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Petroleum Sessions

OIL SPILLS—CONTAINMENT AND REMOVAL

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Experimentation and field-testing have produced an effective method of handling spilled oil efficiently under a wide range of conditions.

Oil which has been spilled on water is expensive—the most expensive in the world.* In addition to costs arising from damage to shorelines, boats, and wildlife, a major reason for the high cost of spilled oil is the cost of cleanup, of attempting to remove it from the water surface. Further, a great need exists for improved oil spill cleanup techniques for use on open seas, preferably a total system which can be used to remove spilled oil efficiently under a wide range of environmental conditions.

Most oil spills occur during some activity of oil production or transport. Examples include tanker grounding, oil well leakage, tank overflows during loading of barges, and pipeline leaks caused by corrosion. From a recent survey,¹ oil spills usually occur close to shore, near a port, and often under adverse weather conditions, with moderate to severe winds, water currents, and waves. Adverse conditions also tend to be the rule after a spill has occurred and to continue for the duration of the incident, which complicates the job of oil spill cleanup. Oils which are spilled range from refined light products to residual fuels and crude oils, and the volume spilled may range from a few gallons to many thousands of barrels. The properties of spilled oil always tend to change with time, owing to evaporation and solution (and, more slowly, owing to oxidation and biodegradation) with the result that both the viscosity and specific gravity of spilled oil increase with time.

This paper describes currently available oil

spill cleanup equipment and techniques, primarily from the standpoint of their advantages and limitations. In addition, a relatively new and novel system for oil spill cleanup is described which is largely unaffected by weather conditions and involves use of a surface active chemical to limit the spreading of spilled oil on the surface of water, polyurethane foam generated on-site to sorb and immobilize the oil, and nets to pick up the sorbed oil. This system has been tested sufficiently to indicate marked advantages in many cases over more conventional oil spill cleanup techniques.

Conventional Oil Spill Cleanup

If oil is spilled on water, attempts may be made to confine it by means of booms, to skim the confined (or unconfined) oil, and to sorb it using available materials such as straw. Alternatively, it may be dispersed, burned, sunk, or gelled. Each of these techniques has certain advantages as well as limitations and disadvantages which are discussed below.

Booms

Confinement of spilled oil by means of mechanical booms is widely practiced, and a large number of different types of booms are available. Basically, any boom will have (1) a means of flotation, (2) freeboard to resist waves washing or splashing oil over the top, (3) a skirt to try to prevent oil from being carried underneath, and (4) a longitudinal strength member which also provides a means of anchoring. It should be noted that a boom must have good hydrodynamic sta-

*Based on reports from recent oil spill cleanup campaigns, oil which is spilled on the ocean costs about \$1/gal or more to clean up.

bility to be effective in either waves or currents. In use, a boom may be deployed roughly perpendicular to the wind or current direction in order to physically block the movement of oil on the water surface or it may be deployed at an angle to the wind or current to guide the floating oil into quiet waters, where it will be easier to collect and remove.

In quiet water or in low waves or currents, booms do contain oil, but containment becomes progressively more difficult with increasing current velocity and with increasing wave heights. Wicks² has shown that no boom can contain oil if the current is more than about 1.2 ft/sec even in the absence of waves. The critical velocity for containment of oil depends strongly on the oil density and decreases as the oil density increases. Use of great skirt depth does not help in most cases.

In the presence of waves (no current), failure of a boom to contain oil results from either mechanical failure of the boom (insufficient strength or insufficient anchoring) or from splashover.

Walker³ shows that the ability of a boom to resist splashover depends on its freeboard; the freeboard must be roughly equivalent to the wave height. Splashover will occur if the wave height is greater than the freeboard of the boom and the wave steepness (defined as the ratio of wave height to wave length) is greater than 0.08. In the presence of both waves and current, the oil containment capabilities of a boom are less than with either waves or currents alone.

A third mode of failure in waves is by droplet formation as the waves impact against the relatively rigid and stationary boom. The droplets can subsequently be carried under the boom quite easily. This mode of failure has not been studied extensively.

The primary limitations of booms thus include current, splashover, anchoring problems, and strength. In addition, there are significant problems of storage, deployment, and handling which need to be considered in the selection of booms for any specific location.

Air Barriers

Confinement of floating oil by air barriers

has several advantages over other means of containment. The primary advantages include no interference with ship or barge movement and rapid activation in an emergency (providing the manifold is already installed). Air barriers have usually been installed in harbors and estuaries where current velocity is very small. Use in rivers or in deep water has been proposed but is not recommended, owing to physical limitations. The primary components of an air barrier are a subsurface manifold containing spaced orifices and an air compressor or other source of air under pressure. Air bubbles issuing from the orifices produce an upwelling current of water which, at the surface, produces horizontal water currents away from the barrier. The horizontal water currents tend to push floating oil away from the vicinity of the barrier.

On still water, air barriers are quite effective for containment of oil. However, as shown by Jones,⁴ air barriers do not positively block the movement of oil in the presence of even very low water currents (e.g., 0.4 knot). Other limitations of air barriers include possible blockage of the orifices by marine growths and by sediments and, of course, mechanical failure of the air supply.

Skimmers

A variety of skimming devices are available for physical removal of floating oil from a water surface. Milz⁵ has classified these into three categories: weir-type, floating suction, and sorbent surface. In each case, operation of a skimmer depends on (1) migration of oil to the vicinity of the skimmer; (2) the action of removal (i.e., flow over the weir, imbibition by a sorbent belt, adsorption on a rotating disk or drum); and (3) recovery by a pump, wringer, scraping blade, etc.

All skimming devices work fairly well if the oil layer is deep, but all suffer a decrease in efficiency when used with very thin oil slicks, owing to the slow rate of arrival of oil. This limitation can be partly overcome on open water by moving the skimmer across the surface, using booms in front of the skimmer to divert oil to the vicinity of the skimmer. Other possible limitations on skimmers include low mobility, poor hydrodynamic stability in

the presence of waves, and inability to handle floating debris, which can clog pumps and transfer lines.

Sorbents

Oil can be immobilized on the surface of water by means of solid materials (sorbents) which either adsorb or absorb the oil. The sorbent plus oil mass can then be picked up mechanically to remove the oil from the water surface. Among the earliest sorbents used were natural sponges, and both hay and straw have been widely-used oil spill sorbents owing to their ready availability in most locations and good efficiency. Other sorbents which have been used include sawdust, wood chips, ground corn cobs, expanded vermiculite, and foamed plastics such as polyurethane and urea formaldehyde. In general, the efficiency of a sorbent (pounds of oil sorbed per pound of sorbent) depends on bulk density; the most efficient sorbents are those with low bulk density. The most efficient we have tested to date is polyurethane foam, which can sorb up to fifty times its own weight of oil. In terms of cost effectiveness, polyurethane foam is at least as low in cost as is hay or straw. As an oil spill sorbent, polyurethane foam has the definite advantage that it does not become waterlogged and sink, which is a disadvantage of all cellulose-based sorbents.

Dispersants

Wave action will tend to break up a floating oil mass into droplets. These droplets can be more readily acted on by bacteria and molds than before dispersion and are eventually converted to carbon dioxide and water. Dispersants reduce the interfacial tension between oil and water and thus aid the natural dispersing action of waves in breaking up floating oil masses. Proponents of dispersants argue that they thus aid in eventual decomposition of spilled oil. Certainly, one of the simplest means of removing floating oil from sight is by use of dispersants. Objections to the use of dispersants arise from (1) the relatively toxic nature of some of the dispersants used and their solvents, (2) the fundamental objection to adding still another contaminant to the environment, and (3)

concern that oil can enter the food chain of marine life more readily when dispersed in fine droplets and that the oil which thus enters the food chain may have long-term damaging ecological effects. In addition, nutrients such as nitrogen and phosphorus are needed to enable bacteria or molds to react rapidly with oil; these nutrients are not necessarily present in sufficient quantity.

Burning

Oil on water is difficult to burn if spread thin (e.g., less than about 1/8-inch) because the water acts as a large heat sink. In addition, oil-in-water emulsions are difficult to burn, as are oils which have weathered (light components lost by evaporation). Several means are available to aid in burning. These burning agents usually float on water, are fairly good insulators, usually are refractory, and act as wicking agents to aid oil to reach the upper surfaces where it can burn. A disadvantage to the burning of oil is the air pollution which results. Additionally, owing to the problems of maintaining combustion, burning usually will not remove all of the spilled oil from water even if combustion can be initiated. The efficiency of burning of heavy oils on the open sea is reported to be no more than 50-60 per cent.

Sinking

Sand, chalk, and other minerals have been used or proposed for use to cause floating oil to sink to the ocean bottom. Chalk was used successfully by the French in the case of the Torrey Canyon spill, and the Dutch have developed a sophisticated system for sinking oil by means of sand. A wetting agent can be added to such materials as sand to cause it to be oleophilic, thus aiding in the oil removal process. Objections and limitations to the use of sinking agents center on possible ecological damage: oil which sinks to the bottom can harm shrimp and oyster beds, the bottom environment has much lower bacterial activity and lower oxygen content so that biodegradation will be impeded, and oil which has been sunk may enter the marine life food chain with resultant potential damage. Further, sinking agents normally leave some oil on the water surface, being only about 90-92

per cent effective. A practical disadvantage to the use of sinking agents is the equipment needed (e.g., dredge barge, pumps, and spray nozzles for the sand-sink method). However, it has been reported that oil removal by sinking is probably the least expensive means presently available (reportedly as little as four cents per gallon of oil) and sinking methods have the possibility of treating very large spills more rapidly than most other methods. Sinking methods increase in efficiency with oil viscosity and density.

Gelling

Chemical additives have been developed which can be added to fuel tanks to cause the contents to gel rapidly for damage control. Use of such agents has been proposed to immobilize oil which has spilled on water. None are yet available commercially which are effective. It seems likely that gelling agents will have very limited application to treatment of spilled oil owing to the problems of distribution and mixing. Further, the same concerns about toxicity which limit the use of dispersants may limit the use of gelling agents, because some of any gelling agent which is used will inevitably mix with water adjacent to the spilled oil. No costs are yet available, but these are likely to be moderately high.

A New System for Oil Spill Cleanup

We have developed and tested a relatively new approach to the problem of oil spill removal, using information from recent laboratory and field studies. This new method is a complete system which appears to be applicable to a wide variety of oil spills under many different environmental conditions, ranging from fresh water to salt water, whether flowing or not, and in the presence of both wind and waves. It has distinct advantages over the older techniques of oil spill cleanup which are described above.

The objectives in cleaning up an oil spill should be (1) to limit the spread of the oil, (2) if possible, to immobilize the oil for ease of subsequent handling, and (3) rapid and efficient removal of the immobilized oil from the water surface. Our new system includes the following components to accomplish these

objectives:

1. To limit the spread of oil, use of a surface-active chemical. A variety of chemicals can be used to accomplish this objective but our data, which include information relevant to effects on the environment in addition to application data, pertain to a particular chemical.
2. To immobilize the oil, use of a flexible, low density, fast-curing polyurethane foam generated at the site of the spill from liquid components and distributed on the surface of the oil by a power mulcher (hay blower).
3. To remove the oil plus sorbent from the water surface, use of one-inch mesh nets or sieves.

The component parts of this system and tests we have made on them are described below.

Surface Tension Modifiers

The spreading of oil on water has been discussed at length by Cochran and Scott⁶ and by others. After the initial spreading period in which gravitational and viscous forces are important, the only important forces tending to cause oil to spread on water in response to a force unbalance. Three forces operate on an oil slick: the surface tension of water σ_{ow} , which tends to spread the oil on the water surface; the surface tension of the oil σ_o ; and the interfacial tension between oil and water, σ_{ow} . Both σ_o and σ_{ow} tend to cause the oil droplet or slick to contract upon itself. It should be noted that σ_o is typically larger than the sum of σ_o and σ_{ow} , in which case the spreading pressure, F , defined as

$$F = \sigma_{ow} - (\sigma_o + \sigma_{ow}) \quad (1)$$

is positive and the oil will tend to spread indefinitely on water.* However, if a chemical can be placed on the water surface adjacent to the oil slick which in effect reduces the apparent surface tension of water there, the oil will not spread and can actually contract upon itself.

In addition to the necessary surface properties, a chemical which is to be used for oil spill control must be readily applied over a wide

*The two angles, θ_{ow} and θ_{ow} , are generally small and their cosines are very nearly unity. For this reason, they are ignored in Equation 1.

range of temperatures and should be essentially nonflammable. Further, it should be biodegradable and should not be harmful to marine life under normal conditions of application.

The effectiveness of a surface active chemical as a containment means depends on its own spreading pressure. As shown by Garrett,⁷ the depth of oil which can be contained under ideal conditions is given by the following equation:

$$t = - \left(\frac{2(F_o - F_t) \rho_w}{g_c \rho_o (\rho_o - \rho_w)} \right)^{1/2} \quad (2)$$

where

t - oil layer thickness, cm

F_t - spreading pressure of the chemical treating agent, dynes/cm

F_o - spreading pressure of the oil, dynes/cm

ρ_o - density of oil layer, gm/cm³

ρ_w - density of water phase, gm/cm³

g_c - gravitational constant, 980 cm/sec²

A large number of chemicals have been examined by Garrett and others, including soaps, amines, alcohols, acids, etc. Many show the desired surface chemical properties but in varying degrees, depending on their spreading pressures. Garrett has concluded that the spreading pressure of a treating agent should be at least 40 dynes/cm to be generally effective in oil spill control; this requirement eliminates most chemicals from consideration. One chemical on which we have obtained a great deal of data has a spreading pressure of 42 dynes/cm.

An indication of the effectiveness of surface tension modifiers is the area covered by oil before and after addition of the treating agent. When tested against a variety of crude oils and refined products, we found that the area covered by the oils can be reduced by factors up to several hundred.

We have made tests of a surface tension modifier in slips, harbors, and offshore. In the offshore tests, 30 miles south of Galveston, it effectively limited the spreading of a crude oil for over four hours in winds of 25 knots and waves from four to six feet. Our experience indicates that 20 gallons of the chemi-

cal per linear mile of oil slick perimeter are sufficient for control. We see no problem with currents in offshore conditions, because the system can be allowed to drift with the prevailing currents. On low-temperature water (e.g., 31°F) the surface tension modifier spreads more slowly than at room temperature, but it is still effective in limiting the spreading of oil on water.

The Sorbent—Polyurethane Foam

The efficiency of an oil spill sorbent depends on its bulk density. In general, the lower the bulk density, the more efficient it will be, and the most efficient sorbent we have tested to date is low density (2 lb/ft³) polyurethane foam. The unit cost of polyurethane foam for oil spill recovery is as low as hay or straw. The major problems to date with the use of polyurethane foam for oil spill control have been storage, transportation, distribution, and collection. The most efficient way to store and transport it would be as a liquid, prior to foaming. Our concept is to transport the liquid components to the spill site, generate the foam on site, allow it to rise and cure (which must occur rapidly), and then to shred the cured foam bun using a hay blower, which will also distribute it on the surface of the spill. We have experimented with polyurethane foam formulations in a search for one which will rise and cure quickly under most environmental conditions. We now have a formulation which rises and cures within two to five minutes at any temperature between 40°F and 120°F and in relative humidities from about 20 to 90 per cent. The mixing and spraying equipment we have used, which includes a hand-held gun, is relatively simple and readily available at nominal cost. The resulting foam has a density of 2 to 3 lb/ft³ and has up to 90 per cent open cells.

One problem with polyurethane foamed on site is the tendency to form a relatively impermeable "skin" on the outside of the bun. This skin interferes with sorption of oil. The effects of the skin can partly be avoided by use of a substrate during foaming and partly by subsequent shredding of the cured foam. The use of substrates is discussed below.

We have done bench-scale testing by spreading the hand-mixed foam components on: 1—wet and dry sand; 2—newsprint paper; 3—Teflon, to simulate a moving belt operation; 4—directly to water surfaces; 5—directly to oil surfaces floating on water; and 6—hay and rice straw, to act as a binder. Good quality foams were obtained in tests 1, 2, 3, and 5. When the foam was spread directly on water, and on oil floating on water, reasonable quality foams were produced at times. The quality of isocyanate and the stage of reaction before contact with the water or oil are both critical. Reasonable quality foam with open cells on the water interface or oil interface side can be made.

We found the foam quality to be excellent when spread on Teflon; the foam removed one minute after pouring had 80 to 90 per cent open cells at the foam-Teflon interface. This operation simulates one possible technique to prepare foam on site. For the oil recovery system which we propose, a moving Teflon belt will be used to produce long thin strips of polyurethane foam with open cells on both sides. The long strips can be shredded or can be applied directly to large or thick spills.

We have found that foam is easily distributed by a slightly modified hay spreader or mulcher.* When one to two-inch thick buns of foam are fed to the hay spreader, the foam is shredded and is blown out in particles ranging from about 1/2 x 1/2 x 1/2-inch to 2 x 4 x 6 inches. These appear to be suitably sized for picking up thin oil slicks from water. The hay spreader has the additional advantage of exposing the open cell structure of cured foams for more efficient sorption. We have obtained good distribution patterns at distances up to 90 feet from our hay spreader with polyurethane foam.

Collection of the Oil-Soaked Sorbent

After the sorbent has been exposed to oil, it must be collected, and it may be desirable to move it on the surface of the water to a convenient location for removal from the water surface. Either booms or nets may be considered for these purposes. Booms and

*For example, Reinco Model TM 7-30, with shredder bars added.

nets may be towed between two boats or, where wind or current is present, anchored in such a manner as to serve as barriers for containment or, preferably, to act as diverters to guide the flow of sorbent to some desired location. Those factors which limit the use of booms are:

1. The wave conditions which limit the use of booms for sorbent containment are similar to those limiting the use of booms for oil retention. Failure occurs by splashover, which depends on both wave height and wave steepness in much the same way as oil splashover depends on these factors. To a lesser degree, splashover is affected by sorbent specific gravity and by the amount of liquid that has been sorbed.

2. For either containment in the presence of currents or for sweeping, the limiting value of water velocity normal to a boom, above which a floating sorbent will be swept under the boom, depends on the quantity of sorbent per linear foot of boom length. For low sorbent concentrations, we have found that failure velocities normal to the boom appear to be on the order to those at which oil would escape under the boom, approximately one ft/sec.

Nets are more readily deployed than are booms and are available world-wide through fishing fleets. Since the flow of water is directed through the net, rather than under it as in the case of a boom, the sorbent is collected against the surface of the net and there is less tendency for it to be washed under the bottom. We have found that polyurethane foam tends to agglomerate when wet with oil, thus facilitating its harvest with a net. For example, polyurethane foam of a size such that 90 per cent will pass through a 1/4-inch mesh screen when dry will be retained almost completely on a 1/2-inch mesh screen after a nominal soaking period in oil. The net must be adequately buoyed at the top and ballasted at the bottom so as to present maximum surface area to the sorbent. Based on tests with one-inch mesh, we estimate that towing speeds of two to three feet per second may be possible with essentially no loss of sorbent, for moderate quantities of sorbent.

For relatively large quantities of sorbents, the behavior during sweeping is somewhat

different. Tests in a current tank with a one-inch mesh screen barrier show that there are two distinct modes of failure: first, the sorbent forms a mat parallel to the surface of the water, and as the speed of sweeping increases to 1-2 fps the mat collapses, covering the face of the screen as it extends under water. Then, as speed further increases the sorbent is swept under the screen. We conclude that, for collection of large quantities of sorbents per unit length of net, the collecting boats must move so as to maintain a low relative velocity through the water, probably below one fps.

A net configuration similar to a purse seine should enable the sorbent to be picked up, drained of water, and deposited on a barge or boat. A net suspended from a spreader bar and attached to a drag line in the place of the drag bucket could be useful in sweeping and collecting.

Field Studies

The proof of any system is its performance in the field against a real oil spill. We have made a number of field trials of the component parts of our proposed oil spill control system and of the whole system, in addition to the laboratory and field tests already described. Our conclusion from these studies is that the new oil spill control system we have proposed is practical for use on a wide variety of difficult-to-control oil spills. As discussed above, the system includes: (1) a surface tension modifier to limit the spreading of the oil; (2) use of a sorbent (polyurethane foam) to immobilize the oil, with on-site generation of the foam and distribution of the sorbent using a hay blower; and (3) recovery of the oil-soaked sorbent using a net boom.

Offshore testing both on simulated oil spills and during accidental spill incidents have resulted in development of the following generalized application suggestions:

1. The surface tension modifier should be applied only to the perimeter of the oil slick, i.e., at the oil/water boundary.
2. Application should be in a steady stream at a rate of 10 to 20 gallons per mile of oil slick.
3. Application can be either from a boat or from a helicopter equipped with a conventional chemical spray boom.

4. Dependent upon weather conditions and water temperature, the effectiveness of a surface tension modifier will decrease with time. Hence, respraying of the slick at intervals may be required to control oil slick size.

5. If preparation time is available, it should always be desirable to apply the surface tension modifier to the water surface prior to oil release.

6. The surface tension modifier to be utilized for spill control should be evaluated against the oil spilled to ascertain the degree of effectiveness to be anticipated, preferably in contact with the actual water of interest.

Surface Active Chemicals for Beach Protection

The class of chemicals that spread rapidly on water also will preferentially wet silicates and carbonates, i.e., the surface chemical will wet sandgrains. Thus, if a beach is chemically treated prior to the arrival of the oil slick, the oil will not soak into the sand but rather will collect in discrete pools on the beach thus making the cleanup job much simpler. For large scale beach treatment the surf should be sprayed with the surface tension modifier at a rate of twenty gallons per mile of beach front.

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ZERO IN ON PLATFORM SAFETY SYSTEMS

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Oil drilling platforms require complex and varied, yet integrated, systems for fire prevention, detection, and extinguishment, and for protection of personnel.

The Dolly Varden Platform is the largest of 14 platforms located in the waters of Cook Inlet, Alaska, some 70 miles southwest of Anchorage. Drilling included 23 wells in the Hemlock reservoir, three wells in the "G" Zone, and one gas well in the McArthur River Field, making a total of 343,875 feet of hole drilled. Currently, production averages 46,000 BOPD, and water injection averages 56,000 BWPD. Oil and gas are shipped through two 8-5/8 inch O.D. and one 4-1/2 inch O.D. submarine pipelines to production facilities onshore.

The platform is a four-legged structure, each leg being 17 feet in diameter. The drilling of wells is accomplished through 33 inch diameter tubular piles located in each leg. There are 12 piles in each leg, and nine piles remain available for drilling at present. Note that compression facilities are set over one leg, eliminating the possibility of drilling through the 12 piles located in that leg. The pilings are 350 feet long, extending 180 feet into the Inlet floor.

There are three deck levels on the platform. The upper level is referred to as the drilling deck. It contains the two drilling rigs with accessories, sand filter building, a gas lift

compressor, living quarters for 72 men, and a heliport over the top and end of the quarters.

The middle level is the production deck. The 20 foot high production deck contains three wellhead rooms, production separator room, generator room, water injection pump rooms, a gas lift compressor, DE filters, a cementing unit, and materials storage area.

The lower level is the subdeck. It contains pumps to transfer liquids from the girder beams to all areas of the platform. The electric firewater pumps are located here along with the standby emergency generator, steam boiler, glycol heating boilers, standby air compressors, and oil shipping pumps. A fire wall separates the hydrocarbon handling systems from the other areas of the subdeck. The subdeck hangs below the production deck into the boxed area between the four cylindrical girder beams. The girder beam tanks, 17 feet in diameter, store diesel, potable water, drill water, waste water, waste oil, and filtered water for injection.

The decks were enclosed with insulated siding, and the steel floor was insulated with a mineral fiber block-type insulation.

For a size comparison, the distance from

mean low-low water to the drilling deck level is 92 feet. The dimensions of the drilling deck are 120 feet long by 120 feet wide.

In the operation of drilling for and producing oil from the platform, we are primarily concerned with the problem of leakage of crude oil and natural gas. Whenever oil and/or gas leaks, then we are faced with the possibility of fire and/or an explosion.

The safety of the personnel and the platform is dependent upon good detection, alarm, and control functions. These functions are built into each of the various safety systems, which I will discuss singly. Reaction to an alarm or warning device is sometimes automatic. At other times, manual control may be necessary or desirable.

Automatic and manual dry chemical and water deluge are provided in seven areas. They are the three wellhead rooms, the production separator room, the shipping pump room, and the two gas compressor rooms. Hose reels for chemical, water, and CO₂ gas are available for manual use in other areas of the platform. Gas detection equipment is used extensively to detect any gas or crude oil leak.

Fire Protection Systems

Dry Chemical

Located on two levels of the platform are two 2,000 pound dry chemical spheres and two 1,000 pound dry chemical spheres. A 2,000 pound and a 1,000 pound sphere are so connected as to supply 3,000 pounds of chemical to the well rooms.

The heat actuating devices or rate of heat rise detectors are used for detecting fires. Upon sensing a rapid rate of heat rise, pressure is transmitted through small tubing to an actuating head on a CO₂ gas cylinder. Through a diaphragm operated valve the CO₂ is released, energizing the pressure switch which signals the fire panel (this will be discussed with the water system) and continues on to the affected zone valve, gas cylinders, and into the master valve of the dry chemical sphere. This CO₂ pressure, once opening the sphere master valve, will set into

play the dry chemical system. Sphere pressure builds to approximately 230 psi from stored nitrogen gas. Dry chemical is expelled through the zone panel, the affected zone valve being opened previously, and into the affected area. Discharge of the chemical occurs within 20-25 seconds through spinner nozzles located in the affected areas. The firewater pumps have been previously locked on by the fire panel control, and after a time delay of approximately 45 seconds the affected area water deluge valve is opened by an electrical signal from the fire panel. Thus we have water following the dry chemical deluge into the affected area.

In the event of failure of the automatic sensing devices resulting from an explosion, parting of control tubing, etc., the dry chemical system can be actuated manually. The following manual trips will activate the spheres: (1) remote actuating device at the seven locations; (2) an actuating device at the dry chemical sphere location; (3) the sphere itself by manually tripping the master valve and opening the proper zone valve.

Also located throughout the platform are nine remote hose reel stations which control the dry chemical sphere.

Our experience to date has shown these systems to be very effective. The detection of the rate of heat rise has been considerably better than expected. Also, the rate of heat rise or "HAD" units furnish high reliability and very positive control of the dry chemical system without requiring any electrical wiring.

Water

The fire panel controls the starting of the fire pumps, sounds the alarms, and shuts in all production. These functions are performed automatically if actuated by the rate of heat rise detectors located in the affected areas. Also, these functions can be manually actuated from the dry chemical fire boss panel, from the nine water hose reel stations, the nine dry chemical hose reels, various break-glass stations located throughout the platform, the operator's fire panel, and the foreman's production office.

Briefly, the fire panel works in this manner: All switches which activate the fire panel are normally open; when one of these is closed,

a series of time delay relays are energized. If the fire panel is activated by the fire boss panel as mentioned above, an additional function is performed—after approximately 45 seconds, the affected area will be flooded with water to prevent re-ignition of the fire by cooling the hot metal. This delay in water deluge is performed by a solenoid-controlled valve located at the deluge manifold. A pressure switch located at the dry chemical actuator stations sends the electrical signal through the fire panel to start the chain of events.

Manually, the following actions will set off a fire signal for approximately 30 seconds, latch in the fire pumps, and shut in production: (1) tripping a switch at a hose reel station; (2) manually operating the fire alarm switch at the fire panel in the production operator's office; (3) manually operating the switch so designated at the fire panel in the foreman's office.

In addition to the manual trips, the following will be performed if the fire control system is activated by a rate of heat rise detecting device located in one of the seven areas previously mentioned: (1) there will be a 30 second sounding of fire sirens; (2) firewater pumps will be latched in; (3) production will be shut in; (4) a water deluge will occur in the area sensing a high rate of heat rise approximately 35-45 seconds after the dry chemical deluge.

Located in the subdeck level are two 40 hp, 500 gpm firewater pumps and one 25 hp, 250 gpm standby emergency firewater pump. These firewater pumps discharge water into a common six inch distribution system which carries water throughout the levels of the platform. Also, nine hose reel stations are located throughout the platform.

Isolation valves have recently been installed to route water to any corner of the platform or affected area if water is lost in other critical areas due to explosion or fire. The typical control of deluge water consists of opening a pneumatically operated ball valve which receives a signal from the fire control panel.

Standby and Emergency Power Firewater Pumps

Recently installed is a 600 gpm, 130 hp

diesel-driven firewater pump package. The pump takes suction from a chute which is connected to the outside Inlet water. Thus we now have a water source from outside as well as stored water in the girder beams from which the electric firewater pumps take suction. The diesel-driven firewater pump is located in the northeast well room, starts on the fire alarm signal, and will prevent loss of complete firewater systems in the event of a major explosion in the boiler room.

The 25 hp electric firewater pump is on the standby emergency generator system. In the event of a power failure on the platform, we have available, for fighting fire, the diesel-driven pump of 600 gpm and the electric firewater pump of 250 gpm capacity.

A recent addition to our firewater system was the tie-in of our cooling water system to our firewater system. By manually opening ball valves, we can supply 45 psi water from large, high volume cooling water pumps to our firewater piping, thereby supplying water for cooling in the event of a major fire.

CO₂ Gas System

To adequately protect our motor control center, distribution centers, and electrical switchgear throughout areas of the platform, CO₂ gas systems have been installed.

Briefly, 200 pounds of CO₂ gas from each storage cylinder can be released by thermal heat switches located throughout the electrical panel gear in various areas. A total of four cylinders are used with addition of zone valves to route the CO₂ gas to the affected area. Manual trips are located in close proximity to the panel gear in the event manual release is desired. At a main internal stairway of the platform are actuation panels which can be used for manual release of the CO₂.

Hand Portable and Wheeled Dry Chemical Units

Located throughout the platform levels are 20, 30 and 150 units, Ansul type, using Purple K powder and FORAY type powder. Due to excessive vibration on the platform causing compaction of powder, these hand portable units have been mounted in the horizontal position with the chemical discharge nozzle on the top side of the unit. In addition to the horizontal mounting, weekly checks of

the powder within the units are made. The roustabout pusher has been designated as responsible for portable hand unit and wheel unit inspections and checks.

Future Fire Protection Systems

Halon gas is being considered for use in protecting the Solar turbine generator room areas. Explosion suppressant systems utilizing Halon gas are being considered for the gas lift compressor rooms and shipping pump rooms. Light water for use with the water deluge systems is under study.

Gas Detection Systems

Presently we have installed onboard the Dolly Varden some 56 remote module-type Johnson-William gas detectors. The sensing elements located in the remote areas of concern detect explosive limits of gases, alarm, warn, and control back at the production operator's SCAM board and control panel. A 20 per cent lower explosive limit gas mixture will warn with a light indication at the production operator's console, and a 40 per cent lower explosive limit will alarm and control certain of the shutdown functions on the platform.

The shutdown capability controlled by the gas detectors includes a complete shutdown in the case of a 40 per cent LEL mixture detected in the production room, shipping room, boiler room, or gas lift compressor room. A well room shutdown occurs when a 40 per cent LEL gas mixture is reached in that particular well room. Whenever 40 per cent LEL gas is detected around the Solar turbines, either AC or the water injection skids, then a shutdown of that area occurs.

Various applications of the gas detection units have been made. For instance, in the area of our shipping pumps, the most troublesome problem is that of ruptured seals in our electric motor-pump combinations. By locating gas detectors at the seal height and in areas of air movement away from these pumps, we've been able to detect at an early stage a loss of pump seal with associated leaks.

Also, at an early date we found that the heavy, rich production gas settled to the floor level and our detectors at ceiling height were

not picking up the gas to alarm. We have located gas detectors at floor level in various rooms and in hidden or dead space areas below our wellhead rooms.

In other cases, such as along our gas lift manifolds, the injection gas, being dry and lighter, presents the opposite problem of rising. Along these manifolds and in the ceilings, we have located detectors to sense this gas as it may rise from a leak.

We feel that the gas detection system is one of our most important safety systems on the platform. Close maintenance checks are performed on this equipment to keep it as effective as possible.

Vibration is the major problem with our gas detection system. Along the truss rows and high vibration areas, we have mounted the remote sensing unit on rubber shock mounts. In many cases, this has eliminated damage to the sensor. Other causes of sensor failure are heat, steam-cleaning, and use of water in cleaning the well rooms and production areas.

Alarm and Shutdown Systems

The SCAM board, including the fire panel, is the nerve center of the alarm and shutdown systems of the platform. A complete platform shutdown occurs with a fire alarm.

The gas alarm and shutdown of equipment affected was covered under the gas detection system. It included a complete shutdown of the platform with gas leaks in the shipping room, the boiler room, production room, and gas compressor rooms. It included a shutdown of well rooms individually on a high gas alarm from that well room. Also, the gas alarm occurring at a water injection pump and/or electrical generator system would control a shutdown of that room or area.

In addition to the gas alarm and shutdown features of the SCAM board, a high pressure shutdown control occurs when a pressure of 180 psi is reached in the production and test separators. High level alarms signal a shutdown in the separators and vent scrubber. High level alarm signals, without control features, are given from the waste water and waste oil tanks. External level controls and dual relief valves make testing simpler and more accurate. A gas well is shut in on a

manual system at the operator's discretion.

A shutdown of production from the B-1 well room occurs on an electrical load shedding priority. A complete production shutdown occurs when the oil shipping line to shore reaches a pressure of 1,200 psi or greater. An alarm is sounded at the 1,000 psi level, with the operator taking immediate action. There is a high pressure shutdown feature of 250 psig on the gas line to shore. Also, the vent scrubber high pressure will cause a production shutdown.

A shutdown of production at the wells is accomplished with manumatic-type valves operated by air pressure. These valves also close on a low flow line pressure of 40 psig, and a high pressure of 200 psig.

Down-hole Otis-type ball valves, located in the tubing strings at 300-350 feet depth, can be closed by bleeding 3,500 psig hydraulic supply pressure.

Thorough monthly checks are made on this shutdown equipment.

The various SCAM board warning and alarm signals are tied in with rotating beacons in areas of high noise so that the operator can observe the signal of an alarm occurring on the platform.

The communication system or public address system is also utilized with ring-in type remote stations located throughout the platform. Personnel can be paged through the speaker system and communicate through the remote hand sets. Also for fire fighting, abandon platform, and man overboard exercises, the platform supervisor can issue instructions over the PA system.

Evacuation Systems

Evacuation procedures are covered on the current station bills. If an evacuation is called by the platform supervisor, personnel proceed to the survival capsules located at the northeast drill deck level of the platform and the production level on the west side. These two capsules of 29-man capacity each were built by the Whittaker Corporation. They are constructed of fire retardant fiber glass and contain a self-breathing air supply for approximately an hour and a half, five day supply of rations and water, 45 hp diesel engine, radio gear, and various and sundry

survival gear including flares and locator beacons.

These survival capsules have hydraulic piston-type launching devices. Once released from the platform level, they cannot be stopped from their vertical controlled fall except by a man at the console located at the launch station. For drills, the capsules can be retrieved by a man located at the sphere launch station. Due to their ability to sustain tremendous shock loads, their ability to withstand fire and cool their outer shell with a sprinkler system, their ability to supply breathing air, and the seat belt arrangement inside, we believe that the survival capsules are the safest means available today to evacuate personnel from an offshore platform. In testing with severe running tides in excess of five knots, the capsules were released with no problem encountered from strain or pull on the release mechanism. Personnel involved with the training were completely surprised in the manner in which they contacted the water. In many cases, the personnel did not know when they were in the water.

Also available for evacuation are life raft davit stations at which we have two 25-man life rafts.

At the subdeck level, where the exterior stairways join the walkaround, we have located scramble nets. These stainless steel wire nets can be unrolled and used to crawl off into the water or rescue boats. Located at various levels of the platform are knotted ropes which can be used for personnel to descend into the water or to rescue boats.

In the quarters rooms, we have located 72 Walrus anti-exposure suits. These suits are flotation coveralls which will allow the individual to jump into 29 to 32 degree water and not become exposed or submerged. Also, life jackets are available in each room, and they are required to be on each person when reporting for a fire drill.

In addition to the systems described above, there is a bartender-type rescue boat, driven with a 190 hp diesel engine, which is available for rescue work whenever ice is not in the Inlet. This boat is positioned so that it can be lowered into the water by either of the drilling deck cranes, east or west side. Launching of the boat during practice usually takes ap-

proximately three minutes from alarm to startup of engine and in the water.

Station Bills and Emergency Procedures

The alarm signals and emergency procedures for fire, man overboard, abandon platform, and drilling well blowout are posted throughout the platform on current station bills.

As functions and numbers of operating personnel on the platform change, revised procedures and duty assignments are prepared. In the event of an emergency or drill, each man has a station assignment and a job to perform; visitors are also assigned reporting stations.

A major disaster plan outlines procedures that the foremen, superintendents, and managers will follow in the event of a major disaster. With preconceived plans and frequent drills, panic might be avoided and the emergency controlled.

Emergency Electrical Generator

We have located in the subdeck area a 90 kw diesel-driven generator. A separate emergency circuit includes equipment such as emergency lighting throughout the platform, radio communication equipment, gas detection, fire alarm, and control panel equipment. Also, we have potable water pumps, a 15 hp air compressor, the 25 hp firewater pump, diesel fuel pumps, two pressurization fans in the boiler room, and two pressurization fans in the engine room, all tied in to this emergency electrical circuit. Upon loss of electrical power, the emergency circuit automatically comes on the line.

Electrical Load Shedding Devices

The total AC load on the Dolly Varden Platform varies between 1,600 kw and 1,800 kw. This load is normally supplied by three 800 kw gas turbine-driven generators operating in parallel on a common distribution bus. A 12 cylinder, 800 kw diesel engine provides standby. A failure of any one of the gas turbine generators would result in an immediate overload condition of the remaining two turbine-driven generators, resulting in a total platform power failure. To circumvent the possibility of a total power failure caused by

the malfunctioning of one generator only, a selective load shedding system was installed. The basis of this system is the assignment of a priority to each electrical load on the platform. Third-priority loads are dropped upon the failure of any one of three generators. The remaining load then does not exceed the capacity of the two generators which are left in operation. Should a second generator fail, the second-priority loads would then be dropped, so that only the first-priority loads are left in operation, these not exceeding the capacity of the one remaining generator. Should all three generators fail as a result of some common problem, for instance a fuel problem, then a small 90 kw diesel-driven generator with its own fuel supply and automatic transfer switch transfers certain emergency loads as discussed above.

Gas Blanket and Pressure Vacuum Relief for Girder Beam Tanks

Of vital concern to us in the past has been the possibility of encountering an explosive gas mixture with ignition in one of our main structural girder beam tanks. We feel we have greatly reduced this possibility by the installation of a gas blanket and pressure vacuum relief system.

A primary gas source is supplied to the beam tanks through regulators set at eight inches of water column. A secondary parallel gas source is supplied through regulators set at eight inches of water column, but actuated by a signal from a girder beam low pressure switch set at two inches of water column, decreasing.

A primary pressure relief consists of two six inch back pressure valves. These back pressure valves with flame arrestors are set to relieve at ten inches of water column.

Flow of liquids to the girder beam tanks can be overboarded when three-way valves are actuated. These are actuated by pressure switches set in the girder beam at two psi, increasing.

A final pressure vacuum relief system incorporates the use of two six inch by eight inch relief valves set at three psig pressure. The vented gases are routed through a vent boom located at the northeast leg of the platform.

At present, this gas blanket system is incorporated on our water flood storage girder beam tank as well as our waste oil and waste water girder beam storage tanks.

Room Pressurization Systems

In rooms containing hydrocarbons (production separator room, well head rooms, shipping pump room) a slightly negative pressure is maintained with exhaust fans. When doors are opened, air goes into the room and gas, if present, does not flow out of the lower pressured area.

In the rooms containing ignition sources (motor room or boiler room) pressurization fans maintain a positive pressure. Air flows out of these rooms when doors are opened.

Alarms sound and the SCAM board warns whenever pressurization systems fail.

Individual Equipment Safety and Shutdown Features

In addition to the many and varied safety systems on the platform, each individual piece of turbine-driven equipment or reciprocating gas engine compressor-type equipment has its own safety alarm and shutdown systems. The manufacturers can be commended in their efforts to install reliable safety alarm and shutdown equipment.

Miscellaneous Other Safety Equipment

Located at the combustion section of the turbines are PS-30 dry chemical units actuated by heat on fusible links. They are provided also with manual pulls outside the injection pump room for actuating the 30 pound dry chemical systems.

A range and duct hood system for the kitchen area of the quarters provides automatic protection from fire in the duct work, over the deep fat fryer, and on the range.

Fire blankets are located at critical stairway levels throughout the platform for use in the event of a person becoming engulfed in flame from a hazardous area fire.

Fresh air and oxygen breathing equipment is located at various levels of the platform and in the production operator's and supervisor's office for use in rescue or transport of injured personnel to the hospital by boat or helicopter.

Emergency battery-powered lighting is located throughout the critical walkways and stairway areas of the platform to permit evacuation and egress throughout the platform in the event of a complete power and emergency power failure.

Two fire-pel entry suits with breathing apparatus and navy-type OBA equipment are provided for use in entering a gas or liquid burning area to perform a shutdown of vital equipment and/or rescue of personnel involved in the fire.

Proper designation of high noise level areas on the platform with notations of the areas requiring ear protection are posted. Containers with mufftype ear protectors are located at the openings to the high noise level areas. Studies are under way to provide equipment and systems to properly define and limit effects of high noise levels on the platform.

Conclusion

We believe the best equipment and systems available should be placed on offshore platforms to protect personnel and the investment involved. As the functions of the platform have changed from drilling, production, and construction to one of production operations, the total number of personnel available to meet an emergency has decreased. The people remaining must have the best and most reliable equipment available to adequately protect themselves and the platform in the event of a major emergency.

The experience gained working with these varied systems, analyzing maintenance problems, and updating equipment will improve operations on future platforms.

ZERO IN ON HYDROGEN SULFIDE

By STANLEY D. ATHERTON

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Houston, Texas

Since we do encounter hydrogen sulfide gas in various operations, we must be aware of its properties, its toxicity, and how to "zero in" on the toxic gas to circumvent not only employee exposure to H_2S but damage to equipment from the acidic gas.

The properties and toxicity of H_2S is well defined in the National Safety Council Data Sheet No. 284, Revised, titled "Hydrogen Sulfide." Also, the properties and essential information for safe handling and use of hydrogen sulfide is fully covered in the Manufacturing Chemists Association's publication "Chemical Safety Data Sheet SD-36." Respiratory protective equipment is well covered in the NSC Data Sheet 444, Revision A (extensive), as well as the U. S. Bureau of Mines publication on the same subject.

As you can see, we do have available important information on hydrogen sulfide and personal protective equipment that will aid us in protecting the employee.

Do we have another route to limit hydrogen sulfide exposure in some operations? Yes! We can zero in by sweetening sour gas in many instances. Some of the methods used to sweeten sour gas would include caustic wash, iron sponge, molecular sieve, and amine treating processes, among others.

As we know, the term "sour gas" is applied to gases containing sulfur compounds. These are principally hydrogen sulfide and the lower molecular weight mercaptans. And, it appears that more and more of the acid gas or gases produced must be removed. With this desire to remove the sour gas, application of sweetening processes becomes necessary.

We do have a number of methods available for the removal of hydrogen sulfide from gases. Generally, carbon dioxide is removed, if present, at the same time the hydrogen sulfide is removed. Hydrogen sulfide and carbon dioxide are both acidic in an aqueous solution and they are referred to as acid gases.

Caustic Treating is used mostly to sweeten small volumes of sour gas. This could be for lease use, such as sweetening gas for lease fuel or for domestic uses. Caustic treating can produce gas that is sweet to the lead acetate test. Most caustic treaters consist of a simple vessel holding the caustic solution through which the gas is allowed to bubble.

An ROLO solid calcium chloride gas dehydrator can be used as a caustic treating vessel by substituting either sodium hydroxide or potassium hydroxide for the calcium chloride.

In the *Iron Sponge* process, iron oxide reacts with hydrogen sulfide to form iron sulfide.

Carbon dioxide in the gas does not react with the iron oxide, hence it is not affected by this process. The iron sponge process is mostly used for treating gas at pressures less than 50 psig and with hydrogen sulfide content under 10 grains per 100 standard cubic feet. There is no limit to treating pressure; however, due to gas velocity limitations through the bed, most high pressure applications are limited due to bed size and bed life. Gas from properly operated iron sponge units will pass the lead acetate test. Bed sizes are designed to provide sponge life at about 30 days as a minimum.

An iron sponge installation is in use at the Cayuga No. 2 Plant located in the Cayuga Field, Anderson County, Texas, operated by Getty Oil Company. This field, discovered in the mid-1930's, produced sweet gas up until about 1965. Some of the wells began producing sour gas in sufficient quantity as to cause the plant residue gas to cease being sweet. Gas from the wells producing sour gas is all processed through the iron sponge unit. We operate it as a batch process and are experiencing about six months' bed life. This is about 75 per cent efficiency.

Amine Treating of natural gas for the removal of hydrogen sulfide and carbon dioxide is probably the most widely used process for

sweetening gas.

Getty Oil Company operates two natural gas sweetening plants in East Texas that were designed for use of MEA sweetening solution. Both plants, however, are presently using DGA sweetening solution.

Molecular Sieve Treating involves molecular sieve absorbents that are used to remove hydrogen sulfide, mercaptans, and heavier sulfur compounds from gases. They can be designed for selective removal of small quantities of hydrogen sulfide gases with high carbon dioxide content without removal of significant amounts of carbon dioxide. Simultaneous sweetening and dehydration are accomplished in the same unit.

The only molecular sieve sweetening units that Getty Oil Company operates in the North American E&P Division are used to sweeten liquefied petroleum gases (LPG).

In summary, we have touched lightly on a number of means whereby we can adequately control hydrogen sulfide gas. You will agree, I'm sure, that there are other processes wherein reduction or elimination of H_2S is possible.

Needless to say, release of hydrogen sulfide gas to the atmosphere is extremely hazardous, especially to personnel. Therefore, steps taken to "zero in" on the elimination of H_2S are beneficial in many ways.

ZERO IN ON ZERO OXYGEN

By WES WALLACE

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Evan C. O'Reilly of the Standard Oil Company of California in his talk before the Petroleum Section of the 1969 National Safety Congress¹ described the problems encountered in modern refinery operations when maintenance work must be performed in an inert atmosphere. The knowledge gained by the industry through O'Reilly's experience has proved most helpful and has caused others to examine more closely their techniques for working in lower-than-normal oxygen atmospheres. Manufacturers of breathing apparatus have used the Standard Oil experience to modify, improvise, and improve their equipment.

The equipment used in 1969 employed two independent hoseline supply hoses, one designated primary, the other designated secondary, and a seven cubic foot escape bottle on the person, thus providing three independent sources of air. A five man crew was considered as essential: two men fully equipped working inside the inert vessel; a third man, also fully equipped, outside, ready to enter the vessel, if needed; a fourth man at ground level to monitor the air supplies; and a fifth man to direct and control the crew. All five men were in constant voice communica-

tion with each other.

The market for the specialized breathing apparatus we have reviewed is small, and manufacturers of respiratory equipment were reluctant to invest the considerable funds required to develop new and more complicated breathing apparatus. It is my understanding that the Shell Oil Company underwrote the development of a new type of redundant supplied air system by Bendix, called the Bendix Life Support System. The system supplies breathing air to maintenance personnel working in reactors, storage tanks, and other confined spaces which contain a limited oxygen content or require a complete nitrogen purge to insure safe working conditions. It consists of an air control console and six helmets each with up to 500 feet of umbilical cord containing the two air hoses, safety line, and communications line. The helmet assembly has a two-way conference communication system connected to the console, to other helmets, and to other parties involved in the operations.

The console supplies breathing air for any combination of one to six helmets. It includes a system to test helmet operation and control console to insure correct operations. Visual

control lights and alarms provide the control console operator with means to monitor each helmet performance and to assure maximum confidence and safety of personnel using the equipment.

The helmet wearer is supplied with three separate air sources, thereby providing the required back-up systems to insure maximum safety. If the primary air source is interrupted by a breakdown in the facility's compressed air service, or the air line is pinched, kinked, or cut, the secondary air supply takes over automatically. The secondary system is under pressure at all times the system is in use. If anything happens to the secondary source, a third or emergency air supply is available through a quick opening valve.

The helmet is constructed of high strength impact resistant fiberglass with a Plexiglass facepiece. Mounted into the facepiece are two Bendix aircraft-type pressure demand regulators. If flow through one regulator is interrupted, the other automatically takes over. The flow of air maintains an internal positive pressure in the helmet so that any leakage will be outward. Helmets are furnished in three sizes, with eight sizes of inner foam liners to provide flexibility in fitting various persons.

For simpler applications involving less hazardous work but still in the heavily toxic area, one of the manufacturers has taken his standard airline/demand respirator and converted it to airline/pressure demand. This is still in a prototype stage, but finished models should be ready for the market by mid-1972. This apparatus was designed for users who require respiratory protection in a hostile environment for a prolonged period of time. The respirator operates on low pressure plant supplied air or high pressure cylinder systems. Supply pressure in either case ranges between 50 psi and 125 psi. A demand feature permits use of the equipment in a non-toxic atmosphere. A pressure demand feature results in a lower inhalation resistance, making breathing more effortless and assures that there is no inboard leakage.

When used with a low pressure or reduced high pressure supply of respirable air, the apparatus provides the necessary amount of

pure air needed for normal breathing. When the slide button on the regulator cover is in "pressure demand" position, the regulator automatically maintains a slight positive pressure in the mask to prevent leakage of harmful air into the mask during inhalation and to make breathing more effortless. Loss of positive pressure is prevented by the balanced exhalation valve assembly. When the slide button is in the "demand" position, the regulator supplies air at a rate and volume demanded by the user without the pressure demand feature.

This year has been one of the most rewarding in my experience so far as establishment of modern bench-marks for respiratory protection for American workers and fire fighters. When I first entered this field the protective device with the highest rating for respiratory protection was the old hand-cranked blower mask. Under the new standards², the paragraph for "Respirators Recommended for Immediately Dangerous Atmospheres," the blower hose mask is rated last with regard to protection offered, while pressure demand apparatus is rated first.

The National Fire Protection Association³ earlier this year made a noteworthy addition to firemen's safety. Their new standard No. 19b⁴ effectively eliminated, it seems to me, the use of red canister-type masks in the fire service; these have been marketed by us and others, I regret to say, under trade names such as "Universal," "All-Purpose," or "All Service."

A few concluding comments about facial hair; beards, to be exact. At the same time, we certainly cannot eliminate concern about the heavy sideburns so popular today. You may wish to refer to a report published in *Fire Command*⁵ magazine. This is an excellent report covering tests conducted on 12 volunteers from the city of Manchester fire brigade.

Two of the subjects normally wore a substantial beard. The other ten men had beard growths ranging from 15 days to one month. Three facemask leakage tests were carried out on each man: (a) unshaven; (b) beard shaved, but sideburns left to below the ear lobe; (c) clean-shaven. Some of the men re-

tained moustaches, but these were always small enough to be completely contained within the masks. The two men who were normally bearded chose not to be completely clean-shaven but retained much smaller beards, supposedly small enough to lie within the sealing rim of the mask.

The three facemasks used in the tests were of the plain-seal, revert-seal, and pneumatic-seal types. Each man wore the same mask for each of the three tests. Additional tests, in which the pneumatic-seal mask was worn by the subjects in the clean-shaven condition, were made with the subjects who wore the plain and revert-seal masks.

As before, the subjects fitted the facemasks themselves and checked for gross leakage by gripping the breathing tubes and trying to inhale. When leakage was apparent, the mask was re-adjusted. No attempt was made to refit a mask during a test even when leakage became apparent.

From this series of experiments it is concluded that when the subject has:

1. A full beard, the results show that beard growth substantially increases the inward leakage rate of all the facemasks used in the tests.

2. Sideburns only, the results, as may be expected, show considerable variation; modest sideburns that lie outside the facemask seal should, of course, give leakage rates very similar to those obtained in the clean-shaven condition. Large, bushy sideburns, when sufficiently large and bushy to lie between the facemask seal and the face, are likely to cause a substantial increase in the leakage rate.

In all cases, when the subject was clean-shaven the pneumatic-seal mask gave a low leakage figure, while the revert-seal and plain-seal masks showed considerable variation in the leakage rate. In the case of the two men who retained a small beard, this was trimmed under the chin so that, apparently, no hair was across the mask seal before a fairly good fit could be obtained. The leakage rate, however, was still noticeably higher than with the clean-shaven subjects.

It is my own conclusion that the protection afforded by any facepiece cannot be predicted for any subject other than one who is

smooth-shaven. ANSI standards⁷ state "Respirators shall not be worn when conditions prevent a good face seal. Such conditions may be a growth of beard, sideburns, a skull cap that projects under the facepiece, or temple pieces on glasses."

The "Respiratory Protective Devices Manual," published by the American Industrial Hygiene Association, discusses the use of knitted cloth covers on respirator masks and goes on to say, "Covers should not be used on respirators for protection against fumes because these fine particles will pass through the covers and into the facepiece cavity."

The official publication of the International Fire Chiefs Association in February 1970 discusses the problem and concludes by stating, "In summation, the best advice to fire fighters is a clean shaven face. Why gamble for the sake of vanity or pride? Your own life may be at stake."

A report⁸ presented at the AIHA Conference last May by representatives of the Los Alamos Scientific Laboratory states: "Our conclusion is . . . that those with facial hair in the sealing areas cannot reasonably expect the same degree of protection from any given respirator that they would experience were they clean shaven."

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A REFINERY ZEROS-IN ON AUDIOMETRIC TESTING

By JOHN G. LIONE, M. D.

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A digest of remarks made by the author at the 1971 Congress.

We Americans have the noisiest society, and unless corrective steps are taken immediately, noise pollution will continue at an alarming rate which may see our urban population deaf by the year 2000. The public is now rapidly becoming aware of this important problem. The Federal government has already recognized its importance with the Walsh-Healy and Occupational Safety and Health Laws. Positive action is required now to protect the worker on the job. This can be accomplished by a hearing conservation program which has the full support of everyone—management, engineering medical, safety, union, and the industrial workers. Such a program is necessary to safeguard the hearing of employees and protect the company from compensation costs. Federal regulations have established 90 decibels as the allowable level of noise exposure and a hearing conservation program is required where such limits cannot be met.

A detailed hearing conservation program for a large petrochemical and refinery population identifies the problem by engineering noise surveys and by developing exposure patterns of noise levels of workers. Engineering measures are utilized to control the noise levels. Workers are identified and protection made available. The details of an audiomet-

ric testing program are presented. The pre-employment and periodic health examinations must include audiometric testing. A baseline audiogram is essential on all applicants for employment. Subsequent periodic audiograms will enable the physician to identify the more susceptible individual, as well as anyone suffering hearing loss requiring auditory protection. In a few cases, it may be necessary to reassign an employee to a work environment with less noise exposure. Education of the workers to the problems of noise exposure is a necessary part of the program.

The audiometric testing program is the final evidence of the effectiveness of our hearing conservation program. An audiometric data form is used to record and follow the hearing test results. The objectives of our medical program are to establish a baseline audiogram in the medical record, to prevent employee hearing loss, to detect any unusually susceptible individual, to check on the effectiveness of noise control measures, and to minimize claims and compensation costs.

Hearing of our workers must be preserved. We must all recognize the significance of the role we must play in the prevention of deafness.

PUBLIC RELATIONS IN EMERGENCY OR DISASTER

By ROBERT R. HURT

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All or most of you have a direct interest in accidents. It is your daily job to prevent them if at all possible and to minimize them when they do occur. I am professionally interested in accidents, too, but in a different way. It is my job to see that once they occur, they do not create a distorted impression of our industry and of the emphasis it places on protecting people, property, and the environment. This paper will tell a little bit about what I and other public relations people in the industry do when faced with emergencies growing out of accidents.

To begin with, effective public relations during an emergency do not just happen. Whether they involve injuries, deaths, property damage, environmental pollution, or all of these, accidents are *news*. And newsmen have the responsibility to determine the facts and to report them to the public. Oil companies, through their public relations departments—working in concert with legal and other concerned groups—have an equal responsibility to make the facts about accidents available not only to newsmen but to employees, their families, and the community as well.

It's the only way to go. Simply as a practical matter, big accidents are obvious to everyone, and small ones are often inflated. Just a few days back, a 10-gallon spill on the West Coast made the *New York Times*, 3,000 miles away. That is how fast and how far even a little bad news travels.

An important part of public relations involves helping newsmen get the facts quickly and accurately. They need such help. They work under pressure of tight deadlines. When they have trouble in reaching responsible individuals, newsmen are limited to reporting only what they learn from personal observation or from talking to willing, but perhaps uninformed, bystanders. If such observations and interviews happen to be lopsided, then the stories newsmen write will be lopsided. It is therefore not only in their best interest, but

also in *ours*, to cooperate fully. The real point here is that the stories will be written with or without our help. "With" is better.

Fortunately, the policy of "no comment" in dealing with news media inquiries about accidents or disasters is fast disappearing from our industry and others. More and more executives are coming to the realization that mutual respect and cooperation between the industry and the news media work to everyone's benefit. In fact, this has been spelled out as formal written public relations policy in most oil companies. I have examined a number of such policies, and I find that all contain these four cornerstones:

1. Accurate information should be promptly provided to the news media.
2. The company's readiness and ability to respond effectively to the emergency should be made crystal clear.
3. The public should be informed that the company is taking all appropriate corrective actions to contain damage, protect lives and property, and safeguard the environment.
4. Emotional statements and exaggerations of damages and possible effects should be avoided.

These policy points are not just written up, filed away, and forgotten—they are implemented. Companies faced with emergencies now provide for media access to the accident site; for the establishment of press centers complete with desks, typewriters, and outside telephone lines; and for press conferences with management and technical staff members who know in detail what is going on.

There is another important aspect to good public relations: credibility. Companies do not earn credibility with hard-nosed reporters simply by doing right on one occasion. They earn credibility by doing right over a long period of time. The continuing effort is very much worthwhile. Whatever we might say will be wasted if nobody is listening. But if our past relations with the news media have been marked with frankness and mutu-

al respect, what we say under the stress of an emergency is much more likely to be believed and reported.

Put another way, it is impossible to have good public relations unless there is good performance on which to build. A case in point is underground leakage of gasoline. By and large, sources of such leaks have in the past been quickly identified, and the responsible company has taken corrective action. But there have been instances when the sources of the leaks could not readily be identified and when considerations of legal liability made marketers reluctant to offer assistance to public officials in solving the problem. The resultant lack of action made the industry vulnerable to criticism and reflected adversely on its reputation for responsibility and its concern for public safety.

Recognizing the need for industry-wide action in this area, the American Petroleum Institute several years ago developed a program for dealing with the problem of underground leaks. State petroleum public affairs organizations began to assist public officials, with financial support from API, not only in locating the source of a leak, but also in remedying the situation.

The first real test of the new API procedure occurred in January 1968 when an underground gasoline leak almost led to the closing down of the town of Archbold, Ohio by its mayor. Local and state officials had established the general location of the leak, but were unable to pinpoint its source. Through the auspices of the Ohio Petroleum Council, a special testing device which had been developed with API funds was brought to Archbold and succeeded in locating the leak in a line connecting service station pumps with an underground storage tank.

Since that time, both the program and the equipment have been widely used from Maine to California. The reporting of these incidents has been generally balanced, with many favorable articles and editorials, as well as letters of commendation for the industry from local, state, and Federal officials. In a very real sense, good performance in this area has become good public relations.

In the case of underground leaks, the industry was dealing with a long-term, persistent

problem. There was time to analyze the problem and to develop an effective long-range program to solve it. But time is not always available. As you well know, emergencies can develop with the speed of light. Such was the case when an explosion occurred at Humble's Bayway Refinery in New Jersey last December. There were some pretty wild early press speculations concerning threatening phone calls and possible sabotage by plane. So far as I know, no connection between the phone calls and the explosion ever was established. As for aerial sabotage, the plane in question turned out to be a helicopter on a routine flight from Newark Airport to Kennedy Airport.

What is really important here is the fact that Humble had an emergency plan and performed responsibly. Helping the assigned firefighting crews were hundreds of volunteers—including working reporters who wrote vivid, on the spot stories about what had happened and what was being done. The company displayed the right kind of followup, too. On the very next day, in what one company spokesman described as the "spirit of goodwill," executives publicly stated that Humble would pay legitimate claims for damages.

Preparation and performance also figured prominently in the handling of the tanker collision last January in San Francisco Bay by the Standard Oil Company of California. I am not much for the numbers game. But I do want to indicate the scope of SoCal's effort, and a few selected statistics ought to do the trick:

1. The spill amounted to about 20,000 barrels of bunker fuel.
2. One headquarters and logistics command post directed the activities of five field centers.
3. Workers included 1,500 SoCal employees and contract crews, plus a large but undetermined number of local residents who volunteered services.
4. Equipment included fleets of tractors, trucks, boats, 11 major oil-skimmers, and nine helicopters.
5. Materials included 155 two-way radios, 42,000 bales of straw, 2,100 pitchforks, 2,800 rakes, 2,000 pairs of gloves, 1,700 pairs of

boots, 29,000 burlap sacks, 60,000 plastic bags, and—for the bird-cleaning operations—more than 22,000 gallons of mineral oil and almost 14,000 pounds of corn meal.

Throughout the whole operation, SoCal held press briefings, issued regular press releases, made special mailings, and maintained constant liaison with conservation organizations like the Audubon Society and the Point Reyes Bird Observatory. The result, with a few exceptions, was one of the fairest jobs of reporting an emergency that I have seen.

Other oil companies have commendable records of positive action, particularly in the environmental field. Just 11 days ago, one of the American Oil Company's offshore platforms in the Gulf of Mexico caught fire. The company lost no time in announcing that it will discharge its responsibilities to the public. It will not snuff out the fire with nitroglycerin—a technique that would permit flowing wells to pollute the sea until they could be plugged. Instead, Amoco will let the escaping oil and gas burn off until the wells are plugged. This technique, which involves drilling relief wells, will take 45 days and will cost an estimated \$10 million. I might add that the first rig for drilling the relief wells was on-site barely 60 hours after the fire broke out. Five rigs are now on-site.

It is too early yet to determine what kind of impact Amoco's decision will have on the general public, just how the whole episode will end. It is not too early to say that from a public relations point of view, Amoco has made an absolutely first-rate beginning.

We do have one fully documented record of a recent accident in which an oil company planned well and performed well. I refer to Shell's Bay Marchand platform also in the Gulf of Mexico, that experienced a blowout and fire less than a year ago.

From the moment that the platform erupted in flames, concern for protection of the environment was one of the company's principal considerations. Despite the great cost involved, the company decided not to extinguish the blaze, but to keep the fire burning and thereby consume as much of the escaping oil as possible until relief drilling had effectively "killed" the wild wells. As a result,

ecological damage to the waters and shoreline was kept to a minimum. Here I might add that in the eyes of many newsmen, this decision made by the management of Shell was received as the most important public relations decision made by the industry in recent years.

Since not all of the escaping oil at Bay Marchand was consumed by the flames, skimmer boats were used to collect as much of it as possible before it could drift more than a few hundred yards from the platform. Special booms were positioned to prevent oil from reaching the shoreline or penetrating bays and estuaries. Bales of straw were dropped by helicopter at strategic points along the coast to be used, if necessary, in picking up any oil that happened to reach the shoreline.

Automatic noise-making devices, activated periodically by charges of propane gas, were used to frighten birds away from oil-threatened areas. The company brought in a well-known consultant on the care and rehabilitation of oil-soaked birds. At his suggestion, three portable buildings were erected and equipped with wash tubs, gloves, aprons, and special cleaning agents. In addition, an old abandoned house was designated as a sanctuary where oiled birds that had been cleaned could remain until they regained their natural oils—a process that sometimes involves many months. The company also employed the services of a marine biology organization to help determine whether the escaping oil had caused any permanent changes in the ecology of the area.

During all of this activity, the company's relations with the news media were excellent, primarily, it would seem, because of honesty. As one Shell official on the scene explained, "We tell the press everything, even though it's not always easy." As a result, reporters "know that what we tell them is the truth. We can even get in touch with a newspaper or TV station that has put out some false information and have it corrected with no hard feelings."

This desirable relationship with the news media was not a matter of luck. It resulted from a great deal of thought, effort, teamwork among operations, alert public rela-

tions and, above all, open dealing. On the day following the blowout, a news conference was held at nearby New Orleans by the general manager of Shell's offshore division. In the following two months, the company arranged many additional press conferences and interviews at which industry specialists explained in detail the technical problems involved. Each day, two company news releases summarized the progress to date. And for the writers, photographers, and cameramen who wanted to get to the scene of action, Shell hired a motor launch for regular close-

up tours. The NBC television evening news program of February 18, 1971, is an example of the fair treatment that can be received from the news media when we do our part.

A company is not going to bat 1,000 every time it finds itself involved in an emergency. But if it has planned well, if it makes the tough decisions that have to be made, if it takes the actions that have to be taken, and if it deals forthrightly with the news media and the public, then a company has every reason to expect fair treatment.

ZERO-IN ON PETROLEUM SPILL CONTROL

By WILLIAM B. KATZ

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A survey of problems and techniques currently seen in the handling of inland petroleum spills on soil and water.

Every year for the past several years there has been one or more catastrophe-type spills of petroleum products into the ocean. The resulting widespread publicity has focused attention of lawmakers, enforcement agencies, equipment manufacturers and, to some extent, the petroleum industry itself almost exclusively on solving the problems resulting from these large spills into the ocean. Inland spills haven't been completely ignored, but up to this time they have had secondary attention.

Yet, there are literally hundreds, if not thousands, of small oil spills annually, varying in size from a few gallons up to hundreds of barrels, which, although no accurate figures are available as to the total, could easily add up to the equivalent of a catastrophe-size spill entering inland waters almost daily, taking the country as a whole. These spills come from many sources, both within and outside the petroleum industry, but that industry frequently gets the public blame for a spill, whether justified or not, and is often expected to furnish the know-how, the equipment, and the manpower to handle the necessary

cleanup.

Many inland spills end up in water, where they are highly visible. In addition to marine terminals and water transport facilities for petroleum products (which, unfortunately, do have accidents), every sewer, every drain from an industrial plant, and any storm runoff water near any place where petroleum products are used or handled, represents a potential or actual source of oil entering inland water. In addition many spills occur on land. These result from vehicle accidents, pipeline breaks, storage tank leaks, and similar sources. Some of these leaks may end up in water because of incorrect handling.

Most such spills are of refined products, rather than crude oil. Equipment and available techniques for handling inland spills are of variable quality and quantity—very good for some situations, extremely poor for others. Unfortunately, much of the new equipment coming on the market, many of the new spill techniques being developed, and most of the control regulations being set forth by all levels of government are designed for ocean spills of oil (usually crude oil but occasionally

refined products), and are poorly suited for application to inland problems.

This paper represents an attempt to discuss various facets of the many problems encountered in handling inland spills on both land and water. It is based on over nine years of experience and, while far from all-encompassing, attempts to indicate criteria for equipment, materials, and techniques. Places where new methods, data, or equipment are sorely needed are also indicated. This is covered under the following subjects: Personnel and Training; Cooperatives and Logistics; Spill Handling—Containment, Primary Recovery, Secondary Recovery, and Final Cleanup; and Miscellaneous Considerations.

Personnel and Training

Time is of the essence in inland spills on moving water. While ocean spills are frequently very large, they tend to spread relatively slowly and men and material can be assembled to counter a spill with much more time available, usually, than in a spill on inland water. The area to be cleaned and the cost of cleaning increases at some multiple power of the time it takes to confine a spill on a fast-moving river. Hence training of personnel and the immediate availability of equipment is extremely important.

Many potential spill sites have few people available for handling spills. Oil distribution terminals, particularly those not in or near large cities, frequently have only one or two persons on duty. Key-lock terminals often have only the transport driver at hand. And spills have a bad habit of occurring at 2:00 a.m. on a moonless, rainy night. So, in addition to having spill handling equipment available at the site, some arrangements must be made to get people to the site quickly—trained people. Often, it is possible to retain some local company on an annual contract, who can be called out on short notice to give quick assistance to the people on hand when a spill occurs. Any such annual retainer should provide, in addition to an hourly rate for actual spill cleanup work, for regular training and drill sessions no less than four times a year. These sessions should include any company personnel who might be involved in an actual spill and should include

actual operation of all equipment on hand. This will increase familiarity with the equipment and assure that it is maintained in workable condition.

Supervisory personnel at each site should be sufficiently well trained and informed about procedures and equipment to make on-the-spot decisions. However, every company should have several experts with practical and widespread experience, who can fly in if necessary to provide back-up assistance. In this regard, it is extremely helpful if some member of the spill handling team has the sole assignment of taking pictures—still and movies—with the aim of recording the technical aspects (as distinct from any public relations aspects) of the spill. Under the stress of an actual spill, people forget the chronology of what was done or not done, and even occasionally overlook obvious control steps. Movies and pictures are an invaluable aid to the inevitable after-spill discussion.

Cooperatives and Logistics

While cooperative spill control groups are in existence or forming at many places along our inland waterways, there is need for a far greater number than exist today. (Incidentally, from a public-relations point of view, such groups are better called "mutual aid" groups, rather than any title with the words "oil-spill" or "pollution control" in them.) Such groups as exist are confined mainly to harbor or river port areas where there are concentrations of petroleum distribution terminals or refineries, and are frequently confined only to petroleum industry members. Often all that is done is for several companies to put up some money and buy some equipment, with poor cooperation when manpower and time are required. There is little training and often no clear-cut idea of who will actually handle the equipment if needed on a spill of indefinite origin. If some one person is interested enough, things get done; more often, little is accomplished after the initial formation of the group. What is really needed, when the group is large enough, is a real commitment to provide equipment, manpower, and funds to a common purpose. Ideally, there should be a full- or part-time

employee of the cooperative, paid by funds subscribed to the co-op, to obtain equipment, plan training, work with local authorities, and generally act as an industry area pollution control agent. Such an ideal situation does not exist today to my knowledge, and there are probably few places with a large enough group to support such an activity.

Effective cooperation is difficult where terminals are few and scattered or where people are spread out over a large area, such as is usual in pipeline operations. At the present time there is little interchange of lists of available equipment even within the petroleum industry, practically none outside of it. Someone with a spill problem may wait hours or days for equipment, when that equipment was only a few miles away and available, if he had only known it was there and whom to call to get it.

Regional supply centers should be established where stocks of emergency supplies are stored in a form ready for immediate transport by truck, rail, barge, or helicopter to provide a first line of defense against a spill. These should be available to anyone joining an area cooperative and providing some part of the funds to maintain the supply center. Such stocks should be available to terminals, pipelines, and refineries in the petroleum industry. (Too often today the complexities of corporate structure confine the use of material to the division or department that bought it.) Information about that availability should be widespread. Little of this is being done today, though there are signs of some companies starting to think along these lines. The man struggling in the field today with either a bad pipeline leak or a broken hose at a remote terminal, has almost no place to turn for help. Intercompany communication is fair at the top staff levels, almost non-existent at the operating level. The average terminal superintendent is starting to get some idea of what his own company is thinking about but has almost no idea at all of how that fits in with what his next door neighbor's company is thinking or doing.

Spill Handling

Containment

The first thing to do when there is a spill is to try to confine it, to reduce the extent of contamination and the magnitude and cost of the cleanup required. The most widely used and discussed containment device today is an oil retention boom. Yet many spills inland are of such a character that a boom is not useful at all. This includes any spill entirely on land, or any spill into a stream too small or shallow for a boom to work properly.

Spills on Land

If a spill is on land, rather than water, the best containment device is an earth dam of some sort. Such a dam can be made by piling up earth with a bulldozer, backhoe, or other earth-moving equipment. The techniques of doing this are haphazard. Field men have no real idea of how best to place such a barrier—whether it should be high and narrow or low and wide, how it should be angled to so direct the spill that contamination of the surrounding area is minimized, and what materials are best (clay, sand, gravel?) if there is any choice. My own experience is almost nil in this area, yet there should be ways to construct such barriers that save time and reduce the spread of oil better than other ways.

Techniques from other industries may be useful here, and study is indicated. Installation of underground impervious barriers of plastic might well be used to restrict the inground spread of the spill. Injection of gelling agents into the soil (using the techniques developed in well cementing, shoring of buildings, and waterproofing of underground walls) would seem to have some merit in preventing spread of a spill and hence be worth some study.

Fire departments invariably wash product spills from accidents into the nearest sewer or ditch, to remove a fire hazard from the accident scene. This often only moves the hazard from one area to another and frequently actually increases the fire hazard at the scene. Occasionally, a well-meaning but inexperienced fire department, in an effort to re-

move a supposed fire hazard, will flush a spill into storm sewers. The spill, which before such action was reasonably well confined in extent, will wind up in a small stream or river where confinement is difficult or impossible. The resulting cost of cleanup is increased quite literally by thousands, and occasionally by hundreds of thousands, of dollars.

The petroleum industry should disseminate basic information on proper procedure for handling such spills, including the use of dispersant chemicals to reduce flash and explosion hazard when large volumes of flammable products are moved with a high-pressure water stream. Every fire department handles such problems differently, sometimes with excellent and sometimes with tragic results.

Spills into Shallow Water

When a spill gets into a shallow creek or stream, a boom is usually ineffective. If a boom does not have enough free space beneath it, it tries to act as a dam. The water pressure will either lay the boom out flat on the surface, permitting product to escape underneath, or, if the boom is restrained in a vertical position with stakes and chicken-wire, will build up behind it and flow over the top. Occasionally it is possible to use a dragline or backhoe, and make an area with a deep enough pool for a boom to work successfully.

One very common procedure is to construct a straw fence, by making a chicken-wire and stake fence, and putting straw up against it. Two common mistakes are made—the fence is constructed at right angles to the stream, and the straw is not changed steadily. This type of fence works only because the straw absorbs the oil coming down the stream. It must be replaced as it becomes saturated, or it will not continue to retain oil, and hence is subject to all the cost and disposal factors discussed later on in this paper under absorbents. If the fence is at right angles to the flow, the oil is spread across the width of the stream, and has far more chance to pass the barrier.

A much better technique is to construct such a fence at an angle to the shore, and on the shore to dig a sump with a backhoe, or

even by hand. The fence should be installed with plastic sheeting used to form a non-absorbable barrier that will deflect the oil into the sump. Such plastic sheeting in rolls can be found in many places; most drycleaning establishments use it for packing material, and construction firms use it for weather-proofing.

Barriers such as this can be spaced along a creek at intervals, but the best technique is to prevent the oil from getting out of the immediate area of the spill by constructing an underflow dam. This is a procedure often used by pipeliners, but is known to surprisingly few others.

An underflow dam consists of a conduit for the water, such as a length of pipe or culvert, placed roughly parallel to the direction of water flow, with the upstream end lower than the downstream end, which should be above the water surface. The stream is blocked by bulldozing earth across this. The resultant dam will pass water and retain anything floating at the surface, such as an oil spill. This sounds like, and is, a relatively simple procedure. But the man in the field needs help. The duct area provided cannot be too large or the water level will not rise above it and the spill will flow through the duct. Neither can it be too small, or water will flow over the top and carry the spill with it. A simple method of estimating the stream flow by measurement of width, depth, and flow rate is needed, together with a simple chart that will help select the proper total duct area, dam height, and duct angle (from horizontal). This can serve as a guide to the non-technically trained field foreman who gets stuck with the initial task of handling the spill. Such men should have a selection of conduit available at any centrally located distribution centers established, or should know the common sources of supply for such material, some of which is readily available in rural areas. An easily adjustable A-frame to support the ends of the conduit would be a big improvement over the usual method of throwing rocks into the stream and might well be prefabricated and stocked along with the conduit itself.

Spills into Deep Water

Booms. The best method of confining a spill on deep water is to use a containment boom designed for that purpose. There are few booms on the market today that are really suitable for use on rivers. When the water is quiet or moving at speeds under about 1/2-knot, almost any kind of a boom will work as far as oil retention is concerned; but there are vast differences in handling ability.

Most of the booms currently available have come on the market as a result of the publicity attendant on ocean spills. They are designed for ocean use, where they must withstand huge wave forces and where the wind makes the waves and, hence, moves in the same direction. While this occasionally occurs in large harbors or turning basins inland, or on the Great Lakes, it almost never is the case on small lakes and rivers. Booms designed for the ocean, with deep fins and high above-water baffles, are ill-suited for river use.

Inland spills on a river invariably are lost by going under a boom, for reasons associated with the hydraulics of booms and independent of the manufacturer (though some would have you believe otherwise). A weighted boom fin at equilibrium with flowing water is canted at an angle to the vertical which depends on the fin depth, weighting, and water velocity. Water at the surface travels further to pass the fin than water just under the fin bottom, hence picks up velocity and creates an area of reduced pressure or "drag" behind the fin. It acts much like an airfoil upside down. This drag is what carries product under the boom.

The velocity at which product will be lost under a boom depends on the viscosity-temperature characteristics of the product, the volume of the product, and the physical characteristics of the boom itself. Anything that creates turbulence behind the boom, instead of smooth flow past it, tends to push product into the drag stream, and when it touches the drag stream it will get sucked under the boom at the point of highest flow velocity just as if it were being poured through a funnel. We have films of river tests run with dyed oil showing this very clearly;

hence, rigid fins, square-edged flotation, projections on the fin surface, are all to be avoided.

One common tendency, when a user sees product escaping under the boom, is to make the fin deeper. This aggravates the situation, since the drag effect is larger because of the higher velocity required for the surface water to get past the boom. Our experience indicates that rarely is a fin deeper than six inches required, provided the boom is properly positioned.

At all costs one must avoid putting the boom in a loop configuration. This will direct the spill to the bottom of the loop, where it will pile up, get deep enough to touch the drag stream, and go under. Rather, a boom should be used to deflect or guide the spill to the shore, where the effect of the river bottom is to slow the water flow to the point where the boom can retain the spill. If possible, the shore end of the boom should terminate in a sump dug into the bank, to remove the spill from the current entirely. This boom position also makes recovery easier, since handling recovery equipment from boats is often difficult on a fast-moving river.

Stresses put on booms by the current are staggeringly large—a 500 ft. boom in a three-knot current can easily have a pull approaching 15,000 pounds with a six inch fin, and doubling the fin depth can double that. Wind effects can equal or exceed stresses put on a boom by the water. A baffle extending above the flotation can make a boom completely unmanageable, pushing the boom configuration upstream against the water current and directing the spill exactly where you do not want it. Or it can put a turning torque on the boom that will cause it to lie flat on the surface, allowing the product to go underneath.

Boom weight is a tremendous factor, since a boom on an inland spill should be used as a guide to direct the spill, rather than to confine it. Hence portability and handling ease are very important.

Boom Requirements. The results of our experience indicate that the most useful boom is one with a shallow fin, no above-water baffle, with weighting just sufficient for the water

velocity expected. We usually recommend 4" float x 6" fin with 1-knot weighting for harbors and lakes, and 6" float x 6" fin with 2- or 2 1/2-knot weighting for fast-moving rivers. Flotation should be just enough to support the weight and allow a three to four inch free-board above the water, to minimize the effects. Such a boom, if properly used, can direct a spill in water running up to about five or six knots, if you know how to handle it.

Many other factors enter proper boom design in addition to fin size, weighting, and portability. Sections should be easily and quickly connectable, since length requirements vary from one spill site to another; such connectors should make a leak-tight seal. (At the present time, booms of different manufacturers can be interconnected only with difficulty and improvisation.) It must be possible to make a tight seal to the shoreline or dockface, to prevent around-the-end leaks. The boom should be essentially non-snagable. The materials of construction must be impervious to anything they may contact, including spilled product. Sealing non-impervious flotation within a closed pocket is insufficient protection; booms always get damaged to some extent, exposing the flotation to the product in contact with it. Mechanical reinforcement is mandatory to withstand the high forces on the booms, and such reinforcement must not stretch and transfer the stress from the reinforcement to the fin material. Finally, booms should be repairable if damaged, and they eventually are! Booms get very rough handling from debris, from being dragged over rocks and sharp dock edges, and from people running boats over them. While a boom with completely sealed-in flotation and weighting looks good and is easy to clean, damage usually means replacement of the entire boom at high cost, rather than repair which is relatively inexpensive.

At some locations it is possible to keep a boom in the water at all times, and easily "diaper" a vessel before connecting a hose to it. Sometimes a boom can be stored for easy access to the water and similarly placed around a vessel before product transfer is started. While this should be considered at all

locations, ice, debris, varying water level, and high current velocities make this possible only at a few places.

Practically, this means there will always be some losses where product is transferred from or to vessels from shore, since there will always be some accidents. On a river with fast water, this means one can rarely catch all of a spill because of the time it takes to get a boom into the water. Some commercially made booms ride well, without twisting, when trailing behind a boat and parallel to the direction of water flow. It is possible to tow a boom at high speeds, up to 30 knots, under such conditions. Therefore, it may be possible to catch up to a spill running down river if you are prepared to do so and have two boats available, one to tow the boom, and the other to catch the trailing end when you have passed the spill and the lead boat has angled into shore with the forward end of the boom. Human nature being what it is, there will always be a tendency not to bother unless the spill is large. One solution is to build slips that will get a vessel entirely out of the current. This in turn probably means cooperative slips, because of the huge investment required, with pipelines running to individual terminals from the slip.

At this point, it might be well to say a word about the boats required to handle booms. They must be large enough to be stable, small enough to be maneuverable, with large enough motors to handle the loads imposed, and capable of moving very slowly (at speeds under one knot) under these loads. Small catamarans or john-boats, about 18 feet long, powered by 30-50 hp outboard engines, have proved very practical. They should be equipped with anchors, life jackets (which should be worn, not under the seat), a tow-hitch to keep the pull from the boom centered at the rear, and some form of ship-to-shore communication, such as walkie-talkies.

Air Barriers. An air barrier is formed by placing a pipe or tube manifold below the surface of the water, usually resting on the bottom. Air is forced into it and is released through a series of holes spaced along the pipe to create a bubble curtain. With enough air, and quiet water, this forms a reasonably effective barrier. The amount of air needed

is large—for a 400 ft. barrier in water 15 feet deep, it may require 1,200 cfm at 15 psi. Technical problems include uniform emission of the air over the length of the barrier; build-up of silt caused by the water flow pattern with resultant plugging of the holes when air flow ceases; and shifting of the position of the manifold with current. In moving water the barrier bends to one side, and oil droplets can get caught in the bubbles and pulled through the barrier.

Air barriers are very attractive in principle. If you have a spill, you push a button and have your containment protection immediately. Practically, air barriers are limited in application to slow-moving or stationary water, such as in a harbor or canal, with fixed banks or shoreline and a stable water level. Operating costs are high and investment, including adequate pumps or compressors, very high. They should be seriously considered where conditions indicate their applicability, however, for the cost of cleaning up a spill that gets away is very high also.

Initial Cleanup

Oil Layers Over 1/2-Inch In Depth

Skimmers. The first step after a spill is confined is to recover as much of the product as possible with as little water as possible. Requirements are very different from ocean spills. There is relatively little crude spilled inland, and most of that is from pipeline leaks and usually occurs (though not always) on land or in small streams. Most inland spills are refined product.

Recovery of heavy residual products—tar, asphalt, number 6 and number 5 oil—is difficult. There is presently no skimmer on the market that will handle these products well, because they won't flow easily. If you cannot get them into a pump or skimmer, you can't recover them that way. Sometimes a spill is close enough to a plentiful steam supply so that a steam lance can heat the material enough to let it flow into a pump or skimmer. More usually, manpower and the use of draglines or similar equipment is required. The cost is high. A skimmer that will handle such products is sorely needed.

There is a trick that one can use to handle such spills, by partially breaking up the solid mass with a fire hose and dispersant chemicals (more about those later), but at the moment such use is rarely if ever permitted.

A basic requirement for skimmers for inland spills is lightness in weight and ease of portability. Spills have a habit of occurring or getting to places remote from established facilities, along shorelines in shallow water or in back areas where access is poor and complicated by debris, marshy areas, etc. Large equipment is not often practical, although in harbor areas and quiet areas of large rivers such may be usable. Self-contained power for skimmers, using gasoline engines or small electric motors driven by portable generators, is advisable.

Much of the equipment on the market will function quite well with a deep layer of oil, two or three inches or more, though some need to be in four to six feet of water to operate properly. Choice then is between capacity, weight, and cost. As oil layers get thinner, the ability to skim without taking water becomes important, since refined products mixed with water tend to form emulsions when going through pumps, and field facilities for breaking such emulsions are usually poor. Eventually, all skimmers start taking water; some sort of separator capacity, with sufficient time for gravity separation, is almost always needed. This can vary from a large storage tank, if one is reasonably close, to a large number of tank trucks. Eventually, all skimmers get to the point where they start taking too much water. There are devices that will remove thin films with essentially no water, such as drum or belt skimmers, but generally they are large, heavy, of low capacity, and costly. Occasionally, it is possible to build up the oil depth by slowly pulling in the confining boom to reduce the spill area, or blowing the oil toward the skimmer with a leaf blower, air boat (those driven by an airplane propeller), or helicopter downdraft. Eventually, however, another technique must be used.

Secondary Cleanup

Rainbow to 1/2-Inch

Ignition Promoters. One possible approach to remove the oil remaining at this point is to burn it. On both land and water, this is not always easy, and on water it is sometimes impossible, unless an ignition promoter is used. One product currently on the market works quite well in this regard but, after burning, leaves the original bulk of ignition promoter as a residue. On land, this may have to be buried or hauled away, which is costly. Smoke is always a factor, since frequently air pollution can be as severe a problem as water pollution.

Gelling Agents. Another approach tried has been to add a material that will cause a fluid product to set up in a gel, which can be removed mechanically. This is a reasonable technique if the spill is in a confined area, but is almost impossible to apply if the spill is spread along miles of shoreline in an area complicated by underbrush and debris.

Absorbents. The common technique for picking up thin layers of oil is to use absorbents. There are many absorbents on the market today, and more are arriving all the time. The vast majority of these products are terribly costly to use. Most advertising stresses the capacity of the particular absorbent to retain oil, under the mistaken idea that the higher the retention capacity, the better the absorbent. Practical field use dictates entirely different criteria for a good absorbent.

The cost of using an absorbent lies in removing it from the water, with its oil load, and disposing of it after you get it out. Any absorbent that cannot be handled by pumping it has an extremely high built-in cost of use. In addition, you must be able to dispose of the mess when you have it out of the water. Most of the new materials are forms of synthetic "plastics." These will not decompose if buried, and they burn poorly, if at all, with great amounts of smoke, creating a severe air pollution problem. Frequently, the bulky, oily mass of used material must be hauled long distances to a permissible burial site, and often a high charge must be paid for use of that burial ground.

An ideal absorbent should be pumpable, preferably without abrasive effect on the pump. It should decompose if buried, should be burnable with little residue, and should aid in complete combustion of its retained oil. Hopefully, it should be easily available and not overly costly.

The most frequently used absorbent is straw. It has one big advantage; it is available, or relatively so, almost everywhere. It can be applied over a large area fairly easily by blowing it on with a mulcher. The cost is relatively low for the straw itself. There are problems, however. Straw varies in its ability to retain oil over a range of about 1:5 to 5:1.

Removal other than by mechanically raking or scooping it up, is usually not possible. Disposal is a major problem, since the bulk after use is far greater than when it was baled. Burning is rarely possible, since the hollow straws entrap a lot of water, and ignition is poor, with much smoke. Burial is usual, and this is severely restricted because of possible ground contamination.

Several absorbents are currently on the market, made from expanded minerals or various manufacturing waste products. These are usually hydrophobic and absorb little water. They provide good area for ignition (large surface area) but suffer from the fact that they must be completely removed from the water, and there is again a disposal problem. Burning off the oil leaves the original absorbent bulk, which requires disposal. Burial is usually required, with restrictions on where this is possible. In addition, while these products can be pumped, reducing the cost of recovery, they are usually very abrasive, and severe damage to the pumping equipment is possible and frequent.

The most useful absorbent currently available is made from ground corn cobs. If the particles do not absorb oil, they slowly absorb water and sink; hence they are somewhat self-cleaning. The sunken material has a BOD of about five ppm, which is quite low. The product, when it has absorbed oil, absorbs little if any water; mechanically entrapped water runs out quite freely. The surface area is large and the cobs are cellulose, so that combustion is excellent, with relatively little smoke. Therefore, permission

can sometimes be obtained for burning at or near the recovery site for disposal; the residue is less than two per cent of the original material. Best of all, the product is non-abrasive, so pumping can be used with no damage to equipment.

With all absorbents, the possibility of spontaneous combustion must be considered and used product stored in safe areas. No absorbent on the market today works very well on cold crude or residual products since, as with skimmers, if the product will not flow, it does not absorb very well.

Final Cleanup on Water

Eventually, a point is reached where the remaining residue from the spill (or the original spill, if very small) leaves rainbows on the water. These are more public relations hazards than any real hazard to the ecology. But product absorbed into wooden dock piling, or on the shore, dock faces or rocks, will bleed visible streaks into the water for days or weeks. The stream can usually take care of this fairly well, if it is fast water; eventually, the film will break up and slow, normal bacterial oxidation will take place. To speed up this process and remove the eyesore, the use of dispersant chemicals must be considered.

A good dispersant is almost the only way to remove the severe hazard resulting from a flammable product spill in an area where a fire or explosion could cause large loss of property or possible injury to personnel. Current regulations, as the result of much hysteria (some justified, some not) about damage to the ecology from the use of detergents has resulted in an almost complete prohibition on their use. Yet there is definite justification for their controlled use under proper conditions; the tremendous increase in surface area available for bacterial oxidation when a spill is emulsified helps nature speed its recovery from the effects of a spill.

There are two criteria generally used at the moment to evaluate a dispersant. One is its effectiveness as an emulsifier; the more stable the emulsion, the better the dispersant. The other is its toxicity to fish, as measured by a standard (more or less) 96-hour TLM (Mean Tolerance Limit) test, which is the concentration in ppm that will kill half the fish ex-

posed to the product for 96 hours. I would arrange a list of criteria for a proper dispersant in quite different order; for example:

1. Safety to personnel: the product should be non-toxic and non-irritating to those using it; pH should be close to 7.

2. The dispersant should be usable under controllable concentrations. Most dispersants now on the market specify application in concentrated form (followed by agitation) which means, since it is difficult or impossible to estimate the amount of product spilled, that too much dispersant is usually used. Application by injection into a fire hose with an in-line eductor permits the dispersion to be formed by the mechanical energy of the hose stream, and it is possible to see where the dispersion has been formed. Concentrations of dispersant are low (six per cent or less), and high local concentrations are avoided by the mixing action of the hose stream.

3. The dispersant should be a weak emulsifier; it should not form stable emulsions. If the product dispersed is volatile, such as gasoline, it is desirable that it evaporate from the water into the air (to take the oxidation load off the stream), but at a low concentration, below the level of flammability. Similarly, if the product is non-volatile, it is desirable that there be no visible film, either to arouse the public or to foul up recreation areas and wildlife. But the small dispersed droplets should be at the surface, where they will not get into water intakes for drinking or cooling water systems, and where the dissolved oxygen content of the water is higher and the water generally warmer.

4. The dispersant should be a product in routine daily use, if possible (perhaps as a maintenance cleaner). It should be effective on a wide range of products. Such a material will not be left in dead storage for long periods, with possible deterioration and hence non-effectiveness when needed.

5. The product should be reasonably non-toxic to fish and wildlife. There have been two sets of 96-hr. TLM tests run of which I am aware, one by the State of Washington and the other by the State of Michigan. Both show a wide variation in values for the many products tested. However, strict reliance on these test values is not as important as practi-

cal considerations of how the products will be used. In the ocean, on the Great Lakes, wherever waves can carry a formed dispersion back onto the shore, a dispersant should not be used. The sand on the shore will act as a filter, leaving the residue on the shore. The proper place to use a dispersant on a large body of water is way out from shore, where forming a dispersion will prevent the wind from blowing the spill onto the shore, and where there is room for the dispersion to dilute away to a non-hazardous state.

Inland, on a quiet water such as a harbor or small lake, dispersants should be used with extreme caution, if at all. If they must be used, they should be applied by hand from a small sprayer, with great care not to use more than absolutely necessary, followed by copious flushing with a fire hose to dilute the emulsion and avoid high local concentrations. Even the safest dispersant (as measured by its TLM value) can quickly reach an unsafe concentration if there is no dilution.

On fast moving water, however, say a stream running at three knots or greater, dilution is so rapid that TLM values have little meaning. One can use dispersants with great effectiveness and little hazard if you know how to use them properly. There is no easier way to handle small spills.

6. Cost is the final factor, to be considered only if all other factors are approximately equal.

Final Cleanup on Land

The final cleanup of spills on land is another matter. If the ground is non-permeable to the spilled product, such as occasionally occurs on dense clay soils or in winter when the ground is frozen, most of the product can be picked up by digging a sump and pump-

ing it out, followed by use of an absorbent to remove all but final traces. This technique is especially useful on ice or frozen ground, provided the product will flow at the temperature involved.

Usually, however, some amount of saturated ground results from a land spill. If it cannot be left to decompose slowly, over a long period of time, it usually must be removed mechanically, which involves (again) finding a disposal area for the saturated soil removed. What is desperately needed is some agent, an enzyme or bacteria or other, that can be used to treat large contaminated areas and which will feed on the petroleum product, breaking it down into harmless degradation products or, hopefully, useful ones that will serve as nutrients for reestablishing the damaged vegetation. As far as I have been able to determine, there is no such material available anywhere today that will prove out in actual field tests as doing more than normal soil bacteria will do.

Miscellaneous Considerations

It hardly seems necessary to mention some of the many items that get used in handling an inland spill, that make the work easier, under what usually turns out to be miserable operating conditions. But some forethought in planning for these items will greatly ease the burden of the men actually engaged in cleanup work. Such a list might include floodlights; a portable generator for running power and the lights; portable heaters; foul weather clothing; enclosed portable toilets; food, especially hot coffee and hot soup in cold weather and an adequate supply of good drinking water in hot weather; communication equipment, either walkie-talkies or truck-mounted radio; first-aid supplies; and proper work clothing (hip boots, gloves, etc.).

RECENT EXPERIENCE WITH SUBSURFACE FOAM SYSTEMS

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Fire fighting foam is the primary agent relied upon for attack of fires involving large storage tanks of flammable liquids. Foam is unique for this purpose because it can travel across a liquid surface, cooling the product and adjacent tank walls, and if properly compounded and applied it forms a vapor-tight blanket over the fuel. This blanket of foam serves a four-fold purpose: it suppresses the fuel vapors, separates the fuel from oxygen in the air, and insulates the fuel surface from sources of reignition. Because of its high water retention, it also absorbs heat from hot metal surfaces. In order for the foam to extinguish the fire it must be applied at a rate high enough to overcome any destruction by the fuel and the heat, and it must retain sufficient water to provide a vapor-tight blanket until the danger of reignition has passed.

The most widely accepted method of applying foam to storage tanks has been through fixed systems involving foam discharge chambers permanently mounted at the top angle of the tank. In recent years, hydraulically operated foam towers erected at the time of the fire, as well as high capacity foam nozzles, have been used for tank fire fighting. There are documented cases where each of these methods of attack has been used to successfully extinguish fires involving large petroleum storage tanks. There are also cases where the fires have burned out of control; and in some instances, tanks and their product have been totally destroyed because of operational difficulties in getting sufficient fire fighting agent and equipment to the scene so that an adequate rate of foam could be applied to the fires involved.¹

For many years the potential advantages of being able to inject foam at the base of a tank have been recognized. The technique has several practical advantages such as: (1) less chance for loss of foam system capability in

the event of tank distortion or adverse movement of the roof; (2) the ability to take advantage of product surface cooling by rolling the tank contents; (3) the ability to knock down and control fires from a remote point from the tank; and (4) lower manpower requirements for operation of foam-generating equipment when compared to the use of towers or monitor nozzles.

The idea of pumping the foam into the bottom of the tank and letting it rise to the fuel surface, rather than somehow getting it up and over the shell, is not new. From an historical standpoint, the idea stems back to at least World War II when British fire protection men were seeking a reliable method of getting foam to tanks which had their fire protection systems damaged by bombings and fires. Successful small-scale test and investigative work has been accomplished by several British investigators,² but it was found that foam quality characteristics were very critical to achieve successful results with regular-type foams. In addition, the U. S. Navy Bureau of Yards and Docks authorized an investigation into the techniques as early as 1942, which was carried on by the U. S. Naval Research Laboratory and is documented in NRL Report 3725.³ The program was of sufficient success that the Navy has relied upon subsurface protection by foam at several of its storage depots. These systems involved the use of conventional six per cent mechanical foam liquid purchased under Federal specification and compressed air foam generation systems which, although effective in generating foam of specific drainage and expansion, were quite expensive.

Industrial acceptance of the subsurface technique has been somewhat slower, and it was not until recent years that investigation into the techniques was reactivated. In 1963 the Research Department of Mobil Oil Cor-

poration initiated a comprehensive investigation into subsurface applications, equipment requirements, and foam agent evaluation. National Foam System, Inc. joined with Mobil in early 1965 in a cooperative test program which has culminated in the standardization of highly simplified subsurface foam generating equipment and the National XL mechanical foam liquids, fluoroprotein products, which produce effective, stable blankets and which were found by Mobil to be a decided improvement over the regular foams and other compounds, such as light water, tested for subsurface use.⁴

The testing program which culminated in the acceptance of the technique has been a major and comprehensive undertaking, and space does not permit detailed elucidation of the development of current subsurface system design parameters. However, to give some idea of the magnitude of the program, it should be noted that Mobil Research conducted more than 250 tests in fire test tanks ranging from eight to 25 feet in diameter in gasoline volumes up to 82,000 gallons, dry run tests in a 120 ft. diameter crude oil tank, and a comprehensive study of subsurface extinguishment of crude oils with free-burning times of more than an hour. In addition, successful subsurface extinguishment tests have been conducted on other products, such as refinery slop oil, benzene, hexane, kerosene (even when heated to 180°F), diesel fuel, JP-4, and styrene monomer. A 115 ft. tank containing a 27 ft. depth of burning hexane was controlled in a test conducted by Esso Research and Engineering Company⁵ in cooperation with the Lago Oil and Transport Company in the Netherlands Antilles, Mobil Oil Corporation, and National Foam System. This test was conducted under conditions of marginal design parameter, i.e., one injection point for 10,000 sq. ft. of product surface. Although final extinguishment of residual fire in the tank was accomplished by auxiliary foam application, it was a successful test in that it showed that the foam was capable of knocking down the fire, travelling 114 feet across the fuel surface, and securing all but the turbulent area over the injection point. It permitted establishment of more exact system design parameters for subsurface

applications for large storage tanks of volatile fuels. The largest total extinguishments by subsurface injection of foam have been accomplished by the Navy on a 55 ft. diameter fuel oil tank and on a 93 ft. diameter crude oil tank. These tests have all been well documented.

Since the Aruba test, there have been several interesting developments. Subsequent testing at Mobil's Paulsboro labs showed that the primary problem in subsurface injection to volatile products was the size of the turbulent area over the injection point. This is simply rectified by limiting the volume of foam injected at one point, and the culmination of this was the presentation of the Aruba test data and the subsequent test data to the NFPA Committee on Foam. The earlier conclusions drawn by the Navy also applied, and the Foam Committee in 1969 issued standards for subsurface systems utilizing fluoroprotein foam reflecting the conclusions drawn and delineating the number of injection points for various size tanks.*

Since then, testing has continued to determine suitability of the technique on other fuels such as styrene monomer, successfully completed in cooperation with Dow Chemical Company. A test was successfully completed by the Baltimore City Fire Department in November 1968 in a 30 ft. tank containing kerosene. In May 1968 a successful subsurface extinguishment test was conducted in a 40 ft. diameter, 30 ft. high tank at the Mobil Oil Cy Refinery at Notre Dame de Gravenchon for the Groupe D'etude de Securite de L'Industrie Petroliere. This again was a cooperative effort involving Mobil Research and National Foam. The fuel involved was 5,000 barrels of a mixture of crude oils from Kuwait and Algeria, into which was mixed 1,100 gallons of gasoline. Fuel depth was approximately 24 feet.

Foam produced from National Aer-O-Foam XL-3 liquid was generated by a National PHB-15 high back pressure foam maker and forced by available hydrant pressure through 50 feet of four inch hose and 60 feet of four inch pipe to an inlet at the base of the tank. The inlet terminated flush with the

*See NFPA Standard 11—Foam Extinguishing Systems

shell. Foam liquid proportioning was by a National LP-12A line proportioner directly upstream of the foam maker, with the foam liquid inducted from five gallon pails. Water was provided from a hydrant through 50 feet of 2-1/2 inch hose to the line proportioner. Hydrant pressure fluctuated slightly during the test, but generally averaged approximately 150 psig. Fire control was obtained in 1-1/2 minutes, and total extinguishment in 10-1/2 minutes. No rim cooling was used. During the test, foam liquid was inducted from five gallon pails, and it was noted that each time the pickup tube was transferred from pail to pail a brief induction of air caused a brief flare-up over the injection point, thus probably slightly prolonging extinguishment. After extinguishment, a complete XL-3 foam blanket covered the tank and provided a good seal around the shell.

Perhaps the most significant test for a fire extinguishing system is an unplanned fire, and in the past two years there have been two in which subsurface injection was used. In Joliet, Illinois, a bulk storage tank containing toluene was ignited by lightning and the roof removed by the initial explosion. This was a terminal, and the operator waited some time for assistance before attempting to fight the fire. Fire fighting operations were commenced more than an hour after ignition. The tank had previously been equipped with a terminal connection for a high back pressure foam maker, and a stock of XL-3 foam was on hand. Using a foam trailer with pump and proportioning equipment, after fire attack was commenced the fire was declared under control in five minutes and extinguished within 15 minutes. A substantial amount of the product was recovered.

In a more recent fire in the Philadelphia area, a 58 ft. diameter gasoline storage tank was extinguished using XL-3 foam applied by a combined attack, using subsurface injection through the product line—the hook-up being made while the tank was burning—and XL-3 applied from a monitor nozzle located on an adjacent tank.

When injected subsurface, the foam rises through the fuel in a column of discrete particles resembling marshmallows which tend to coalesce at the surface and travel across the

tank. The foam blanket builds back toward the turbulent area over the injection point. In our test work with Mobil and Esso, we found that XL-3 foam could effectively withstand 115 feet travel across a burning tank of hexane, but that the size of the turbulent area and fire intensity over the inlet was a limiting factor. For Class 1-B fuels, i.e., those with a flash point below 75°F and a boiling point above 100°F, we are limiting the maximum flow from any one inlet to 500 gpm of solution. This will permit use of one injection point for tanks up to 80 feet in diameter. Either the product line or separate foam line can be used. The only limitation on the size of the line is that the inlet velocity of the foam to the tank not exceed 10 feet per second for Class 1-B fuels and 20 feet per second for heavier fuels. With heavier fuels, such as kerosene, the turbulent area poses less of a problem because of the self-extinguishing effect of cool product being rolled to the surface, so for large tanks of such product, fewer points of injection are needed. This is in agreement with the early Navy work in Findlay, Ohio. As with any tank fire, cooling of the shell is a distinct aid to extinguishment, especially if the cooling streams can be directed to the shell in the area at and above the product surface.

The components of a subsurface system involve water under pressure, XL foam liquid, and a conventional proportioning system to introduce it into the water stream, and one or more high back pressure foam makers. The high back pressure foam makers are air-aspirating venturi devices which produce foam of proper expansion (2-4) for subsurface injection and are designed to recover sufficient pressure to permit forcing the foam through considerable lengths of hose or piping. The pressure available at the discharge end of the foam maker can be as high as 25 per cent of the inlet pressure. This allows adequate pressure for forcing the foam against the friction losses in piping and against the head of product in the tank. These may be located either on the product line or on separate foam lines to the base of the tank. In either case they can be located outside the dike wall. These foam makers have no moving parts and are, therefore, not subject to malfunction. All that is

needed to operate them is foam solution under pressure. High back pressure foam makers with capacities ranging from 100 to 550 gpm are available and can be used in combination.

In a typical semi-portable system, the foam pumper which carries a water pump, XL foam concentrate, and proportioning equipment (as well as auxiliary nozzles and equipment) is connected to the water supply and discharge connections are made to the foam maker. The foam maker may be permanently installed at a connection near the dike, or it may be carried on the truck and connected at the time of fire. In modern foam pumpers, the proportioner automatically adjusts to the water flow; this is the type of system now most common for refinery tank farm protection.

Another system of potential interest to municipal fire departments is one which has been adopted already by at least one municipality. This involves permanent installation of the foam maker at an inlet connection remote enough from the tank to be protected, and a fire department connection leading to an automatic pressure proportioner containing the foam concentrate. The fire department only has to make water connections and supply water at the proper pressure to the proportioner. Self-contained pressurized units are available for protection of remotely situated tanks and for installations where water supplies may be severely limited.

A typical fixed system such as may be used for a small tank farm would consist of foam system components contained in the house where foam may be introduced into the product manifold. Such systems can be manually or automatically actuated.

One of the main sources of resistance encountered with respect to conversion of old foam systems to subsurface in existing plants, or in adding subsurface protection to existing tanks not otherwise protected, has been determination of points of entry to the tanks. One approach to making the necessary survey is to assign a project engineer to the job and allocate personnel, time, and money specifically to the task. The other approach, which is in fact being taken at some installations, is to make the conversion survey a part

of routine maintenance or safety inspection. As the inspector makes his rounds he takes a few minutes at each tank to note the location of blind flanges, tees, or the like which would be suitable points of connection, noting required adapters, hydrant locations, and so on. As these data are accumulated, they are logged in the fire house or emergency headquarters and eventually the job is accomplished. With proper records of these inspections and assuming adequate equipment is available, conversion and adaption can be made at the time of fire rather than making costly conversions beforehand on every tank. This general approach has been used already with success.

The Aer-O-Foam XL liquids have the same physical characteristics as conventional foam liquids and, hence, can be proportioned and generated from conventional equipment already available. They can be used at a temperature range of 20 to 120°F and generated effectively from either fresh or salt water. For outdoor storage, XL-6 cold foam is available for storage and use at temperatures down to -20°F. Their chemical makeup, which was developed in a cooperative effort by National Foam System, Inc. and Pennsalt Chemicals Corporation, is such that their foam can withstand severe saturation by fuels and provide a more secure and longer-lasting vapor seal. This is attributable to a highly stabilized foam bubble containing purified natural polymers in combination with specific oleophobic fluorochemical compounds. Without the fluorochemical, the foam is relatively rigid and non-resistant to hydrocarbon saturation. Without the protein-type stabilizer, the foam is weak and frothy with little heat resistance and subject to rapid drain-out and to disruption by wind and thermal currents.

The culmination of this work has been the development and establishment of subsurface foam system engineering design requirements for protection of petroleum and petrochemical products in bulk storage. Subsurface protection is not suitable for water-soluble products or polar solvents such as alcohols, esters, aldehydes, ketones, and so on which require top-side protection by special alcohol-type foams. Specific engineering

standards for subsurface protection have been prepared by National Foam System, Inc., by the Mobil Research and Engineering Company, and now appear in NFPA 11.

The high back pressure foam maker and National Aer-O-Foam XL-3 liquid are listed for subsurface applications by the Underwriters' Laboratories, Inc. In addition, National Aer-O-Foam XL-6 has been issued a Federal stock number for procurement by the Navy and Air Force for subsurface protection of fuel tanks. Both these military services, as well as several major oil companies have, or are in the process of installing, National subsurface systems for tank farm protection.

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National Safety Council

March 21, 2001

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A handwritten signature in cursive script that reads "Robert J. Marecek".

Robert J. Marecek
Manager, Library

A handwritten signature in cursive script that reads "Marilyn P. Petersen".

