Vapor Phase (Ebullient) Cooling of Internal Combustion Engines

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HISTORY

For years engineers have known the value of elevated temperature cooling of internal combustion engines. As far back as 1916, Muir, Rushmore, Harrison, and others applied cooling systems to automobile engines which they called "controlled temperature," "steam cooling," and "evaporative cooling." While tests included operating at various controlled pressures to raise or lower the boiling point of the coolant, the control utilizing the natural law of boiling was found to be the most suitable.

All of these early writers appear to agree on the following benefits of boiling-condensing cooling systems:

1. Uniform coolant temperature
2. Faster warm up
3. Increased mechanical efficiency resulting in greater mileage per gallon
4. Reduced oil sludge
5. Greatly reduced cylinder wear

Since the benefits of elevated temperature cooling were proved years ago and are understood by engineers today, why has the industry been so reluctant to adopt some of these old methods? In my opinion, the reason that these steam and evaporative cooling systems were not generally used was that mechanical troubles developed in the steam separators and water pumps and that the space under the engine hood was restricted. Fortunately, the writer's company selected stationary and marine engines for its cooling system and thus, in the early years of our experiments, avoided the mechanical problems inherent at that time with automobiles.

Since the invention of VAPOR PHASE by our engineers in 1939, we have applied the system to nearly all types, makes, and sizes of internal combustion engines. While the results in general have been very good, we have had to solve many mechanical problems. The field of cooling is so varied, because of many different types of engines and their wide range of service, that we are constantly confronted with new problems. However, I believe that the system, when properly engineered and applied, has few limitations, particularly in cooling the modern engines of the stationary, marine, and automotive type.

THE VAPOR PHASE CYCLE

I believe most engine builders and operators are familiar with our system; however, I wish to point out by drawings the modern aspects of the VAPOR PHASE system as built by our company today. In Fig. 1 two circuits are employed. In the primary circuit water flows through the engine and

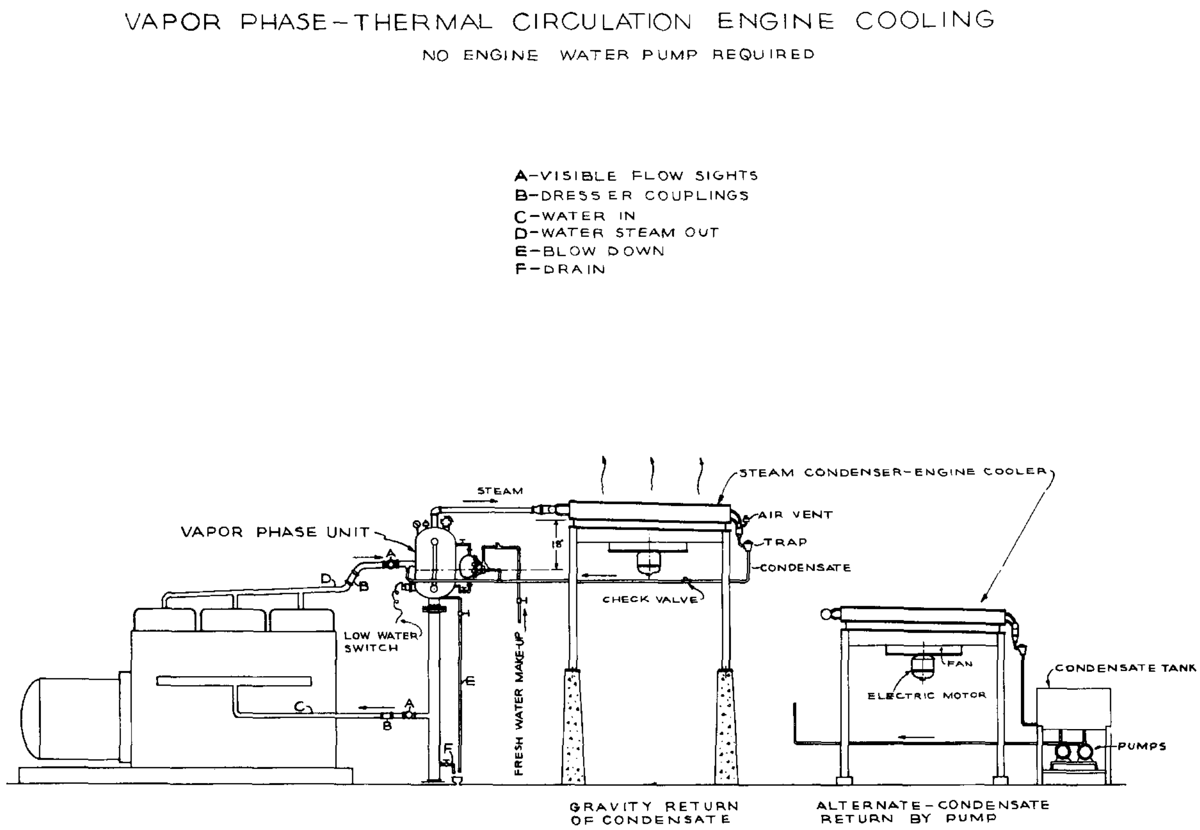

Fig. 1 Vapor Phase Cycle

VAPOR PHASE unit. The steam-water mixture enters the VAPOR PHASE unit tangentially and swirls around inside the vessel. By centrifugal force all solids, such as dirt and scale, are thrown down into the mud drum, where they are trapped for blowdown. The mud drum is very important because even new engines contain some rust from factory test runs and old engines usually contain considerable rust and scale, all of which are eventually cleaned out of the jackets by the boiling action, trapping, and blowdown. In the cylindrical VAPOR PHASE unit, the steam is separated from the boiling water by baffles built into the upper part of tne vessel. This type of unit is compact and relatively small in size per horsepower and requires the minimum of space for installation.

In the secondary circuit, steam passes to the condenser or heating process, which will be described later, and condensate flows back to the primary circuit.

EBULLIENT COOLING

Many people believe that ebullient cooling, so-called, is an entirely different system from VAPOR PHASE. This belief is incorrect. In fact, our engineers developed and perfected the system illustrated in Fig. 2 in 1940. We call it thermal circulation because circulation through the engine

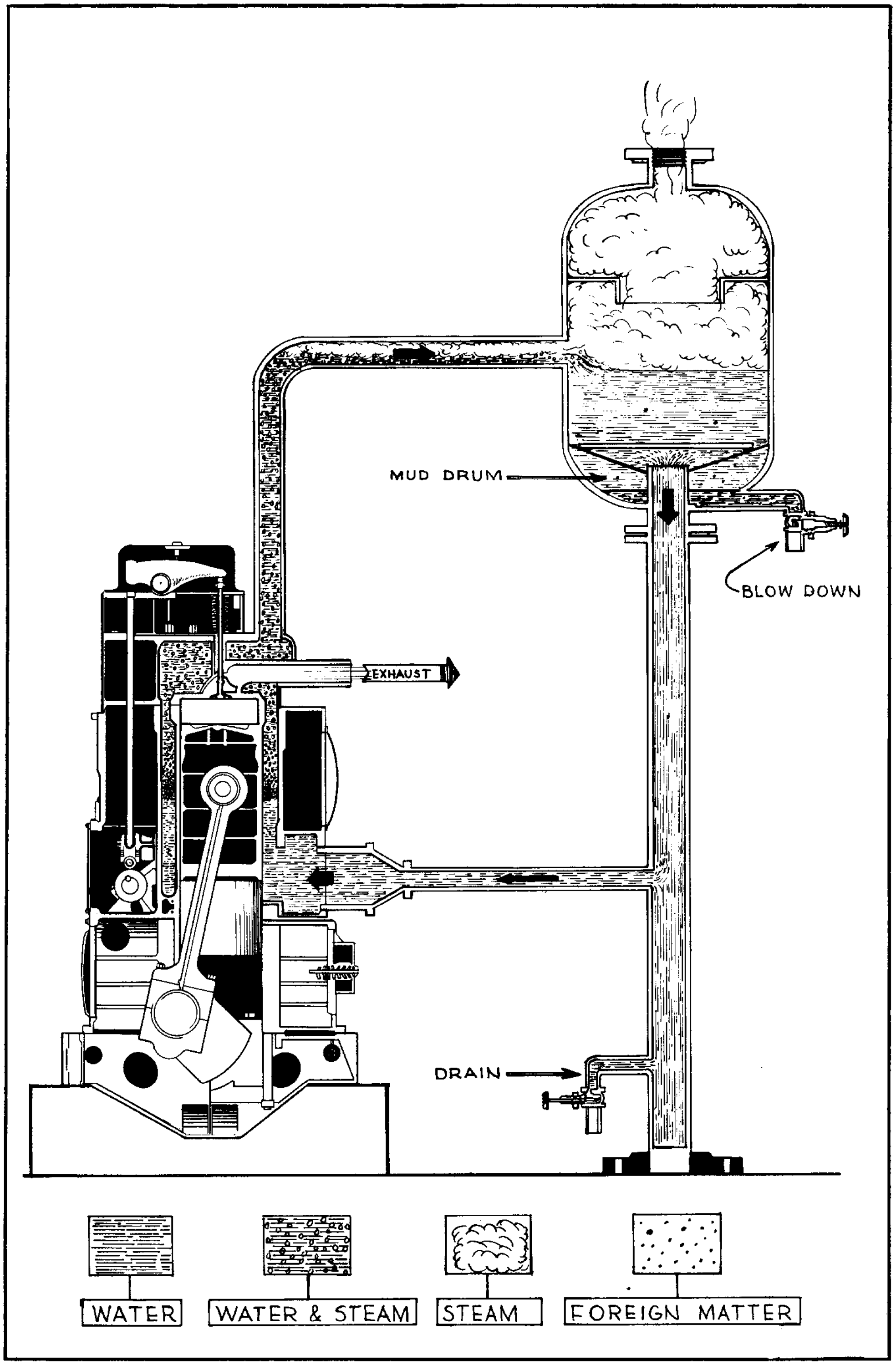

Fig. 2 Vapor Phase Thermal Circulation Cutway

is accomplished by natural flow solely by thermal energy. Fig. 3 shows one of several thousand thermal circulation systems built by our company during World War II for the United States Armed Services.

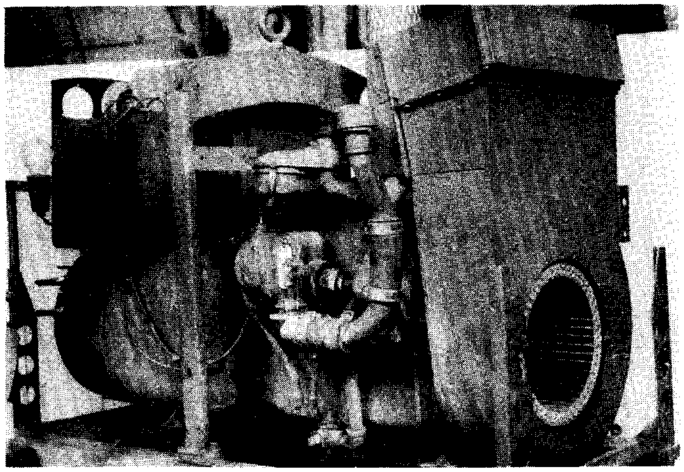

Fig. 3 Vapor Phase Thermal Circulation Military Engine

Thermal circulation, Fig. 2, is true VAPOR PHASE because the boiling action washes the hot metal walls of the engine jackets, preventing laminar flow and film formation, and thus removing the heat at a more rapid rate. The word ebullition is a fancy word for boiling and is defined by Webster, in part, as "State of boiling or bubbling up; hence, agitation or excitement; also sudden burst or violent display."

Sizing and arranging of the piping are critical, as are also the water jackets of the engine. Removing the water pump without taking into account all things that affect natural flow may result in engine damage, excessive carbon formation, and even piston seizure.

Most modern engines are so constructed as to provide a gradual upward flow of the coolant, and these require only minor changes to the engine water jumpers, the water outlets, and the piping. Older engines usually require considerable alteration, and cooling without a pump should not be attempted until all factors have been carefully analyzed and provision has been made for ample passage of the water-steam mixture through the upper part of the jackets and the outlet piping.

For some of the older engines or engines having restrictions in their water jackets, we definitely recommend the use of circulating water pumps. When forced circulation is employed, water is pumped through the engine where the heat is absorbed, mainly as sensible heat. As this stream enters the VAPOR PHASE unit some of it flashes to steam. The actual cooling of the engine takes place in the steam phase regardless of the method of circulation.

In order to utilize thermal energy to circulate the coolant, the entire system must be free of restrictions in order to prevent reverse flow. When properly engineered the VAPOR PHASE thermal circulation system will be designed to permit the proper velocities and pressure drops through all jacket openings and outlet piping. In a well designed thermal circulation system formation of steam pockets is impossible.

The hot water enters the engine and starts to boil about midway of the piston stroke. This hot water in the down leg, being heavier than the water steam mixture in the up leg, is constantly urging the water-steam mixture upward, where violent boiling of the coolant reaches its maximum turbulence in the upper part of the cylinder and in the heads.

The system has many advantages, prime of which is the fact that it creates a natural turbulence that cannot be accomplished by forced or pump circulation. In a thermal circulation system only a small part of the heat being rejected is removed as sensible heat, as is done in a conventional system. By permitting the water to boil in the engine jackets, most of the heat is removed in the latent form, thus requiring much less gallons per minute of circulating water. Another very important advantage caused by boiling is that the very even metal temperature permits greater engine overload capacity. Also, where the VAPOR PHASE unit, its mounting pedestal, and the water inlet line are all insulated to reduce radiation losses, temperature differences across the engine are in the order of 2 F in large engines and as low as 1 F in small engines. Another valuable feature of the thermal circulation system is the heating of idle engines. When two or more VAPOR PHASE units are properly manifolded together in the steam and water equalizing lines, the idle engine or engines are automatically maintained at substantially the same temperature as that of the operating engines, thus permitting quick start and application of full engine load almost immediately, as seen in Fig. 4.

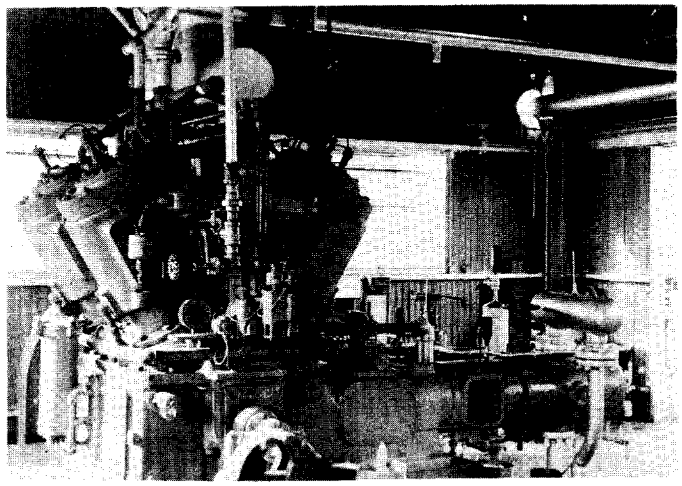

Fig. 4 A 150-hp Gas Engine

This gas engine-compressor, rated 150 bhp, was fitted with clear pyrex ports and tubes. While the machine was operating at 117% load, the circulation was observed and photographed. Two of the ports can be seen on the side of the right hand power cylinder. Also, the clear tube in the water-steam-mixture outlet line can be seen at the top of the picture.

The picture in Fig. 5, taken close up, shows the two ports in the power cylinder. The lower port, positioned at the bottom of the piston stroke, shows solid water, while the top port, positioned near the top of the piston stroke, shows active ebullition.

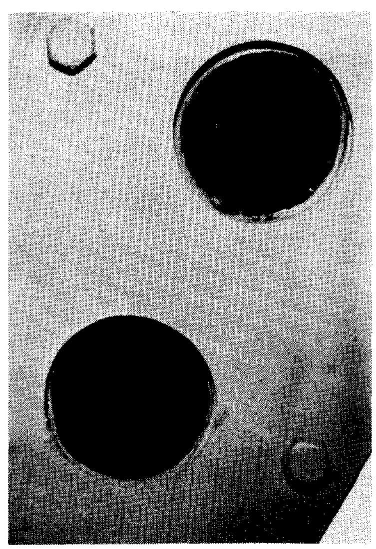

Fig. 5 Visible Ports and Cylinders of a 150-hp Gas Engine

The view in Fig. 6, taken in the wet exhaust manifold below the cylinder heads, shows violent turbulence.

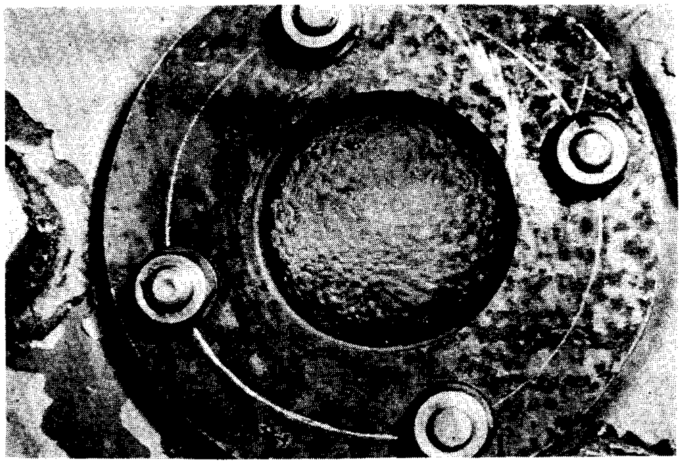

Fig. 6 Visible Ports and Exhause Manifold of a 150-hp Gas Engine

The two ports seen in Fig. 7, positioned in the lower part of the cylinder head, show the water-steam mixture at the hottest part of the engine jackets, with the water at the bottom and the steam on the top.

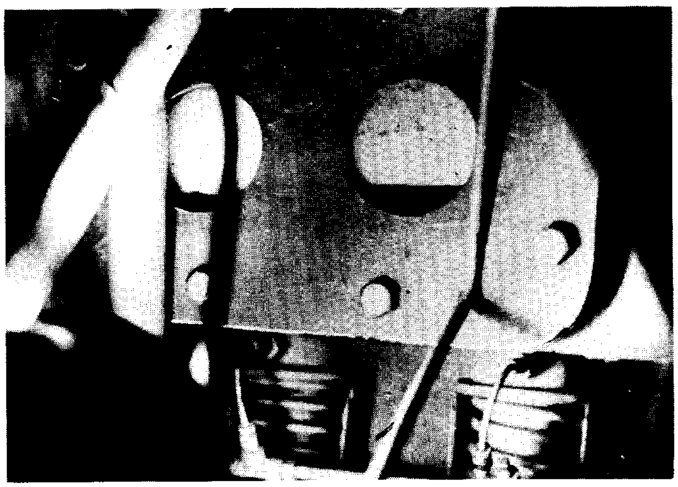

Fig. 7 Visible Ports in the Lower Cylinder Head

In Fig. 8, the four ports in the top of the heads appear to show only steam; however, at 117% load each pound of steam carries along 14 pounds of water.

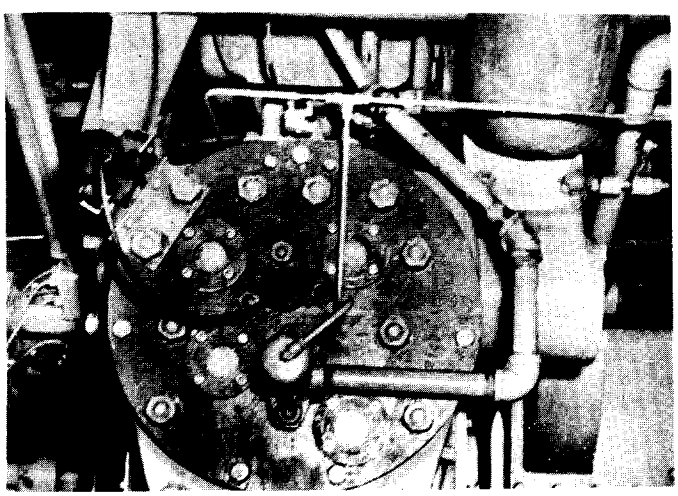

Fig. 8 Visible Ports in the Top Cylinder Head

At the top of the picture in Fig. 9, in front of the exhaust stack, is the outlet water-steam-mixture line, with the water below the steam on top. This figure illustrates the necessity of having ample sized water jackets and outlet lines to carry away the steam, which requires greater space than water because of its greater volume.

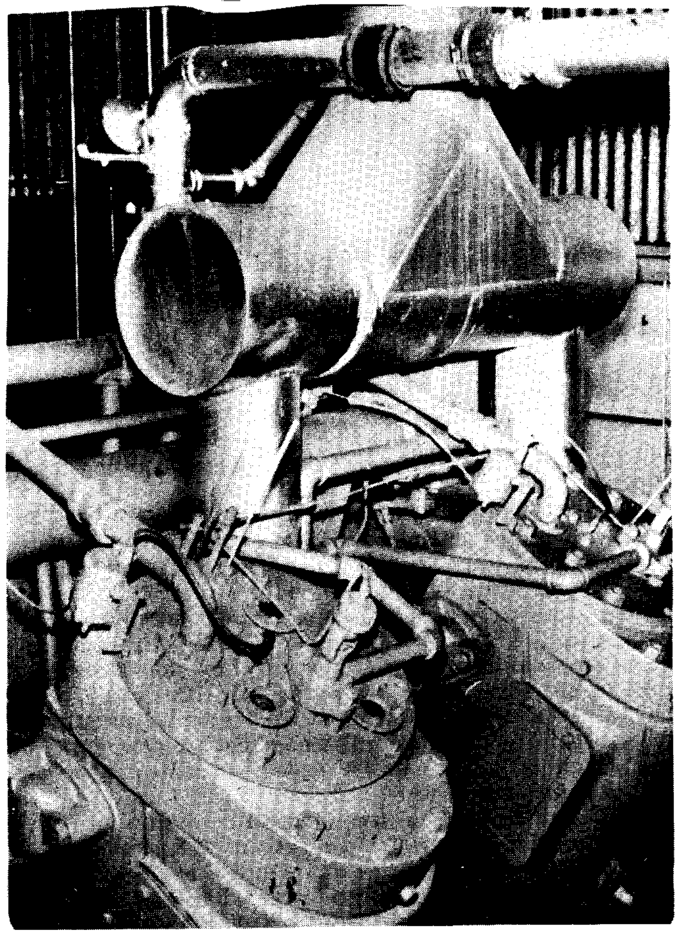

Fig. 9 Visible Tube-outlet Pipe

WASTE HEAT

In a VAPOR PHASE system, engine heat, usually wasted, is recovered in its most usable form -- low pressure steam. We have many systems using single engines as small as 10 bhp to multiple engine plants as large as 17,000 bhp where the VAPOR PHASE steam is used for heating water, space, fuel oil and viscous fluids, for distilling water, and for operating the absorption type of refrigeration units for air conditioning.

As illustrated in Fig. 10, we put the steam to work operating a steam turbine for driving cooling-air fans. When so used, the turbine removes the parasitic fan load from the engine, replacing electric motors and mechanical fan drives and thus effecting considerable dollar savings.

The turbine is an ideal fan drive because it varies in speed with engine load and ambient air temperature. It is governed automatically by a temperature switch in the condensate tank that by-passes steam around the turbine to the engine cooler in cold weather. This procedure reduces pressure and turbine speed in winter and directs more steam to the turbine in summer, when the greatest quantity of cooling air is required.

Another function of the engine cooler is to make the cooler act as a standby to a steam heating process. A steam line to the heaters is taken off up stream from the turbine inlet.

VAPOR PHASE THERMAL CIRCULATION ENGINE COOLING
WITH
STEAM TURBINE DRIVEN FAN CONDENSER
FOR
GENERAL MOTORS

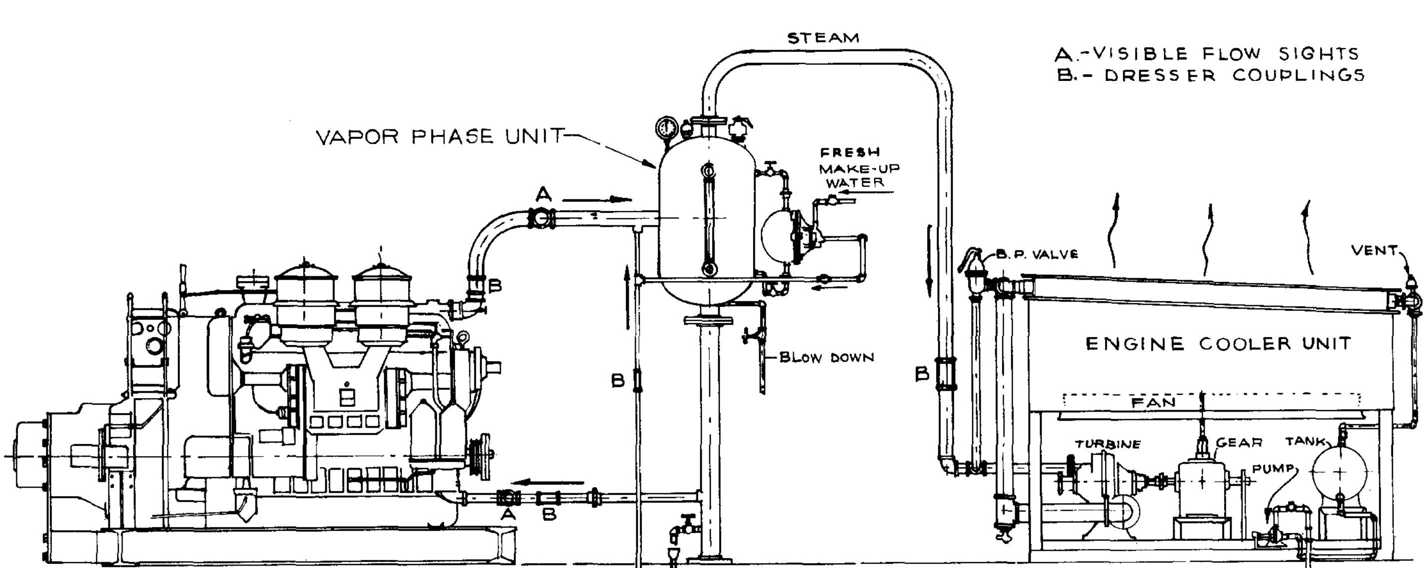

Fig. 10 Turbine-fan Engine-cooler and Engine

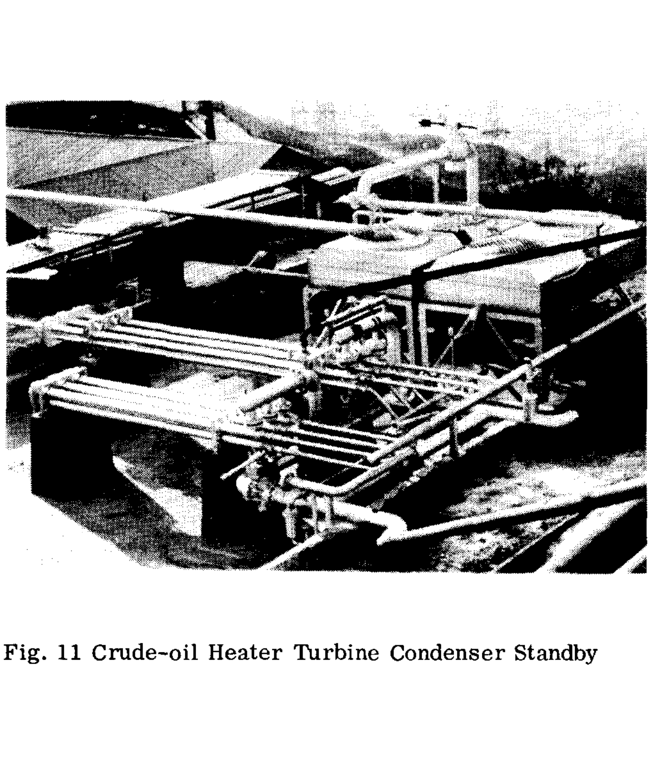

Fig. 11 Crude-oil Heater Turbine Condenser Standby

By adding a steam back pressure valve at the turbine inlet, all, or part, of the steam, produced may be used in the process. When there is an excess of steam the back pressure valve will open, starting the turbine. When the heating process is again using all of the steam, the valve will close, automatically stopping the turbine.

In the oil industry the VAPOR PHASE steam is used for many purposes. Illustrated in Fig. 11 is a crude oil-salt water-mixture treating process. In this gas engine compressor plant engines of 1650 bhp produce 5000 pounds of steam per hour at 20 psig pressure, from one of our central-type VAPOR PHASE thermal circulation systems. The concentric-tube heat exchangers in the foregound cool the engines at 260 F and transfer the heat to the crude oil-salt water-mixture, separating the water from the oil. The steam produced is equal to 145 steam boiler horsepower and replaces an equal amount of gas-fired boilers, formerly used for this process.

When an excess of steam occurs, causing pressure build up to 22 psig, the back pressure valve at the top of the picture opens and the excess steam passes to the turbine-fan aerial condensers, resulting in a completely closed engine cooling-waste heat recovery system, requiring no make-up except the replacement of distilled water drain off for use or piping leaks. Some steam, in this installation, is used to heat shower water and the workmen's change room.

Multiple steam turbine units were used, in this case, because engines have been added from year to year, requiring additional units. In our large coolers only one turbine unit would have been used to condense all excess steam, if all engines had been installed at one time.

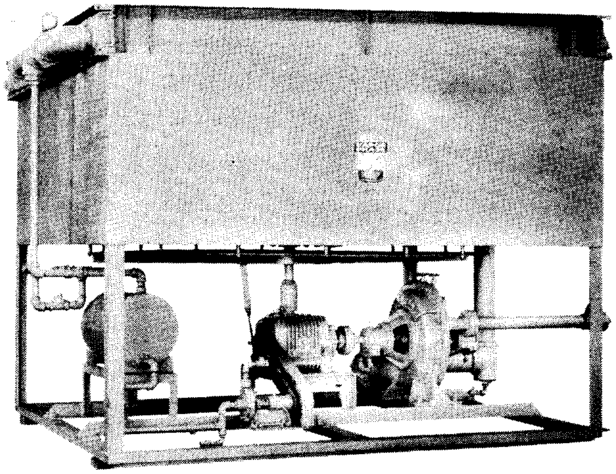

Fig. 12 Unitized Engine Cooler with Turbine

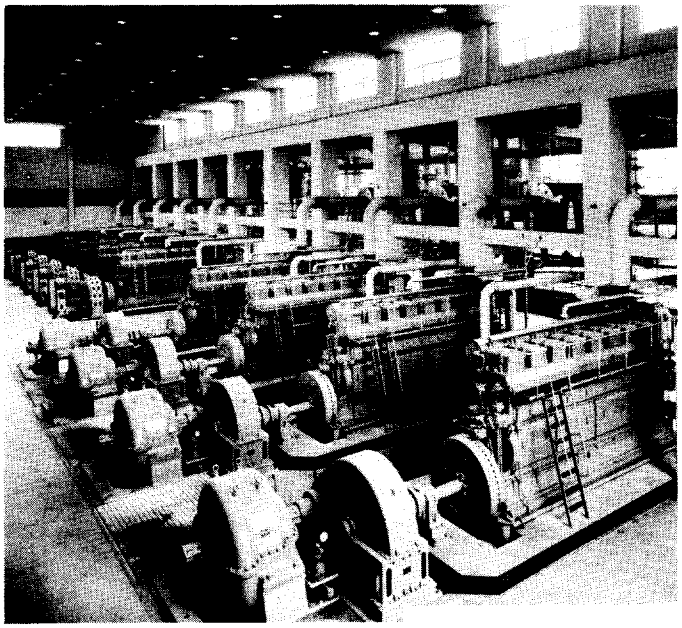

Fig. 13 Hyperion Engine Room

Fig. 12 illustrates one of our units used to cool a 400 bhp gas engine compressor. The turbine turns at 3000 rpm in summer, driving the fan at 500 rpm through a cooling tower worm-type speed reducer. These units, built in sizes to cool any sized engine, are also equipped with coils to cool lubricating oil and compressor cylinders.

The quantity of heat recoverable varies with the type of engine. For example, the engines shown in Fig. 13 are the turbocharged dual-fuel type, operating on pilot oil and sewage sludge gas. These engines develop 1 bhp from only 6462 Btu input. Ten engines in this plant, each rated 1688 bhp, supply power and air for the City of Los Angeles Sewage Treatment Plant. Because of the low input of British thermal units, the VAPOR PHASE system recovers only two pounds of steam per bhp per hour from both cooling jackets and exhaust, whereas as much as 4 1/2 pounds/steam/bhp/per hour can be recovered from naturally aspirated spark-ignition engines that require 10,000 Btu/per bhp/per hour of fuel input. The VAPOR PHASE equipment mounted on the mezzanine above the engines is illustrated in Fig. 14.

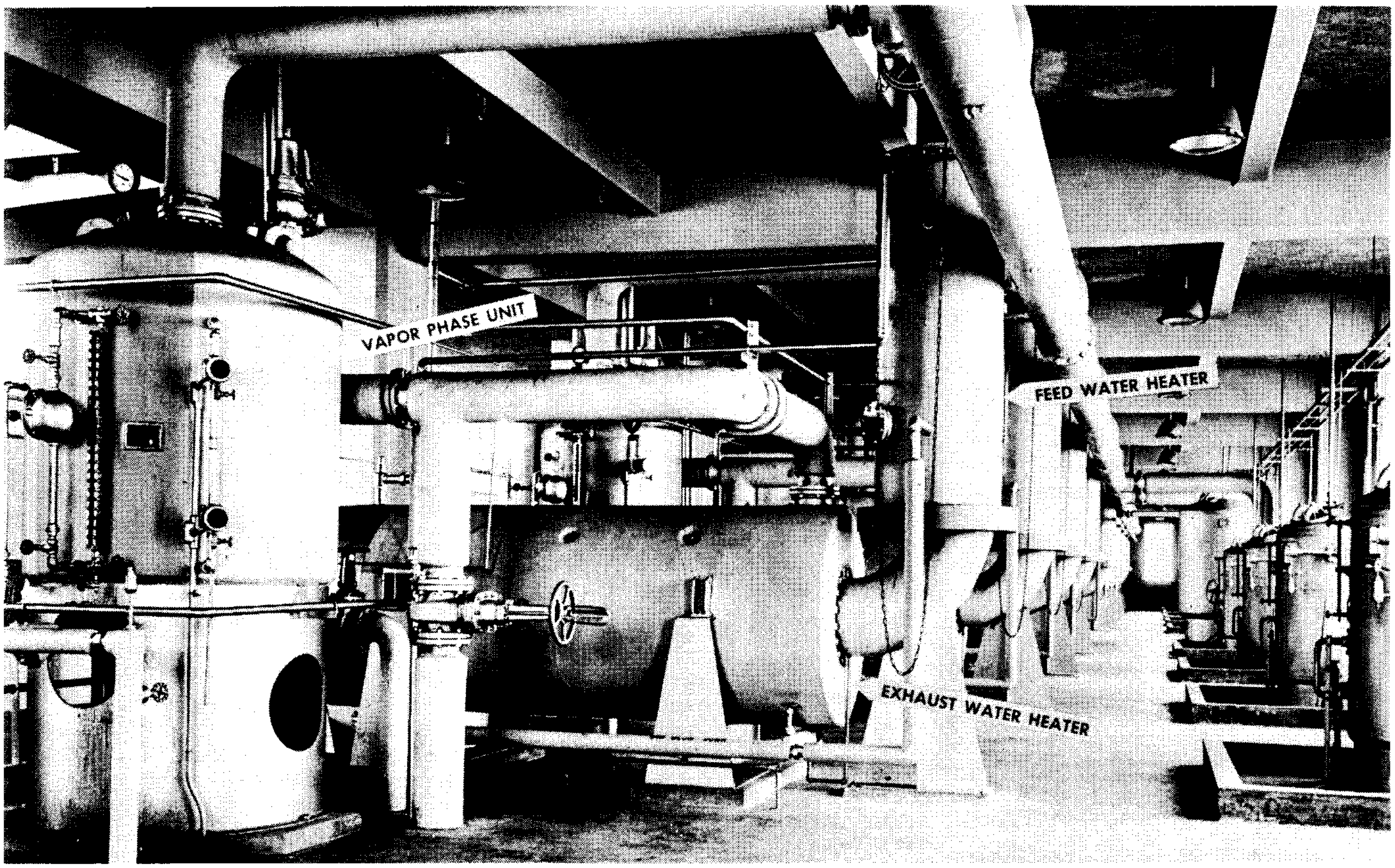

Fig. 14 Hyperion Vapor Phase Equipment

This figure shows that all heat recovered is used in the sewage-treatment process. Each engine, at full load, produces 3510 pounds of steam at 15 psig pressure, this being equivalent to 100 steam boiler horsepower, or 1000 steam boiler horsepower from the ten engines. As a result of the VAPOR PHASE heat recovery system, these engines operate at 75% overall thermal efficiency.

Engine waste heat is also recovered from gas engines of 30 to 125 hp used to drive triplex pumps for artificial lift of crude oil, as shown in Fig. 15. This is a spark-ignition engine developing 55 bhp and pumping 650 bbl of power oil per day. The heat recovered from the jackets and the exhaust is produced at atmospheric pressure or 212 F. Located in the top of the VAPOR PHASE unit is a tube-type heat exchanger through which the power oil flows on its way to the oil wells. As the steam rises in the VAPOR PHASE unit, the heat is absorbed by the power oil as it condenses the steam; thereby the engine heat is transferred to the oil, raising its temperature 65 F to prevent the formation of paraffin in the pipe lines and in the well tubing.

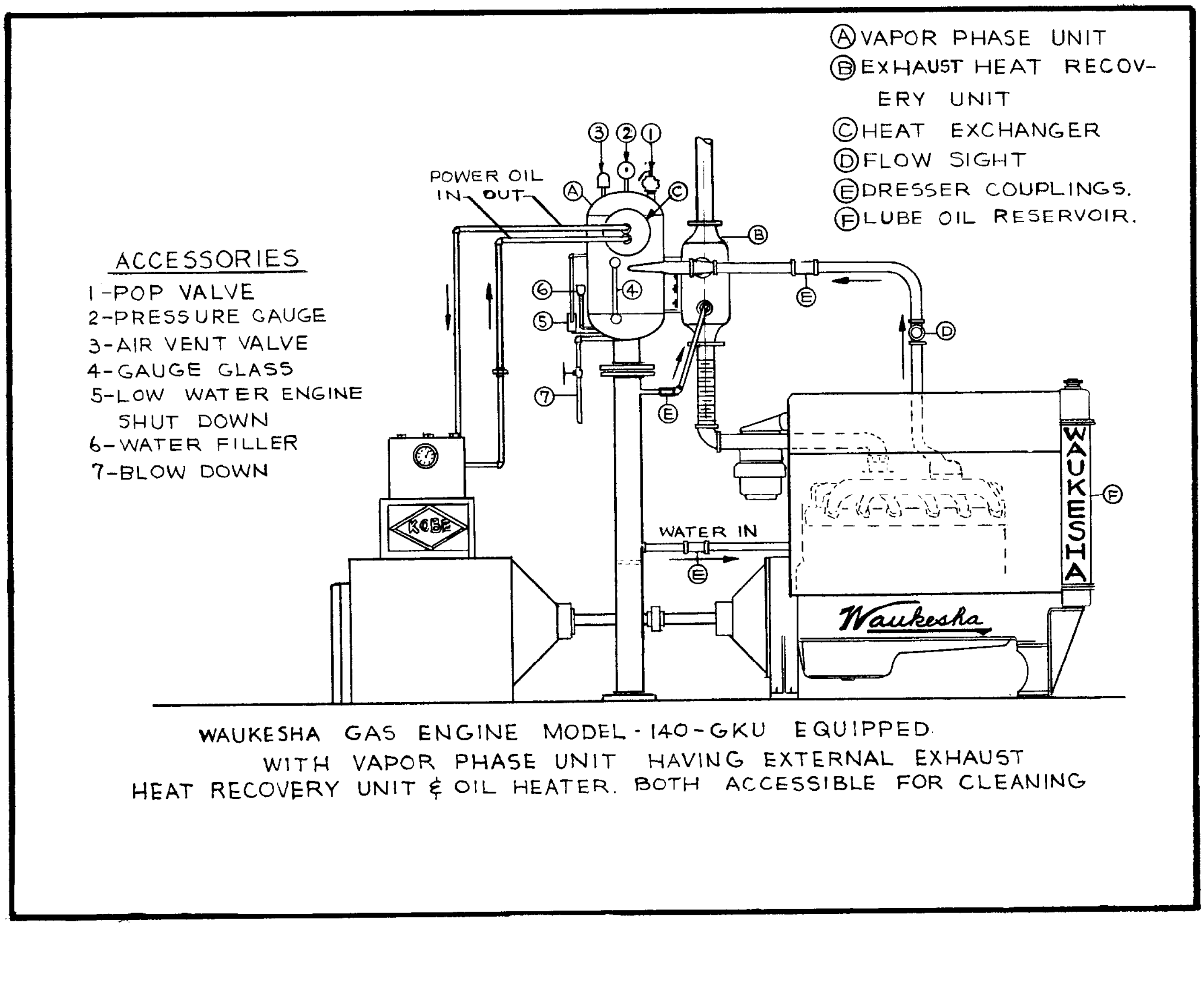

Fig. 15 Single-engine Kobe Heater

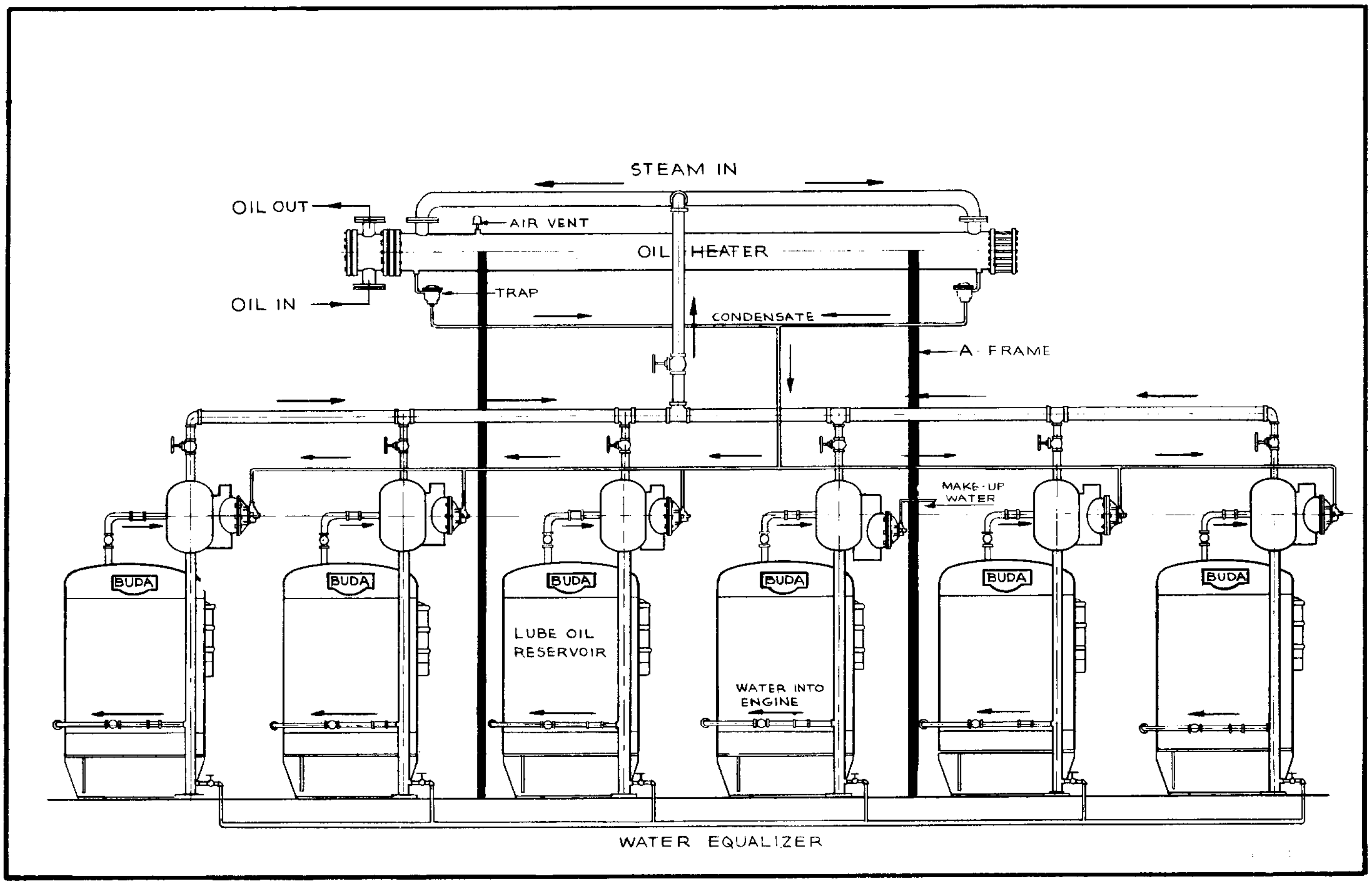

Fig. 16 Multiple-engine Kobe Heater

In multiple engine installation as shown in Fig. 16, one large power oil-heat exchanger is used; however, each engine has its own VAPOR PHASE unit. The engines are manifolded together by the steam header and a water equalizing line. By this manifolding any idle engine is automatically maintained at the same jacket temperature as that of the operating engines.

Another type of waste heat system is one that uses the steam to treat crude oil-salt water-mixture produced by a small lease diesel engine-generator set used to develop power for pumping wells, as shown in Fig. 17.

The power house is shown in Fig. 18. In the foregound are two crude oil treaters with the VAPOR PHASE and the steam turbine condenser built in one unit. Each treater has a U-tube heat exchanger near the bottom where the steam is condensed, transferring the heat to the oil to separate the salt water from the oil. The turbine-fan condenser acts as a standby to the heating process. When one of the oil treaters is "run down," the steam is turned off, causing the turbine to start and run until steam is turned on again in the treater. The reason for using a diesel engine, in this case, is to use the treated crude oil for engine fuel.

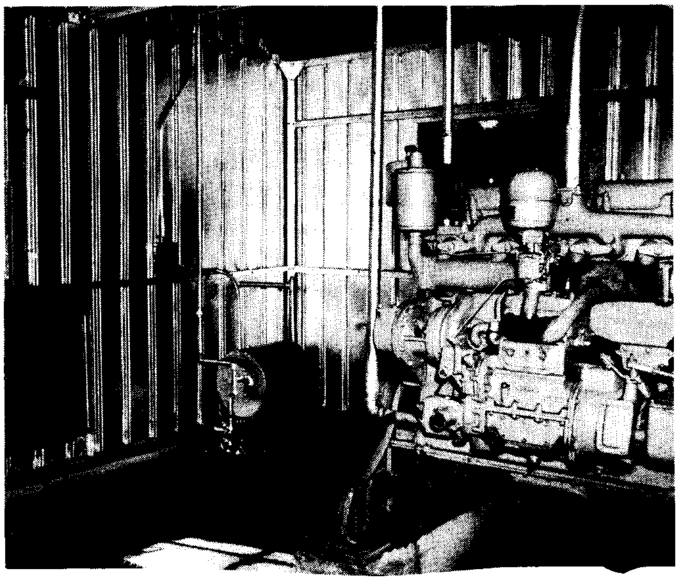

Fig. 17 Diesel Electric Set

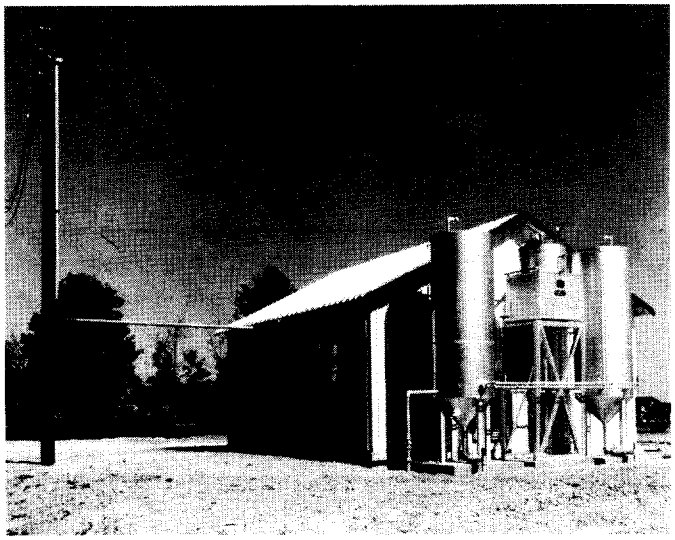

Fig. 18 Heatine Process with Steam Turbine Standby Condenser foı No. 17

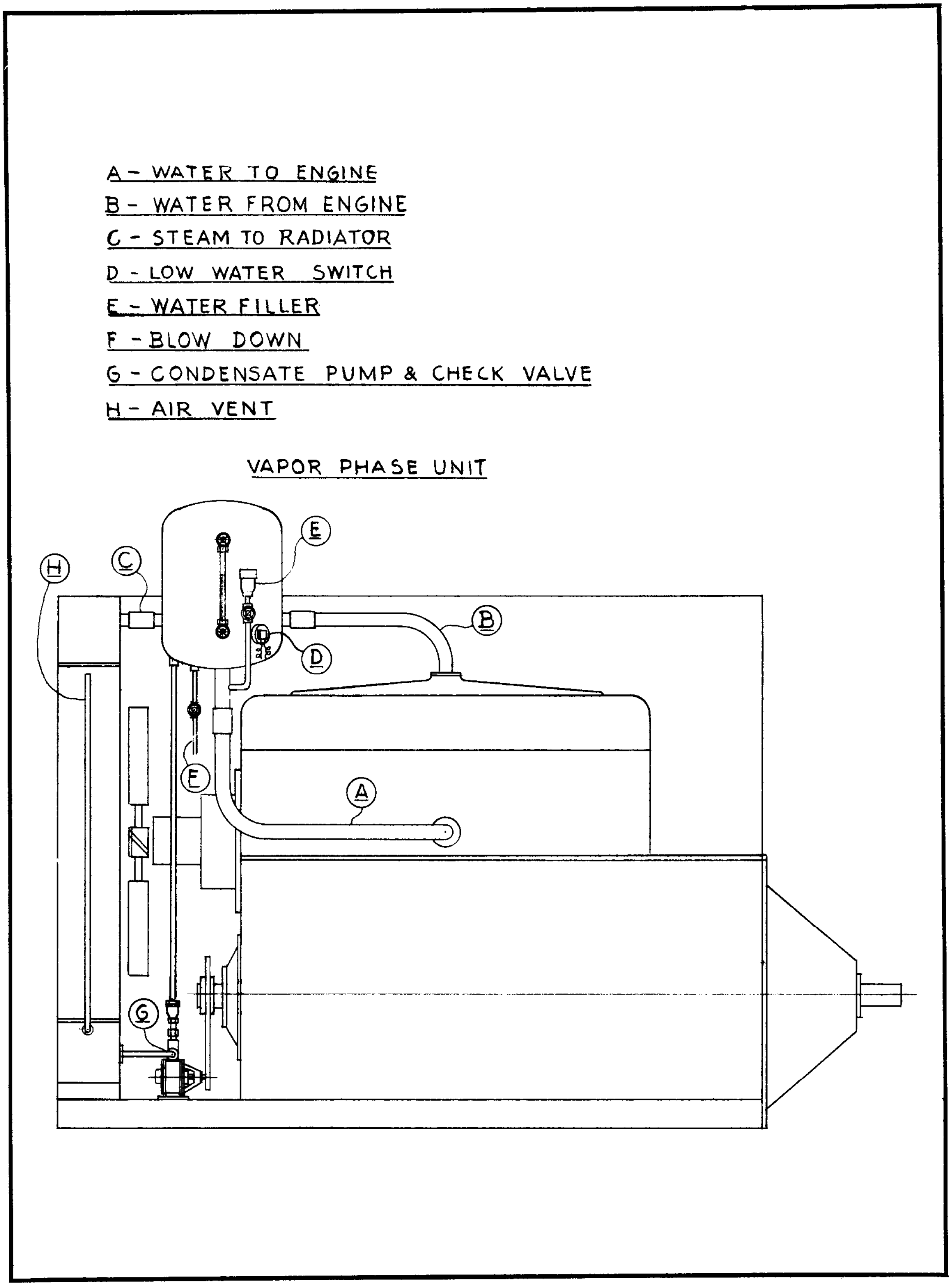

Fig. 19 Type R Package Vapor Phase

SOUR GAS

Fig. 19 shows a package-type VAPOR PHASE thermal circulation system used to cool an oil well pumping engine. When hydrogen sulfide is present in the fuel gas the elevated jacket temperature prevents acid formation because the system operates above the dew point at all times, thus eliminating condensation of the water of combustion in the engine cylinders. Since no water is present, acid in the fuel gas cannot form.

OPERATION AND MAINTENANCE

The VAPOR PHASE unit shown in Fig. 20 has no moving parts inside to cause wear or to require service. This one was designed for four 300-hp engines in an oil pipe line pumping station where no operators are in attendance. Equipped for automatic operation, it has steam-pressure relief valves, an air vent valve, a pressure gauge, a liquid level float valve, two float valves to control the condensate pumps, a low water alarm, and a low water engine shutdown switch. During the first few days of operation the vessel should be blown down several times to remove all dirt and scale. After that time, some water should be drawn off monthly. During blowdown, the liquid level valve, connected to the plant fresh water line, will make up for the water lost by blowdown.

All accessories are externally mounted and are piped up with valves and unions for removal when service is required. All controls should be checked for function at four to six-week intervals.

The control of the temperature is automatic, by the natural law of boiling. No manual or mechanical devices are required. The system operates at atmospheric pressure for 212 F where the steam is not used and at ten to twenty pounds of pressure where the steam is used in a heating process, and in a steam turbine cooling-air fan drive.

Aerial heat exchangers should be checked periodically, and if the finned tubes are dirty, they should be brushed off. The fan and its prime mover should be checked occasionally for alignment.

Some kind of boiler treatment compound should be added to the engine jacket water to insure clean jackets. A non-toxic type of compound is recommended.

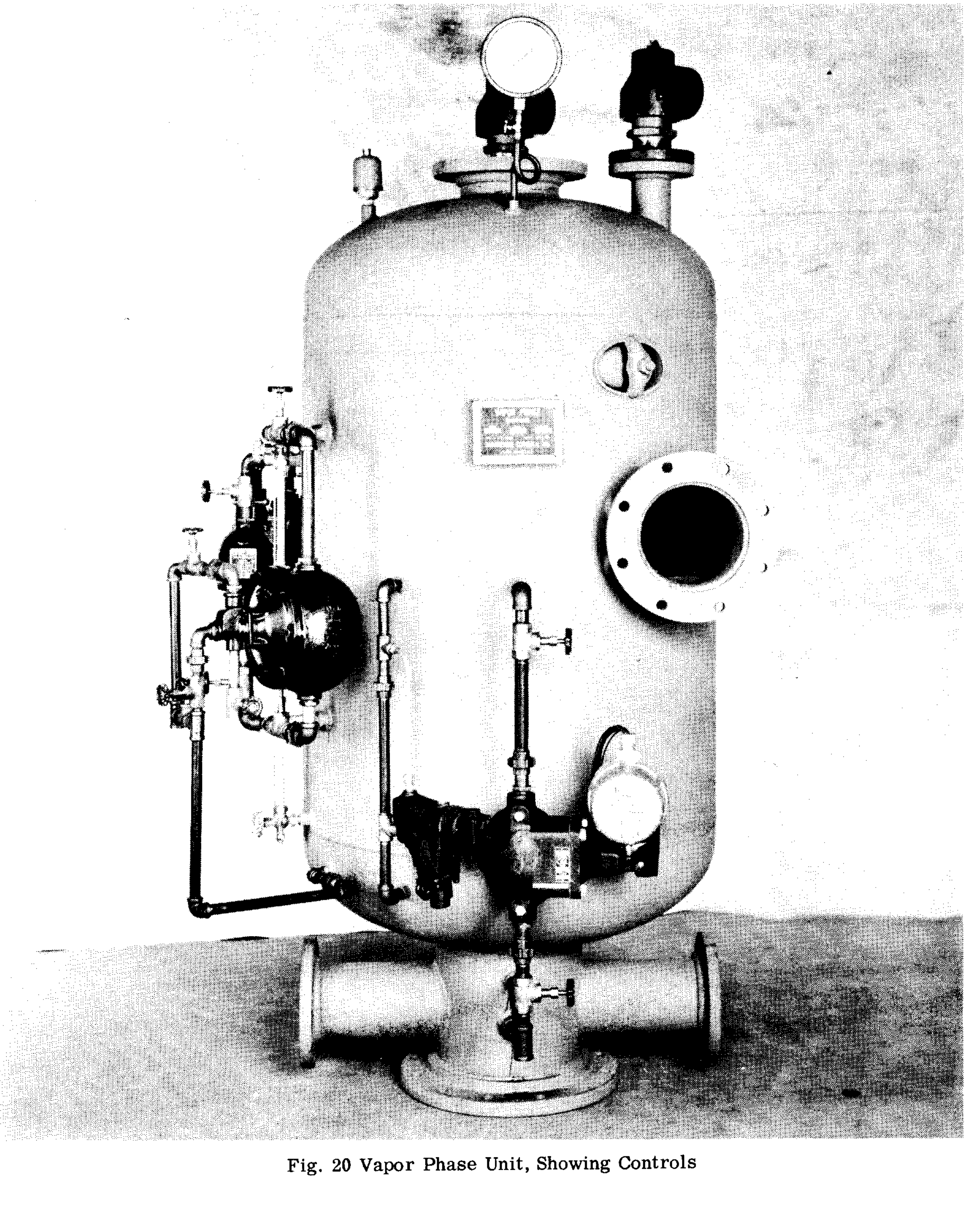

Fig. 20 Vapor Phase Unit, Showing Controls