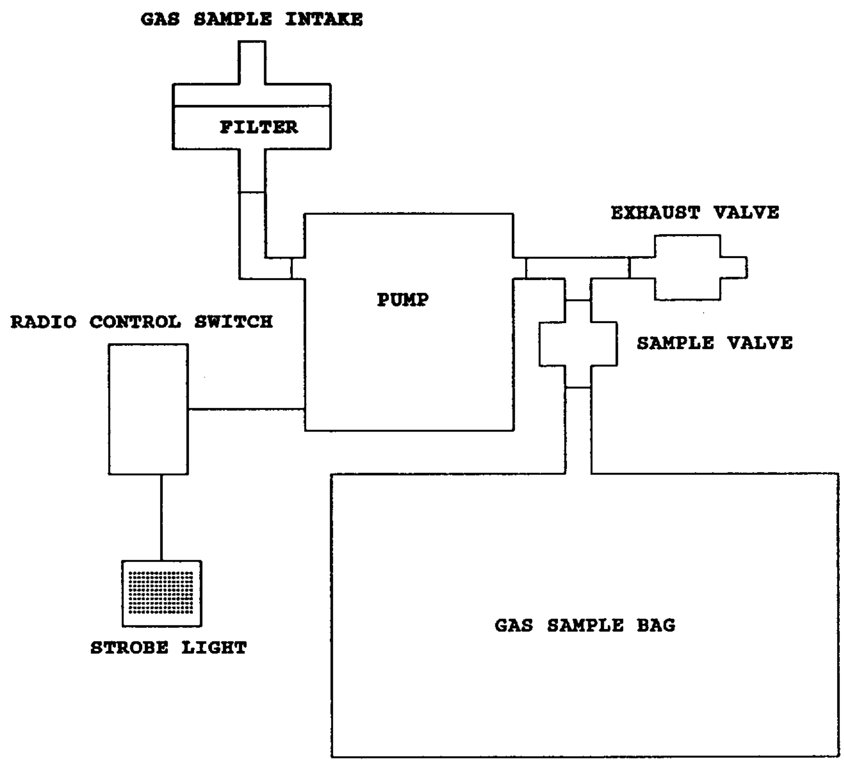

Figure 7 Diagram of smoke sampling package components.

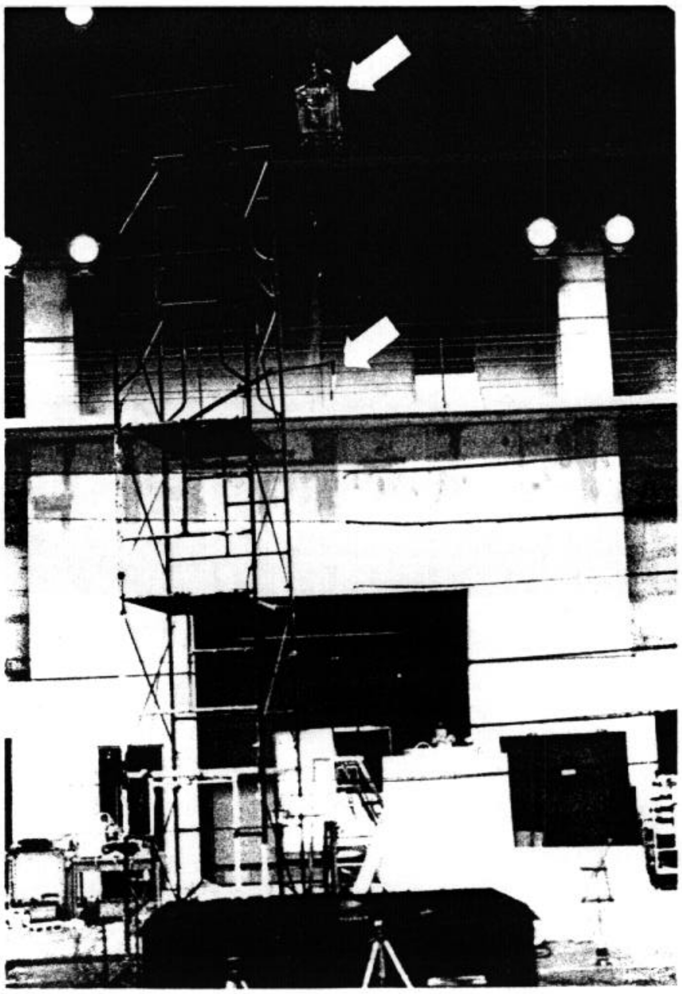

Figure 8 Picture of relative location of high temperature smoke probe and of the portable smoke collector in FRI experiments.

generally provides a flow of 67 cm^3/s. In addition, a set of micrometer adjusted flow control valves are used to split and meter the exhaust gas flow from the sample flow to a 5 liter sample collection bag. A radio controlled switch provides means for starting and stopping the pump remotely as the sample package is carried into and removed from the fire plume. The sample package is designed to be suspended below a blimp which is stationed well above the plume in clear air such that the package can be brought into the plume flow without subjecting the blimp to the heat and turbulence of the fire plume. Since the package is generally positioned in the plume tens of meters above the ground, the pump switch also operates a high intensity strobe light which provides a visual indication that the smoke yield system is sampling. This strobe also provides a visual marker for accurately timing the duration of the sampling period.

Equipment Evaluation

To evaluate the performance of this new portable smoke sampling equipment, relative to an existing laboratory system for high temperature smoke sampling, both sets of equipment were used to sample smoke from 1 and 3.1 meter diameter pool fires at the Fire Research Institute in Japan. Tests were performed with a mixture of Arabian light and Murban crude oils in a 1 meter diameter circular pan and in a square pan with 2.7 m sides. The effective diameter of the square pan is defined as the diameter of a circle (3.1 m) with area equal to the square pan. In these experiments the fuel layer was 0.024 m deep floating on a 0.2 m layer of water for the 1 meter pool and .027 m deep layer floating on a 0.45 m layer of water for the 3.1 m pool. In addition to evaluating the portable sampling equipment, these experiments provided an opportunity to collect data on the effect of pan diameter on smoke yield and agglomerate structure.

Figure 8 illustrates the location of the two sampling sites in the FRI laboratory; the probe for the high temperature smoke collection system was located 4 m above the pan and the new portable smoke collector 6.5 m above the pan. In the 1 meter diameter crude oil pool burns, the flame reached a maximum height of about 3 m as shown in Figure 2. The gas temperature at the high temperature probe was about 80°C with ± 20°C variations and that of the portable sampler was about 40°C as illustrated in Figure 9. The temperature variation results in part from the turbulent nature of the plume and in part from the tendency of the plume to bend in response to the wind outside the building. The pronounced peak during the later stage for the high temperature probe is a result of "thin layer boilover" causing an enhanced burning rate [10]. The portable probe was removed from the high temperature plume before the onset of this boilover.

The smoke particulate drawn from the high temperature probe was collected on a thimble shaped fiberglass filter. A portion of the gases flowed through a silica gel moisture trap and then to CO and CO_2 nondispersive infrared analyzers. The low flow through the gas analyzers combined with the integrating effect of the volume of the desiccator and the instrument cell volume resulted in a 50 - 100 s

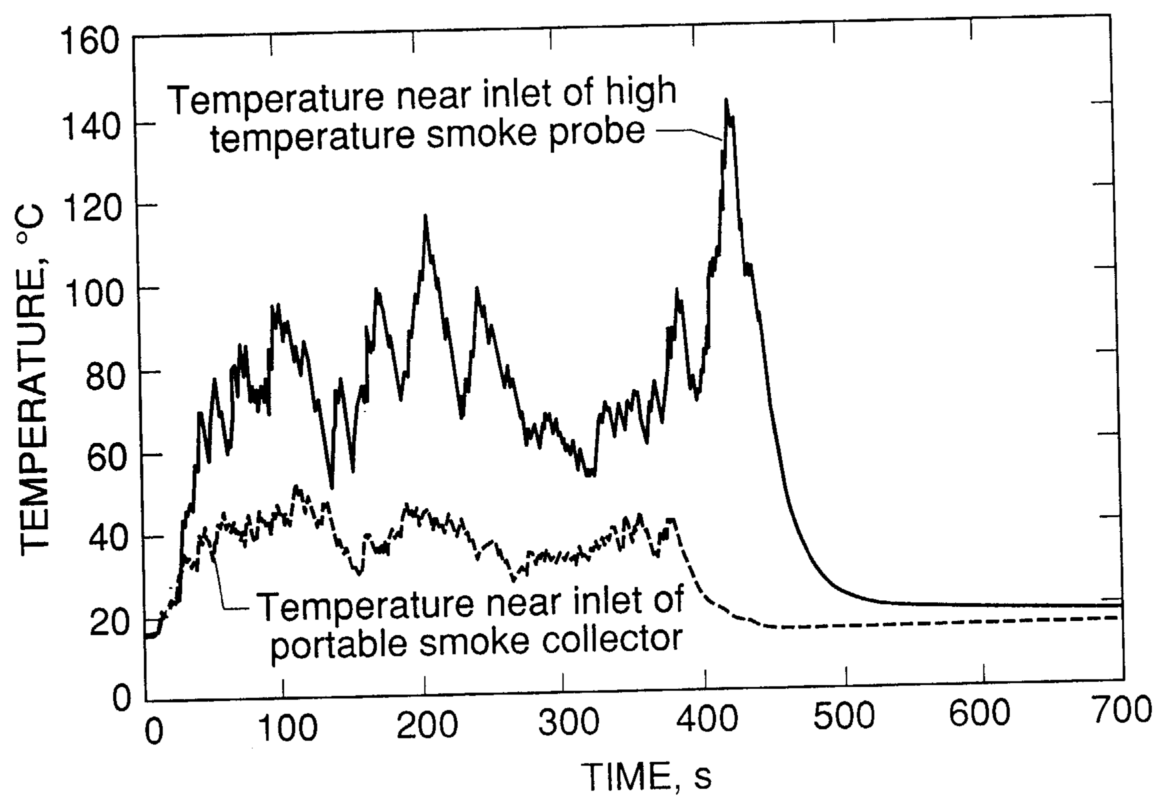

Figure 9 Temperature versus time near smoke collection inlets for a crude oil fire in a 1 meter diameter pool.

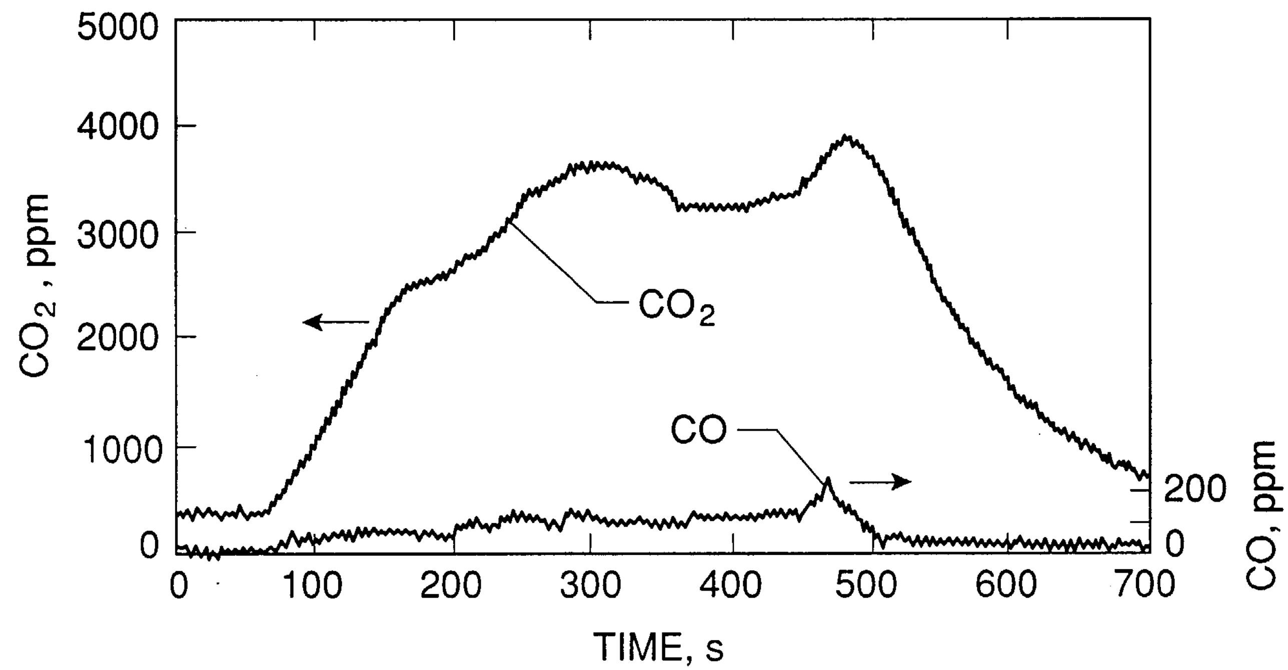

Figure 10 Volume concentration of CO_2 and CO versus time sampled by the high temperature smoke probe.

time delay in the concentration data. There is also a significant smoothing of the data as shown in Figure 10. The gas concentration curves are integrated to compute the average concentration over the test. From the mass of smoke collected on the filter, the carbon fraction of the fuel (.855), and the average gas concentrations, the smoke yield was determined using the carbon balance method [1,13].

The portable sampling equipment collected smoke on a polytetrafluoroethylene (PTFE) filter at a constant flow rate of 67 cm^3/s (4 liters/min). A small fraction of the flow, about 4 cm^3/s, was collected in a 5 liter sample collection bag for subsequent analysis by gas chromatography. From the concentration of the CO_2 and CO in the bag and the mass of smoke collected on the filter, the smoke yield was determined by the carbon balance in much the same way as with the high temperature smoke collector. The bag sample provides an integrated sample from the entire test, while the real time results of the high temperature require averaging over the time of the test. As the fire was ignited, the sampling pump was started and then immediately positioned above the fire by pulling on a wire drawn over a crane mounted hook. The portable sampler was removed from the smoke before boilover and the pump turned off.

Because of the much larger flames from the 3.1 m diameter crude oil pool fires, the high temperature collection probe was positioned in the stack and the portable sampler was positioned out of the smoke plume in the smoke layer, which filled the upper half of the facility. The stack temperature was about 110°C for the large fires. The temperature at the inlet of the portable collector was about 70°C.

As indicated in Table 1, the smoke yield obtained by the two different methods are comparable for the large fires with an average value of 0.148 for the portable and 0.149 for the high temperature collection probe. For the smaller fires, the results from the portable collector, 0.100 are significantly larger than the results obtained with the high temperature probe, 0.061. The measurement repeatability is about $\pm$ 10% as indicated in Table 1. One reason for the lower yield for the high temperature probe is the collection of smoke during boilover, which may have a lower smoke yield, while the portable smoke collector collects smoke only before boilover. Because of the large tare weight of the thimble filter, 1800 mg compared to the 250 mg PTFE filter, and the sensitivity of the thimble filter to moisture, we consider the results from the portable collector to be the more reliable.

These results indicate that the portable sampling device is capable of an accuracy on the order of 10-20%, assuming accurate gas analysis. The primary limitation is the accuracy of the flow control in an environment of variable temperature and pressure. Work is in progress to define the magnitude of these uncertainties for the range of conditions expected during plume sampling in the meso-scale experiments.

		Smoke Yield		
Test #	Pan Size, m	High Temp. Probe	Port. Sampler	Diameter of Spherule, μm
C-2	1		0.090	
C-3	1	0.065	0.109	
C-4	1	0.057	0.097	
C-5	1		0.103	0.060
Average of C-2 to C-5		0.061	0.100 ± 0.008	
C-6	3.1	0.133	0.148	0.15, 0.064[a]
C-7	3.1	0.153	0.160	
C-8	3.1	0.162	0.137	
Average of C-6 to C-8		0.149 ± 0.015	0.148 ± 0.011	

[a] The two sizes correspond to the larger and smaller primary sizes shown in Figure 13.

Table 1 Smoke Yield Measurements From Experiments at FRI

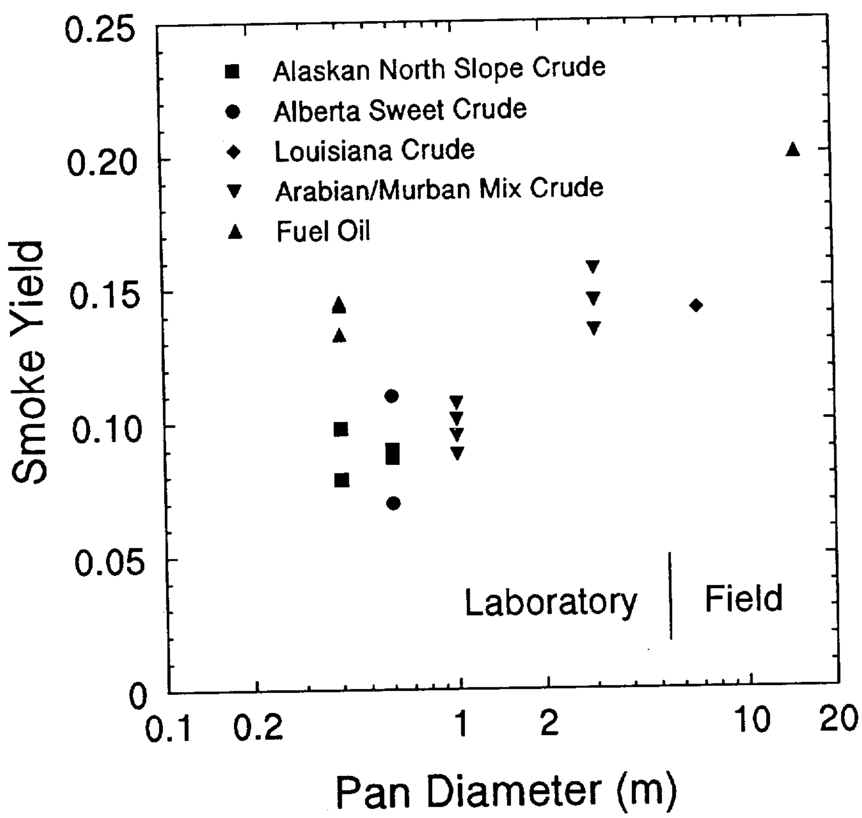

Figure 11 Smoke yield from oil pool fires.

Effect of Scale

As with burning rate, there is an effect of scale for smoke yield. Smoke yield for smaller laboratory fires appears to be less than for larger fires. As with burning rate the smoke yield is expected to become independent of pool fire diameter at large diameters. Figure 11 shows a compilation of smoke yield measurements from various crude oil burns in this research program. The data from several different facilities burning different fuels are divided into laboratory experiments which indicate fires conducted indoors and field experiments which are outdoors. As expected, smoke yield increases with increasing pool diameter. Burns of the mixed Arabian and Murban crude oils at the Fire Research Institute in Japan indicate a 50 percent increase in smoke yield from 0.1 for the 1 m diameter pool fires to 0.15 for the 3 m diameter. Field experiments at the Navy Fire Fighter Training facility in Norfolk, Virginia indicate that the fuel oil used there has a greater smoke yield (0.20) than any of the unrefined crude oils tested in both laboratory and field burns. Preliminary results indicate a 0.14 smoke yield in the new facility shakedown test at the USCG Fire and Safety Test Detachment in Mobile Alabama in which a 6 m x 6 m pool of Louisiana crude oil (6.8 m effective diameter) was burned. Based on these measurements, it is expected that in the offshore field tests a nominal 0.15 smoke yield can be expected from the large crude oil in-situ burn.

Smoke Particulate

Smoke samples were collected on carbon coated TEM grids (3-mm diameter, 0.13 mm thick, and 200 mesh copper) in the exhaust stack. Two grids were attached to a metal rod with double stick tape in such a way that only a small outer portion of the grid was in contact with the tape. The metal rod was inserted and removed from the stack three times for about five seconds each. One of the grids was then removed from the rod. The remaining grid on the rod was reinserted and removed from the furnace in a series of five second exposures until a particulate loading approximately five times that on the first grid had accumulated on it. The primary mechanism of particle deposition is thermophoretic resulting from the temperature gradient between the high gas temperature in the stack (about 110°C for the 3.1 m diameter pan) and the near ambient temperature of the grid attached to the metal rod. Thermophoretic collection has the advantage of being relatively insensitive to particle size so that a representative size distribution is collected. In the case of the 3.1 m pan diameter, TEM grids were also attached to the portable smoke collector being evaluated in the experiments.

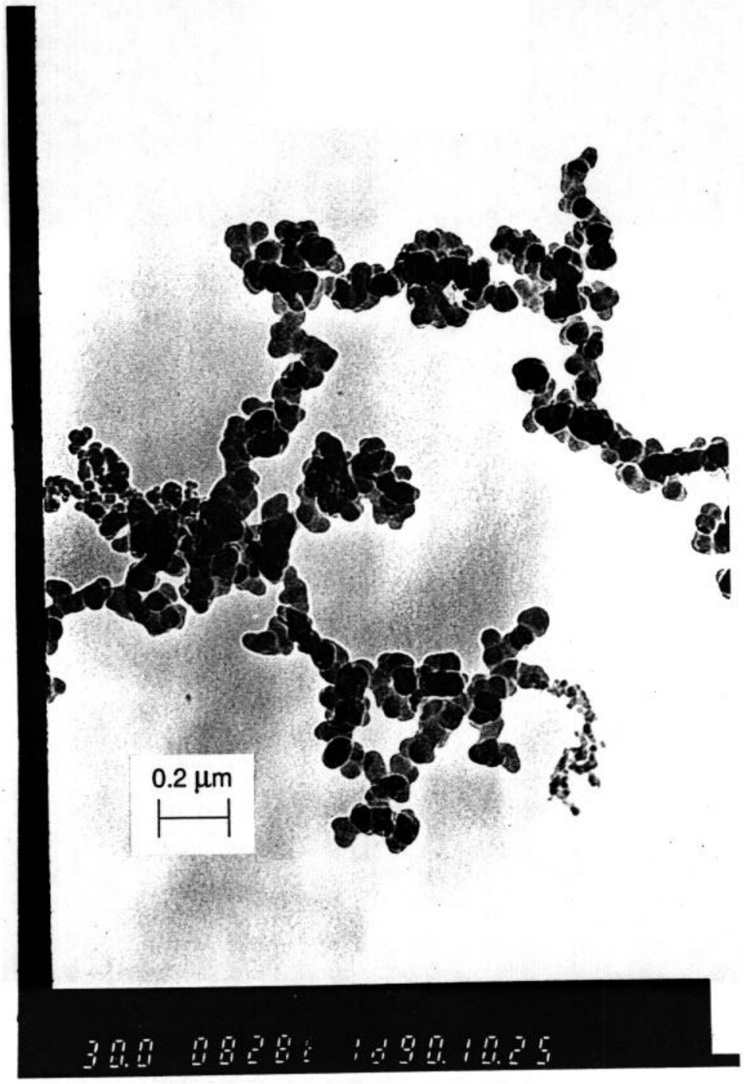

Figure 12 Electron micrograph of smoke agglomerate collected from a 1 m diameter pan diameter fire.

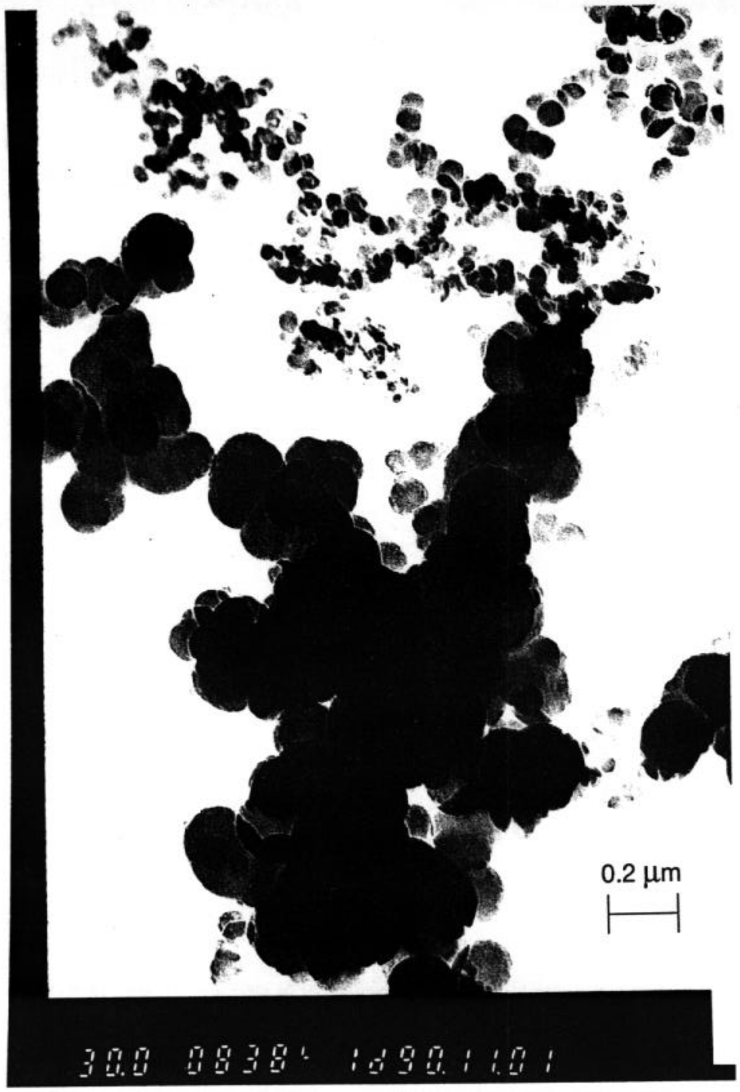

Figure 13 Electron micrograph of smoke agglomerate from collected from a 3.1 m diameter pan diameter fire.

The smoke samples were analyzed at Tokyo Science University using a Hitachi-H800[1] transmission electron microscope operating at 100 keV at a magnification of 30,000. Representative micrographs of the smoke agglomerates are illustrated in Figure 12 for the 1 m diameter pool fire and in Figure 13 for the 3.1 m pool fire. As seen from Figure 12, the primary spherule size is relatively uniform for the 1 m pool fire and a preliminary analysis based on sizing ten primary spherules gives an average diameter of 0.060 μm. For the larger pool fire, both large primary size spherules and smaller spheres are present on all of the ten micrographs from the analysis. From sizing 10 of the larger spheres and 10 of the smaller spherules from the micrograph shown in Figure 13, an average value of 0.15 μm is obtained for the larger and 0.064 μm for the smaller. The size of the smaller spherules from the 3.1 m diameter fire is close to the size observed for those produced in the 1 m diameter fire.

The increase in pool diameter and therefore size of the combustion zone leads to a population of primary particles significantly larger than seen at the smaller scale. The appearance of a distinctly larger spherule size suggests the possibility of a different growth mechanism. Perhaps a lower temperature growth mechanism becomes important at the longer residence time of the larger fires. Although not tested for as yet, there is a possibility that the larger fires produce a less graphitic smoke with a smaller carbon/hydrogen ratio compared to the smoke from smaller fires. These measurements will be made as part of future meso-scale experiments.

SMOKE PLUME TRAJECTORY

In recent years, advances in computational methods and hardware have made practical the use of techniques to simulate numerically the turbulent mixing of smoke in the atmosphere. In cooperative research between NIST and the Massachusetts Institute of Technology (MIT), a method has been developed to simulate smoke dispersion and settling from crude oil pool fires. Present capabilities are limited to analysis of smoke flow in a uniform wind. This simplifies the analysis to one of dispersion and settling of a negatively buoyant particulate laden flow. Smoke particulate position downwind of the burn is related directly to time, given the uniform wind field.

The model is started by initializing a plume shape as represented at its maximum stabilized altitude by an ellipse whose aspect ratio can be chosen to match an observed vertical and lateral extent of the smoke. The subsequent motion of the plume is calculated by applying the transport element method developed by

[1] Certain commercial equipment, instruments, and materials are identified in this paper to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

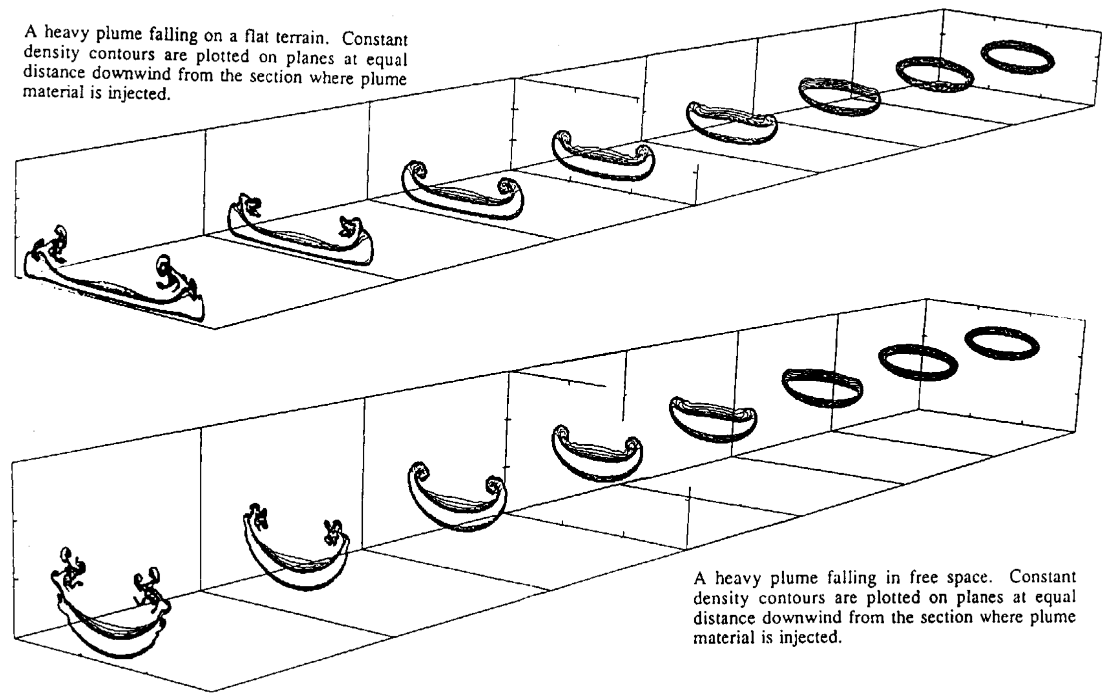

Figure 14 Calculated constant density smoke plume contours at eight locations separated by equal distances downwind from the initial station.

Ghoniem [14] to the mathematical model presented in earlier AMOP proceedings [4]. This calculation differs from many of the commonly used models of particulate or pollution transport in that no assumptions are made regarding the shape of the smoke density profiles in the plume as it proceeds downwind, nor is any empirical turbulent mixing rule applied. All calculations are based directly on the solutions to the equations of fluid mechanics.

To demonstrate the capabilities of the calculation method, two sample calculations are illustrated in figure 14. They show a set of constant density contours at eight locations separated by equal distances downwind from the initial station. The initial plume cross-section in each case is a 3:1 aspect ratio ellipse. The calculations differ only in that the center of the initial plume is 1/2 the plume width above the ground in the upper sequence, and there is no ground in the lower sequence. Comparison of the two simulations shows that for approximately the first half of the downwind trajectory, there is almost no ground effect on the plume development. Thus, as the initial plume altitude is raised further above the ground, more and more of the lower sequence will appear to characterize the plume mixing with the atmosphere. In particular, the development of the characteristic horseshoe shaped cross-section is quite evident. The shape is generated by the increasing concentration of buoyancy induced vorticity at the outer edges of the plume. This produces the intense mixing made visible by the secondary eddies which entrain large amounts of clear air into the plume at the end of the sequence. The modification of this picture due to the ground effect can be observed in the latter portions of the upper sequence. The flattening of the cross-sectional profile is followed by a rapid lateral spreading as the vortices concentrated at the edge of the plume generate their mirror images due to the presence of the ground. The induced image vortices generate the lateral ground level velocities which spread the smoke out.

The results allow some useful estimates to be made of particle deposition distances for oil spill scenarios, even in the absence of a complete plume model (one that accounts for plume rise and stabilization as well as settling). As an example, consider a crude oil pool of about 2.5×10^3 m^2 area burning in a fire resistant containment boom. Assuming a regression rate of 5.8×10^{-2} mm/s and a fifteen percent fuel/smoke conversion efficiency, a 18 kg/s mass flux of particulate matter is generated. Figure 15 shows the vertical and lateral extent of the plume as a function of distance downwind. The distance downwind is measured in units of

$$(LU)^{3/2}/(g\dot{m}/\rho_o)^{1/2}$$

Here L is the half depth (semi-minor axis) of the initial plume, U the wind speed, g the gravitational acceleration, $\dot{m}$ the particulate mass flux through the plume, and ρ_o the ambient air density. The vertical and lateral distances are measured in units of 10L. If the length L is taken as 300 m, and a 5 m/sec. wind is assumed, then the downwind deposition distance corresponding to seven distance

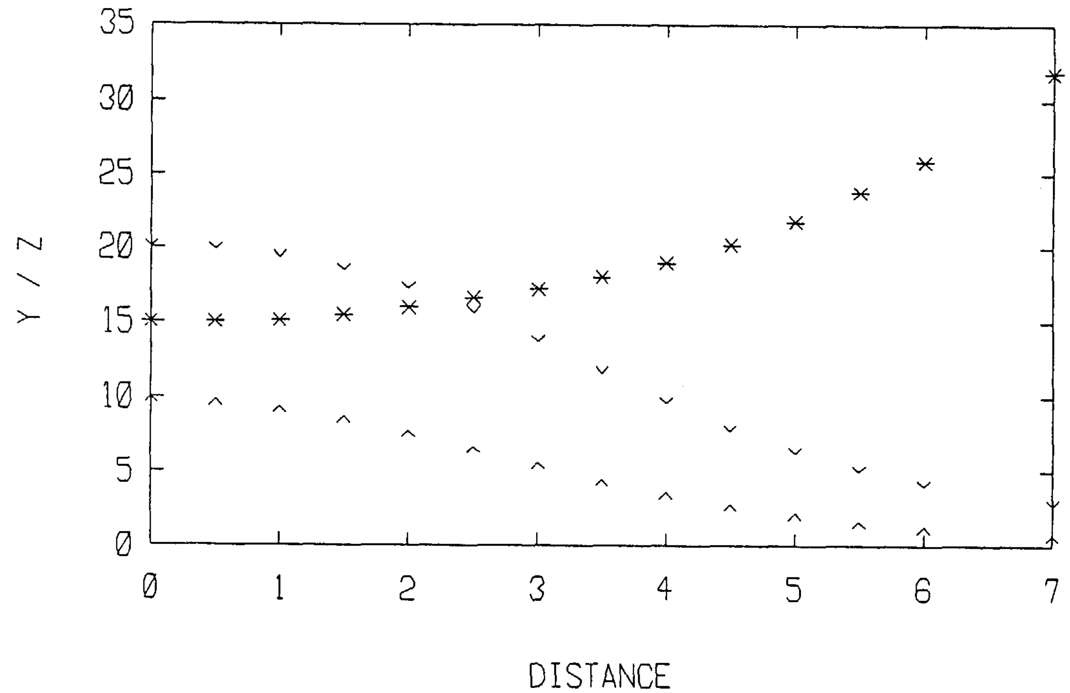

Figure 15 Calculated vertical and lateral extent of a smoke plume as a function of distance downwind. Shown are the variation of the elevation of the highest (V) and lowest (^) point on the plume center line, and the half width of the plume (*) with distance downwind.

units in figure 15 is about 28 km. Doubling the wind speed to 10 m/sec. would bring this distance to 80 km. The width would be approximately 2 km in either case.

The next stage of this work involves extending the model to study the positively buoyant thermal plume, including the effects of vertical wind shear and density stratification of the atmosphere. When that work is completed, the entire trajectory for the smoke particulate from generation at the fire to deposition downwind will be predicted. Data from meso-scale experiments will be used to evaluate the method. This methodology offers the promise of major improvements in predictive capability.

FUTURE PLANS

A series of meso-scale crude oil pool fires are planned. These pool fires up to 15 m x 15 m will provide an opportunity for measurements of crude oil burning characteristics, combustion products, and plume trajectory in a carefully planned and controlled field experiment. In addition to the data obtained from these fires, the experiments also serve as partial preparation for measurement in future offshore demonstrations of in-situ burn technology for oil spill response.

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The program of meso-scale burn experiments is coordinated through the Burn Evaluation Steering Team (BEST).

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