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SMOKELESS IGNITION OF OIL FIRES IN SHIP SIMULATORS FOR U. S. NA--ETC(U)

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SMOKELESS IGNITION OF OIL FIRES IN SHIP-SPACE SIMULATORS FOR U. S. NAVY FIRE-FIGHTING SCHOOLS

TO

DEPARTMENT OF THE NAVY
ATLANTIC DIVISION
FACILITIES ENGINEERING COMMAND

CONTRACT NO. N62470-72-C-1260

September 15, 1972

BATTELLE
Columbus Laboratories

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SMOKELESS IGNITION OF OIL FIRES IN SHIP-SPACE SIMULATORS FOR U. S. NAVY FIRE-FIGHTING SCHOOLS

by

H. R. Hazard, R. D. Giammar,
and D. W. Caudy

INTRODUCTION

Large oil fires are used for fire-fighting instruction in U. S. Navy fire-fighting schools. These are burned on the surface of water pools, which provide a smooth, level surface upon which a relatively thin, uniform layer of oil can be burned. Such fires produce large clouds of heavy, black smoke, which is undesireable in populated areas. Accordingly, the Navy has investigated elimination of smoke from fire-fighting schools by use of afterburners to destroy smoke after it is formed, and by use of water-spray systems that suppress formation of smoke. Water-spray systems are much less expensive to install and operate than afterburner systems, and would be preferred if fully satisfactory.

The use of water sprayed over the surface of burning oil to suppress smoke has been developed by Alexander Goldsmith, of IIT Research Institute, under contract with the Naval Devices Training Center[(1)*]. Experimental water-spray systems have been installed in three fire-training simulators at the Norfolk Fleet Training Center and good control of smoke has been demonstrated after a well-developed fire has been established. However, a period of 30 seconds or more of operation with heavy smoke has been required to establish a well-developed oil fire, as this cannot be done with the water-spray system in operation. Accordingly, effective use of the water-spray system for smoke suppression is dependent upon the development of a smokeless ignition system.

This report describes the development and initial operation of two smokeless ignition systems for the Norfolk Fleet Training Center. These systems are based upon injection of sufficient gasoline to permit flame development with the water-spray system in operation. The Battelle research included laboratory development of the ignition systems, and construction and shakedown operation of two experimental prototype ignition systems at Norfolk. These systems have proven practical and effective in controlling smoke.

PROGRAM OBJECTIVES

The primary objective of the program was to demonstrate a safe, reliable, and effective smokeless ignition system for two simulators at the Norfolk Fleet Training Center. This objective was met by developing design criteria in Battelle 6-foot and 15-foot fire tanks, and demonstrating a complete ignition system at Battelle, followed by design, construction, and demonstration of experimental prototype ignition systems at Norfolk. In the course of the program all objectives were met.

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* Reference is given on page 51.

SCOPE OF PROGRAM

The program was planned for completion within a 4-month period by tight scheduling of research tasks, with overlapping of simultaneous tasks to the extent possible. The major tasks carried out in the course of the program were:

Phase 1. Experimental development of a smokeless ignition system

1. Experimental study of design alternatives, using a Battelle 6-foot-diameter fire tank, and selection of design criteria.

2. Construction of 15-foot-diameter fire tank at Battelle.

3. Study of design criteria using the 15-foot fire tank, including comparison of 4-injector and 1-injector systems and optimization of gasoline-injection variables.

Phase 2. Engineering design of ignition systems for the Norfolk Fleet Training Center, including a system for the 15-foot tank and a system for the engine-room simulator.

1. Selection of type of system

2. Selection of all apparatus

3. Detailed design of components and systems to confirm operating characteristics

4. Construction and operation of system in Battelle 15-foot fire tank.

Phase 3. Installation of experimental prototype ignition systems at Norfolk

1. Procurement and fabrication of components

2. Installation of prototype systems

3. Initial operation and adjustment of systems, including replacement of several unsatisfactory components.

Phase 4, not yet implemented, will include measurement of air pollutants within the engine-room simulator throughout a number of typical ignition and operating cycles.

PART I. EXPERIMENTAL DEVELOPMENT OF A SMOKELESS-IGNITION SYSTEM

Experimental development of a smokeless-ignition system employed two test facilities, a 6-foot-diameter fire tank at the Battelle-Columbus Laboratory and a 15-foot-diameter fire tank at Battelle's West Jefferson Facility. The 6-foot tank, constructed within a few days, could be operated within the city with the approval of fire and smoke regulation authorities. It was used to screen a number of ideas and to develop design information to the extent possible. The 15-foot tank, similar to the 15-foot tank at the Norfolk Fleet Training Center, was located in an unpopulated area, and was used for larger scale studies as soon as it was available.

EXPERIMENTAL STUDIES USING 6-FOOT TANK

Description of the 6-Foot Fire Tank

Figure 1 is a schematic drawing of the 6-foot fire tank and its auxiliary equipment. The tank, 6 feet in diameter and 4 feet high, was arranged for positive control of water level by spillover of excess water through an adjustable 12-inch overflow weir. A layer of No. 2 fuel oil was floated on the water and burned to make large fires. The water depth was 32 inches, and could be adjusted by changing weir level.

A spray nozzle located at the center of the tank, 2.5 inches above the water level, injected water radially over the surface at a rate of 2.8 gpm with water pressure of 80 psi. The purpose of this spray was to suppress smoke.

An ignition system based on IITRI recommendations(1) was also installed in the tank. This included a high-voltage spark plug located near the center of the tank just above the water level, and a gasoline-supply pipe terminating in a spreader located at the water surface near the tank center. This system was operated by turning on the water spray and energizing the spark plug, then introducing gasoline at a controlled rate for a predetermined time period. The gasoline was ignited almost instantly by the spark, and the gasoline flame spread from the center to the edge of the tank within 2 to 16 seconds depending upon the rate of injection. With the water spray operating, the smoke level during the ignition period was similar to that during normal burning of No. 2 oil alone.

The tank was fitted with a fire-extinguishing system consisting of three large flat-spray water nozzles directed across the water surface at an elevation about 3 inches above the water surface. When water was introduced through these nozzles the fire was extinguished within 2 seconds. The flow of water to the central smoke-control nozzle was determined by measuring water pressure to the calibrated spray nozzle. Water was supplied from the city water system at 90 psi.

The flow of gasoline to the fire tank was measured by a rotameter and controlled by a metering valve. The gasoline flowed from a tank pressurized with nitrogen to about 50 psi. A solenoid valve in the gasoline line controlled the period of gasoline injection. The gasoline tank was placed on a scale, and the total weight injected was determined by weight change.

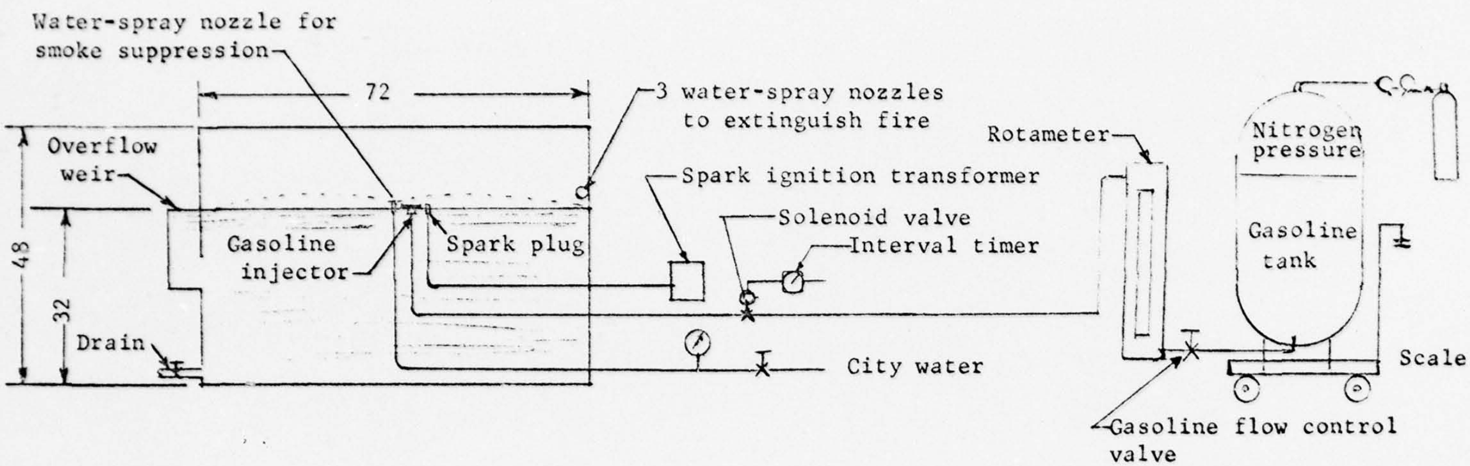


FIGURE 1. SCHEMATIC ARRANGEMENT OF SIX-FOOT FIRE TANK AND AUXILLIARY EQUIPMENT

Screening Studies in 6-Foot Tank

The 6-foot-diameter fire tank was used for convenient screening of several ideas relative to gasoline dispersion and ignition, and for study of the effects of water temperature, oil thickness, and smoke suppression with water spray. The following changes were made in carrying out these studies:

(1) The gasoline-supply system was improved by addition of an interval timer to provide automatic timing of the injection period. The injection period could be selected in 0.1-sec increments over the range from 0 to 6 sec. Injection periods of about 1 sec proved most effective.

(2) A gasoline injector having a screw-supported cap for continuous adjustment of the height of the annular exit slot was installed. This permitted selection of injection velocity independently from flow rate and injection period.

(3) Two gas burners were installed to permit heating of the tank water. Each burner fired into a 4-inch fire tube which extended across the tank, near the bottom. Water temperatures up to 190 F were studied.

(4) A spray ring was installed to spray water on the outside of the tank above the water level to minimize metal heating and excessive fuel evaporation from the edge of the tank. Under some conditions this made a large difference in flame appearance and reduced smoke significantly. Steam from outside the tank was induced into the flame by convection currents.

(5) Several spark-plug modifications were made, but none proved better than the initial commercial plug.

(6) Some experiments were made with armored diesel-type glow plugs as igniters, but the design of the sample plugs was such that the surface temperature was not high enough for gasoline ignition under tank conditions.

(7) The height of the water spray for smoke suppression was varied between 0.5 and 3.0 inches, and the flow quantity was varied between 1 and 5 gpm, with significant effects on the flame.

Optimization of Gasoline Injection

A principal objective of the experimental program was to minimize the amount of gasoline used for an ignition cycle and to burn the ignition gasoline in each cycle so that gasoline content of the fuel oil on the tank surface would not become high enough to influence simulator operation or safety. This is particularly important in closed-space simulators.

Work was begun using the IITRI concept of flowing gasoline slowly over the oil surface to minimize turbulence and the mixing of gasoline and oil. For these tests, gasoline was injected at a rate of 1 lb/sec over an oil layer 0.125 inch thick. In two trials it was found that spreading the flame from the center to the edge of the tank required about 16 sec with injection of 16 pounds of gasoline. In a third trial, 9 pounds of gasoline were introduced in 9 seconds and the fire still spread to the edge of the tank in 16 seconds. These tests were carried out with the smoke-suppression water spray operating.

The design of the gasoline injector was then changed by placing a flat cap over the center to direct the gasoline radially outward through an annular slot. An immediate reduction of the quantity of gasoline needed for oil ignition was demonstrated. In further development, the injector cap was mounted on a screw at the axis to provide a means of varying the height of the annular slot, and further decreases in the quantity of gasoline for oil ignition were observed as slot height was decreased and injection velocity increased.

Figure 2 shows three gasoline injectors used for these studies

The most effective range of slot height and injection rate was found with a slot height of 0.032 to 0.064 inch, and an injection rate of 1 lb/sec, which provided an injection velocity of 7 to 14 fps. With this combination, burning gasoline spread to the edge of the tank within 1 second, with immediate ignition. A large oil fire was obtained within 10 seconds with the smoke-suppression spray in operation. With these injection conditions only 1 to 2 pounds of gasoline were required per ignition, and the smoke level during ignition was about the same as that for later burning of oil.

The design of gasoline injectors for the 15-foot tank was based on these results. Two alternative injector arrangements were installed, one with four injectors, each like that in the 6-foot fire tank, and one with a single large injector at the center.

Gasoline Injection With a Central Spray Nozzle

A few tests were run by injecting gasoline through a 5 gpm spray nozzle at the center of the 6-foot tank. The spray nozzle was similar to nozzles used for smoke-suppressing water spray, but was larger. The spray nozzle distributed droplets of gasoline over the entire tank surface, rather than spreading it as a flowing wave. When the spray was ignited immediately, by energizing the spark plug before starting gasoline flow, much of the gasoline immediately flared up in a very large flame that died down within 5 seconds. A small oil flame remained, and this required about 30 seconds to develop into a large flame with water sprays operating. Alternatively, the gasoline could be sprayed on the oil surface, then ignited. This resulted in a flame very similar to that when injecting gasoline along the oil surface. At this point there seemed to be no advantage to spray distribution of gasoline, and there appeared to be the disadvantage of a possible explosion if ignition were delayed until after distribution within a closed space, so this idea was dropped.

Spark-Plug Design

Initial experimental studies used an Auburn I-132 spark plug, which had been specified by IITRI in their design recommendations[1]. This plug had a center electrode that extended 1/2 inch beyond the threaded metal body of the plug, and an L-shaped ground electrode that extended from one edge of the plug body to the central electrode. This plug proved reasonably satisfactory during ignition experiments, arcing most of the time that it was energized. However, at times immediately after energizing, a few seconds were often required before arcing began, especially when the plug was filled with water from the smoke-suppression spray nozzle. A 6,000 volt oil-burner ignition transformer was used to energize the spark plug.

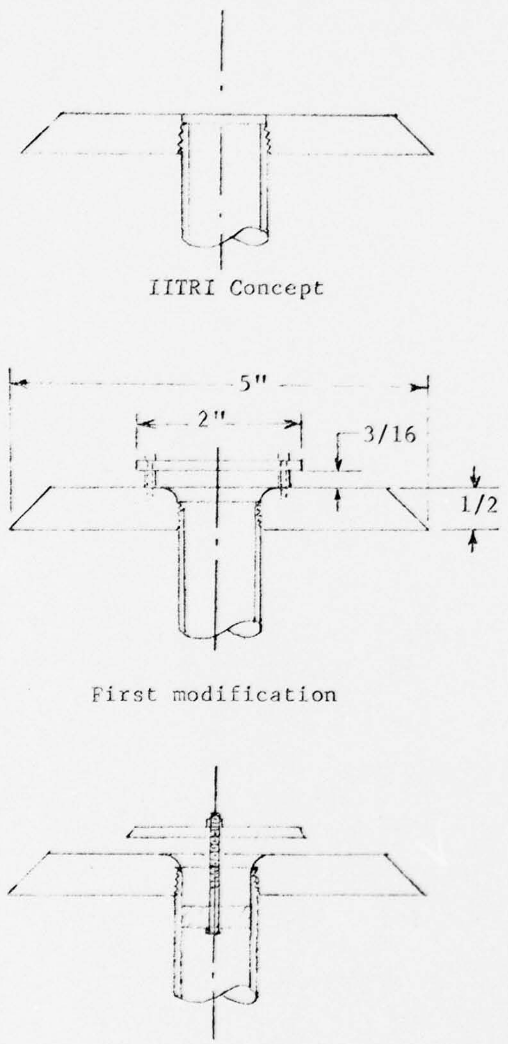


FIGURE 2. THREE GASOLINE INJECTORS USED IN SIX-FOOT FIRE TANK

Some spark-plug modifications were made, but these did not improve arcing reliability:

(1) The unglazed porcelain insulator was covered with silicone rubber to avoid soaking of the insulation with water.

(2) A disk was welded to the central electrode, and a vertical ground electrode extending from the metal body to within 1/8 inch of this disk was installed. Silicone rubber was used over the porcelain for waterproofing. Performance did not appear to be improved.

It appeared that the Auburn I-132 spark plug was only marginally adequate for this service. (A better plug design was found later during studies in the 15-foot tank.)

Low-Voltage Glow Plugs

Two low-voltage armored diesel-engine type glow plugs were obtained for trial as igniters. However, it was found that, at the rated voltage and current, the surface temperature of these plugs was only about 1400 F. This temperature proved too low for ignition of gasoline, and any higher power input resulted in burnout of the heating element. Thus, these plugs were not suitable for fire-tank application.

Because of the good experience with the high-voltage spark-ignition system, further work with glow plugs was not carried out. However, if necessary, it should be possible to construct suitable exposed-coil glow plugs that would provide satisfactory ignition. Coil surface temperatures in the range of 1800 to 2000 F are needed for positive ignition.

Glow plugs were of interest because they operate at 6 to 12 volts and large numbers of them could be operated from a single power source. However, it became apparent that the 15-foot fire tank would require only two spark plugs and the engine-room simulator only four to six spark plugs; thus, an ignition transformer for each spark plug does not appear unreasonable. Furthermore, with so few spark plugs, provision for redundant spark plugs appears reasonable if needed.

Height of the Smoke-Suppressing Water-Spray Nozzle

A single water-spray nozzle was installed at the center of the 6-foot fire tank for smoke suppression. This nozzle was a Spraying Systems No. 8686-1/4-1, the same type used in the Norfolk 15-foot fire tank.

The height of the nozzle above the oil surface was varied from 1/2 inch to 3 inches. For heights greater than 1.5 inch, little water spray fell into the oil surface, but considerable spray impinged on the tank wall and much of the water appeared to evaporate in the flame. Under these conditions the flame was easy to ignite and the oil flame grew large within a few seconds. However, with nozzle height below 1.5 inch, much of the water spray impinged on the oil surface with relatively uniform distribution over the surface. The outward momentum of the water spray pushed oil toward the edge of the tank, leaving a hole in the center if the oil film was too thin. Furthermore, the drops of water falling into the hot oil layer appeared to evaporate in the oil, thus reducing the size of the oil flame and causing considerable sputtering and popping in the oil film, with burning droplets of oil frequently projected out of the tank. The smoke density was about the same for either mode of operation.

It was concluded that operation of the 6-foot fire tank was best when the height of the water-spray nozzle was about 2 inches above the oil surface. This height provided faster ignition and larger oil flames than lower heights, at which water spray reduced flame size significantly.

Tank-Wall Cooling

During normal operation smoke often appeared heaviest at the edge of the tank. This may have been partly due to the nature of water distribution from the smoke-control water nozzle, but it is also probable that some oil vaporization took place from the tank wall, which became hot enough to burn off paint. As this wall was only 1/8-inch thick, heat was not conducted rapidly into the water.

In an attempt to reduce smoke from wall effects, a water-spray ring was placed around the tank, with jets of water directed against the outside of the tank above the water level. With this spray ring in operation the smoke level was reduced significantly. Steam and water from the external spray was induced into the fire by air convection, reinforcing the internal water spray. This effect might not occur with a heavier walled tank, in which the tank wall would be cooled by conduction to the tank water.

Effect of Elevated Water Temperatures

It has been observed that, after a few burns, the oil in a fire simulator ignites faster and burns with a larger flame. This is probably an effect of an increase in oil and water temperatures. To investigate the effect of water temperature on ignition and burning, two gas burners were installed in the 6-foot fire tank for heating the water. These fired into 4-inch pipes that were installed across the tank near the bottom. In ignition trials at water temperatures of 60 F, 120 F, and 190 F, the differences in ignition and in burning were rather small. With 190-F water, the oil fire was slightly larger and more intense than with 60-F water, and the ignition gasoline seemed to vaporize and burn somewhat more quickly, but the effects were not very significant.

It appears that the oil film actually boils after a minute or so of firing at any water temperature. The initial boiling point of the No. 2 fuel oil is about 400 F, indicating that the surface of the oil is much hotter than the water. Thus, the differences in burning characteristics observed after a few burns were probably the result of high oil surface temperature, and did not require high water temperature. Actually, the water temperature 1 inch below the surface of the 6-foot fire tank never increased more than 10 F during a long series of ignitions, although the oil surface appeared very hot.

Burning Rates

An attempt was made to determine approximate burning rates by measuring the time required for burnout of injected gasoline, and of a 16-pound layer of No. 2 fuel oil. However, the measurements were not very consistent, as they depended upon a definition of burnout. In general, combustion proceeded at a high and nearly constant rate for a time, after which the rate fell quickly to a low level and continued. In one test, for example, 16 pounds of oil and 3 pounds of gasoline burned at a high level for 3 minutes, following which a small fire around the rim of the tank persisted for an additional 2 minutes. The rates for various ignitions varied from 100 to 300 lb/hr for the 28.3 ft^2 burning surface--equivalent to values of 3 to 10 lb/hr per ft^2.

Effects of Oil Thickness

All of the work discussed to this point was with oil layers 1/8 to 1/4 inch thick. This thickness was used for convenience in making burns, then burning out remaining oil so that changes could be made. In a check run with an oil thickness of 2 inches, ignition and burning were considerably different.

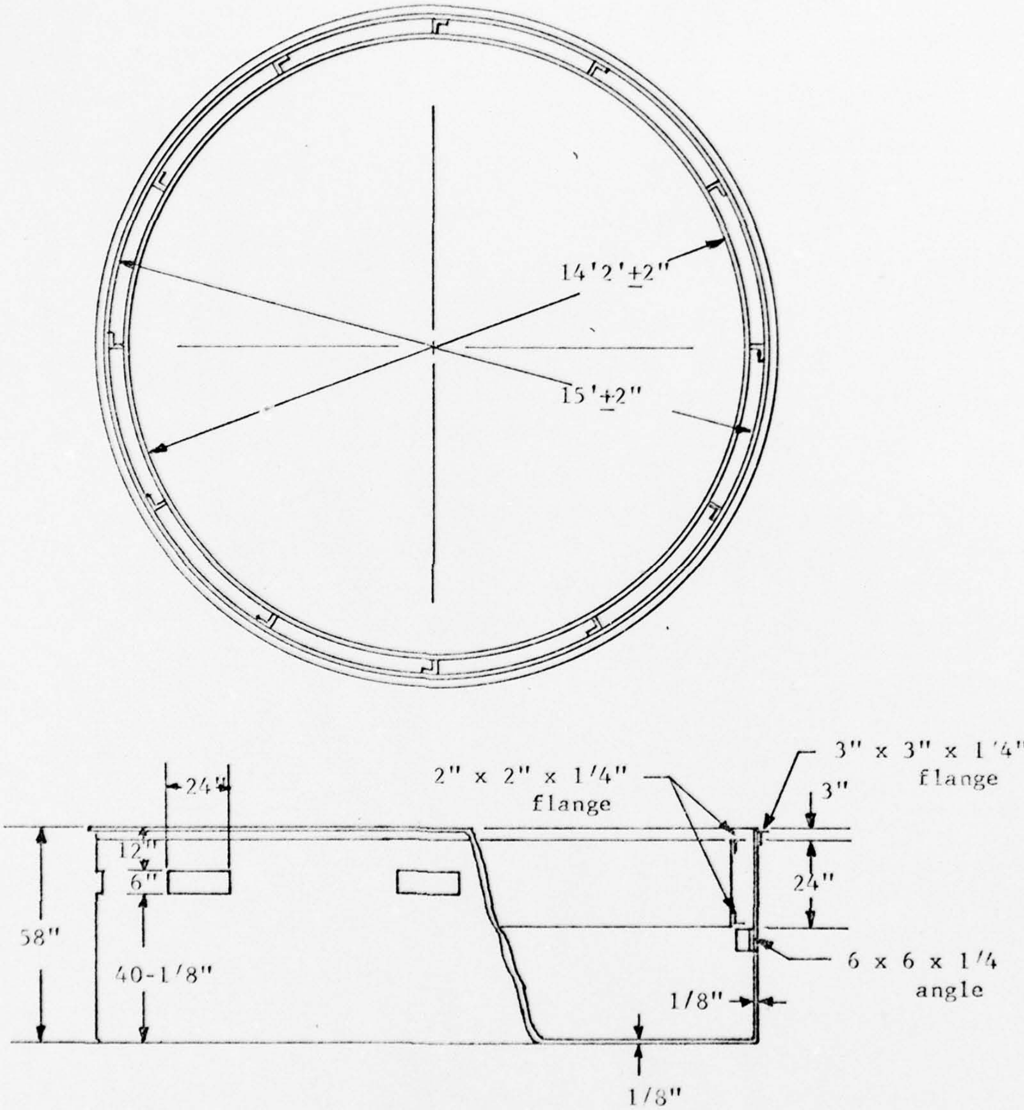


FIGURE 3. DIMENSIONS AND STRUCTURE OF 15-FOOT TANK

One major difference was that injecting 1 to 2 pounds of gasoline provided excellent ignition with a 1/4-inch layer of oil, but ignition with a 2-inch layer was very slow. Apparently the gasoline mixed with the oil during injection and did not vaporize and burn immediately. It was necessary to increase the gasoline quantity to 6 pounds for good ignition, but flame development still required 45 to 60 seconds. Once developed, the flame was difficult to extinguish because of the large amount of gasoline in the oil. Once such a gasoline-oil mixture had been established, however, ignition was obtained with as little as 1/2 pound of gasoline.

It did not appear possible to burn all of the gasoline out of the oil, as checked by the difficulty of extinguishing the flame with the built-in extinguishment nozzles. When gasoline was present, small flames remained at the void around each extinguishment nozzle, and these flames then spread rapidly to reignite the fire when water flow stopped. After most, or all, of the gasoline was burned out of a mixture, the flame extinguished quickly and did not reignite. In tests with thick oil layers, once gasoline content of the oil became high it was necessary to burn all of the oil to eliminate all of the gasoline.

LARGE-SCALE STUDIES WITH 15-FOOT FIRE TANK

Description of 15-Foot Fire Tank

The 15-foot fire tank erected at Battelle was designed to duplicate the dimensions of the 15-foot tank at the Norfolk Naval Station, including diameter, heights above the liquid level, and spacing of water-spray nozzles for smoke suppression. However, the Battelle tank was made 8 inches deeper to provide extra water storage if needed for fire fighting, and the liner of the Battelle tank extended only 9 inches below the liquid level to facilitate installation of piping through the tank wall. The maximum water depth of 40 inches was limited by spillover through eight rectangular ports spaced around the periphery of the tank. A Dwyer liquid-level controller of the same design as that used at Norfolk was used to control water level.

Figure 3 shows the dimensions and structural details of the 15-foot tank.

Figure 4 is a photograph showing the general arrangement of the 15-foot tank, and Figure 5 shows the internal piping and underwater catwalk. Five separate piping systems were installed, as follows:

(1) A smoke-suppression water-spray system, having four spray nozzles equally spaced on a circle of 64-inch radius, with a nozzle at the center. Each nozzle is a Spraying Systems Corporation Model No. 8686-1/4-1 nozzle which delivers a 180-degree spray at 2 gpm with 40 psi water pressure.

(2) Piping for four gasoline-injection points equally spaced on a circle of 4.5-foot radius, as recommended by IITRI. One-inch pipe is used in this system.

(3) A single, large gasoline injector at the center of the tank, piped with two-inch pipe, for use in developing a one-injector system.

(4) Electrical conduit to support five spark plugs--one at each gasoline injection point.

(5) An exterior ring of 2-inch pipe, connected with eight large flat-spray nozzles used to extinguish the fire after each burn. Extinguishing water is taken from the bottom of the tank and pumped to the spray nozzles by a pump rated at 180 gpm at 20 psi. The pump and spray ring can be seen in Figure 2. (This spray system extinguished oil fires within 2 seconds.)

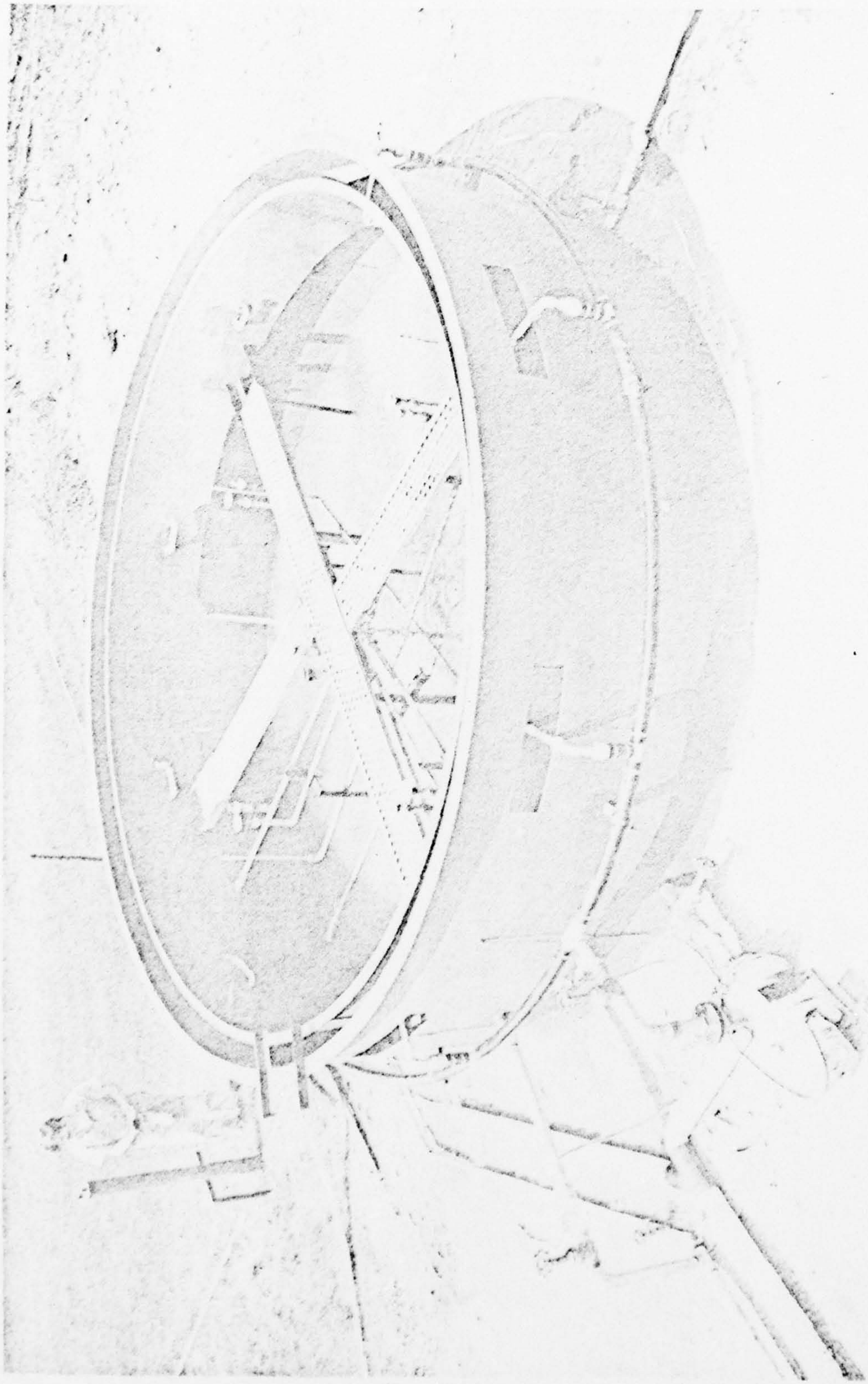


FIGURE 4. OVERHEAD VIEW OF 15-FOOT FIRE TANK SHOWING GENERAL ARRANGEMENT

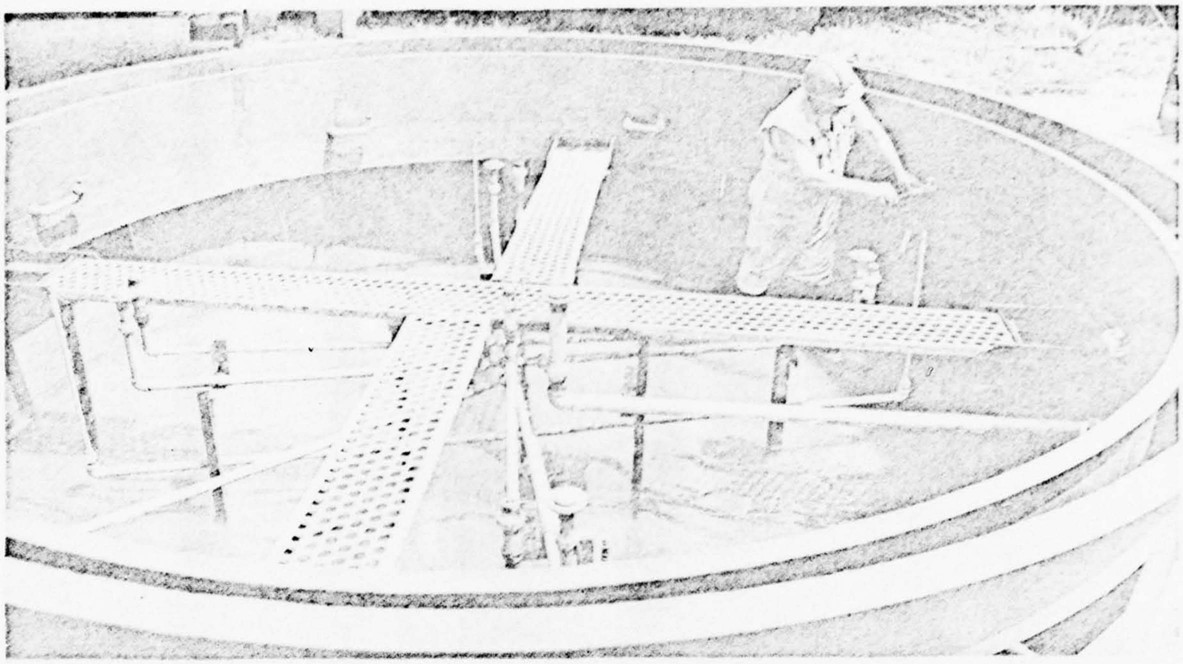


FIGURE 5. VIEW OF 15-FOOT FIRE TANK SHOWING INTERNAL ARRANGEMENT

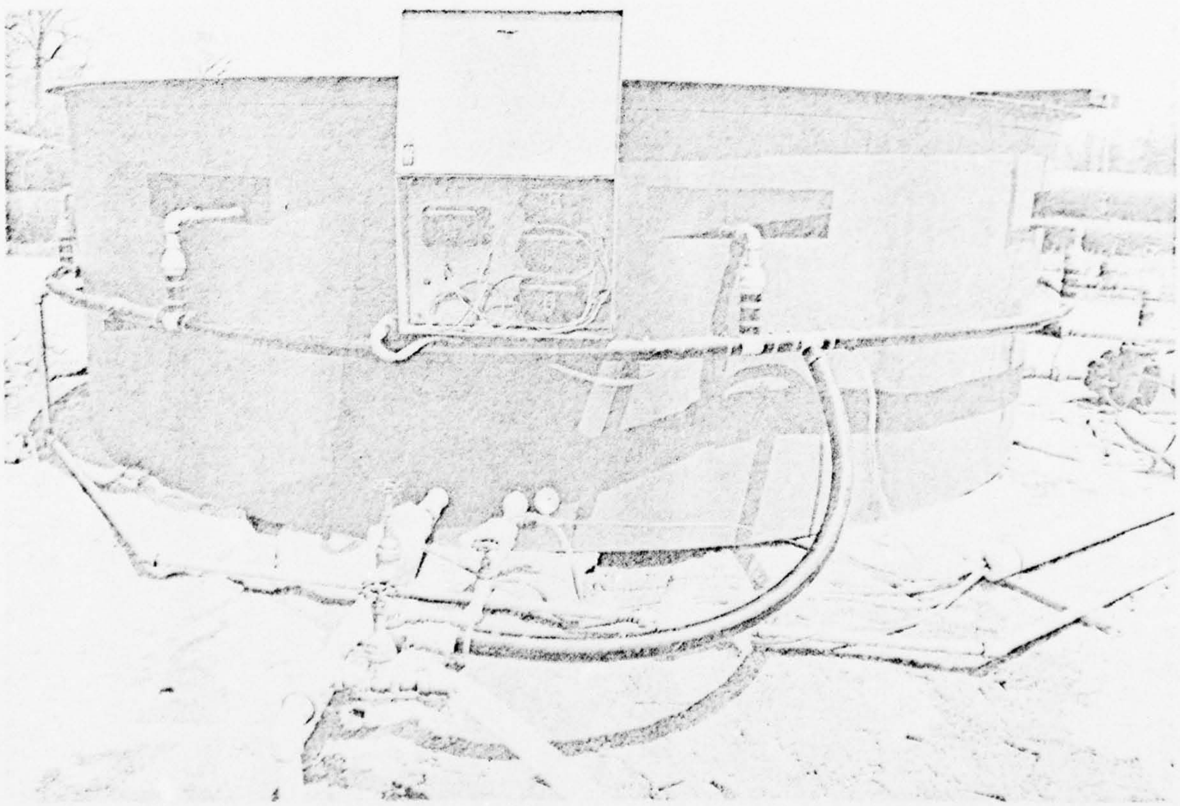
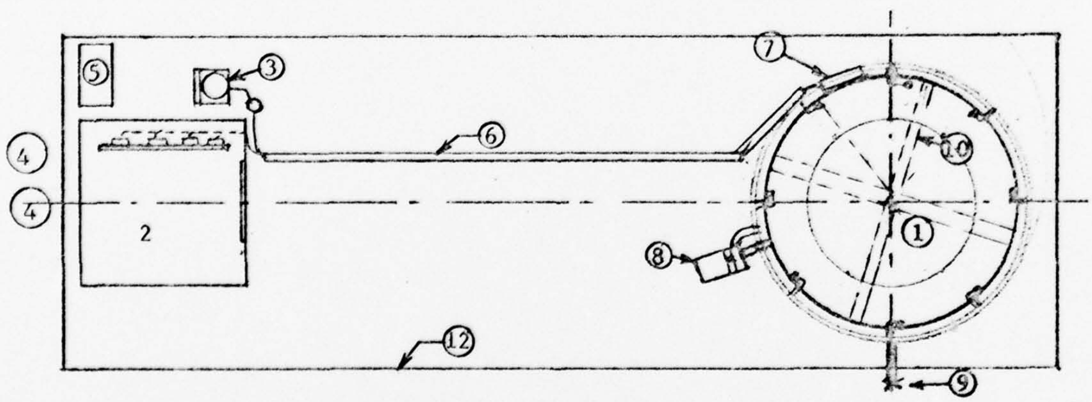


FIGURE 6. OUTSIDE VIEW OF 15-FOOT FIRE TANK SHOWING IGNITION TRANSFORMERS AND CONTROL VALVES

FIGURE 7. OVERALL VIEW OF 15-FOOT FIRE TANK AND ITS EQUIPMENT



1. 15-ft fire tank
2. 10 x 10 ft control building
3. Gasoline feeder
4. Gasoline storage drums
5. 275-gal fuel oil tank
6. Conduit for wiring and piping
7. Ignition transformers
8. Water pump for fire extinguishing
9. Tank drain
10. Grating catwalks under water surface
12. Crushed stone pad, 20 x 60 ft.

FIGURE 8. ARRANGEMENT OF 15-FOOT FIRE TANK AND ITS EQUIPMENT

A cross-shaped catwalk 12 inches wide is installed 8 inches below the liquid level to provide access to all installed equipment without dropping the liquid level.

Figure 6 is a view of the outside of the tank showing general arrangement and appearance. The high-voltage spark transformers, and the manual and solenoid valves used for control of gasoline flow and water flow can be seen at the center of the picture.

Figure 7 is a photograph of the overall installation.

Figure 8 is a sketch showing the general arrangement of the fire tank and its supporting equipment, which included a small steel building in which controls were mounted, a gasoline feeder, and storage for gasoline and fuel oil. The apparatus was installed on a 20 x 60-foot pad of crushed stone.

The Gasoline-Injection System

The first gasoline-injection system used with the 15-foot fire tank was a pressurized tank of gasoline mounted on a scale. The quantity of gasoline injected was determined by the tank pressure and by the period during which a solenoid valve between the tank and the gasoline injector was open. Such a system was not considered for the Norfolk installation because of safety considerations; it appeared that any solenoid-valve leakage, or failure of a solenoid valve to close, could result in injection of excessive gasoline into the simulator. Accordingly, a different system utilizing injection from a small hydraulic accumulator was developed as a prototype for the Norfolk installation and proved by operation in the 15-foot fire tank.

Figure 9 shows the arrangement of the accumulator-type gasoline injection system used on the 15-foot fire tank. Gasoline was pumped from a storage tank by a 5 gpm gear pump, passed through a pressure regulator that controlled pressure at 25 psi, and charged into a 5-gallon bladder-type hydraulic accumulator precharged with nitrogen at 16 psi. During each operating cycle the gasoline pump was operated until the accumulator was charged to the gasoline-regulator controlled pressure, at which time the accumulator contained 6 pounds (1 gallon) of gasoline. This took 12 seconds, but the pump could be run longer without changing the amount of gasoline injected; excess gasoline would be by-passed through the pressure regulator back to the storage tank. With the accumulator charged, the gasoline injector was opened by energizing the solenoid valve that admitted nitrogen to the actuating piston. The spark system was then energized, and gasoline was injected by opening the solenoid valve at the accumulator outlet. This dumped the entire quantity of gasoline in the accumulator through the injector. The solenoid valve and the gasoline injector were then closed until the next cycle.

This system was installed in the 15-foot fire tank and used for 100 ignition cycles. It proved very consistent in operation. The bladder pressure was adjusted to the level needed for completing gasoline injection within 1 second, and the pressure regulator was adjusted to charge 6 pounds of gasoline to the accumulator per cycle. The quantity of gasoline charged could be adjusted easily by changing the setting of the pressure regulator. The gasoline supply tank was mounted on a scale for these experiments.

It is believed that this system provides adequate safety for the Norfolk installations by limiting the possibility of accidental gasoline leakage into the simulators. During normal operation, only the quantity of gasoline stored in the accumulator can be injected into the simulator. Leakage of the solenoid valve, for example, can take place only during the charging period of a few seconds, and cannot change greatly the amount of gasoline injected; at other times the gasoline system is not pressurized. At the end of the cycle the gasoline injectors are completely sealed so that gasoline vapor or liquid cannot seep into the simulators over a period of time.

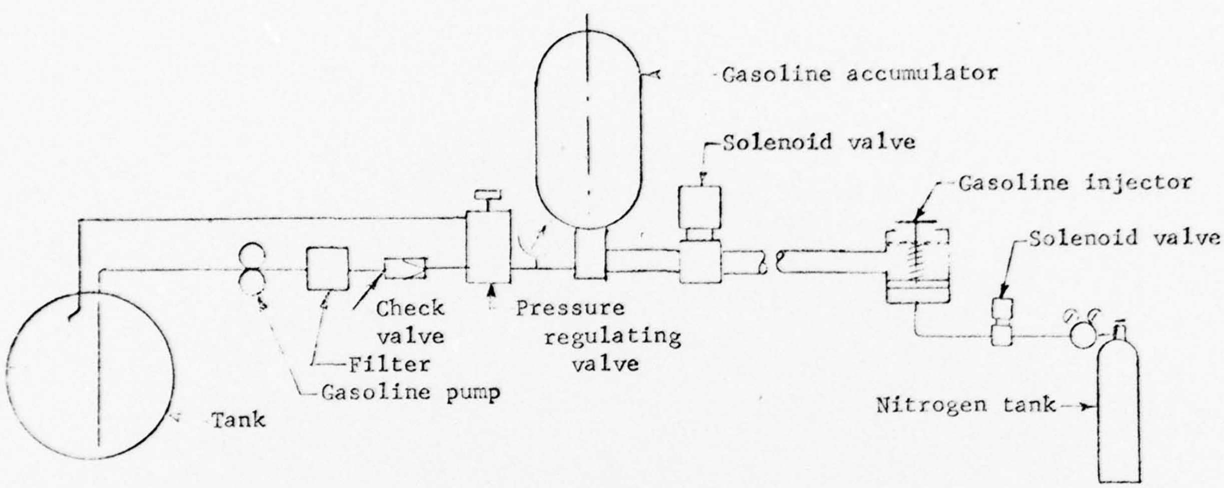


FIGURE 9. SCHEMATIC ARRANGEMENT OF GASOLINE INJECTION SYSTEM

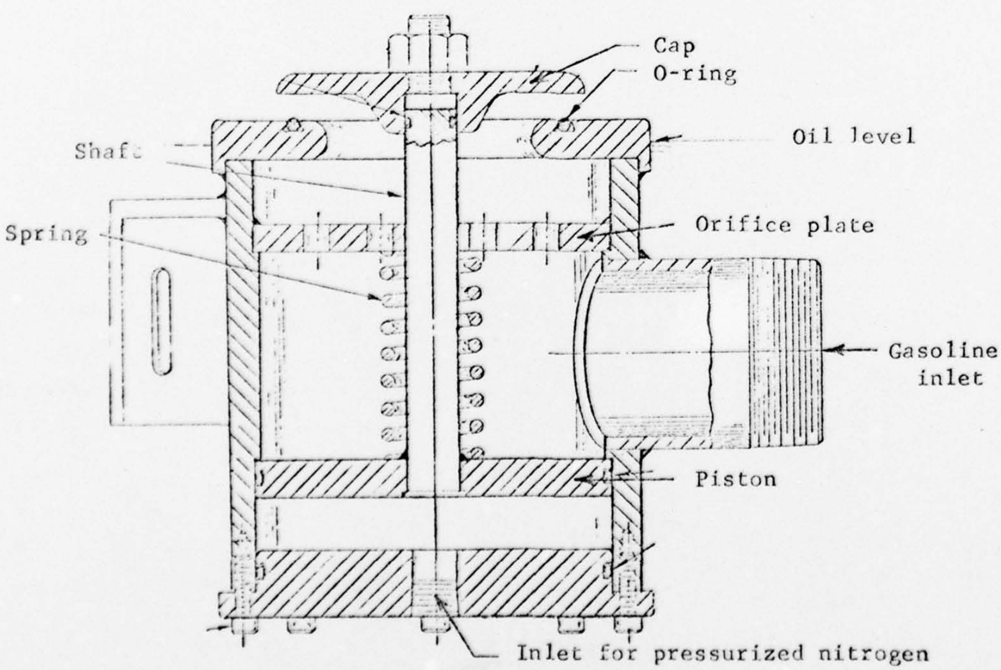


FIGURE 10. CROSS SECTION OF GASOLINE INJECTOR

Tests of Gas-Operated Gasoline Injector

Figure 10 is a cross-sectional view of the gas-operated gasoline injector. A gas piston at the bottom of the injector, sealed with an O-ring, raises the poppet valve at the top of the injector for a few seconds during the injection period, after which the gas pressure is vented and the poppet closes to seal the gasoline from leakage out of the injector.

The area of the piston is larger than the area of the poppet, so that increasing gasoline pressure has the effect of increasing the sealing force on the poppet-valve O-ring seal. The areas are such that 20 psi gas pressure will open the poppet when gasoline pressure is 36 psi.

After a few minutes of operation as first constructed, the O-ring seal friction increased to the extent that the poppet could not operate. It was apparent that gasoline lubrication was not adequate for the normal "squeeze" specified for hydraulic systems. The O-ring groove was deepened to provide only 0.005-inch compression of the O-ring, following which the injector was cycled through 18,000 operating cycles at a rate of 10 per minute while filled with gasoline. No gasoline leakage into the actuating-air space occurred during this time, and operation appeared entirely satisfactory.

The consumption of operating gas was very small. During operation in which the poppet mechanism was cycled 18,000 times--equivalent to 10 operations per day for six years--less than a quarter tank of nitrogen gas was used. Thus, it is feasible to use a nitrogen tank for poppet actuation. A standard 180 ft^3 tank of nitrogen cost $4 in June, 1972, so that operating cost would be nominal. Actual gas consumption at a large installation would be higher, as supply piping would be filled during each cycle.

Pressure drop and flow disttribution from the injector were checked by flowing water through it. Pressure drop closely checked calculated values, and the radial distribution of water appeared uniform.

The Spark-Ignition System

System Development

An electrical spark-ignition system is used to ignite the gasoline as it is injected into the simulator. Ignition takes place when the wave of flowing gasoline reaches the spark gap, and the fire immediately flashes over the entire gasoline surface and grows as the gasoline wave advances over the oil surface. The electrical components include a high-voltage ignition transformer, a heavy-duty gas-turbine spark plug, and waterproof conduit connecting them. An ammeter in the primary of the transformer will indicate secondary current, which is the same for an arc or a shorted gap.

The Spark Gap

Experimental ignitions were begun using an automotive-type spark plug with extended electrodes, but these proved unreliable as they were frequently shorted by capturing a drop of water between the electrodes. Although the plug would usually clear itself of water within a few seconds, ignition failures occurred about 10 percent of the time. Accordingly, other spark plugs and spark-gap arrangements were tested in the laboratory by immersing them in a pan of water while firing, and sprinkling them with water before and during firing. They were also immersed for several days at a time, then fired. Seven different types of heavy-duty gas turbine igniters and several industrial-type spark plugs were evaluated and one, the Champion FS47-11 gas-turbine igniter, proved entirely satisfactory and greatly superior to all others. This igniter was installed in the 15-foot fire tank and used for 100 ignitions without one failure.

The FS47-11 igniter has a central electrode that terminates in a 1/4-inch-diameter cylinder, in turn centered within a tube of 1/2-inch ID and 7/8-inch OD. The 0.125-inch space between the tube and the center electrode is great enough that water cannot bridge the spark gap, but falls through without shorting the arc. A 7/16-inch hole through the side of the outer tube provides for equalization of the water level inside and outside the tube, so that water cannot stand in the tube and cover the top edge. The top of the spark plug is placed about 1 inch above the surface of the oil and water in the simulator.

The Ignition Transformer

Four identical ignition transformers, one for each igniter, were used in the 15-foot fire tank. The transformers were standard oil-burner ignition transformers which have undergone extensive development for extremely high reliability, and no difficulty has been experienced with any of the transformers in the course of the experimental program. The transformer operates with a primary voltage of 110 volts and a primary current that varies from 0.10 ampere with an open secondary to 1.5 amperes with an arc in the secondary circuit. The secondary operates at 8,500 volts and 20 milliamperes, either shorted or with a normal arc. The transformers used in the Battelle experiments were Webster-Electric Type 822-6A06.

Spark-Detection Ammeter

Because of the large difference between open-circuit current and normal current for the ignition transformers, an ammeter can be used in the transformer primary circuit to indicate proper firing of the spark plugs. The transformer primary current is only 0.1 ampere when the spark-gap circuit is open, and 1.5 amperes with a normal spark. However, primary current is also 1.5 amperes with a shorted spark gap, which occurs if a drop of water bridges the electrodes. Since shorting of the spark gap is highly undesireable because ignition does not occur, considerable effort was directed toward obtaining a spark gap that does not short with water, and no shorting has been experienced at Battelle with the present gas-turbine igniter. It appears satisfactory to use only one ammeter for all transformers, as normal readings will be 3 amperes for the two transformers in 15-foot tank-fire simulator and 9 amperes for the 6 transformers in engine-room simulator; a change of 1.5 amperes from either value would be easily seen on a 10-ampere meter.

Lead-Wire Capacitance

In designing the Norfolk ignition systems there was some concern about the effect of capacitance in the high-voltage igniter leads if the transformers were located 50 feet or more from the spark plugs. Accordingly, the ignition system was checked with 100-foot leads, with two 50-foot leads taped together, and with the taped 50-foot leads coiled into a small-diameter coil. The sparks obtained at the spark plug were all more intense that those with short, low-capacitance lead wire. Primary current to the transformer increased under conditions causing more intense sparks.

Ignition Studies in 15-Foot Fire Tank

Comparison of 1-Injector and 4-Injector Systems

The 15-foot tank was set up for gasoline injection through four injectors located on a 128-inch circle, as recommended by IITRI(1) and also for injection through a single larger injector at the center. The principal objectives of ignition studies in the 15-foot fire tank were to compare these two injection systems, and to determine optimum injection and ignition conditions for the best system.

Work was begun by firing gasoline directly upon the water surface, with no oil present. It was found that, with the four-injector system, complete merging of gasoline flames could be obtained by injecting 6 to 8 pounds of gasoline in 1 second. With the larger, single injector at the center, complete coverage was obtained by injecting only

3 to 4 pounds of gasoline. In this respect, the single injector appeared to provide equal flame coverage with less fuel. The fire obtained with the single large injector was also considerably larger than the four smaller fires formed with four injectors. A spark plug near each injector was used to ignite the gasoline.

Ignition With One Central Injector. In oil ignition tests with a single gasoline injector, oil layers 1/8 to 1/4-inch thick were used. The quantity of gasoline needed to form a gasoline fire completely covering the surface of the tank was found to be about 6 pounds--roughly twice that needed to cover the surface of the water when oil was not present. With slow, low velocity injection over periods up to 6 seconds, the flame spread relatively slowly from the injector, and 9 to 12 pounds of gasoline were required to cover the tank surface. Time for full development of an oil flame was about 30 seconds. However, with wind velocity of 10 mph, the gasoline was pushed to the leeward side of the tank and did not spread to the windward side until a large oil flame developed.

Gasoline injection at higher velocities over shorter periods resulted in better coverage of the surface in wind. Best results were obtained when injecting 6 pounds of gasoline within 1/2 second. The gasoline flame covered the surface uniformly within 1 second. Height of a large gasoline flame peaked within 5 seconds and decreased, then the oil flame grew full size after a total elapsed time of about 30 seconds.

Ignition With Four Injectors. When injecting gasoline from four injectors, the optimum conditions of velocity and injection period were found to be about the same as those for one injector. Injection of 6 pounds of gasoline (total) in 1 second or less provided complete flame coverage within a second or two, and an oil flame developed within 30 seconds. When gasoline was injected slowly, the effect of wind was small because gasoline was supplied on the windward side of the tank and it burned there as well as at other points. However, this difference was not significant if high injection velocities were used.

The rate of gasoline burnout was checked by extinguishing the flame 15 seconds and 30 seconds after ignition. After the 15-second extinguishment, sufficient gasoline remained that the flame could be reignited with the spark plugs and remanents of flame around extinguishment nozzles. After the 30-second period, the oil could not be reignited without injection of more gasoline. It appears probable that sufficient gasoline can be burned out of the gasoline-oil mixture during each cycle that the oil residue will not be highly flammable, even though some gasoline may remain in the mixture.

It was concluded that performance of the single-injector system, using one injector and one spark plug, was as good as that for the four-injector system using four injectors and four spark plugs. Accordingly, the one-injector system was selected for further development and optimization because of its simplicity.

Optimization of Ignition Conditions

In systematic ignition tests, gasoline pressure, injection period, and injector opening were varied using 6 pounds of gasoline per cycle. The thickness of the oil layer was 1/8 to 1/4 inch for one group of tests, and about 1-1/2 inch to 3/4 inch for a second group of tests. Gasoline was injected through a single injector at the center of the tank. The optimum injection period was found to be between 1/2 and 1 second, and the optimum injector opening was 1/4 to 3/8 inch. Timing of water spray was varied between starting the spray before gasoline injection, to starting the spray 10 seconds after gasoline injection. The best smokeless ignition occurred when the spray was started about five seconds after gasoline injection. Good ignition could be obtained with either thick or thin oil layers. However, the thick oil layer required more gasoline for the first ignition; after it had become "primed" with gasoline, subsequent ignitions were about the same as for a thin oil layer.

Ignition With a Thin Oil Layer. For operation with a 1/4-inch oil layer, the best ignition condition was one in which the injected gasoline followed a radial wave in the oil surface to a 10-foot diameter; if the injection time was lengthened beyond 1 second, the flame diameter did not grow enough. With excessive injection velocity, obtained with an injector opening of less than 1/8 inch, mixing of gasoline and oil increased and ignition was not as good as with lower velocities. Injection velocities up to 100 feet per second were investigated. With the 10-foot diameter gasoline flame, the oil flame grew to fill the tank within 30 seconds. Considerably more gasoline was required to spread gasoline over the entire tank surface, as the spreading wave of gasoline was attenuated in the viscous oil layer to a much greater extent than in water alone. (In previous calibration runs, with gasoline injected over water alone, the entire tank surface could be covered with only 3 pounds of gasoline.)

The gasoline flame covered the oil surface to a 10-foot diameter in 2 to 3 seconds. The rate of growth of the oil flame then seemed to depend almost entirely upon the rate of water spray used for smoke suppression. With 20 gpm of water spray from the start of gasoline injection, flame growth required 60 to 90 seconds. If water spray was delayed for 5 seconds the oil flame developed in about 30 seconds. This technique appears feasible because there is almost no smoke during the first 5 seconds after gasoline injection.

As little as 3 pounds of gasoline could start a fire and bring it to full size. However, manipulation of water spray was critical, and the time for flame development was about 90 seconds. At the other extreme, ignition was not significantly better with 12 pounds of gasoline than with 6 pounds. The optimum gasoline quantity is probably between 5 and 8 pounds depending upon conditions, and any amount in that range produces satisfactory ignitions. The optimum water-spray pressure during the ignition period varies with time and with the gasoline quantity used.

The gasoline injection pressure for optimum ignition conditions was only 16 psi. Thus, it should be possible to work with accumulator pressure in the range of 30 psi and gasoline-pump pressure in the same range.

Ignition With a Thick Oil Layer. Ignition with a thick oil layer was studied by pouring 110 gallons of oil into the 15-foot fire tank, for an oil layer 1-1/2 inches thick. This was used until it burned to a thickness of 3/4 inches, after which more oil was added to restore the oil thickness to 1-1/2 inches. During these tests the wind velocity ranged from 4 to 10 miles per hour.

Ignition of the thick oil layer did not appear to differ greatly from ignition of thin oil layers much of the time. However, there were some differences. For example, the first ignition with fresh oil seemed to require more gasoline than subsequent ignitions. Once the oil had been "primed" with gasoline it ignited readily with a 6-pound gasoline injection. After some of the tests the fire was difficult to extinguish with the built-in spray system. This usually indicates that gasoline vapor is leaving the oil surface; this vapor is easily ignited from the spark plugs, or from small residual flames. When no gasoline is present, the fire does not reignite from the spark plugs.

On another day, ignitions with a thick layer of oil were less satisfactory, in that the flame did not grow to a large size with 20 gpm of water spray. Once the water spray was turned on, the fire stopped growing or developed large holes around spray nozzles. In one test, with large holes in the fire, a second charge of 6 pounds of gasoline was injected. This immediately flared up in a large fire that remained large after the gasoline burned. It is probable that ignition under these conditions required either more gasoline or less water spray.

In all ignitions, regardless of oil thickness, the flow rate of smoke-suppressant water spray was very critical. If spray was near 16 gpm, the fire developed quickly and grew large, but sometimes smoked rather badly. At 20 gpm, the fire never smoked but, under some conditions, the growth of the fire was arrested and it never grew large. With slightly more than 20 gpm, the fire would gradually go out.

In view of the differences in ignition and burning noted from day to day, it appears desireable to provide means of adjusting both the quantity of gasoline injected and the quantity of water spray used for smoke suppression.

Optimum Oil Thickness. In all of the Battelle experiments, operation using thin oil layers (of the order of 1/4-inch or less) was more consistent than that with thick oil layers. It was concluded that thin oil layers should be preferred at Norfolk as a way of minimizing mixing of gasoline and oil, and any problems that might arise from gasoline dissolved in oil. However, in subsequent operation of the prototype ignition systems at Norfolk it was found that thin oil layers were easily emulsified and mixed with water by the action of high-pressure fire hoses, and then did not ignite well. Thus, the optimum oil thickness at Norfolk proved to be about 1/2 inch.

Smoke Suppression With Water Spray

A water-spray system identical to that in the Norfolk 15-foot fire tank was installed in the Battelle 15-foot tank. When water pressure was fixed at 40 psi, smoke suppression was erratic, and considerable smoke was evolved after the fire grew large. With larger water nozzles and higher pressure, smoke could be controlled adequately.

Water spray from the five nozzles could drive the gasoline film into four discrete pockets at the edge of the tank under certain conditions of water pressure and oil thickness, thus greatly increasing the time required for flame development. These undesireable effects were most apparent when spray nozzles were close to the water surface and the spray was very coarse because of low water pressure. With good water atomization and distribution, and optimum water-flow rates, smoke suppression was good and a large, clean fire could be obtained.

Figure 11 shows the appearance of smoke with insufficient smoke-suppression water. Five Spraying Systems Model 8686-1/4-1 (180°) nozzles, each passing 2 gpm at 40 psi were used when this picture was taken.

Figure 12 shows the appearance of smoke using more smoke-suppression water. For this condition the center nozzle was replaced with a larger Spraying Systems Model 8686-1/4-2.5 (180°) nozzle passing 5 gpm at 40 psi, and water pressure was increased to the range of 55 to 60 psi. Total water flow was 16 gpm, and water atomization was greatly improved. Smoke level appeared completely satisfactory, measuring about No. 1 Ringleman or less throughout the ignition cycle.

In subsequent operation of the prototype ignition system at Norfolk, it was found that best ignition and smoke suppression throughout the ignition and burning period required considerable manipulation of water pressure. Water admission could be delayed for several seconds, until the fire started to smoke. Initial water pressure of about 60 psi permitted good flame growth with good smoke suppression for a few seconds. Then, as the flame size increased, it was necessary to increase water pressure up to a maximum of 120 psi for a fully developed fire. Excessive water pressure early in the flame development resulted in a small, poorly developed fire, or extinguished the fire. With careful manipulation of water pressure it was possible to limit smoke to about No. 1 Ringleman.

FIGURE 11. HEAVY SMOKE FROM OIL FIRE WITH INADEQUATE SMOKE SUPPRESSION
(10 gpm water from five 2-gpm nozzles)

FIGURE 12. LIGHT SMOKE FROM OIL FIRE WITH ADEQUATE SMOKE SUPPRESSION
(16 gpm water from four 2-gpm and one 5-gpm nozzles at 55 to 60 psi)

Conclusions From Studies in 15-Foot Fire Tank

From the experiments described above, the following conclusions were drawn:

(1) Good ignition can be obtained using a single gasoline injector at the tank center and a single high-voltage spark plug.

(2) If oil thickness is limited to the range of 1/8 to 1/4 inch, ignition requires the injection of 6 pounds of gasoline. Ignition can be obtained with smaller quantities of gasoline but the oil flame develops slowly.

(3) Good smoke suppression throughout the ignition cycle has been demonstrated. In general, smoke levels during gasoline burning early in the cycle are often lower than smoke from a fully developed oil flame.

(4) The spray from the smoke-suppression nozzle array affects the distribution of gasoline on the surface and the growth of the oil flame. For quickest development of a large flame, it is necessary to start with low water pressure, then gradually increase water pressure as flame size increases.

(5) Good, positive ignition of gasoline is obtained with a high-voltage spark so long as the arc is not quenched by immersion in water and oil. To avoid arc quenching under all conditions, some redundancy of spark plugs appears desireable, and some improvement in the nature of the spark gap seems necessary.

On the basis of satisfactory results obtained in the 15-foot fire tank, work on engineering design of systems for the Fleet Training Center at Norfolk was begun.

PART II. ENGINEERING DESIGN OF PROTOTYPE AUTOMATIC SMOKELESS IGNITION SYSTEMS FOR FLEET FIRE-FIGHTING SCHOOL AT NORFOLK NAVAL STATION

INTRODUCTION

This task was concerned with engineering design, construction, and initial operation of a smokeless, automatic ignition system for two fire simulators at the Fleet Fire-Fighting School of the Norfolk Fleet Training Center. Two automatic, smokeless systems sharing the same gasoline pump, fuel-oil pump, and control console were designed, one for the engine-room simulator and one for the 15-foot tank. Both of these simulators were already fitted with smoke-suppressing water-spray systems, which were used in conjunction with the ignition systems.

DESIGN CONSIDERATIONS

Design Objective

The objective of the smokeless, automatic ignition system is to provide for convenient, safe, and reliable ignition of fire simulators with minimum smoke. In the course of the design work considerable effort was applied to consideration of safety and reliability, as well as to the effectiveness of smoke suppression and the convenience of operation. It is believed that the system that evolved is safe and reliable.

Operating Principles

The general approach used in design of the smokeless ignition system is to inject a small amount of gasoline over the surface of the oil to be ignited, and ignite the gasoline with an electric spark. The amount of gasoline used is near the minimum that will provide good ignition and flame growth with the smoke-suppressing spray in operation; burnout of gasoline should be completed by the time the oil flame grows to full size. The thickness of the oil layer is maintained at the minimum practical level of 1/4 to 1/2 inch by replacing the oil burned in each ignition cycle by frequent injections of small amounts of oil. Control of these functions has been centralized in a control console providing for either automatic or manual operation.

Two automatic, smokeless ignition systems sharing the same gasoline pump, fuel-oil pump, and control console were designed, one for the engine-room simulator and one for the 15-foot tank. The two systems are the same in principle but differ in size: the surface area of the engine-room simulator is six times as great as that of the 15-foot tank. The operating cycle for both simulators is the same, but the time periods required for oil injection and charging of gasoline accumulators differ. The cycle is as follows:

(1) Oil is injected before each cycle, if needed, to restore oil thickness to the desired level. Use of automatically timed oil injection permits addition of small quantities for operation with a constant thickness of oil layer.

(2) Gasoline is charged to an accumulator by a gasoline pump, operating at a regulated pressure so that the gasoline charge is controlled closely.

(3) The spark igniter is energized.

(4) The poppet valve in the gasoline injector is opened to prepare for gasoline injection.

(5) Gasoline is injected by opening a solenoid valve, which dumps the pressurized gasoline stored in the accumulator through the injector. The gasoline lights immediately and covers the simulator surface quickly.

(6) Flow of smoke-suppressing water is started by opening a solenoid valve. Flow of water is adjusted manually as the fire grows,and stopped at the end of the cycle.

(7) The fire is given 30 to 60 seconds to grow large,after which it is extinguished.

Although the system is designed for automatic operation, variations in fuel quality and weather conditions can be accommodated by adjustments in the amounts of oil, gasoline, and water injected. In addition to the automatic operating cycle, manual operation is possible for component checking and for added flexibility of operation.

Safety Considerations

A primary safety objective was positive control of gasoline flow to the engine-room simulator to eliminate any possibility of an explosive mixture of gasoline vapor and air under any conditions. Design features selected for positive control of gasoline included the following:

(1) A gasoline injector having a nitrogen-operated poppet valve sealed with an O-ring was developed to eliminate the possibility of leakage of gasoline liquid or vapor into the simulator under any conditions.

(2) Gasoline to be injected is metered by charging an accumulator of limited volume to a preset pressure, and injected by dumping the accumulator. This eliminates the possibility of charging an excessive quantity of gasoline because of malfunctions such as valve leakage, or failure of a timer or pressure regulator.

(3) The quantity of gasoline to be injected is minimized by using the optimum injection velocity and flow rate, so that all of the gasoline injected is burned during the ignition cycle.

(4) The retention of unburned gasoline in the fuel oil is minimized by using the minimum practical amount of fuel oil in the simulator. This is equivalent to a thickness of about 0.5 inch, as limited by emulsification by fire hoses. The use of thin oil layers is made practical by an automatic oil-injection system.

Other safety measures were use of highly reliable spark plugs for ignition, in combination with an ammeter to indicate proper operation of the ignition transformers, the use of explosion-proof electrical equipment, and the use of appropriate safety interlocks in the control circuits.

Other Design Constraints

Design of the ignition systems was influenced by the requirement for quick installation with minimum disruption of the fire-fighting school, high reliability, simplicity of maintenance, and economical operation.

Quick construction and installation of the system required use of standard, readily available components to the extent possible; design for the minimum number of gasoline injectors, oil injectors, and spark plugs; and use of a relatively simple piping system. The relatively complex control wiring was localized within a prefabricated control console using standard industrial grade components that are readily available and highly reliable.

Reliability was approached by use of reliable, heavy-duty industrial components having a low probability of failure, and by making the system as simple as possible considering the functions to be performed.

Ease of maintenance depends upon having a relatively simple system with low probability of component failures. Trouble-shooting techniques to find malfunctioning components have also been devised and included in the instruction manual.

Two aspects of economy are maintenance costs and operating costs. Maintenance costs are minimized by use of readily available, reliable industrial components to the extent possible. Operating costs are almost entirely the costs of gasoline and fuel oil, and these are minimized by minimizing the quantities used per cycle.

DESIGN CRITERIA FOR IGNITION SYSTEM COMPONENTS

In designing ignition systems for the 15-foot tank and the engine room simulator, it was necessary to select optimum conditions for injection of gasoline and oil, and reasonable cycling periods. The quantities of gasoline and fuel oil to be injected were selected on the basis of experimental ignitions carried out in the Battelle 15-foot tank, and the sizing of the gasoline and oil pumps was based on carrying out an ignition cycle within one minute.

Gasoline Supply Criteria

In Battelle experiments it was found that one gallon of gasoline, injected over the surface in a period of 0.5 to 1 second, provided optimum ignition; these conditions were selected for the Norfolk 15-foot tank. A 5-gallon accumulator was selected for storage of the 1-gallon gasoline charge with a moderate pressure rise, and 1.5-inch gasoline piping between the accumulator and the gasoline injector was selected to minimize pressure drop. With these dimensions, the accumulator discharges one gallon in one second when charged to an initial pressure of 16 psi.

Gasoline flow to the engine-room simulator was calculated as the same quantity per unit surface area as for the 15-foot tank. The surface areas of the 15-foot tank and the engine-room simulators are 160 ft^2 and 1025 ft^2, respectively, for a ratio of 6.4. Thus, for the same gasoline weight per unit area, the engine-room simulator gasoline charge should be 6.4 gallons. Because of the geometry of the engine-room simulator, six gasoline injectors were used. Each of these, thus, passed approximately the same flow as the single injector in the 15-foot tank, and all injectors were made alike.

In order to store 6 gallons of gasoline with moderate pressure rise, accumulator capacity of 20 gallons is required. This was met by using two parallel 10-gallon accumulators, each charged with 3 gallons of gasoline. Each accumulator discharges through 2-inch piping to three gasoline injectors, and accumulator discharge piping is not interconnected. However, both accumulators are charged from a common 1-inch supply line.

Although 2-inch piping was used in the engine-room simulator accumulator-discharge lines, 2-inch solenoid valves suitable for the service conditions could not be found. Accordingly, a 1.5-inch solenoid valve was used in each accumulator discharge line.

The gasoline supply pump, located above the underground gasoline tank, is used to supply both the engine-room simulator and the 15-foot tank. It was selected to have sufficient capacity to charge the accumulators for the engine-room simulator in about 20 seconds. The Viking Model HJ-195-D pump installed provides 22 gpm at 50 psi sufficient to charge six gallons to the engine-room simulator accumulators in 16.4 seconds. The same pump will charge one gallon of gasoline to the accumulator for the 15-foot tank in 2.7 seconds.

Fuel-Oil Supply Criteria

The fuel-oil system was designed to inject an amount of fuel oil during each cycle equal to the amount burned, to permit operation of each simulator with a thin oil layer of nearly constant thickness. In order to provide such injection, the pumping rate was selected to permit oil injection to the engine-room simulator within 30 seconds.

In Battelle ignition studies it had been found that the consumption of fuel oil in a well-established, large fire was equivalent to 0.1 inch of oil thickness per minute. With this number as a guide, the amount of oil burned for each fire-fighting exercise was estimated. It was expected that about 30 seconds would be required to establish the fire, during which time the oil-burning rate would gradually increase to the maximum, and then the fire would be extinguished within 15 seconds, with the burning rate declining. Thus, the total oil burned might be represented by a burning period of 45 seconds at about half the maximum burning rate, equivalent to a reduction of oil thickness of 0.0375 inches per cycle. This depth is equivalent to oil consumption of 24 gallons per cycle in the engine-room simulator, and 3.75 per cycle gallons in the 15-foot tank. Subsequent experience at Norfolk indicates that actual fuel consumption is about 30 gallons per cycle for the engine room simulator and 3 gallons per cycle for the 15-foot tank.

The fuel-oil pump was selected to supply fuel needed for the engine-room simulator in less than 30 seconds. The Viking Model AL-195-D pump selected provides flow of 120 gpm at 80 psi, so that the required 30 gallons per cycle for the engine-room simulator is supplied in 15 seconds. Supply of 3 gallons to the 15-foot tank, using the same pump, requires about 3 seconds. Flow to the 15-foot tank is limited to 70 gpm by pressure drop through an existing 1.25-inch underground pipe.

Smoke-Suppression Water Flow Criteria

The amount of gasoline needed to privide good ignition is dependent upon the amount of water sprayed into the fire for smoke suppression. In general, the optimum rate of water flow is low during early flame development and increases with flame size. Excessive water flow will result in gradual extinction of the flame. In experiments in the Battelle 15-foot tank it was found that good flame development took place with water flow rates between 10 and 16 gpm and that 16 gpm was enough water for good smoke control in most flames. If a flame burned for several minutes and became very large, however, flow of 20 gpm might be needed for good smoke control. The largest flame could be gradually extinguished with a flow rate slightly above 20 gpm.

In subsequent experience using the Norfolk 15-foot tank it was found that the optimum combination of fast flame development with minimum smoke could be obtained by initiating water spray 3 or 4 seconds after gasoline ignition, at a pressure of 60 psi and flow of 12 gpm. As the fire size grew it was necessary to gradually open the manual water valve to control smoke, until the wide-open condition of 17 gpm at 120 psi was reached. When the ignition was carried out with a constant water pressure of 120 psi the fire did not grow large and did not cover the entire surface of the tank.

These water flow rates can be expressed in terms of pounds of water per square foot of burning area per minute as follows:

Condition	Water Flow Rate gpm	Water Flow Rate lb/ft^2 min.
At start of ignition period	12	0.6
At end of ignition period	17	0.85
Maximum flow rate for largest fire	20	1.0
Flow rate for gradual fire extinction	21	1.05

Materials

The gasoline-distribution system requires special consideration because of the corrosive nature of wet gasoline. Although all piping in the system is of galvanized steel, it was found that precision hardened steel parts of a gasoline pressure regulator rusted together within a few days. Accordingly, a bronze pressure regulator was specified. Viton fluorocarbon rubber was specified for O-rings, solenoid-valve diaphragms, and accumulator bladders, as this material swells less and lasts longer in gasoline than other available elastomeric materials.

The gasoline injectors, oil injectors, and spark-plug holders were machined from brass, which is easy to machine and relatively corrosion resistant in fresh water. Type 304 stainless-steel tubing was used as conduit for the high-voltage ignition wire, and galvanized steel pipe was used for all piping. All exposed parts of the spark plugs are of Inconel.

Electrical Components

All electrical components used in the ignition system are standard components of industrial grade. All solenoid valves and electric motors are of explosion-proof construction. Ignition transformers, the control console, and the contactor box, are in water-proof enclosures. The switches and contactors used in the control console are not explosion proof, because no gasoline enters the Field Office, but the switches, and timers are of heavy-duty, oiltight construction.

DETAILS OF SYSTEM DESIGN

Listing of Design Drawings

The design of the automatic ignition systems for the Fleet Fire-Fighting School at the Norfolk Naval Station is shown in ten drawings, listed in Table 1. The numbers listed are NAVFAC drawing numbers, and original drawings are filed at NAVFAC.

In the discussion that follows, details will be referenced both to the NAVFAC drawings and to less extensive report illustrations.

TABLE 1. DETAILED DRAWINGS OF AUTOMATIC IGNITION SYSTEM FOR FLEET FIRE-FIGHTING SCHOOL, NAVAL STATION, NORFOLK, VA.

NAVFAC	Title
4005872	Overall pipe and conduit layout
4005873	15-ft tank modifications
4005874	Overall pipe and conduit layout for engine-room simulator
4005875	Fuel oil piping in engine-room simulator
4005876	Gasoline piping in engine-room simulator
4005877	Gasoline injector
4005878	Spark-plug holder and fuel oil injector
4005879	Control panel layout and field office arrangement
4005880	Wiring schematic
4005881	Wiring diagram

Arrangement of Fire-Fighting School

Figure 13 shows the layout of fire-fighting simulators at the Norfolk Fleet Fire-Fighting School. Numbers identify the various simulators. Ignition systems were installed in the 15-foot tank (1) and the engine-room simulator (2). The control console was located in the Field Office (3), and flow of smoke-suppressing water is controlled manually from a bank of control valves at (4). Gasoline for ignition is taken from a 550-gallon underground tank at (5), and diesel fuel used as the basic simulator fuel is taken from a 25,000 gallon underground tank at (6), 200 feet away. In the course of the construction, underground piping and wiring were installed as indicated by dotted lines in Figure 13.

The 15-Foot Tank

Figure 14 shows the arrangement of the 15-foot tank. One gasoline injector, one oil injector, and two spark plugs are installed near the center of the tank, at the water surface. A catwalk of open grating, placed 4 inches below water level, provides access to the ignition components by dropping water level a few inches. Ignition components are supported from the end of this catwalk.

Gasoline is supplied from a 5-gallon accumulator placed 50 feet from the tank, at the water-valve manifold (4), Figure 13. This accumulator is charged with 1 gallon of gasoline within 3 seconds through a 1-inch pipe, and it discharges through the gasoline injector in 1/2 to 1 second, through a 1.5-inch pipe, for a flow rate of 60 to 120 gpm. The gasoline injector is supplied with nitrogen at 25 to 35 psi through a 1/8-inch pipe.

The oil injector is piped to an existing 1.25-inch pipe that ended at the edge of the tank. Because of pipe friction the oil injection rate is limited to about 70 gpm.

Each spark plug is wired to a separate ignition transformer with 18-gage wire insulated for a working voltage of 40,000 volts. The wire is enclosed in 3/8-inch stainless steel tubing to serve as a waterproof conduit. The transformers are enclosed in an existing waterproof junction box located near the gasoline accumulator at (4), Figure 13.

The gasoline injector is shown in Figure 10, and in NAVFAC drawing 4005877. The oil injector and the spark-plug holder are shown later in Figures 18 and 19 and in NAVFAC Drawing 4005878.

The existing smoke-suppressing water spray system includes one central nozzle and four nozzles spaced equally on a circle of 128-inch diameter.

The Engine-Room Simulator

Figure 15 shows the arrangement of the engine-room simulator. Four existing baffles divide the oil surface and serve to prevent flame travel. Accordingly, six gasoline injectors and six oil injectors are used for good distribution of gasoline and oil. A spark plug is installed near each gasoline injector.

Fuel oil is supplied to the six injectors through a single piping system. Oil enters the simulator at a rate of 120 gpm through a 2-inch pipe, which branches inside the simulator to two parallel 1.5-inch pipes, each supplying three oil injectors.

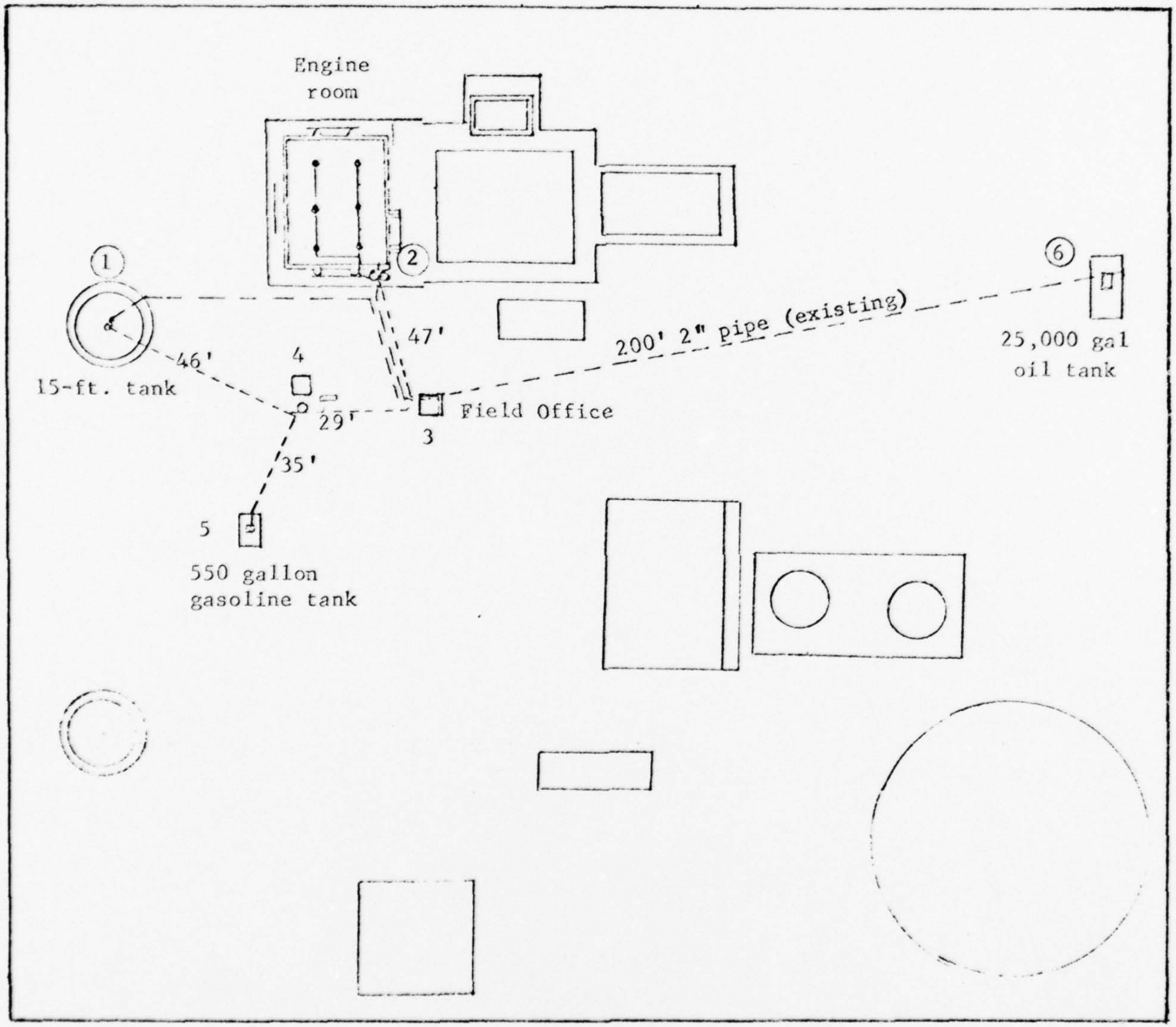


FIGURE 13. ARRANGEMENT OF FIRE-FIGHTING SCHOOL AT NORFOLK FLEET TRAINING CENTER

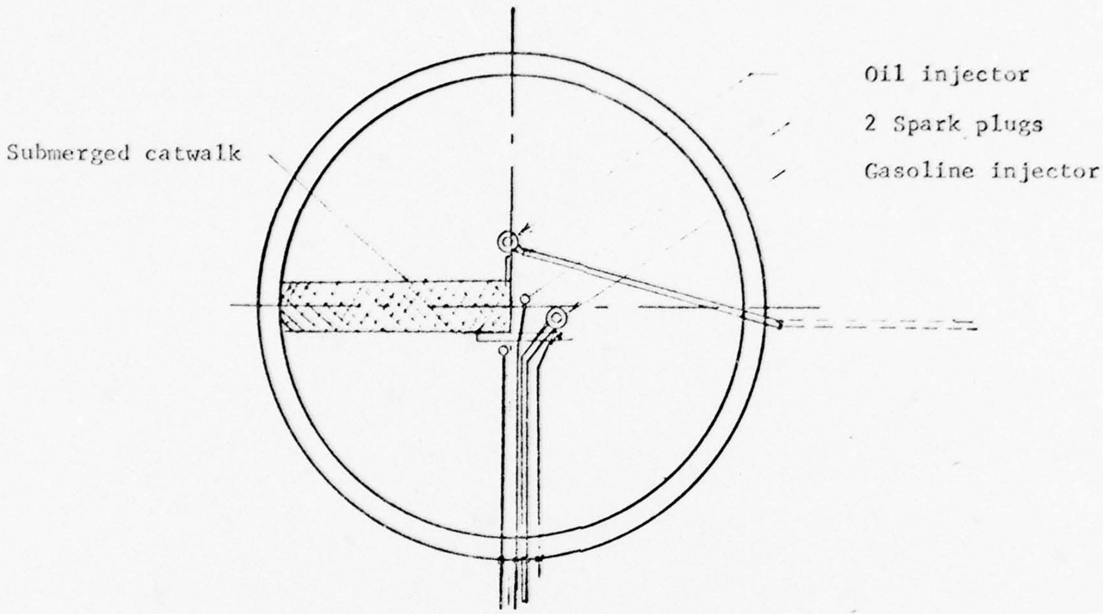


FIGURE 14. ARRANGEMENT OF THE 15-FOOT TANK

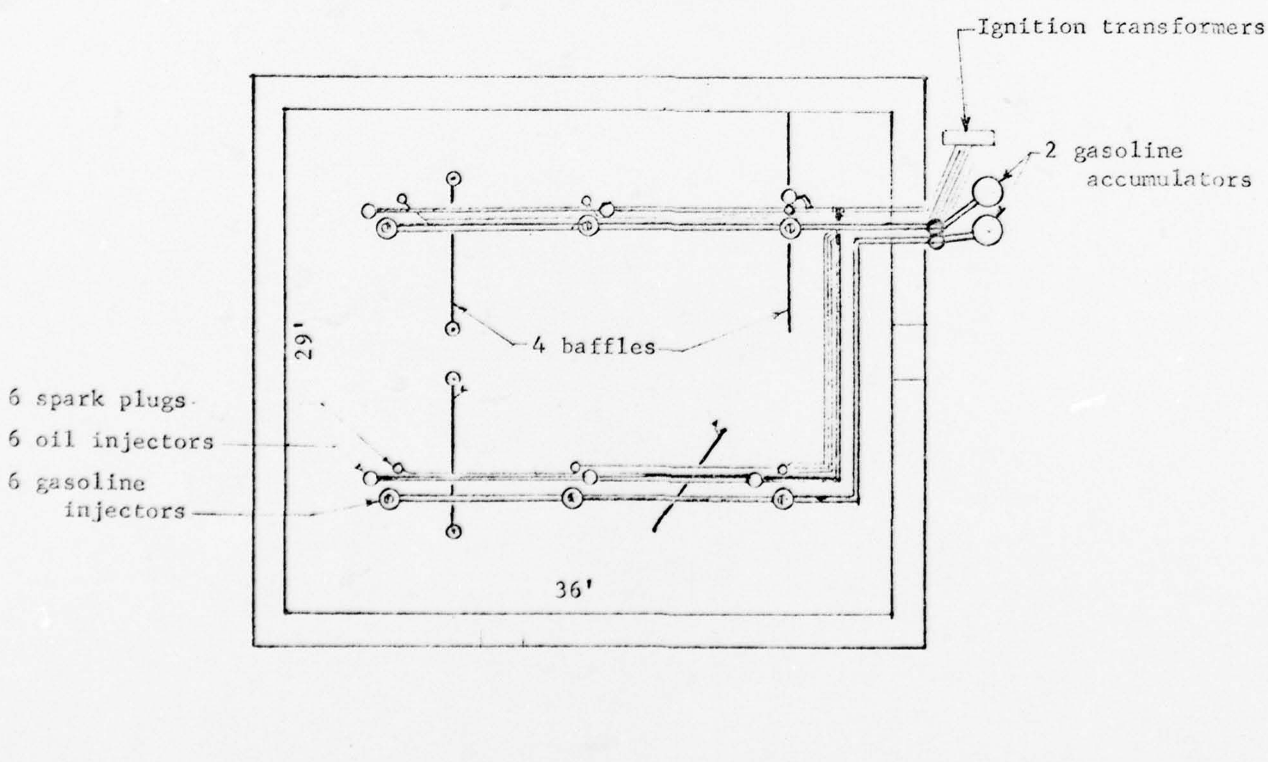


FIGURE 15. ARRANGEMENT OF THE ENGINE-ROOM SIMULATOR

Gasoline is supplied through two separate, parallel piping systems, each supplying three injectors. Each gasoline system includes a 10-gallon accumulator connected to three injectors with 2-inch pipe. Gasoline is supplied to the accumulators at 22 gpm through a 1-inch pipe, charging them each with 3 gallons of gasoline in 17 seconds. The accumulators are discharged through the gasoline injectors within one second, at a rate of 180 to 360 gpm for each parallel system, depending on accumulator pressure.

Each spark plug is wired to a separate ignition transformer with 18 gage wire insulated for 40,000 volts working voltage. Ignition wire is installed in 3/8-inch Type 304 stainless steel tubing, used as waterproof conduit. The ignition transformers are located in a waterproof junction box outside the simulator.

Piping details of the gasoline and oil systems are shown in NAVFAC Drawings Nos. 4005874, 4005875, and 4005876. Gasoline injectors, oil injectors, and spark plug holders are shown in Figures 10, 18, and 19, and in NAVSAC Drawings Nos. 4005877 and 4005878.

The Gasoline Supply System

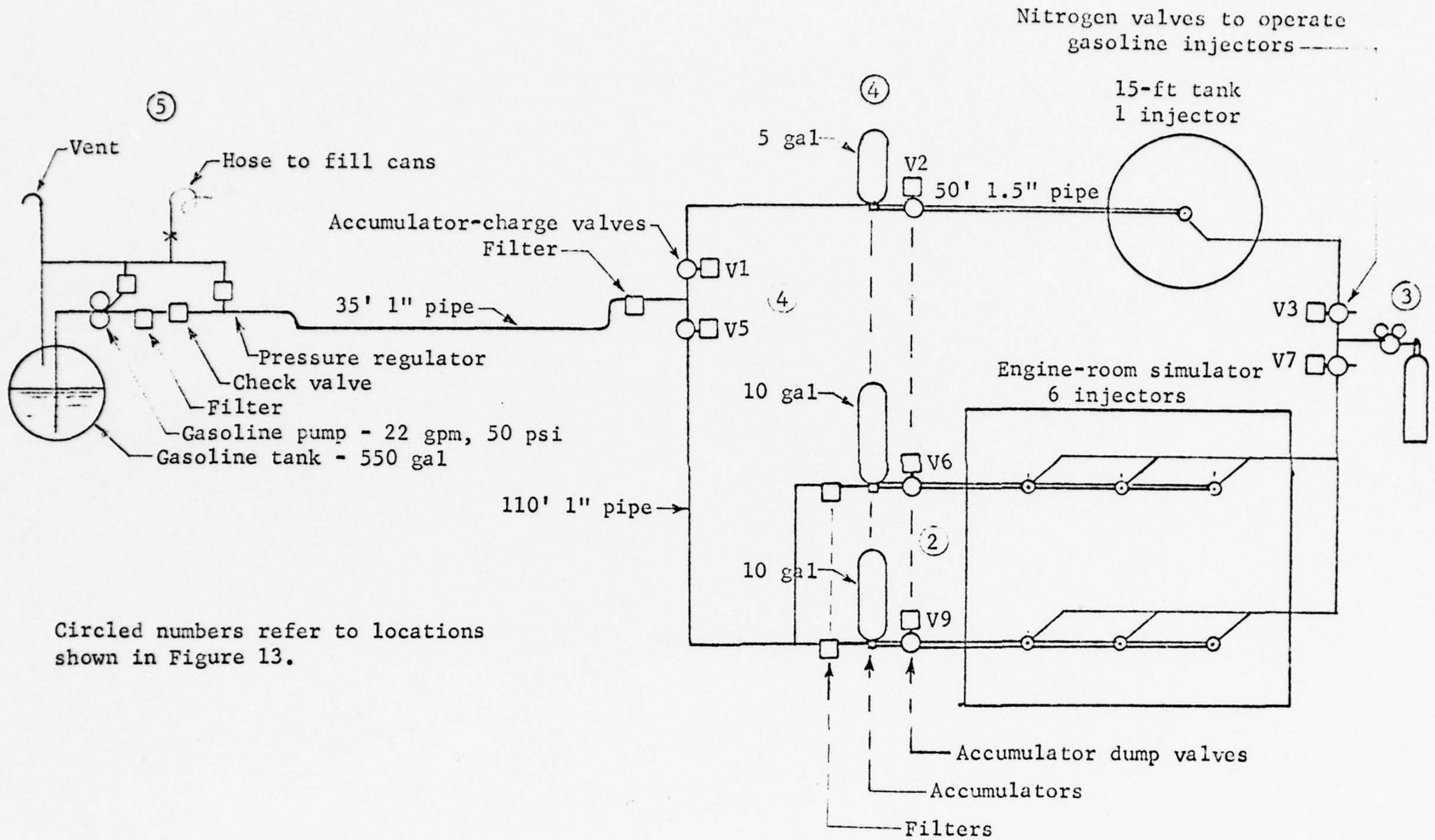
Figure 16 is a schematic of the gasoline supply system. Gasoline is taken from an existing 550-gallon underground tank at (5), Figure 13. A Viking Model HJ-195-D positive-displacement pump, mounted on the slab above the tank, delivers 22 gpm gasoline at 50 psi through a filter, a check valve, and a pressure regulating valve that bypasses gasoline back to the tank when pressure rises above the set pressure. An internal pressure relief valve built into the end of the pump is set to relieve at a somewhat higher pressure than the pressure regulator. The pressure regulator is set for the accumulator final pressure of somewhat less than 50 psi. A connection for a filling-station type gasoline hose and nozzle is provided in the pressure-regulator outlet piping for use in filling gasoline cans, as a convenience to school personnel.

From the pressure regulator, the 1-inch gasoline line goes underground for 35 feet to the water-control-valve header at (4), Figure 13, where a filter and solenoid selector valves for the 15-foot tank and the engine-room simulator are located. Gasoline for the 15-foot tank charges a single 5-gallon accumulator, also at this location. The accumulator discharges through the gasoline injector in the 15-foot tank by opening the accumulator-dump solenoid valve. The accumulator is piped to the gasoline injector by 55 feet of underground 1.5-inch pipe, to permit discharge of one gallon of gasoline within one second with an accumulator minimum pressure less than 20 psi.

Gasoline for the engine-room simulator is carried approximately 110 feet in underground 1-inch pipe to two parallel 10-gallon accumulators located at the engine-room simulator, each protected by a filter. Each accumulator is piped to three gasoline injectors with 2-inch pipe. A 1.5-inch solenoid valve is used to discharge 3 gallons of gasoline from each accumulator within one second, with minimum accumulator pressure of 20 psi or less.

As shown in Figure 10, each gasoline injector contains a poppet valve that is opened by nitrogen gas supplied at a pressure of about 25 psi, and closed by venting this gas. All of the injectors in the engine-room simulator are piped to a small 3-way solenoid valve in the field office that controls nitrogen flow for injector opening and closing. The injector in the 15-foot tank is piped to a similar valve. The injectors are opened for only a few seconds, during gasoline injection, then closed.

Details of the gasoline supply system are shown in NAVSAC Drawings Nos. 4005872 (overall layout), 4005873 (15-foot tank), 4005876 (engine-room simulator piping) and 4005877 (gasoline injector).



Circled numbers refer to locations shown in Figure 13.

FIGURE 16. SCHEMATIC OF GASOLINE SYSTEM

The Fuel-Oil System

Figure 17 is a schematic of the fuel-oil supply system. Fuel oil is taken from an existing 25,000-gallon underground tank located 200 feet from the field office. A Viking Model AL-195-D positive-displacement pump at the tank supplies 120 gpm of oil against a pressure of 80 psi. Oil passes through a check valve and a pressure regulator, which opens to return oil to the tank when oil pressure exceeds the set pressure of 80 psi. An internal pressure-relief valve is also built into the end of the pump. From the pump, the oil is piped underground through an existing 2-inch pipe to the field office, 200 feet away. In the field office the pipe connects to an existing valve manifold serving other fire simulators at the school, and to two motorized ball valves, one controlling oil flow to the 15-foot tank and one controlling flow to the engine-room simulator. An existing 1-1/4-inch underground pipe carries oil about 80 feet to the 15-foot tank, at a rate of about 70 gpm, as limited by piping pressure drop. The oil is injected through one oil injector located near the center of the 15-foot tank.

Oil for the engine-room simulator, 47 feet away, passes through a new underground 2-inch pipe. Inside the simulator this pipe branches to two legs, of 1.5-inch pipe, each supplying three oil injectors. The oil pump and 2-inch pipe size were selected to provide a flow rate of 120 gpm so that the engine-room simulator could be charged with 30 gallons of oil in about 15 seconds as part of the ignition cycle.

Figure 18 is a section of a fuel oil injector. The injector is designed for uniform radial dispersion of oil through an annular slot at a velocity of about 10 fps. The single injector for the 15-foot tank has an annular slot 3/16-inch high, and the six parallel injectors for the engine-room simulator have annular slots 1/16-inch high.

The fuel-oil pump and motor-operated selector valves are operated from the control console. Three modes of operation are provided: operation of the pump only to supply oil to other simulators through manual valves; manually controlled oil injection to either the engine-room or 15-foot tank by energizing push-button switches; or automatic, timed oil injection in which an interval timer controls operation of the motor valves and pump.

Details of the fuel-oil system are shown in NAVFAC Drawings Nos. 4005878 (overall layout), 4005873 (15-foot tank), 4005875 (engine-room simulator), and 4005878 (fuel-oil injector).

The Spark-Ignition System

The spark-ignition system is shown in NAVFAC Drawings Nos. 4005872, (overall layout), 4005874 (engine-room simulator), 4005873 (15-foot tank) and 4005878 (spark-plug holder).

In general, a spark plug is placed within one foot of each gasoline injector, with six spark plugs in the engine-room simulator and two in the 15-foot tank. Heavy-duty Champion FS-47-11 gas turbine-type igniters are used, as they proved least susceptible to shorting through immersion in oil and water and sprinkling with water spray. Each spark plug is mounted in a brass holder, sealed with an O-ring. High-voltage wire enclosed in 3/8-inch Type 304 stainless steel tubing connects each spark plug to an ignition transformer. Ignition transformers for the 15-foot tank are located at the water-valve header (4), Figure 13, and transformers for the engine-room simulator are located just outside the simulator. All transformers are enclosed in waterproof junction boxes.

Webster Electric Type 822-6A06 transformers are used throughout the systems. These are standard oil-burner ignition transformers. Each transformer operates with a primary voltage of 110 volts and a primary current that varies from 0.10 amperes with an open secondary to 1.5 amperes with an arc in the secondary. The secondary operates at 8,500 volts and 20 milliamperes, either shorted or with a normal arc, with normal short lead wires. However, as installed in the Norfolk system with long, enclosed high-voltage lead wires, primary current is increased to 2.4 amperes.

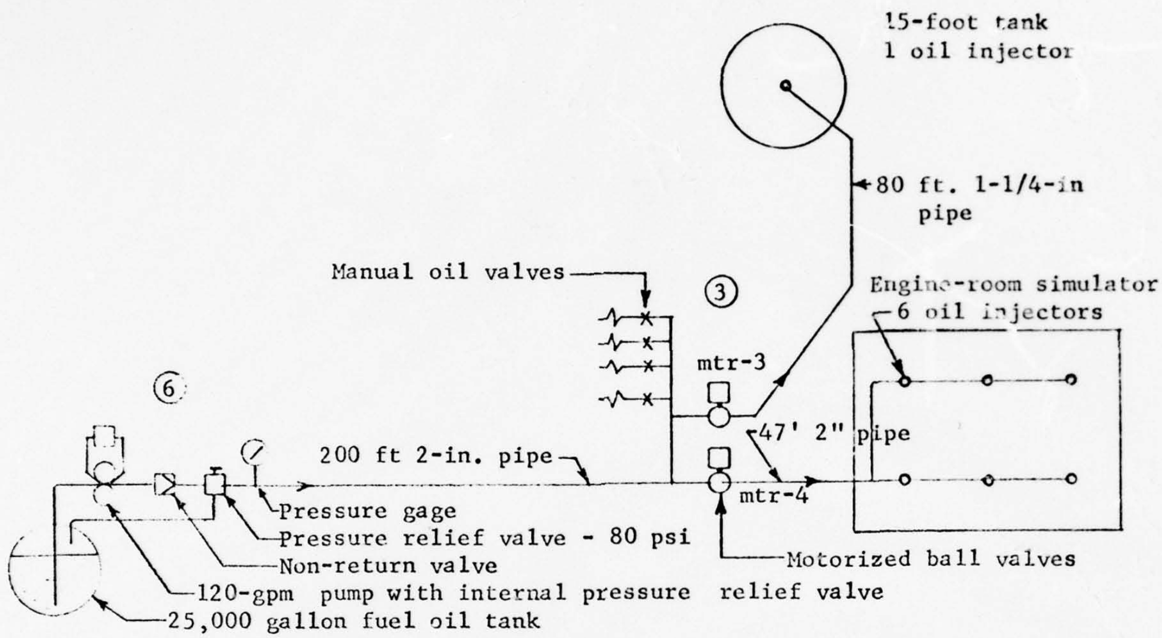


FIGURE 17. SCHEMATIC OF FUEL OIL SYSTEM

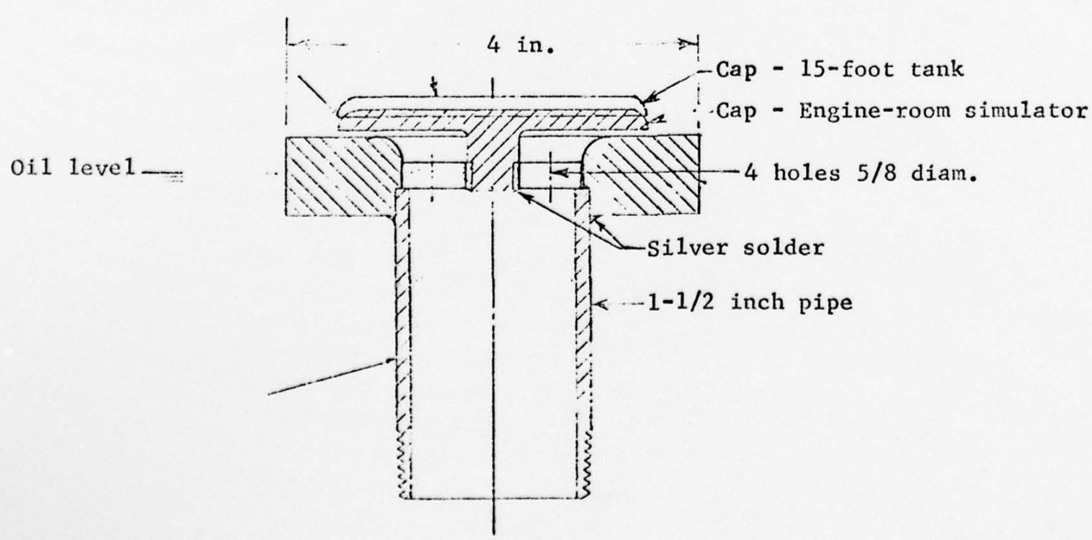


FIGURE 18. FUEL OIL INJECTOR

A 20-ampere ammeter is included in the control console to measure primary current. If all transformers are operating satisfactorily the engine-room system draws 14.5 amperes and the 15-foot tank draws 4.8 amperes. With an open circuit in the secondary of one transformer the current drops by 2.3 amperes. However, the ammeter reading is the same for a shorted spark plug as for one firing normally, so it is necessary to inspect spark plugs to assure that they are firing properly.

Figure 19 shows the spark plug mounted in the spark-plug holder. The holder utilizes standard aircraft-type contact hardware, and the spark plug is sealed in the holder with an O-ring. The holders are installed so that the water level is about 1 inch below the top of the spark plug.

The Control System

All functions of the automatic ignition system are controlled from a control console installed in the Field Office. The control console provides means for operation with automatic ignition cycles and for manual operation of each function.

Figure 20 shows the arrangement of control equipment in the Field Office. The control console is mounted in the corner of the office between windows facing the 15-foot tank and the engine-room simulator. An enclosed power contactor panel is mounted on the wall below the window opposite the 15-foot tank. This panel contains the main power disconnect switch and fuses, motor starters, and the multicam sequencing switches used to control automatic ignition cycles. A separate disconnect switch mounted above the control console controls power to the ignition transformers to assure against accidental ignition or electric shock when personnel work inside a simulator.

Drawing No. 4005880 is a wiring schematic for the control system, and No. 4005881 is a wiring diagram for the control console and the contactor panel.

Functions of Control Console Switches

Figure 21 shows the arrangement of the control console front panel. This panel is symmetrical from right to left except for the top row of switches; the left side controls operation of the 15-foot tank and the right side controls operation of the engine-room simulator. Two switches at the center of the panel provide means of operating the fuel-oil pump and the gasoline pump, as needed for supplying oil to other locations and for filling gasoline cans. A brief instruction list is also attached at the center of the panel. The top part of the panel provides switching for automatic operation, and the bottom part of the panel provides switching for manual operation.

The switches in Figure 21 are numbered to simplify the discussion that follows, but they are not numbered on the control panel.

The top row of the panel includes the EMERGENCY STOP button (1), a key switch with MANUAL and AUTO positions (2), a CONSOLE POWER switch (3), and an ammeter for checking power to ignition transformers (4).

The EMERGENCY STOP button (1) shuts off all power to the console, stopping pumps, de-energizing ignition transformers, closing solenoid valves, and stopping automatic cam timers. However, it does not close motorized ball valves used on the fuel-oil supply lines, as these require power to close.

The key switch (2) is provided so that only authorized personnel can operate the system. This switch has two positions, marked AUTO and MANUAL. When the switch is in AUTO position it is possible to operate the AUTOMATIC OIL INJECTION system, the AUTOMATIC IGNITION system, and the smoke-suppression water STOP switch. With the switch in the

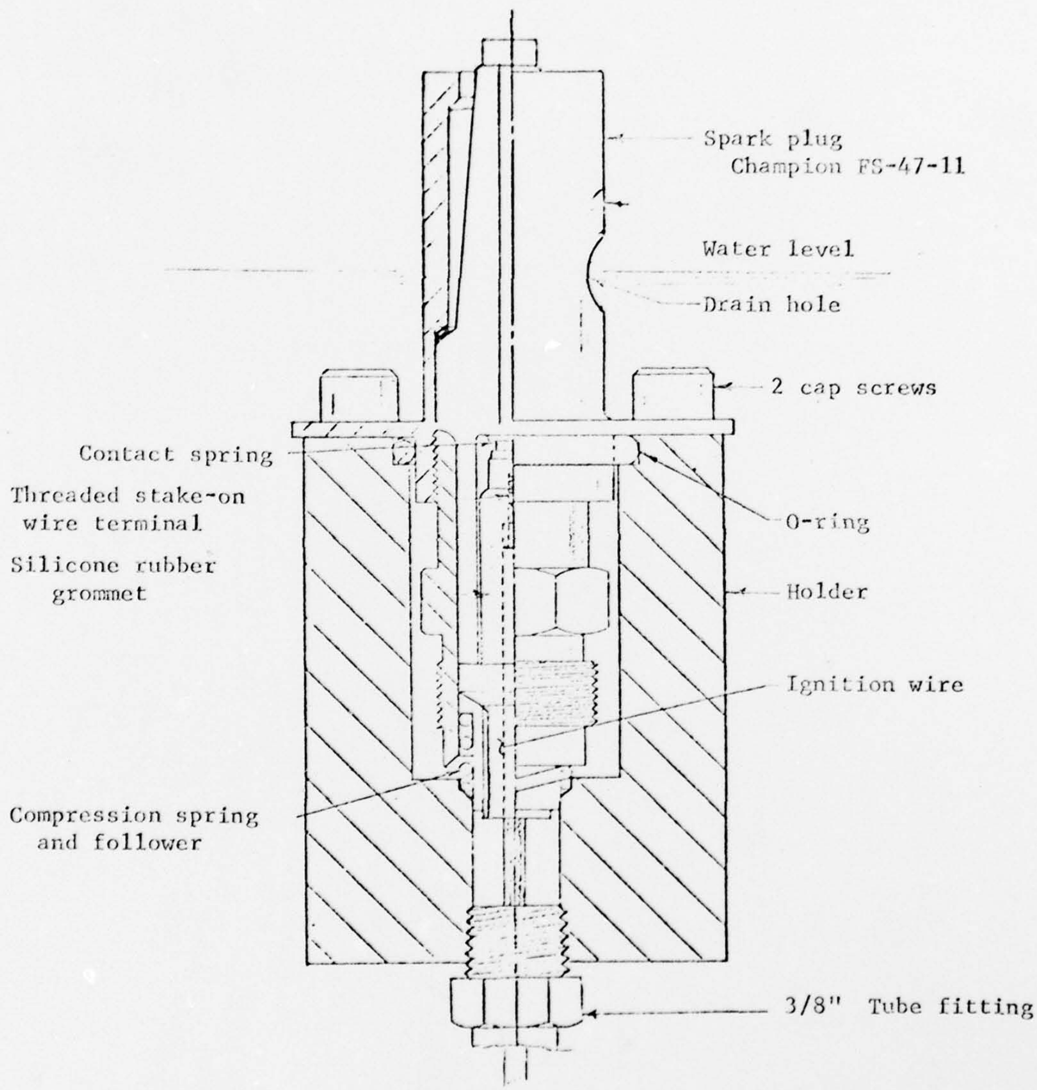


FIGURE 19. SPARK PLUG MOUNTED IN SPARK-PLUG HOLDER

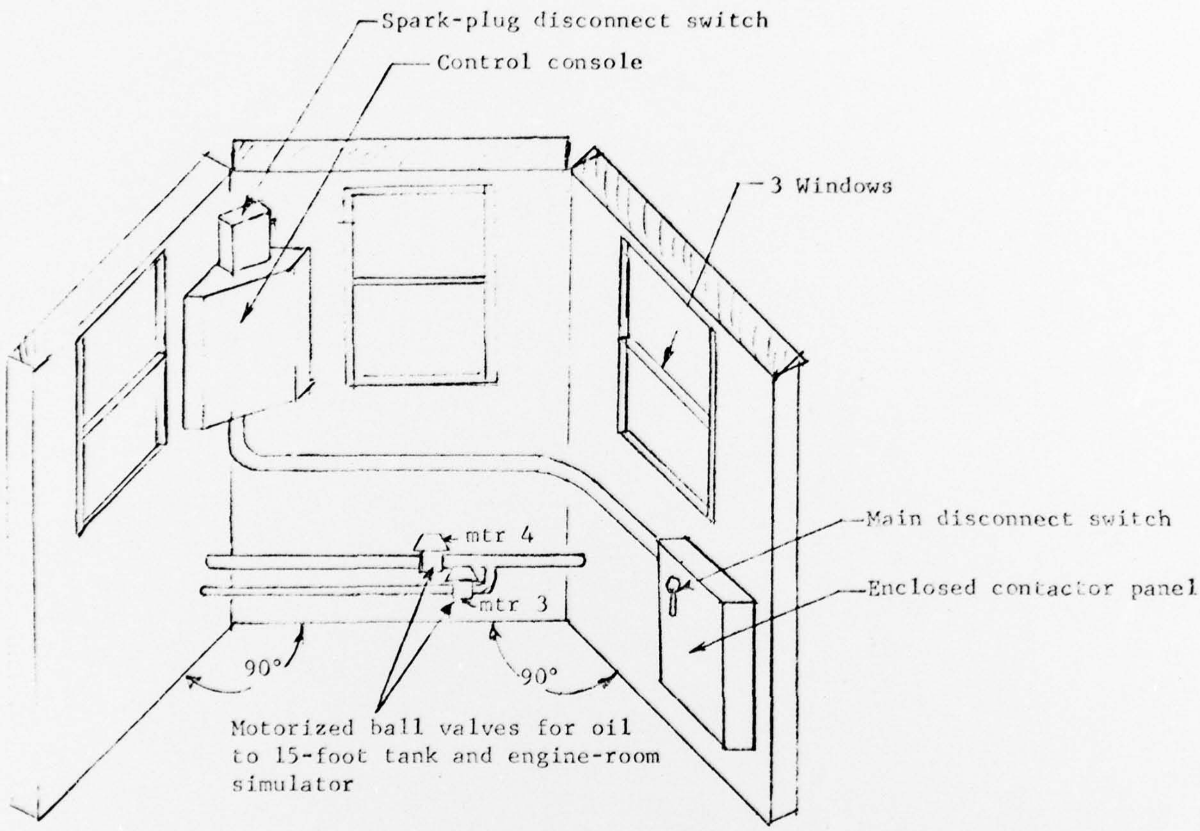


FIGURE 20. ARRANGEMENT OF CONTROLS IN FIELD OFFICE

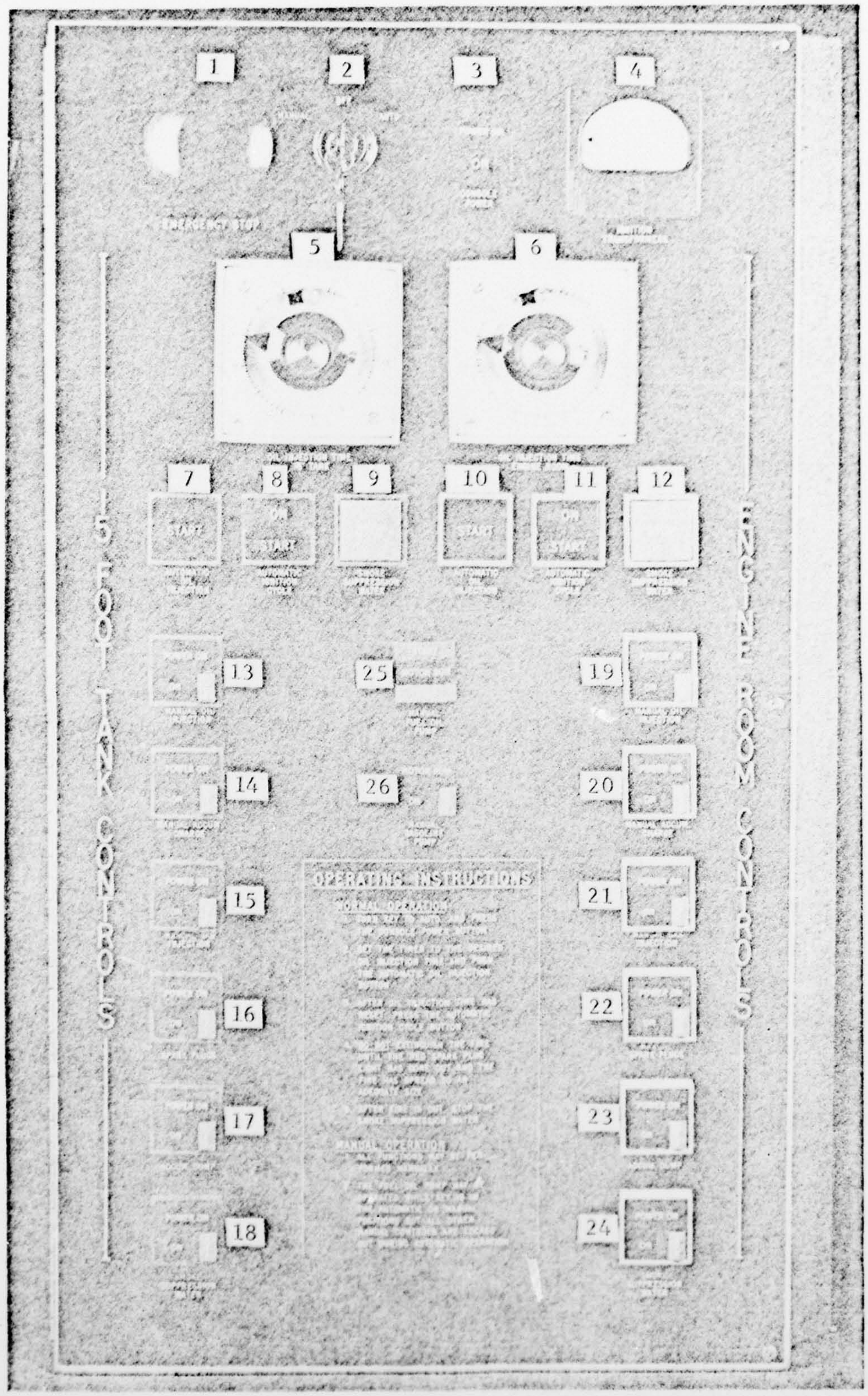


FIGURE 21. FRONT OF CONTROL CONSOLE, WITH SWITCHES IDENTIFIED BY NUMBERS

MANUAL position it is possible to operate the six manual switches on each side of the console, and the MANUAL GASOLINE PUMP switch. The MANUAL FUEL-OIL PUMP switch (25) at the center of the console can be operated with the key switch in either the AUTO or MANUAL position.

After the key switch is turned to the desired position, the console is energized by pressing the CONSOLE POWER switch (3). The red light on this switch indicates that the console is powered and ready for use.

An ammeter, marked IGNITION TRANSFORMERS, indicates the current to the ignition transformers. For normal operation the two transformers for the 15-foot tank move the ammeter needle only slightly (they require about 4.8 amperes). The engine-room simulator, with six transformers, draws 14.5 amperes for normal operation. The ammeter reading is not changed greatly when spark plugs are shorted with oil and water emulsion, so that the ammeter reading alone is not a positive indication of spark-plug malfunction. However, in case of an open circuit, the ammeter reading should fall off by 2.3 amperes for each inactive transformer. Any failure of an ignition transformer resulting in a short circuit would probably greatly increase the ammeter reading.

Two oil injection timers are located in the second row from the top, one for the 15-foot tank (5) and one for the engine-room simulator (6). These are used by setting the time for injection using the center knob on the timer, then pressing the AUTOMATIC OIL INJECTION switch. This switch energizes the fuel-oil pump and opens the motorized ball valve that supplies the simulator selected. A red pointer in the timer turns backward until it reaches zero time, when the fuel oil pump is de-energized and closing of the motorized fuel-oil valve is begun. Closing this valve requires three seconds, so that it is important not to interrupt power until the valve has had time to close. If power is interrupted, the motorized valve can be closed by setting the key switch on MANUAL and energizing the MANUAL OIL INJECTION switch (13) for about five seconds, then de-energizing it. <u>The timers should not be set for an injection period of less than 5 seconds, to assure proper valve closing.</u>

Although the fuel-oil pump has a capacity of 120 gpm (gallons per minute), the flow into the 15-foot tank is limited by piping size to 70 gpm. A 0.10-inch oil layer in the 15-foot tank requires 9.6 gallons of oil, which would be admitted in 8.2 seconds. Likewise, 64 gallons of oil are required for a 0.10-inch oil layer in the engine-room simulator, and this requires operation of the fuel-oil pump for 32 seconds. When starting up an empty simulator a 0.3-inch oil layer should be admitted. In subsequent ignition cycles much less oil will be required; this can be judged by the amount of time the fire burns and the size of the fire. A 0.1-inch oil layer will provide a large fire for about two minutes. If a fire is required for a longer period, the AUTOMATIC OIL INJECTION switch can be energized again and more fuel admitted at any time.

The third row of switches controls automatic operation of the fire simulators. The three switches on the left (7, 8, and 9) control the 15-foot tank, and the three on the right (10, 11, and 12) control the engine-room simulator. Automatic oil injection is begun by pressing the START AUTOMATIC OIL INJECTION switch (7 or 10) as discussed above. The automatic ignition cycle is begun by starting the START AUTOMATIC IGNITION CYCLE switch (8 or 11). Finally, after the fire has been extinguished, the smoke- suppressing water spray is turned off by pressing the STOP SMOKE SUPPRESSION WATER switch (9 or 12). The automatic ignition cycle is controlled by two motor-driven multiple-cam timers, one for each simulator. Each timer requires 60 seconds to carry out a complete cycle. If power is interrupted before completion of a timer cycle, the timer will continue to run when power is restored, carrying the cycle to completion.

Figure 22 shows typical automatic ignition cycles, controlled by multicam timers. The time at which each function is started and stopped can be changed readily by resetting the cams. The long periods of spark-plug operation before ignition are provided to burn oil and carbon off the spark plugs. Convenient manual cycles are also shown in Figure 22.

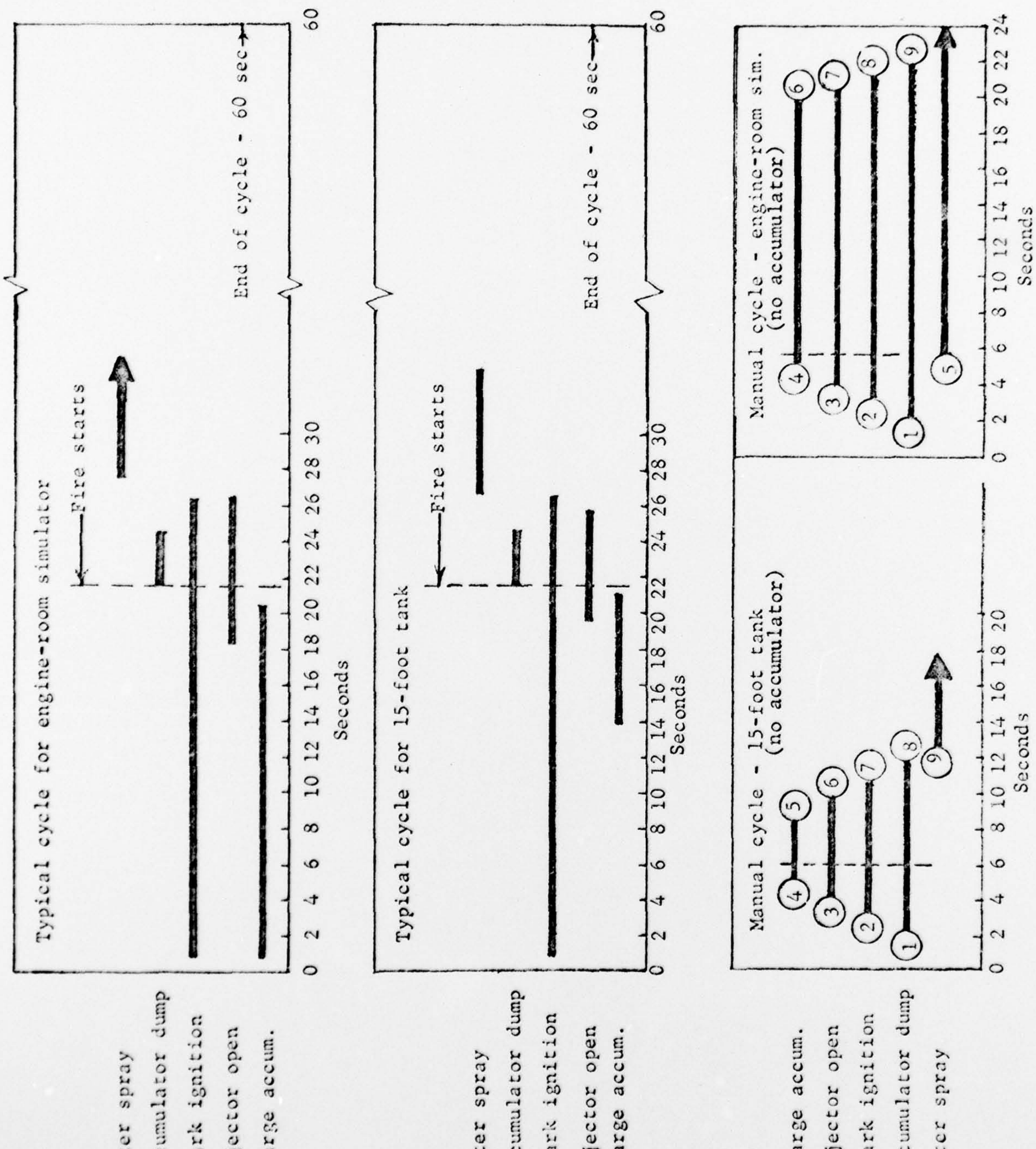


FIGURE 22. TYPICAL IGNITION CYCLES

Below the automatic-cycle switches are two vertical rows of manual switches, with switches for the 15-foot tank on the left and those for the engine-room simulator on the right. The principal purpose of these switches is to permit manual actuation of any function for checking operation. However, they can also be used to experiment with different time periods for carrying out ignition sequences, in preparation for selection of an optimum sequence for the automatic-cycle control. Normally, manual cycles similar to the two cycles shown at the top of Figure 22 would be used. However, during initial operation of the system the accumulators were inoperable, and satisfactory ignitions were obtained using the cycles shown at the bottom of Figure 22, in which the accumulators are not used.

The function of the manual switches are nearly self-explanatory, and are as follows, from top to bottom:

(13) and (19) Manual Oil Injection

This switch energizes the oil pump and opens the motorized ball valve in the fuel-oil line to the desired simulator, then closes the ball valve when the switch is turned off. It should be energized for no less than 5 seconds to assure closing of the motorized valve.

(14) and (20) Manual Accumulator Charge

This switch energizes the gasoline pump and opens a solenoid valve controlling gasoline flow to the accumulator. The gasoline fills the accumulator to the pump set pressure, after which excess gasoline is returned to the gasoline storage tank through the pressure-control valve. When the switch is turned off, the solenoid valve closes and the pump stops. The 15-foot tank accumulator is charged with 1 gal of gasoline, and the two 10-gal accumulators on the engine-room simulator are each charged with 3 gal of gasoline.

(15) and (21) Open Gas Injector

This switch opens a solenoid valve that admits compressed nitrogen into the gasoline injector, actuating a piston that raises the injector cap. This leaves an annular slot 1/4-inch high through which gasoline is injected. When the OFF switch is pressed the pressure is released through the solenoid valve and a spring closes the injector cap. The injector should be closed immediately after gasoline injection.

(16) and (22) Manual Spark Plugs

This switch energizes the spark plugs by providing power to the ignition transformers.

> CAUTION: Some of the salvaged fuel used at the Fire-Fighting School contains gasoline and can be ignited by the spark plugs. Don't energize spark plugs with such fuel unless a hose crew is available to put out the fire.

(17) and (23) Manual Accumulator Dump

This switch opens a solenoid at the outlet of the accumulator, dumping stored gasoline through the gasoline injector into the simulator.

> CAUTION: Spark plugs should be energized before injection gasoline to avoid the possibility of a gasoline-vapor explosion later.

(18) and (24) Manual Smoke-Suppression Water

This switch opens a solenoid valve in the line that supplies smoke-suppression water to the simulator. For best smoke control the water flow should be varied by manipulation of the manual water valve.

Arrangement of the Power-Contactor Panel

Figure 23 is a photograph of the inside of the enclosed power contactor panel. This panel contains the main disconnect switch and fuses for the ignition system, motor starters for the gasoline pump and the fuel-oil pump, a transformer with 220-volt primary 110-volt secondary to supply 110-volt power to switches, solenoid valves, relays and timers; and two multicam sequencing timers to control automatic ignition cycles for the 15-foot tank and the engine-room simulator. The function of each cam on each timer is identified in the photograph.

SYSTEM ADJUSTMENT AND OPERATION

Setting Accumulator Pressures

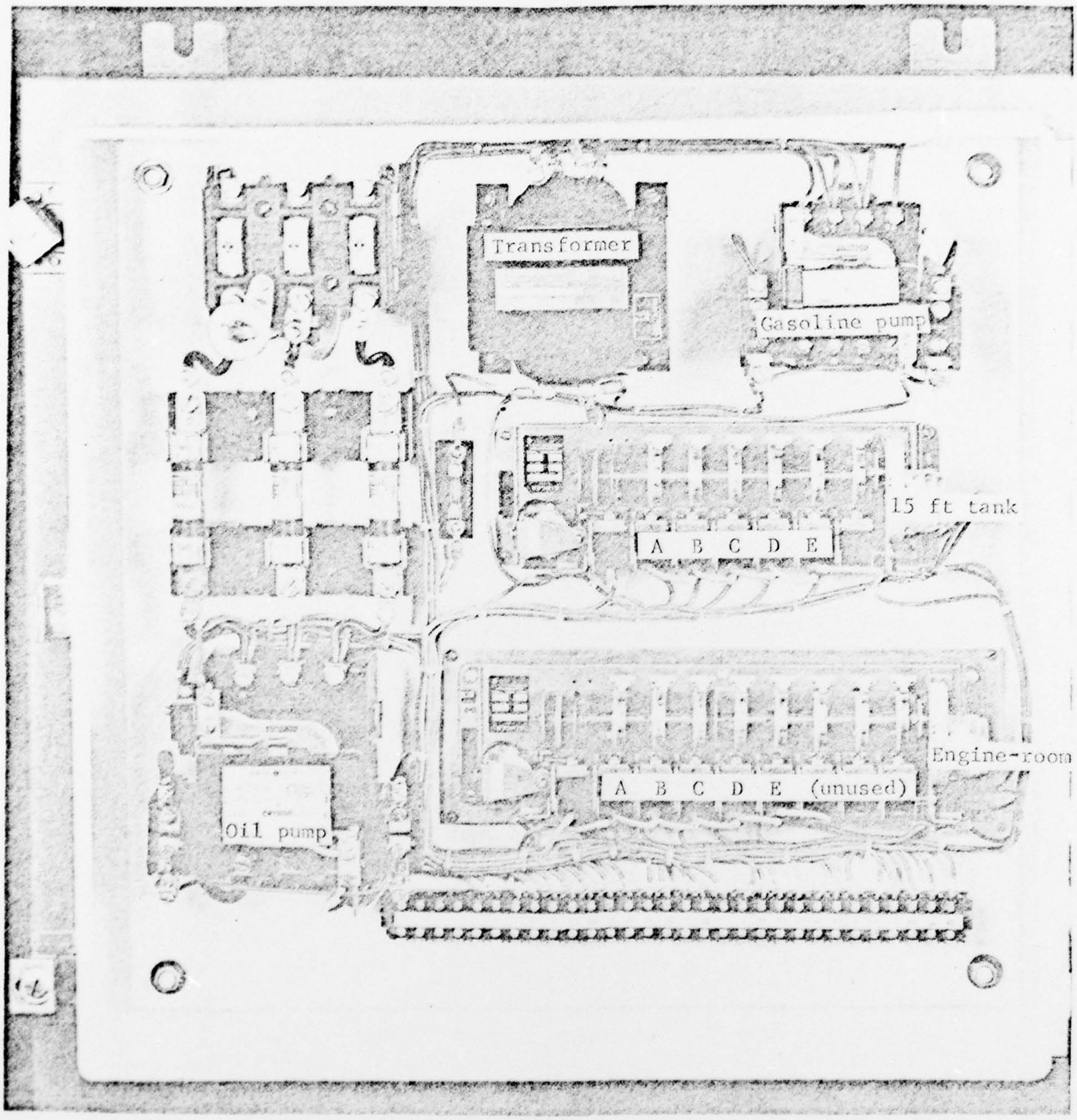
The amount of gasoline stored in an accumulator will depend upon its total capacity, its initial pressure, and its final pressure. The initial pressure is determined by charging the accumulator bladder with nitrogen with the gasoline piping vented,by opening the accumulator dump valve and the gasoline injectors. The final accumulator pressure is determined by the gasoline pumping pressure, which is adjusted by a pressure control valve at the pump. The accumulator for the 15-foot tank has a capacity of 5 gallons, and two accumulators for the engine-room simulator each have a capacity of 10 gallons. Based on Battelle experimental ignitions in a 15-foot tank, the optimum quantity of gasoline to be stored should be one gallon for the 15-foot tank and 6 gallons (3 per accumulator) for the engine-room simulator.

Figure 24 shows the relation of initial pressure, final pressure, and stored gasoline volume for the 5-gallon accumulator used with the 15-foot tank. To use Figure 24 a final pressure is selected, a line is drawn vertically upward to the desired gasoline volume, and the initial pressure is read from the left margin. Dotted lines illustrate that, with a final pressure of 45 psi, an initial pressure of 33 psi is required for storage of 1.0 gallon of gasoline.

Figure 25 shows similar curves for one of two 10-gallon accumulators for the engine room simulator, for which the optimum storage quantity is 3 gallons. As in the above example, a final gasoline pressure of 45 psi would require an initial accumulator pressure of 27 psi for storage of 3 gallons of gasoline.

The accumulator initial pressure will vary somewhat with temperature, decreasing in cold weather and increasing in hot weather. This will have the effect that slightly more gasoline will be injected in cold weather than in hot weather, which appears desireable. A change of 70 degrees in accumulator temperature will change stored gasoline volume by about 13 percent, which does not appear great enough to require compensation.

The accumulator initial pressure, once set, should not change with time, and should not require adjustment unless a change in gasoline quantity is to be made. The quantities of 1 gallon and 3 gallons per accumulator mentioned above are adequate for clean No. 2



Cam A - Accumulator charge
Cam B - Ignition spark
Cam C - Accumulator dump valve
Cam D - Injector opening valve
Cam E - Water spray valve

FIGURE 23. INSIDE VIEW OF POWER CONTACTOR PANEL SHOWING MULTICAM TIMERS

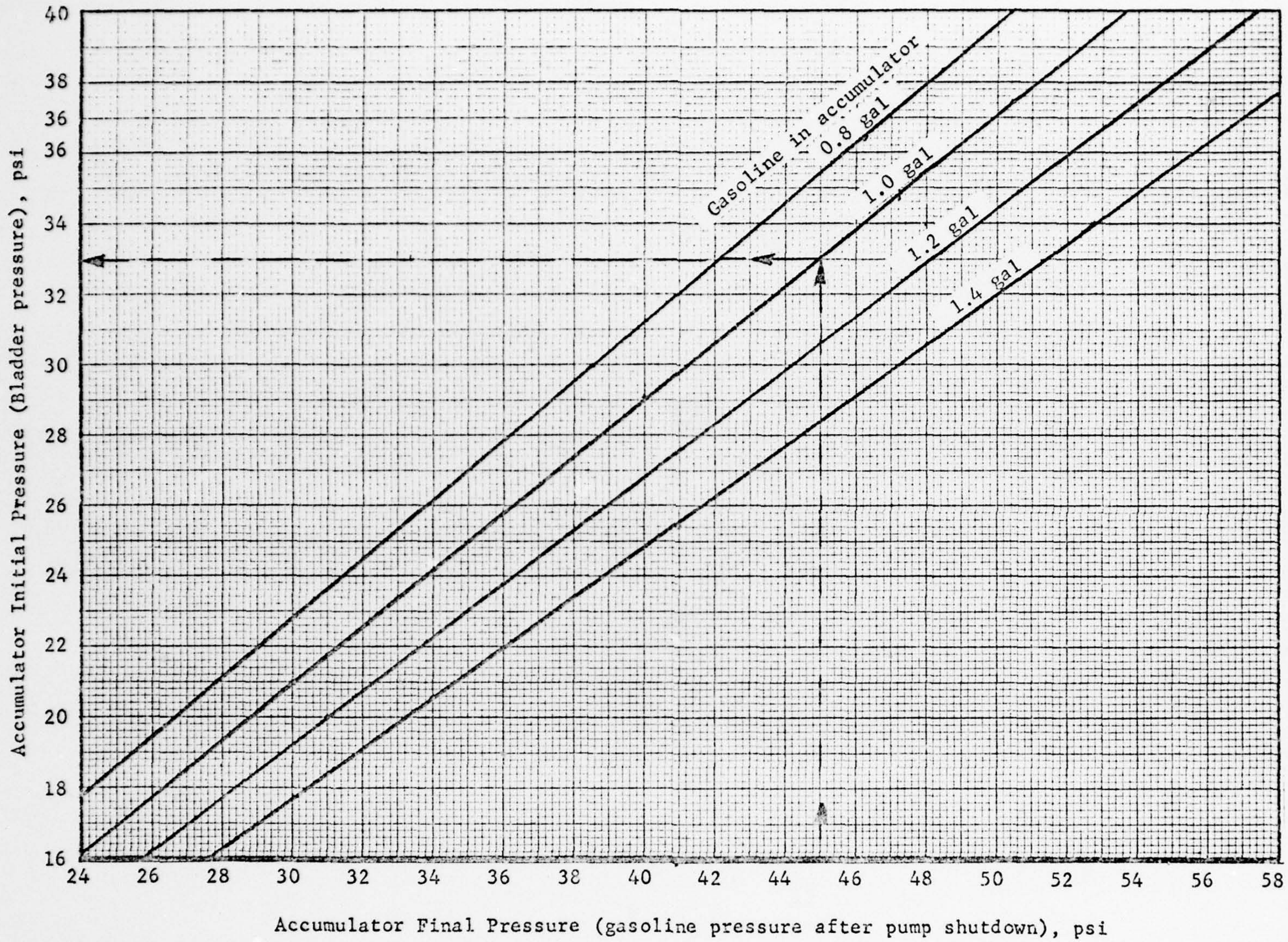


FIGURE 24. VARIATION OF GASOLINE STORAGE WITH ACCUMULATOR PRESSURES - 15-FOOT TANK

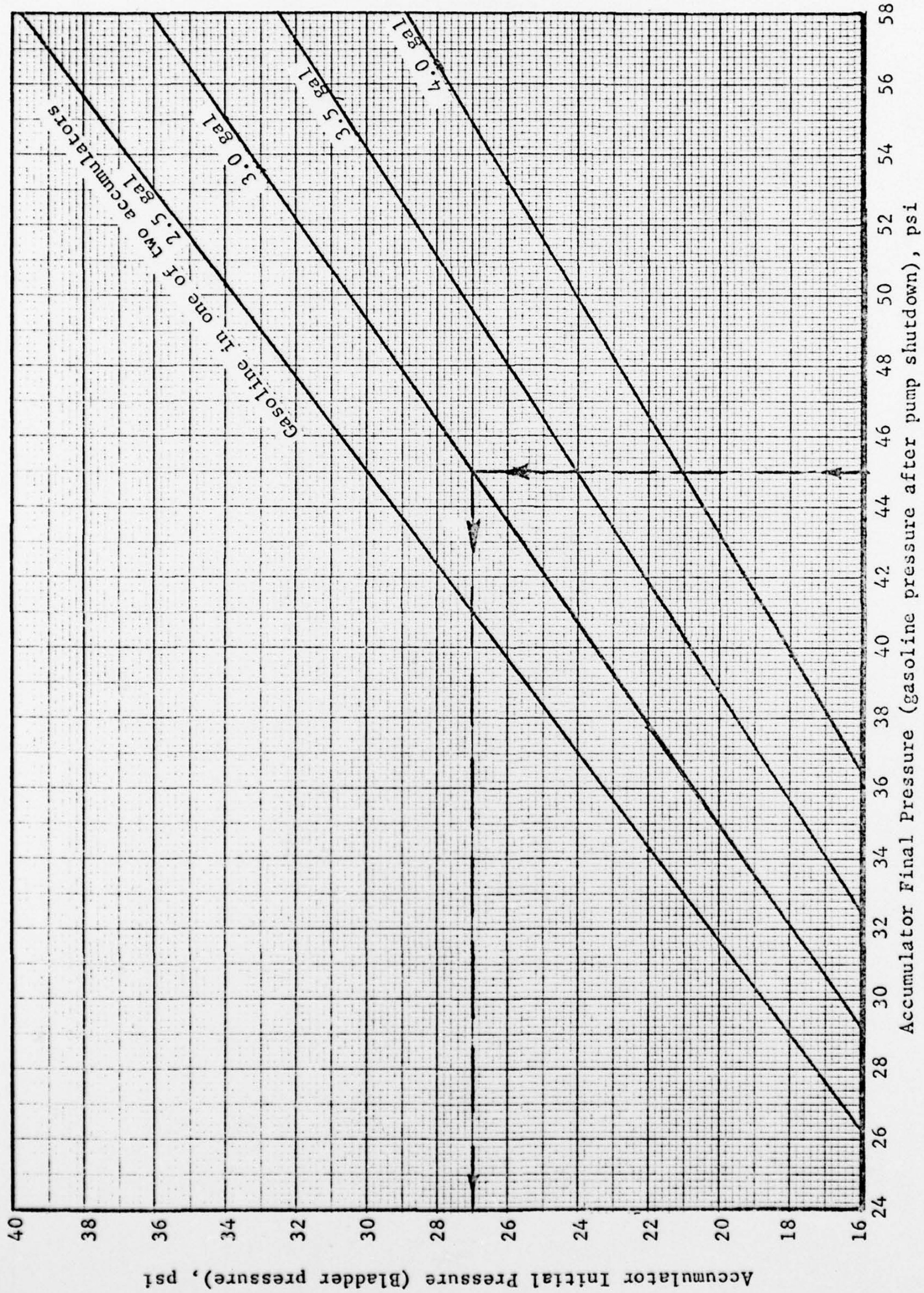


FIGURE 25. VARIATION OF GASOLINE STORAGE WITH ACCUMULATOR PRESSURES - ENGINE-ROOM SIMULATOR

diesel oil. Lighter fuels, especially those mixed with gasoline, kerosene, or JP-4, could be ignited with less gasoline but it does no harm to standardize the injected quantity at the level required for the least volatile fuel.

The accumulator bladder is inflated through a standard automotive-type tire valve at the end of the accumulator, and can be read with a tire gage. As a matter of convenience, the bladders are charged with nitrogen from the same tank used for actuating gasoline-injector pistons. However, if necessary, they could be charged with a tire pump or any other source of compressed air or nitrogen.

At the relatively low pressures at which the gasoline accumulators are used, they must be placed in an upright position to function properly.

Setting Gasoline Pumping Period

The calculated period for filling the engine-room accumuiators is 17 seconds. However, it is probable that the gasoline flow rate will taper off as the set pressure is approached because of pressure drops in the system and opening of the pressure regulator. Accordingly, the time needed to fill the accumulators should be measured. This can be done by installing a clip-on pressure gage at the nitrogen fitting on the top of one accumulator and timing the period for pressure rise to the desired value with a stop watch. The longest period measured in several successive runs should be set into the multicam timer. Excess filling time does no harm, as the gasoline pressure-relief valve at the pump opens at the set pressure and then by-passes gasoline. After a long shutdown, a few extra seconds of charging time may prove necessary on the first ignition if the pump is not primed.

Setting Multicam Cycle Timers

The automatic ignition cycle for each simulator is controlled by a multicam sequencing timer located in the Power Contactor Panel, as shown in Figure 23. The function of each cam is identified in this figure.

Each timer contains 5 active cams mounted on a shaft that is driven at 1 rpm. This shaft starts to rotate from the same position each time the timer is actuated, and returns to this position at the end of the cycle. Each of the cams actuates a microswitch below the cam by means of a roller-tipped lever that rides the cam surface. When the microswitch roller drops into the notch in the cam the circuit is energized, and when it is raised at the end of the notch the circuit is de-energized. The time at which the circuit is energized is set by rotating the cam on the shaft, where it is held by two set screws. The length of time that the microswitch is energized is set by rotating half the cam to change the length of the notch. Each cam includes a drum, numbered from 0 to 100, and a pointer, so that timing sequences can be set readily. The particular timers used in this system were obtained on short notice from stock: both have more cams than needed, and the extra cams are not used. Interchangeable gears are available for about $1.20 each that permit varying the time per revolution from 15 seconds to 120 seconds. The 60-second gear installed proved most suitable for present cycles.

Setting of the multicam timers is done most easily by first graphing the sequence of events to be followed by the timer. The baseline of the graph should be in 1/100 minutes instead of seconds, as the timer-cam drums each have 100 graduations. In setting the timers the drive gear, at the right end of the shaft, can be disengaged by loosening one screw so that the shaft turns freely. The shaft can then be rotated and cams adjusted to actuate each microswitch at the desired angles. One cam drum with its zero under the pointer at the starting cam angle should be used as a reference for setting all cams. Cam B could serve this purpose, or one of the unused cams to the right of the shaft. Cams would be adjusted with the power off, to avoid cycling of equipment.

NORFOLK INSTALLATION AND INITIAL OPERATION

Installation Experience

The ignition system was installed at the Fire Fighting School during the 2-week period from July 10 to July 21, 1972. All on-site work was completed during this period and initial ignition trials were carried out on July 21.

Preparation for installation of the ignition system at the Fire-Fighting School began in late June, 1972, with ordering of all components. A few of the components selected in designing the system were not available on short notice, and substitutions were made as needed for delivery in two to three weeks. The only components that could not be obtained in time for installation were solenoid valves with Viton fluorocarbon rubber diaphragms and seals, and accumulators with Viton bladders. Accordingly, valves with Buna-N parts were installed and the Viton parts ordered for future delivery. The life of Buna-N bladders in accumulators was expected to be more than a year, so substitute bladders were not ordered.

On-site work was reduced to the extent possible by prefabrication of parts and assemblies at Battelle under shop conditions. Gasoline distributors, oil distributors, and spark-plug holders were made and assembled before on-site work began, and the control panel and associated power-contactor panel were assembled, wired, and checked at Battelle before delivery to the site on July 17.

On-site work was begun on July 11, 1972, and completed on July 22. During this time underground piping and electrical conduit were installed and paving replaced, the gasoline pump and new oil pump were installed, and all ignition components, piping, and wiring were installed and checked.

Component Problems

During initial operation of the system several component problems were identified and corrected. Some of these were not anticipated, and these are described below for future design consideration.

Accumulator Orientation

Accumulators were installed in a horizontal orientation for convenience, and it was found that they did not discharge gasoline reliably. Although it is routine to use hydraulic-system accumulators in any position, the combination of low bladder pressure and use of only about 20 percent of accumulator volume resulted in holdup of gasoline in the accumulators. This was corrected by installing the accumulators in a vertical position. The design drawings were changed to specify vertical orientation.

Gasoline Pressure Regulator

A precision balanced-piston pressure regulator made for hydraulic systems was installed in the gasoline supply system, but it failed within two days because the hardened steel piston rusted into the cylinder. It was then found that gasoline usually contains sufficient water to rust ferritic parts, so that noncorrosive parts must be used in gasoline service.

After a very extensive search for noncorrosive hydraulic-system regulators failed to locate anything suitable, a cruder bronze pressure regulator made for gasoline service was substituted.

Gasoline-Injector Failure

The gasoline injectors were installed with a brass central shaft attached to the top cap with a 1/4-20 thread. On the first pressurization of the injectors in a closed position, with the caps exposed to pressure in the range of 60 psi, one of the shafts broke off at the 1/4-20 thread. Subsequently, with pressure regulator problems mentioned above, another injector was overpressured and another shaft broken off. Accordingly, the shaft was redesigned as a 1/2-inch diameter stainless steel shaft with a 7/16 thread at the top, and all injectors reworked. Injector construction should now be adequate for any conceivable overpressure application.

Pressure-Gage Failures

Pressure gages installed at the outlet of the gasoline pressure regulator, a few inches from the gasoline pump, failed within a short time because of pressure pulsation from the positive-displacement pump. A gage snubber alone did not solve this problem. Accordingly, the gage was installed at the top of a 6-inch length of air-filled pipe, and a 2-foot length of air-filled, 2-inch pipe was installed at the pump outlet to dampen pressure pulsations.

Spark-Plug Fouling

Considerable difficulty has been experienced with keeping spark plugs clean enough to fire on every ignition cycle. This problem had not occurred in more than 140 ignitions carried out in the Battelle 15-foot tank, and was not anticipated. Observation of fire-fighting exercises showed that when hoses are "goose-necked", or directed downward on the oil surface, large waves wash over the spark plugs, submerging them momentarily in oil and water. With repeated submergence and heating, oil retained within the spark plug body forms a thick sludge of carbonized oil and water. Eventually, this sludge does not burn off when the spark plug is energized, although there is a period of many operations when energizing the plugs for 10 to 20 seconds will burn off sludge and provide a good spark. The sludge shorts the spark gap by coating the insulator for the center, high-voltage electrode with a conductive coating. Energizing the spark plug releases energy into the shorting sludge at a rate of 250 watts, which will often heat it quickly and dry the insulator sufficiently to permit proper firing of the spark plug.

Two plugs of an alternate design were evaluated at Norfolk and Battelle, but proved no better. In these, the external tubular body surrounding the central electrode was removed and replaced by two electrodes extending from the base to the top of the center electrode. These plugs were fouled by soot that deposited on the surface of the central insulator during normal burning, rather than by sludge trapped within the tubular body, but the net result was no better than for the original plug.

In an attempt to ease the spark-plug problem the automatic ignition cycles were modified to energize spark plugs for 20 seconds before gasoline injection, to burn off fouled plugs to the extent possible.

A satisfactory solution to the spark-plug fouling problem has not yet been demonstrated. Two possible approaches are: (1) a retractible spark plug that is not exposed to fouling conditions, and (2) a convenient water-jet cleaning device that can be manually held over each plug for a thorough cleaning each day with minimum effort.

Ignition-System Performance

The automatic ignition system has been used on a routine basis since August 4, 1972. At this date, six weeks later, the system is still operating without any problems except that of spark-plug fouling. It is generally liked by the several field chiefs who operate the system and has presented no problems that they cannot cope with.

The automatic cycles as now set, shown in Figure 22 provide nearly smokeless ignition if pressure to the smoke-suppression water spray system is manually controlled to optimize flame growth. The water pressure on ignition of the 15-foot tank should be about 60 psi, which permits rapid growth of a large oil fire. As the fire grows, smoke gradually becomes denser, and more water pressure is required to suppress it. However, excessive water flow will arrest flame growth or put out the fire, and constant, very careful water-pressure adjustment is needed to provide both good flame development and smoke of about No. 1 Ringleman. If the water pressure is set for about 80 psi and ignored, the flame will grow, but light smoke will form and gradually grow heavier as the flame grows large. However, this smoke is not comparable to that produced without water spray.

When the ignition cycle is started with full water pressure of 120 psi, the fire usually is pushed into four pockets around the edge of the tank by the water spray and burns there, but never grows to cover the entire oil surface. Although the usual technique is used to extinguish these fires the effect is not the same as that of a large, hot fire.

On two occasions the fire was allowed to grow for several minutes before it was extinguished. A very large fire, without smoke, resulted. However, the fire was so hot, and the oil surface so hot, that it could not be extinguished by the usual technique using two hoses: additional hoses set up for the engine-room simulator were needed. These incidents demonstrate that almost any degree of difficulty of fire extinction is possible with smokeless combustion, with the proper burning technique.

REFERENCE

(1) "Development of Spray-Water Smoke Abatement Systems", Alexander Goldsmith, IIT Research Institute. Tech Report NAVTRADEVCEN 71-C-0083-4, April, 1972.

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Design of the Norfolk systems was carried out by Don W. Caudy, William Dick, and Paul Tack. The electrical system and control console were designed by Robert W. Mowery and constructed by Woodrow Bates and Ronald Brubaker. Installation of the systems at Norfolk was carried out by Don Caudy, Robert Poling, Paul Tack, and Ronald Brubaker within a very short time under difficult working conditions.

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13. ABSTRACT

An automatic, smokeless ignition system for use in ship-space simulators for U. S. Navy fire-fighting schools was developed and two prototype systems were installed at the Norfolk Fleet Training Center. In principle, a measured amount of gasoline is injected over the surface of fuel oil and lighted with an electric spark while smoke-suppressing water is sprayed into the fire. In six weeks of operation the system has provided smokeless ignitions on a routine basis. One unsolved problem is fouling of spark plugs with oil sludge.

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