OPERATION OF OIL-FIRED DOUBLE EFFECT EVAPORATOR

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SUMMARY

In order to determine the feasibility of the use of the Cleaver-Brooks Portable Distillation Unit, Model M2E-10D, in the Unit Operations Laboratory of the University of Tennessee, Knoxville, Tennessee, necessary repairs and parts replacements were made on the equipment and tests were run to determine the hourly capacity.

The distillation unit was operated until the desired conditions were reached, namely, a pressure of 7 lb. per sq. in. gage in the first effect, and operation was continued at these conditions for one hour. The distillate was measured and was found to be 40 gallons per hour. This was 60 gallons per hour less than the rated capacity of 100 gallons per hour.

It was concluded that this equipment might be added to the present equipment of the unit operations laboratory.

Further investigation should be conducted in order to determine (1) the overall coefficients of heat transfer, and (2) the overall heating efficiency.

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INTRODUCTION

During World War II, several new pieces of equipment for the purpose of water purification were used by the U. S. Army. One of these was the Cleaver-Brooks Portable Distillation Unit, Model M2E-10D, which was manufactured by the Cleaver-Brooks Company, Milwaukee, Wisconsin.

As a part of a shipment of war-surplus equipment, the University of Tennessee received from the War Assets Administration one of these distillation units.

The question was immediately raised as to its possible use in the Unit Operations Laboratory. Realizing that some changes would be necessary before permanent installation, tests were initiated to determine the possibilities of this newly acquired equipment.

EQUIPMENT

A flow diagram of the equipment tested is shown in Figure 1. A detailed drawing of the distillation unit is shown in Figure 2. Figure 3 is a cut-away drawing of the unit and Figure 4 is a photograph of the burner end. In this photograph, it should be noted that electric motors have been substituted for the gasoline engine and the cold water feed pump has been removed. Figure 5 is a flow diagram of the oil system, Figure 6 is a detailed drawing of the burner, and Figure 7 shows the details of the continuous blow-down.

The cold water feed pump was removed as the use of city water furnished sufficient pressure in the cold water feed line. Since the equipment was operated inside the laboratory, the exhaust from the gasoline engine would have been a nuisance. Because of this electric motors were substituted for use in driving the pumps and the blower.

The heating element of the first effect is a removable fire tube assembly of eight passes into which the oil flame is projected, and which is attached to the front outer plate at the power end.

An automatic blow-down maintains the water level in the second effect evaporator at a height of about 3 or 4 inches in the water sight glass. The automatic blow-down is built into

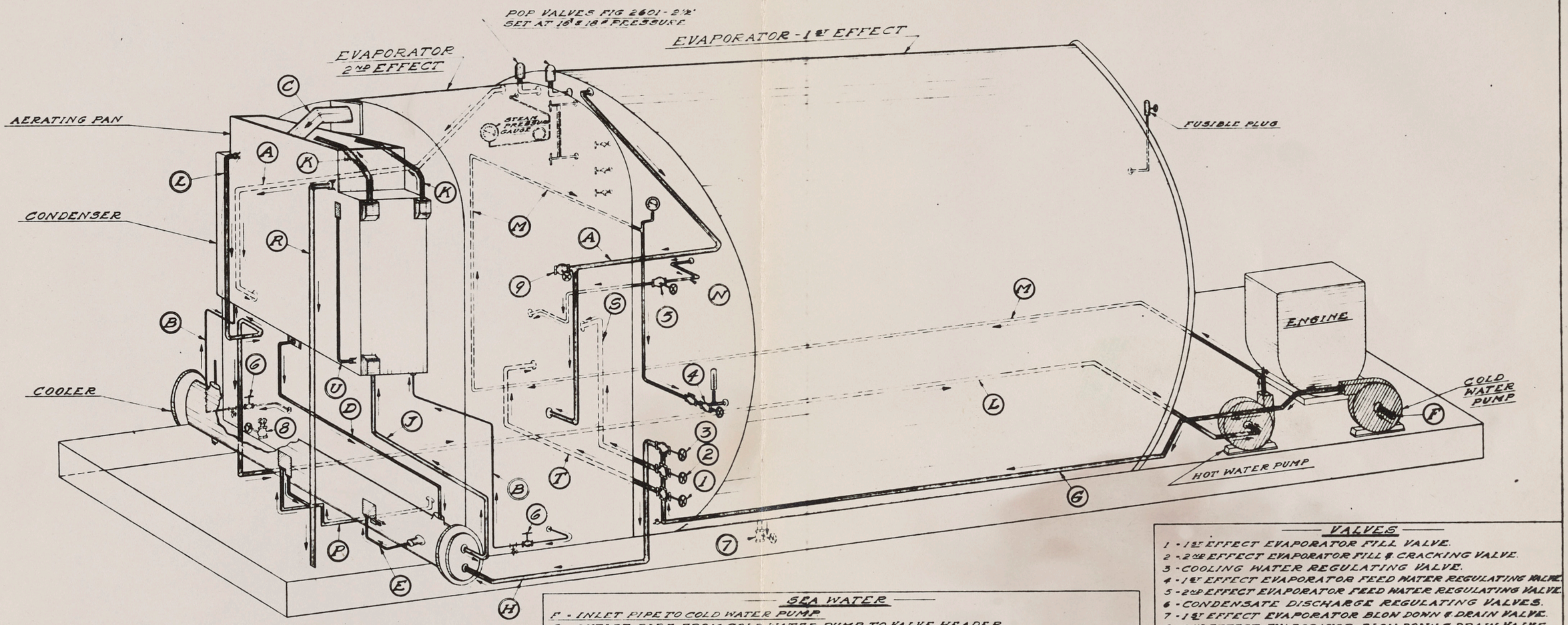
the bottom of the second effect evaporator and is so designed that a water seal is created to retain the vapor within the chamber, even though blown-down water may be freely drawn off. So long as water is running out of the blow-down pipe, the water level will be correct.

Vapor is driven off the top of the second effect evaporator and passes to the condenser. The condenser assembly is located at the end opposite the firing end. The cooling water is circulated through the condenser and the vapors are completely liquified.

The steam in the coils in the second effect evaporator is condensed and forced by steam pressure into the condenser where it joins the condensate from the second effect.

From the condenser, the distillate flows by gravity through the cooler. All the coldwater pumped through the machine first passes through the tubes of the cooler and then through the tubes of the condenser to liquify and cool the distillate outside the tubes. At the same time, the cold water is being heated so that hot water is available in the aerating pan to be fed to the first effect evaporator.

All water to be evaporated initially passes to the first effect. This feed water is withdrawn from the aerating pan on the top of the condenser, having been brought to a temperature near the boiling point.



CONDENSATE

A - VAPOR PIPES FROM 1ST EFFECT EVAPORATOR TO COILS IN 2ND EVAPORATOR
B - CONDENSATE PIPES FROM 2ND EFFECT COILS TO CONDENSER
C - VAPOR PIPE FROM 2ND EFFECT TO CONDENSER
D - DISTILLED WATER PIPE FROM CONDENSER TO COOLER
E - DISTILLED WATER PIPE OUTLET FROM COOLER

SEA WATER

F - INLET PIPE TO COLD WATER PUMP
G - OUTLET PIPE FROM COLD WATER PUMP TO VALVE HEADER
H - COOLING WATER PIPE FROM VALVE HEADER TO COOLER
J - COOLING WATER PIPE FROM COOLER TO CONDENSER.
K - WASTE AND FEED WATER PIPES FROM CONDENSER TO AERATING PAN.
L - FEED WATER PIPE FROM AERATING PAN TO HOT WATER PUMP
M - FEED WATER PIPE FROM HOT WATER PUMP TO 1ST EFFECT EVAPORATOR
N - CONTINUOUS BLOW DOWN PIPE FROM 1ST EFFECT EVAPORATOR & FEED TO 2ND EFFECT EVAPORATOR
P - CONTINUOUS BLOW DOWN PIPE FROM 2ND EFFECT EVAPORATOR
R - WASTE WATER DISCHARGE PIPE
S - 2ND EFFECT EVAPORATOR FILL PIPE
T - 1ST EFFECT EVAPORATOR FILL & CRACKING PIPE
U - CONDENSER VENT PIPE

VALVES

1 - 1ST EFFECT EVAPORATOR FILL VALVE.
2 - 2ND EFFECT EVAPORATOR FILL & CRACKING VALVE.
3 - COOLING WATER REGULATING VALVE.
4 - 1ST EFFECT EVAPORATOR FEED WATER REGULATING VALVE.
5 - 2ND EFFECT EVAPORATOR FEED WATER REGULATING VALVE.
6 - CONDENSATE DISCHARGE REGULATING VALVES.
7 - 1ST EFFECT EVAPORATOR BLOW DOWN & DRAIN VALVE.
8 - 2ND EFFECT EVAPORATOR BLOW DOWN & DRAIN VALVE.
9 - AUXILIARY STEAM TAKE OFF VALVE

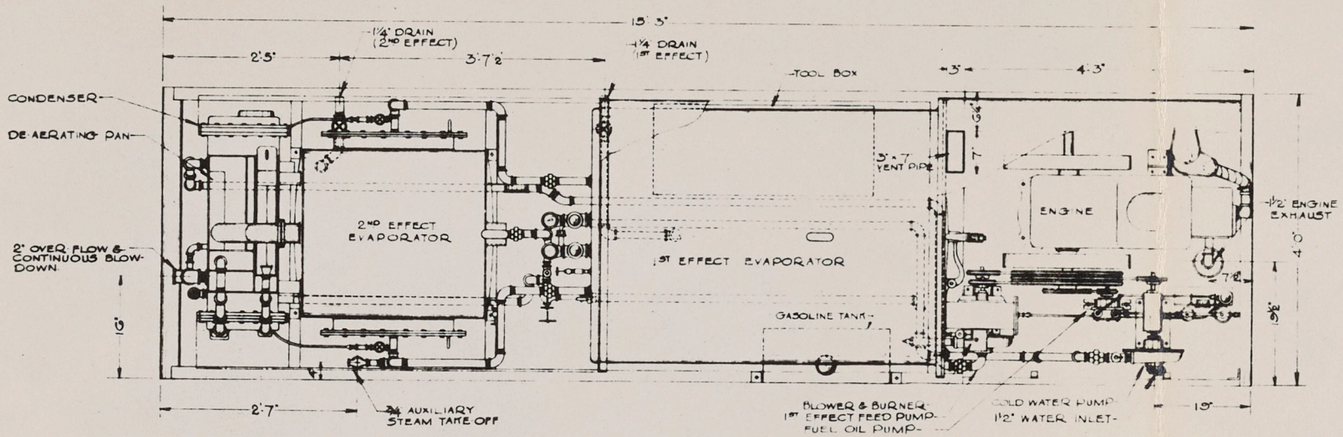
NOTE:

HIDDEN PIPES SHOWN IN BROKEN LINES.

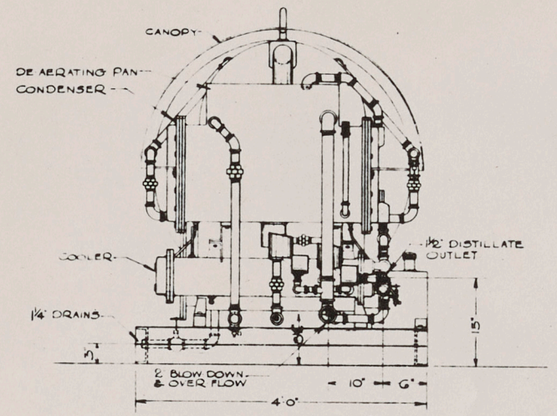
("F-M" PUMPS & BLOWER EXTENSION)

— FLOW DIAGRAM — MODEL M2E - 10B DISTILLATION UNIT.

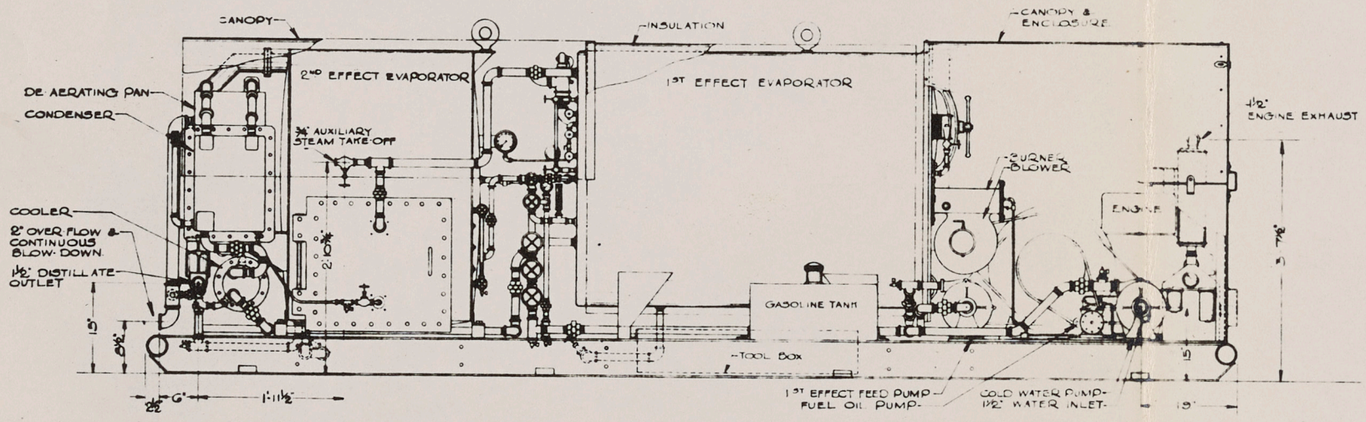
FIGURE 1



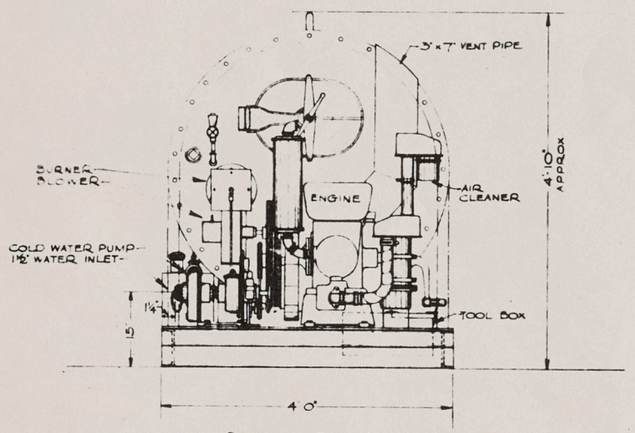
TOP VIEW



CONDENSER END VIEW



SIDE VIEW



BURNER END VIEW

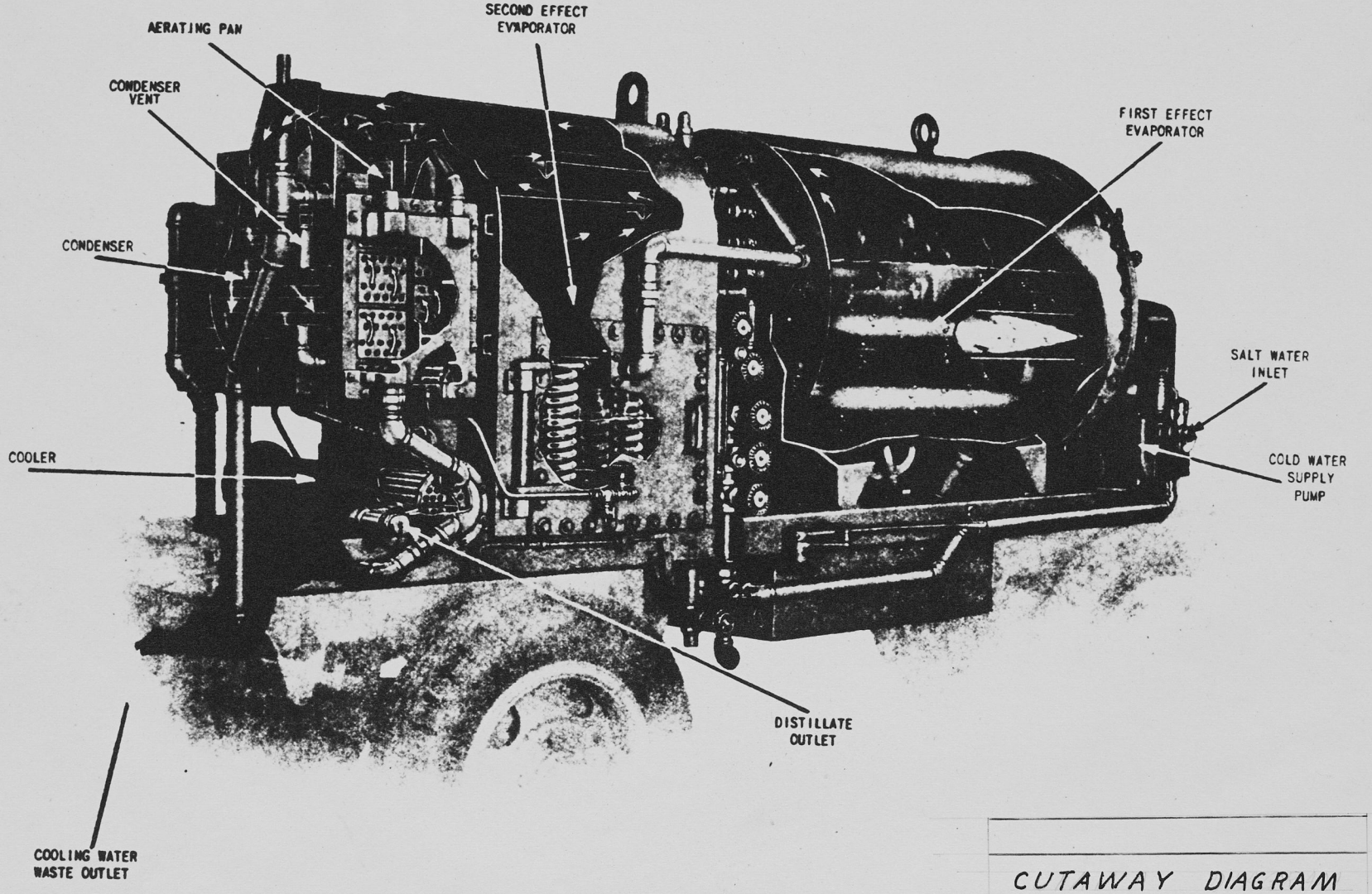
ASSEMBLY OF
MODEL M2E-10D
DISTILLATION UNIT

FIGURE 2

Once in operation the oil burner runs at a constant setting and the operator may handle all the control and regulating duties from one side of the unit.

A fuel oil tank to serve the oil burner on the unit is provided and piped to and from the burner as shown in Figure 5.

The fuel oil burner is an integral part of the distillation unit and is of the pressure atomizing type, designed to operate with oil not heavier than No. 3, having a viscosity not exceeding 50 seconds Saybolt Universal at 100°F. Kerosene may be used if no other fuel is available, but it is necessary to add a pint of light lubricating oil to each five gallons of this fuel to lubricate the gear-type fuel oil pump. Gasoline may be used also, treating it with lubricating oil as instructed for kerosene. The capacity of the nozzle which was used in the test was 5 gallons per hour.



CUTAWAY DIAGRAM
MODEL M2E-10 D
DISTILLATION UNIT

FIGURE 3

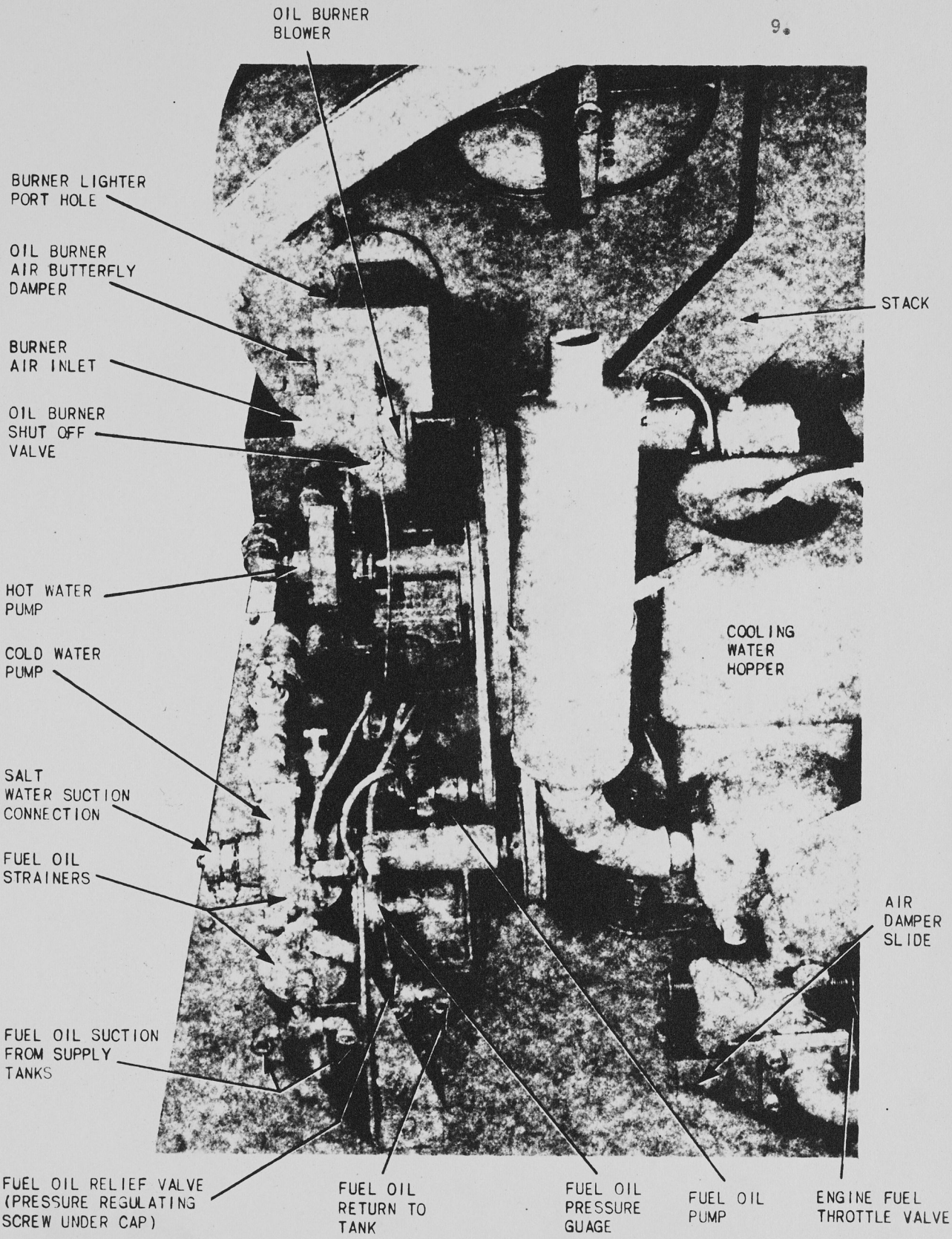
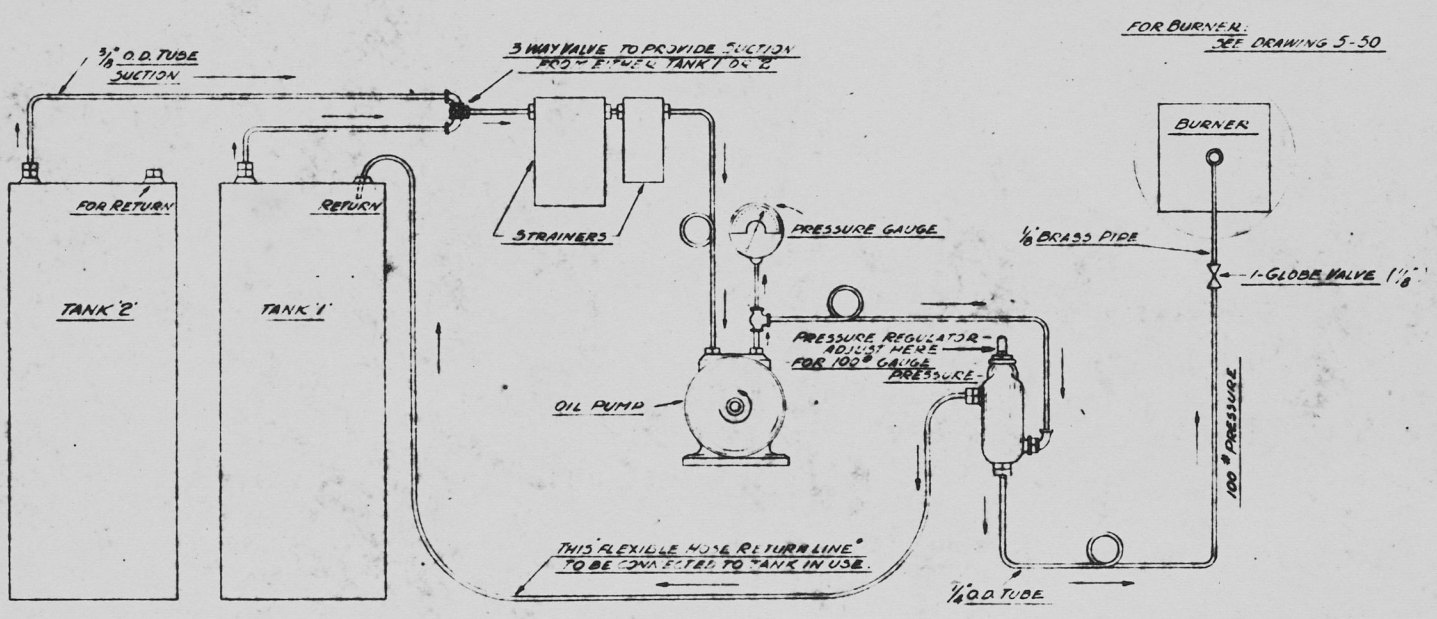


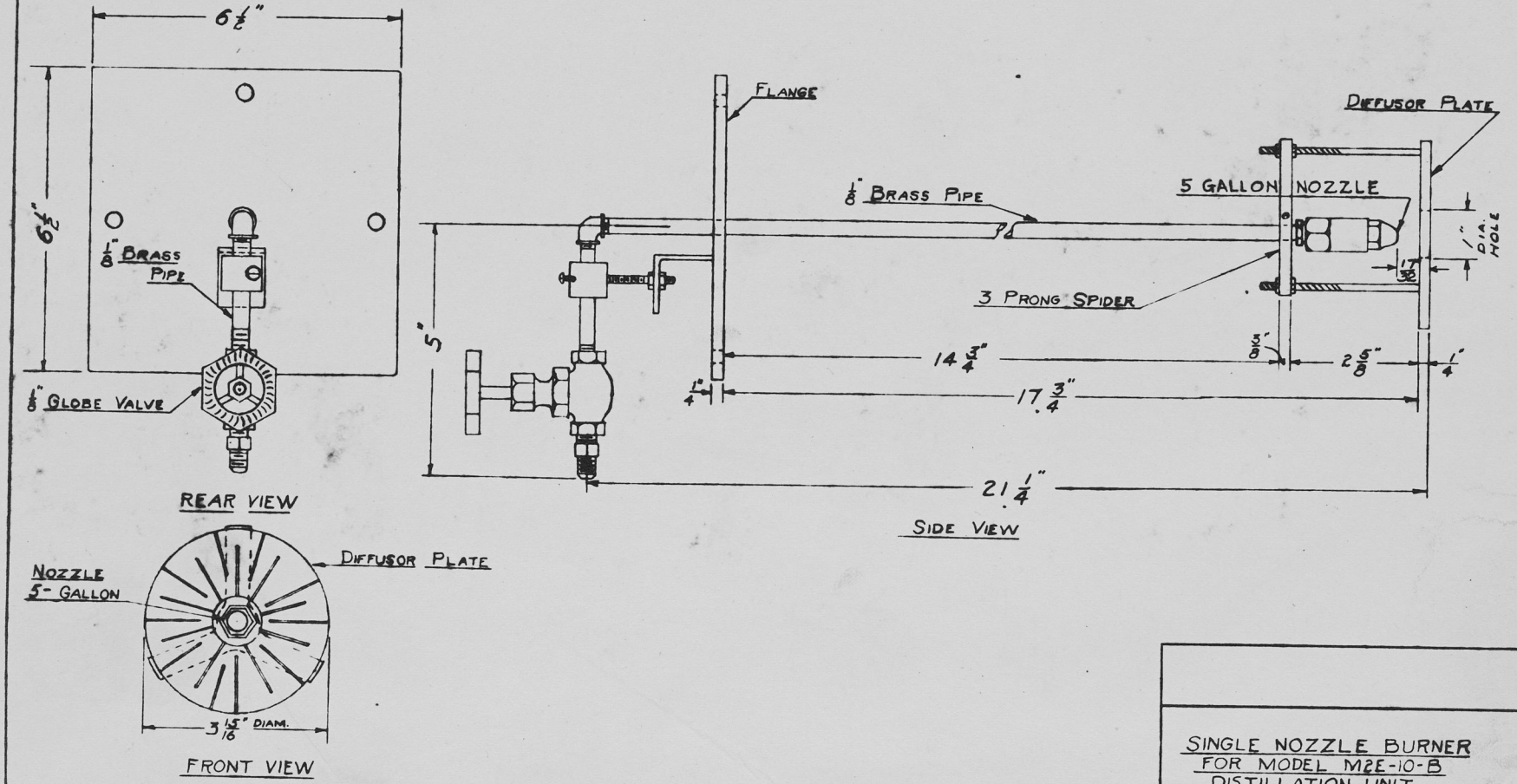
FIGURE 4

BURNER END ASSEMBLY



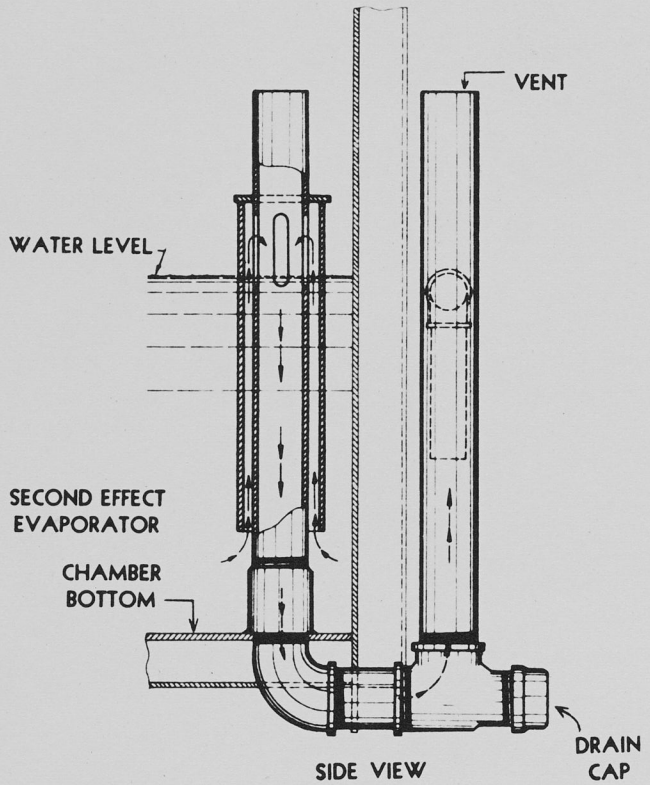
OIL PIPE DIAGRAM
MODEL M2E-100
DISTILLATION UNIT

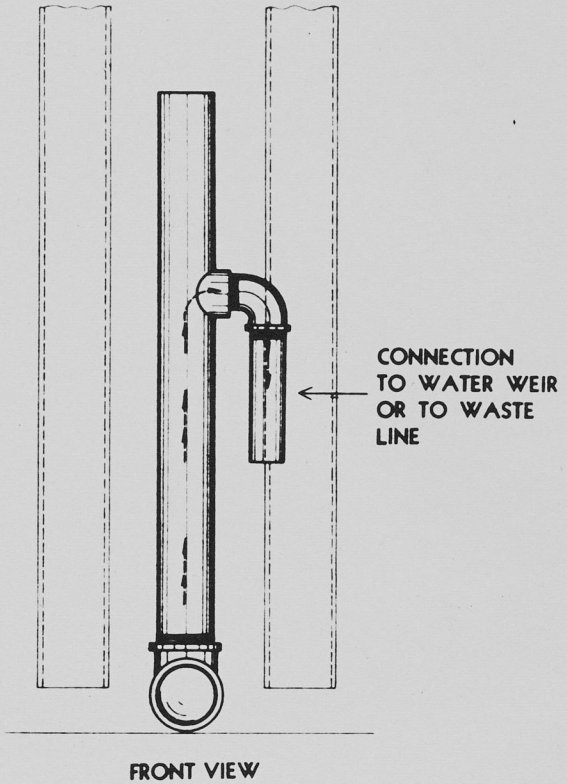
FIGURE 5

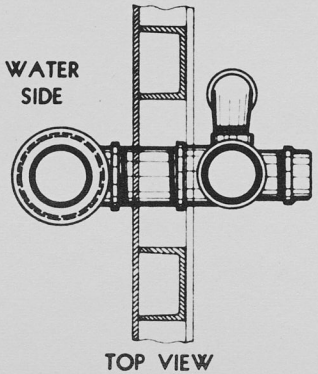


SINGLE NOZZLE BURNER
FOR MODEL M2E-10-B
DISTILLATION UNIT

FIGURE 6







DETAILS OF CONTINUOUS BLOW-DOWN MODEL M2E-25

FIGURE 7

PROCEDURE

Referring to Figure 1, valves No. 1, the first effect fill valve, No. 2, the second effect fill valve, No. 3, the cooling water regulating valve, No. 4, the first effect feed valve, No. 5, the continuous blow-down from the first effect to the second effect, and No. 6, the condensate discharge regulating valves were all closed.

After the cold water was put in circulation, the following procedure was followed.

All water gage sight glasses were opened and all drain cocks were closed. The first effect was filled by opening the first effect evaporator fill valve (No. 1) until 2 inches of water showed in the sight glass. The second effect was filled to a similar level by operation of the second effect fill valve. When these water levels were attained, the valves were closed and the burner was lit.

The fuel oil burner on the distillation unit was provided with an oil atomizing nozzle having a capacity of five gallons per hour. The capacity of firing rate of the nozzle cannot be altered by manipulation of the globe valve in the fuel oil line leading to it. The valve must be fully open or closed.

The burner was lit by immersing a lighting torch in the fuel oil, opening the lighter port at the left of the burner air

manifold, closing the air damper in the blower air inlet, igniting the lighter and inserting the flaming end into the lighter hole sufficiently far to rest on the bottom of the fire tube directly in front of the burner. The main fuel oil supply valve was fully opened and ignition took place immediately. The lighter was removed and the air damper in the blower outlet was opened sufficiently to clear the smoke emitted from the stack. The air adjustment was set to provide sufficient air in proportion to the fuel burned. This was determined by gradually opening the damper valve until only a slight wisp of smoke was noticed coming from the stack. In making this adjustment, it was borne in mind that the flame must travel through eight passes of fire tube in the heating element before the results of damper adjustments could be seen at the stack outlet.

From 45 to 60 minutes after the fire started, steam pressure was generated in the first effect, at which time steam began to pass to the two banks of steam coils in the second effect. When the pressure reached 5 pounds per square inch gage, the condensate discharge regulating valves No. 6 were opened one-half turn. When the pressure reached 7 pounds per square inch gage, these valves were opened another half turn or a total of one full turn.

If the valves are opened too far, live steam will be passed, and the first effect pressure will drop. If the valves are closed too much, not all the condensate can pass through and the pressure will rise. Both valves must be opened an equal amount in order that the same flow comes through both sides.

The cooling water feed valve, No. 3, was opened about a half turn. This allowed some cooling water to circulate through the cooler and condenser, keeping the aerating pan filled with water ready to be withdrawn as needed for feed-water. Cooling water discharged as waste was at temperatures varying from 180°F. to 200°F. After normal operation was attained, vapor was discharged from the condenser vent. If water should bubble over with this vapor, the rate of cooling water flow should be increased.

As the steam pressure was raised, the resulting evaporation of water from the first effect lowered the water level and the first effect feed valve was opened to allow the inflow of feed-water from the aerating pan. The second effect feed valve was next opened to feed-water from the bottom of the first effect to the second effect. This served the purpose of feeding water at the boiling point to the second effect.

After the flow of distillate began, cooling feed valve No. 3, the first effect feed valve No. 4, and the second effect feed

valve No. 5 were adjusted to maintain constant levels. Valve No. 3 was opened only enough to provide cooling water to condense all vapors, keeping the feed water temperature not over 200°F. Normal operating temperature is between 180°F and 200°F. The temperature of the water fed to the first effect from the aerating pan is indicated by the thermometer above valve No. 4.

The Cleaver Distillation Unit is operating correctly when the firing rate is 5 gallons of fuel oil per hour, there is little or no smoke coming from the stack, the water levels remain constant, the pressure in the first effect is 7 pounds per square inch gage, and the first effect feed water is at a temperature between 180°F. and 200°F.

RESULTS

The Cleaver-Brooks Distillation Unit was repaired and placed in operation.

The operation of the unit was carried out at the recommended conditions[1], using city water as feed.

The capacity of the unit was 40 gallons per hour, as compared with the rated capacity of 100 gallons per hour.

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[1] War Department Technical Manual, TM 5-2060.

DISCUSSION AND RECOMMENDATIONS

The Cleaver-Brooks Distillation Unit never attained its rated capacity of 100 gallons per hour. The best production which was obtained was 40 gallons per hour.

This production was obtained while operating the unit at the recommended conditions of operation.[1] The pressure in the first effect remained constant at 7 pounds per square inch gage. The feed water entered the first effect at temperatures ranging from 180°F. to 200°F.

There were several unknown quantities concerning the operation of the unit. With the present operation set-up, the amount of oil burned per hour was not known. The nozzle was supposed to be a 5 gallon per hour nozzle, but this fuel consumption should be checked.

The original oil pump was removed and a new one added. This new pump, which was designed for operation with water, overheated during the first 5 hours of operation. It is possible that this pump was not pumping the capacity required. The pressure in the oil line should remain at 100 pounds per square inch gage, but before the pressure gage broke, the pressure was usually about 75 pounds per square inch gage. The pressure was erratic, however, with occasional bursts as high as 150 pounds per square inch gage.

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[1] War Department Technical Manual, TM 5-2060.

The fire tubes in the first effect need further cleaning. An attempt was made to chip the scale off the outside, but working conditions prohibited a good job. The inside of the tube is scaled and would be extremely difficult to clean. It is possible that heat transfer was cut down and caused a drop in the operating capacity.

Another factor to consider is that Army equipment often failed to reach the rated capacity.

Tests[1] conducted by the U. S. Army, Corps of Engineers, showed that at 100 pounds per square inch gage, the flow of fuel through a 5 gallon per hour nozzle was only 4.3 gallons per hour. Further tests[2] showed that the output of the unit, when operating at a fuel oil pressure of 100 pounds per square inch gage, with a 5 gallon per hour nozzle, was 95 gallons per hour. The distillate production dropped to 88 gallons per hour when the pressure was 75 pounds per square inch gage.

Since there are so many variables, each of which should be checked, it is impossible to point with assurance to the reason for the low capacity.

Further tests should be conducted to determine the overall coefficients of heat transfer and the overall efficiency of the unit as an evaporator. The latter test would provide a good

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[1] War Department Technical Manual, TM 5-295, p. 176.

[2] Ibid., p. 177

overall picture of the operation, since the flow at each point of the unit would be required.

If the equipment is to be installed as a permanent part of the unit operations laboratory, the unit should be taken off the present framework and mounted with more space between the first and second effects. The Army was concerned with having a compact portable unit, which caused piping repairs between the two effects to be extremely inconvenient.

BIBLIOGRAPHY

War Department Technical Manual, TM 5-295, Military Water Supply and Purification.

War Department Technical Manual, TM 5-2060.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Mr. Ben Thomas for his assistance in repairing the equipment, and to Colonel Robert J. Fleming, Jr., U. S. Army, Corps of Engineers, for his loan of the War Department Technical Manual, TM 5-2060.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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