Water sprays suppress gas-well blowout fires

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Large-scale simulation tests were conducted to demonstrate the effectiveness of water spray systems to control and extinguish gas well blowout fires.

Selected results from small-scale experiments performed in this research program are given primarily to help explain the development of the water spray extinguishment method, but also to examine scaling of important phenomena.

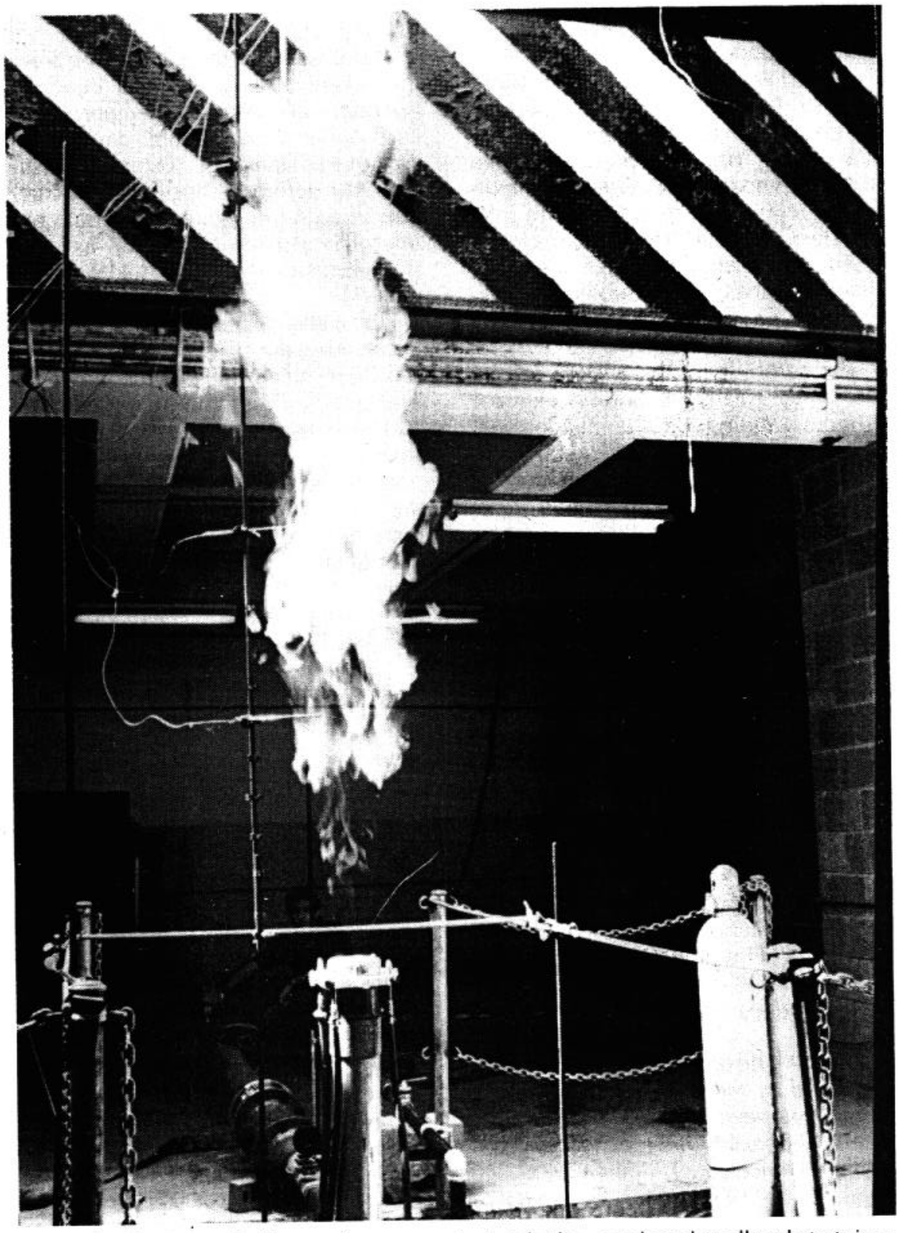
Two techniques of water spray injection, internal and external to the initial gas jet, were tested at large scale on fires with heat release rates from 144 megawatts (138 cu ft/sec, or about 12 MMcfd methane flow) to 222 megawatts (212 cu ft/sec, 18 MMcfd).

Using external water injection from four nozzles surrounding the gas jet, fires of nominal 200 megawatt size could be extinguished with a mass flow ratio (water/gas) of 2.17 (129 gpm water flow) and continued to burn at a ratio of 1.56 (86 gpm water flow).

This technique of water injection could be the basis of a practical blowout fire suppression system.

Blowout extinguishment. The blowout of oil and gas wells during drilling, production, and workover presents a serious hazard to personnel, the environment, and equipment. The only practical method to control a well fire subsequent to a blowout is to shut in the hydrocarbon flow at the well.

Well blowout fires normally create large heat radiation hazard zones. Consequently, it is extremely hazardous for personnel to approach these fires in the fire control process. Also, the heat radiation load on well-control equipment can be so severe that this equipment is damaged and control functions cannot be achieved with normal well head control procedures.



Center for Fire Research, blowout fire suppression test facility, conducted small-scale tests in a shielded pit (Fig. 1).

Little quantitative data are available that describe the size of full scale well fires, the temperature profiles within the fire zone, and the heat radiation hazard zones adjacent to a fire.[1] Although some individuals have used water effectively to mitigate well fire hazards, the quantitative effect of water sprayed into the fire zone is not known.

To design effective blowout fire-control systems, both the hazards associated with the fire and the efficiency of water to control fire hazards must be quantitatively understood.[2]

Table 1

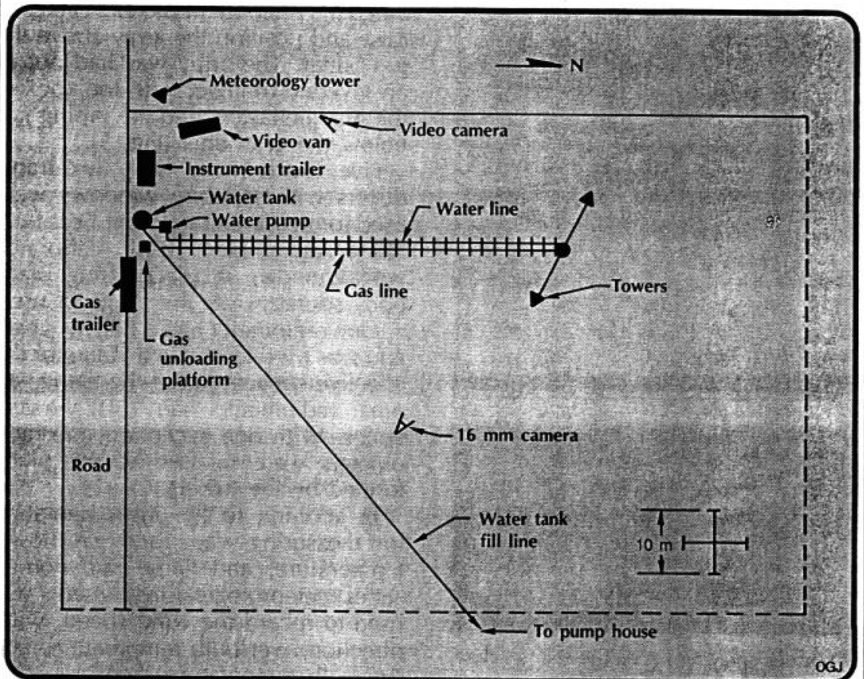
Gas and water flow rates

Rates	Test 1	2	3	4	5	6	7
Injection location of water	Internal	Internal	Internal	External	External	External	Internal
Gas flow rate,cfs	138	220	212	196	192	178	150
Heat release rate, MW (complete combustion)	144	230	222	205	201	186	157
Water flow rate, gpm	25.4*	33.3	51.4	258	129	86.1	
Water flow rate/gas flow rate mass ratio	0.59	0.50	0.920	4.26	2.17	1.56	—
Average wind speed, mph	3.4 (σ=0.5)	3.5 (σ=0.6)	3.5 (σ=.04)	0.9 (σ=0.15)	0.8 (σ=0.24)	1.3 (σ=0.17)	1.8 (σ=0.05)
Extinguished	yes†	no	no	yes	yes	no	—

*Approximation
†Flame tilted off axis by wind prior to water spray injection.

Fig. 2

Large scale test site



Laboratory-scale studies have been conducted at the Center for Fire Research (CFR) of the National Bureau of Standards (NBS) to quantify the effects of water sprays on jet flames that are characteristic of gas well blowout fire accidents.

This work was part of a large research program of technology assessment of offshore minerals operations supported by the Minerals Management Service (MMS) of the Department of Interior.[3]

It was shown in these laboratory studies of fires with heat release rates from 0.1 to 10 megawatts that it was feasible to reduce radiation from jet flames and extinguish the fire using relatively small quantities of water.[4] The efficiencies of many different water-spray-system geometries in terms of ability to extinguish fires have been studied.

The most efficient spray geometries were tested at large scale for CFR by Energy Analysts Inc. to demonstrate scaling of laboratory results for reduction in flame radiation, reduction in gas temperatures, and extinguishment efficiency. These large-scale tests consisted of a series of seven tests to quantify the burning characteristics of high velocity methane discharges that simulate accidental gas-well blowouts.

CFR lab test facilities. Two scales of laboratory experiments were conducted by CFR, Gaithersburg, to examine the phenomena of reduction in flame radiation and fire extinguishment.

Bench-scale experiments with fire-heat-release rates of up to 0.1 megawatts (1-m flame height) were performed under hoods in general laboratory space.

Larger experiments up to 10 megawatts heat-release rate (5-m flame height) were performed in the CFR blowout fire suppression facility, a concrete test pit operated by NBS. A below-ground arrangement for the gas-jet release provides shielding of the flame base from the wind.

Measurements of axial flame and plume temperatures and radiative heat flux from the flame were routinely performed. Methane-gas flows were burned in a jet after being forced through orifice plates mounted at the exit of a 4-in. diameter piping system.

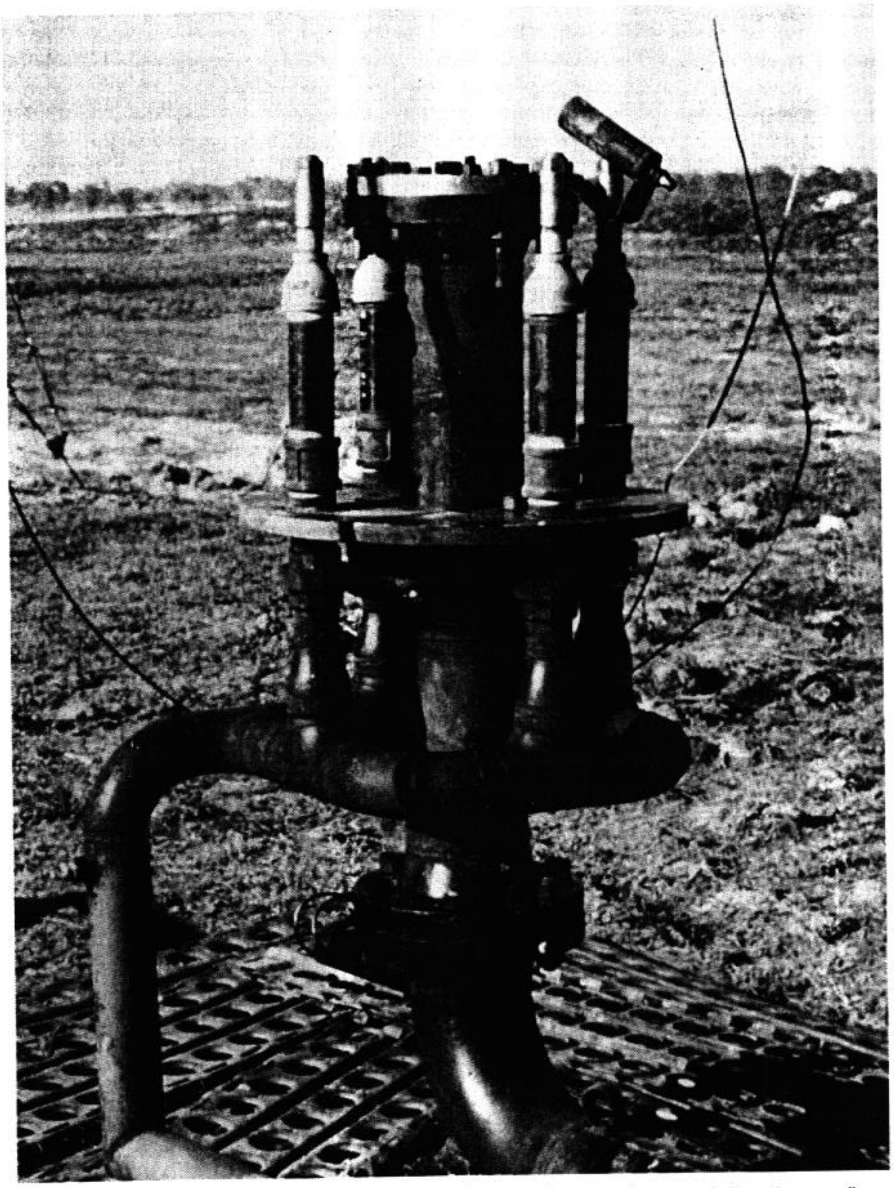
Water-spray nozzles were mounted both inside the supply-gas pipe to provide internal water injection and surrounding the supply pipe to provide various external spray geometries (Fig. 1). Additional information on the small scale test facility can be found in reference 4.

Large scale test. Energy Analysts' test site was located 15 miles south of Oklahoma City. The layout of the test facilities is presented in Fig. 2.

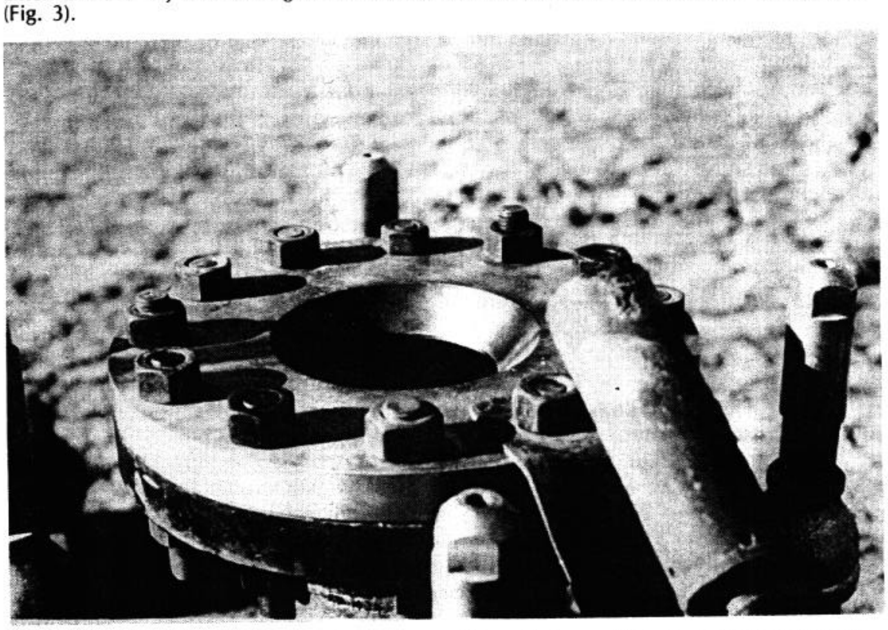
High pressure (2,500 psi) over-the-road tank trucks were used to supply gas which was 96.35% methane by volume for testing. The remaining fraction contained higher molecular weight alkanes, nitrogen, and carbon dioxide. Gas-flow rates from the 10 cylinder-truck manifold were controlled with a pressure regulator on the unloading platform. Flow rates were calculated from differential pressure measurement across orifice plates in the 6-in. gas-supply pipe.

Water for the tests was supplied from a 3,750-gal tank, and pressurized using a diesel-engine-powered pump capable of delivering up to 1,000 gpm at 100 psig. Water flow was contolled manually and measured by pressure differential across an orifice plate installed in the 6-in. water-supply pipe. Two types of spray headers were used for the tests.

The first type discharged water from a 15° solid spray cone nozzle inside the gas discharge. The nozzle was centered in the gas pipe approximately 2 in. below the bottom of the restriction orifice plate at the gas discharge.



External water injection configuration features four nozzles spraying parallel to the gas flow (Fig. 3).



External water-injection configuration, shown with restriction orifice gas outlet in place (Fig. 4).

The alternate spray header consisted of four 15° solid spray cone nozzles placed around the gas discharge (Figs. 3 and 4). Distance from the center of the gas discharge to the center of each water nozzle was 9 in. All nozzles were fitted on 2-in. threaded pipe. The water piping was anchored at a concrete pad supporting both the gas and water-outlet piping.

An array of 20 (type K) thermocouples with 0.5 mm bead size was used to measure the temperature profile of the flame, both axially and radially. Two 80-ft towers were erected at the site 50 ft apart, with the gas outlet pipe located halfway between the towers. A system of pulleys and take-up reels attached to the towers enabled the three stainless steel cables to raise and position the array above the gas outlet. The array was laid out as an inverted triangle, with the apex of the triangle fastened to the piping just below the gas outlet (Fig. 5).

Five Gardon-type heat flux transducers with sapphire windows were used to measure the radiant heat flux. These radiometers were calibrated with windows in place using black body sources over the range of use.

One radiometer had a narrow angle and was used to obtain a value for the effective surface flux of the flame. All other radiometers had 150° viewing cones. With one exception, the radiometers were focused in the plane formed by the towers.

In addition to the instrumentation for measuring water and gas flows, temperature, and flame radiation, a set of meteorological instruments was used to record the wind speed, wind direction, wet bulb temperature, and dry bulb temperature. Sensor output was scanned once per second.

Testing program. In both laboratory and large-scale testing, measurements were made on stable vertical-flame jets established above the gas outlet. Temperature and radiation measurements were made over a 15-30 sec period after ignition.

Water was then applied.

If the flame was not extinguished and a new stable flame condition was achieved, measurements were taken over an additional 15-30-sec period. Generally, if the flame was not extinguished by the the water flow, radiation was reduced and the lift-off height increased.

Many laboratory studies were conducted to quantify the interaction of water spray with the jet flame. Only seven large-scale tests were performed with fires from 144 to 222 megawatts heat release rate (Table 1). Of the seven, tests 4, 5, and 6 provided the best measurements of temperature

Fig. 5

Thermocouple suspension

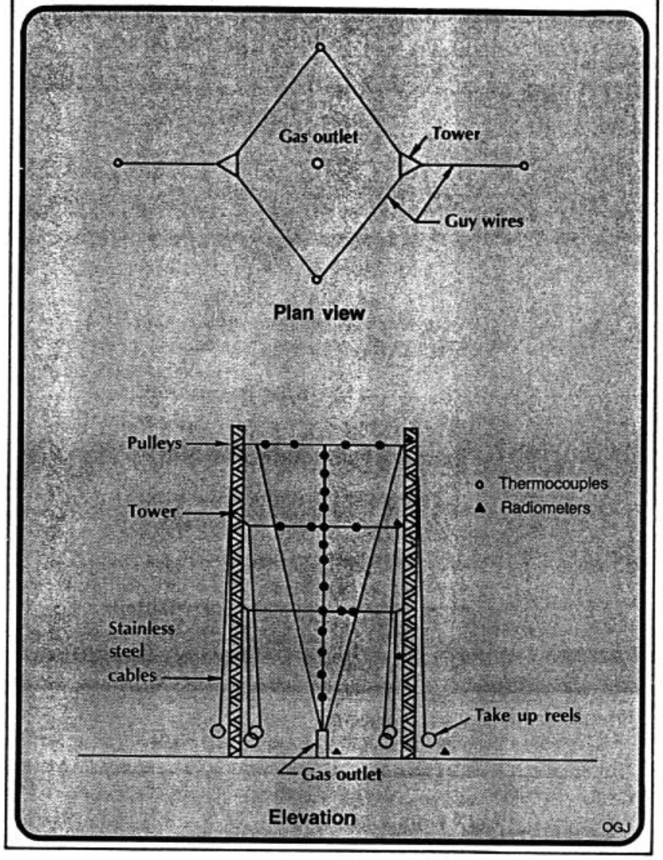
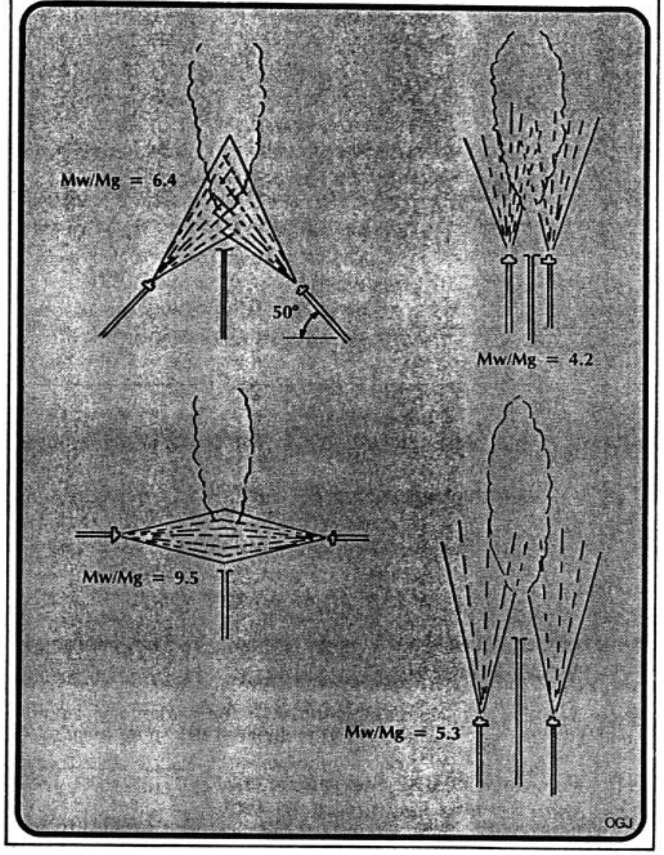
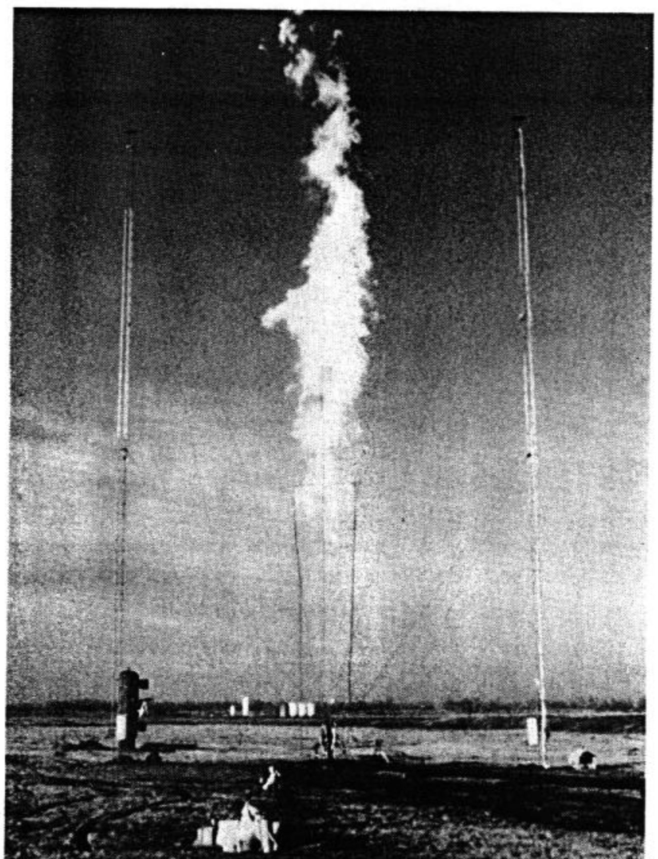
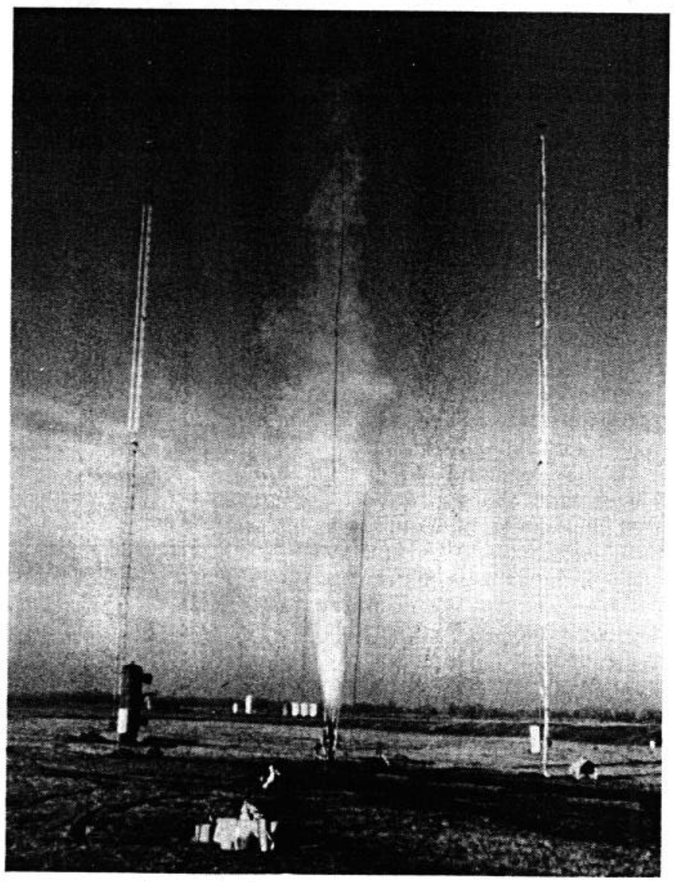


Fig. 6

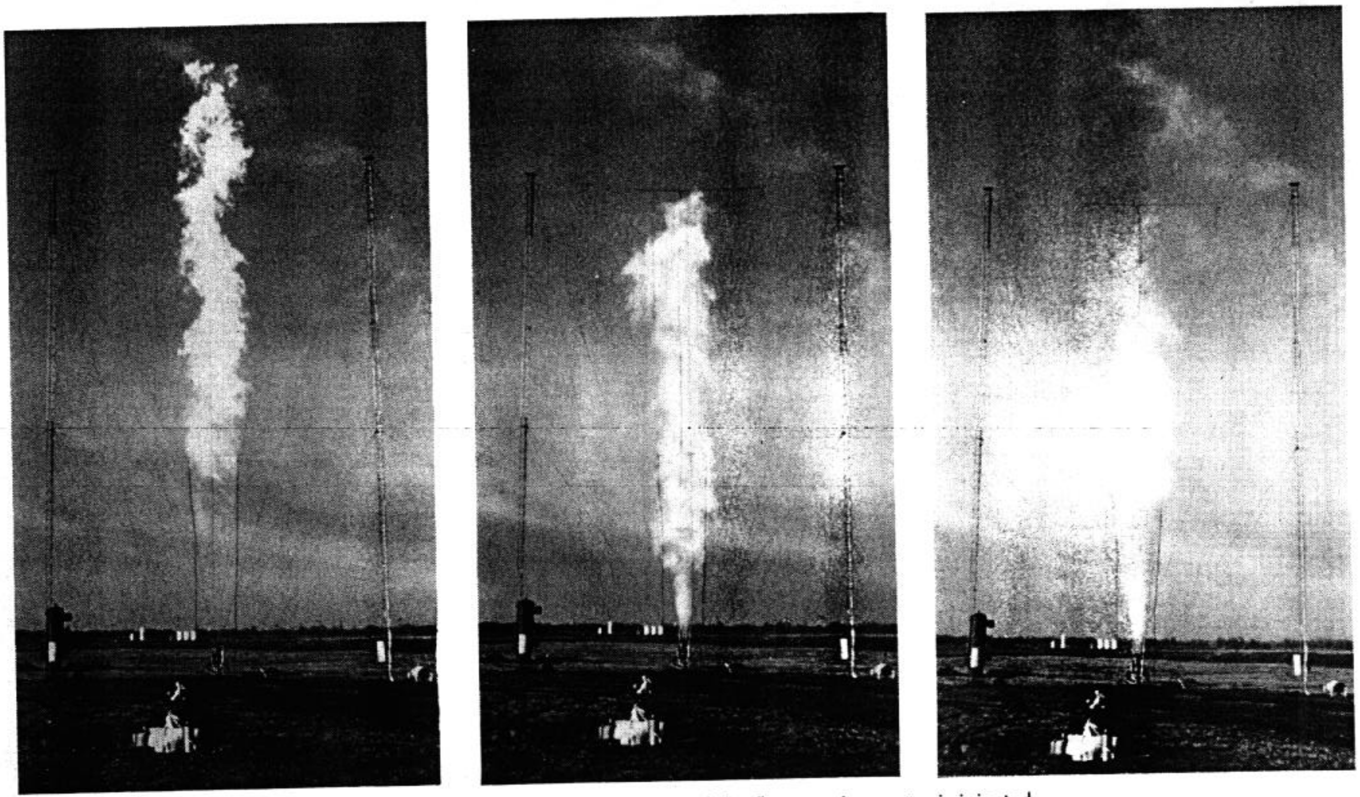
Spray geometries, effectiveness







Jet flame extinguished in test 5 using only 10 gal of water; (left) Flame prior to water application; (right) Flame being extinguished (Fig. 7).



Three photographs taken during test 6 show fire before water application (left), flame at time water is injected (center), and steady burning of the methane-water spray mixture (Fig. 8).

and radiation, because the low local wind speeds were insufficient to tilt the flame away from thermocouples and radiometers placed to measure conditions directly over the gas outlet.

The undistorted vertical flame-jets in these large-scale tests, were geometrically similar to those studied at small scale and provide the best basis for comparing the effectiveness of water sprays to extinguish the fires.

Extinguishment efficiency. Small-scale testing in the CFR blowout fire suppression facility was used to determine the efficiency of fire extinguishment for many different water-spray geometries.

The measure of effectiveness was the ratio of mass flow rate of water to mass flow rate of fuel being burned (m_w/m_g) at extinguishment.

At the beginning of these gas-well suppression studies, it was thought that an effective blowout fire suppression system could be built and supplied with water using pumping capabilities available on offshore platforms, if the ratio m_w/m_g for extinguishment was below 10.

Several spray geometries that directed spray at the base of the flame were found to be capable of extinguishing the fire, but relatively inefficient with m_w/m_g ratios of 6.4 and 9.5 for extinguishment (Fig. 6). A nozzle system spraying vertically parallel to the flame axis was found to be very efficient.

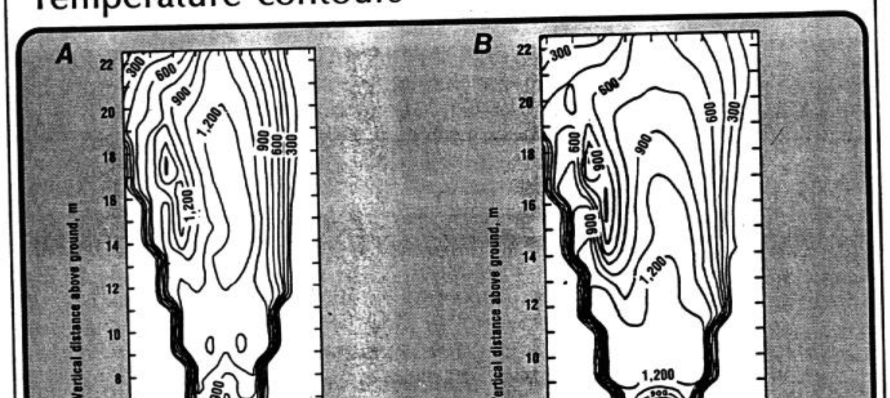
In tests, at small scale, a two-nozzle water spray system was able to extinguish fires at an effectiveness ratio $m_w/m_g = 4.2$, with the discharge level at the same elevation as the gas outlet, 0.3 m below the base of the lifted flame.

The effectiveness of this system was only slightly diminished by increasing the distance between the bottom of the flame and the water discharge by a factor of three. In this case, the ratio m_w/m_g at extinguishment increased to 5.3 (Fig. 6).

In small-scale testing, the system of nozzles that sprayed water vertically to surround the flame was both the most efficient external spray method tested and also the least sensitive to

Fig. 9

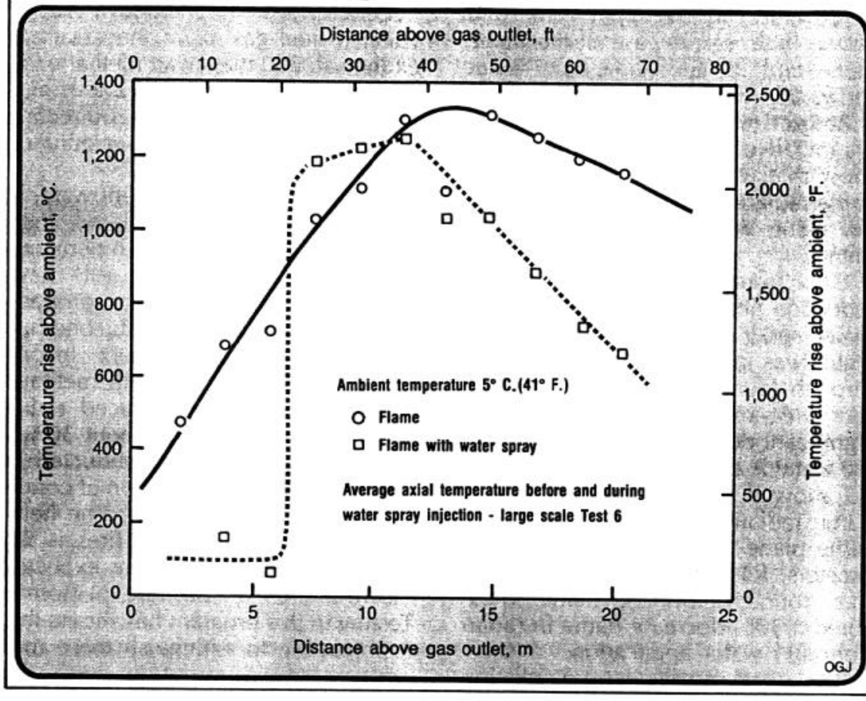
Temperature contours



Temperature contour plot for test 6 before and after water application (contours from 150° C. to 1,200° C. with interval of 150° C.)

Fig. 10

Water spray cooling



geometry changes between the flame base and water-discharge points.

A scaled-up version of this system was built for testing at large scale (Fig. 3) with the change that four nozzles would be used in large scale instead of the two used in small-scale development work. This change was expected to make the system more effective because asymmetries of the two-nozzle discharge would be reduced.

Large-scale tests 4, 5, and 6 tested the effectiveness of this external spray system to extinguish fires with heat release rate from 186 to 205 megawatts (about 15-17 MMcfd).

In test 4, a ratio of $m_w/m_g = 4.26$ was used to correspond to water flow rates shown to be effective at small scale. The flame was extinguished easily.

In test 5, the water flow rate was decreased to 129 gpm ($m_w/m_g = 2.17$). The flame was extinguished in 5 sec using only 10 gal of water.

Fig. 7 shows photographs taken during this test.

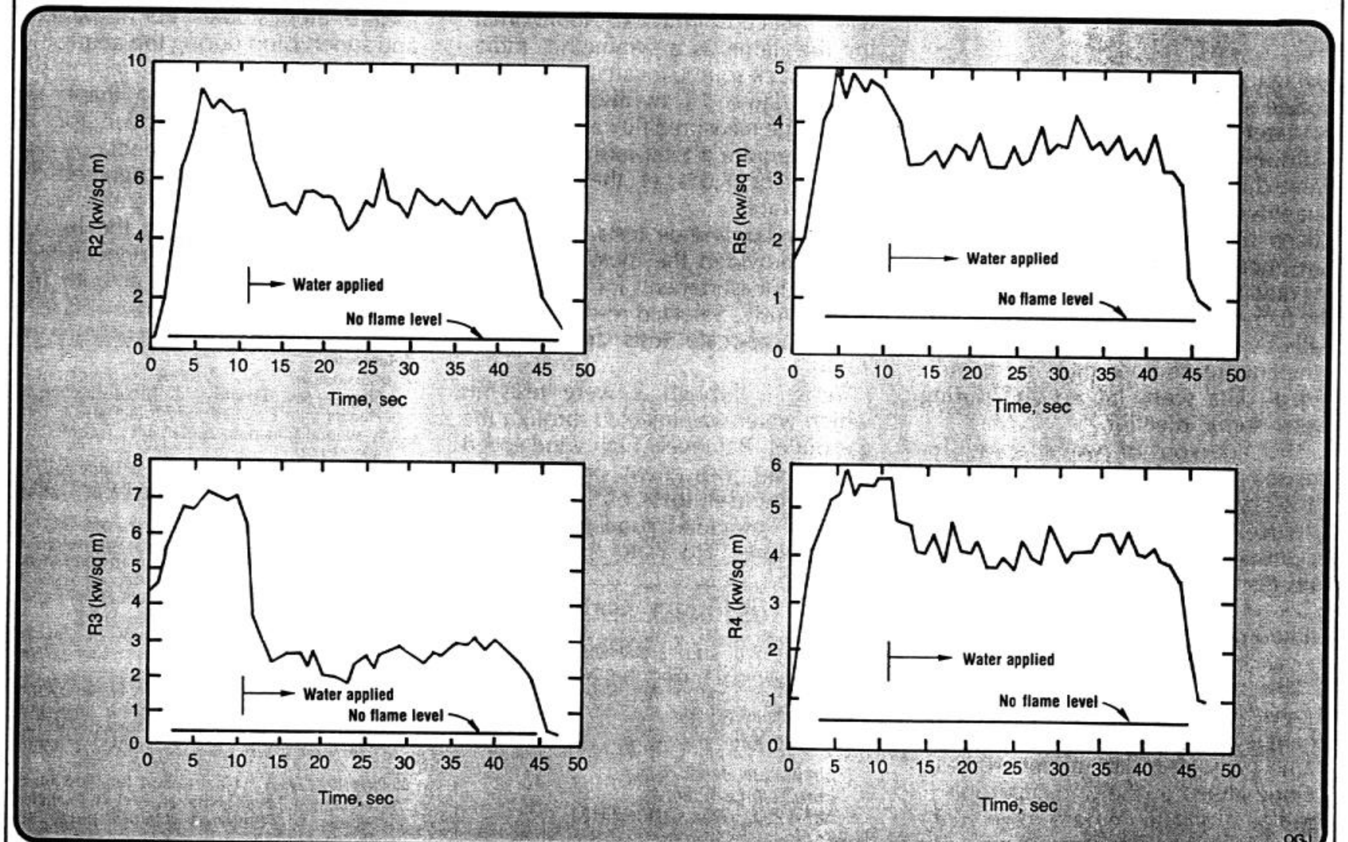
Decreasing the water flow further to 86 gpm or $m_w/m_g = 1.56$ for test 6 resulted in insufficient water flow to extinguish the fire.

Fig. 9 shows three photographs from test 6. This fire was interesting because two steady conditions were established; one, the natural burning of the methane, and two, the burning of the methane-water spray mixture.

The tests showed that the four-nozzle spray system was more effective, ($m_w/m_g = 2$) for extinguishment of large-scale fires than the two-nozzle systems ($m_w/m_g = 4$) for extinguishment of small-scale fires. Experiments are being planned to determine the ratio of water to gas necessary to

Fig. 11

Radiation from fire



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extinguish the gas fire with a four-nozzle system at small scale.

Water spray cooling. Temperature measurements taken in and near the flame during test 6 provide a means of quantifying temperature changes produced by the water spray. Temperature measurements were uncorrected for radiation effects. Fig. 8 shows that the flame shape was changed dramatically by water injection. Fig. 9 shows temperature contour plots from individual data scans before and during water spray injection.

The addition of water spray increases the flame lift-off height and causes very steep temperature gradients 20-30 ft above the gas outlet. Fig. 10 shows a plot of two axial temperature distributions; one averaged over 6 sec of steady burning before water addition, and the other 15 sec during the water application period.

This plot shows clearly that even though the temperature distribution changes, peak temperatures in the flame only decrease about 100° C. Temperatures in the upper portion of the flame and plume are lowered by the heating and evaporation of water spray in the flame. Using data from laboratory-scale tests with hydrogen jet-fires, McCaffrey[5] has correlated temperatures in the upper flame and plume both for the case of the flame alone and for the flame and water spray.

Reduction in flame radiation. Quantitative radiation measurements show that water addition can reduce flame radiation to one-half of its original value without flame extinguishment.[5]

Data from test 6 determined the reduction in radiation produced by water spray injection. In test 6, the water was injected external to the jet through four nozzles. Data from the four wide-angle radiometers all show significant decreases in radiation after the water is applied (Fig. 1). Data from R3 showed the greatest decrease in flame radiation but did not view the same plane as the others. Both radiometers, R4 and R5, positioned near the ground below the flame, measured a 30% decrease flame in radiation after water application.

The actual change in total radiation from the flame is complicated to calculate because both the emissivity and shape of the flame change when water is applied, and the water spray itself can absorb radiation.

Even without the addition of water, the large methane jet-flames radiated a relative small amount of energy. Radiative flux to positions R4 and R5 was approximately 5 kw/m^2 before water injection in test 6. Approximating the flame as a symmetric, radiatively black source located on the axis of the flame 15 m above the gas outlet, the measured flux at R4 and R5 would require a total radiative loss of 14 mw or 7.5% of the total heat release rate.

Other large-scale tests. Tests 4, 5, and 6 provided the most useful and reliable measurements for the purpose of this study. Selected results from the other large-scale tests are given in Table 1.

Tests 1 through 3 were tests in which water was injected through the gas outlet. Relatively high wind speed and some instrument problems reduced the usefulness of these tests.

Test 7 provided good data for the flame alone. No water was applied during test 7. Further details of the experiments are provided in a report by Pfenning.[6]

Conclusions. The mass-flow ratio of water to fuel gas m_w/m_g necessary to extinguish 200 megawatt methane jet-flames is between 1.6 and 2.2 using a system of four spray nozzles directing water vertically upward surrounding the flame.

In cases where insufficient water is added to extinguish the flame, thermal radiation and plume temperatures are reduced. Laboratory tests have shown that radiation from propane jet-flames may be reduced by one-half before flame extinguishment. In one of the large-scale tests with methane jet-fires, water spray reduced radiation to ground level by about 30%.

The large-scale tests conducted in this study are an idealization of conditions during blowout fires. The heat-release rate of these test fires is the same order of magnitude as expected blowout fires on offshore platforms. Testing in this program has shown that it is feasible to extinguish these fires and/or reduce radiation from the flame using water sprays.

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It should also be recognized that these research test programs could only be completed with the help of many talented and experienced technical support personnel at both NBS and Energy Analysts.

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