SOLAR-ONE
10 MWe PILOT PLANT
ULLAGE MAINTENANCE UNIT (UMU)
DESCRIPTION
OPERATION &
ANALYSIS

13 MARCH 1981

REVISED

5 NOVEMBER 1982

INTRODUCTION

Solar One is a 10MWe Solar Thermal Central Receiver Pilot Plant which generates electricity exclusively from solar energy. The pilot plant is a joint under taking between the U.S. Department of Energy and the Utility Associates composed of the Southern California Edison Company, the Los Angeles Department of Water and Power, and the California Energy Resources Conservation and Development Commission. The pilot plant consists of several major systems (shown in Figure 1) including the Thermal Storage System.

The Thermal Storage System is designed to absorb and store thermal energy by condensing receiver generated steam and to serve as a source of thermal energy for a simultaneous or subsequent steam generation process (see Figure 2.) The thermal energy is absorbed into the subsystem (charging process) by circulating low temperature (nominally $425^{O}F$) Caloria HT-43 (heat transfer oil) through charging heat exchangers which condenses receiver steam and exits from the heat exchangers at an elevated temperature ($580^{O}F$). The high temperature Caloria flows to either the storage tank (thermal storage unit) or on to the inlet of the steam generating heat exchangers.

The thermal storage unit (TSU) is a vertical cylindrical tank filled with a sand/rock mixture through which the Caloria passes. Hot Caloria is introduced at the top of the TSU through a distribution manifold and passes downward through the tank. As the oil passes through the rock/sand mixture, it transfers its heat to the sand and rock and is cooled to the low temperature ($425^{O}F$) condition. The zone of heat transfer within the tank (thermocline) occurs over a small fraction of the entire tank height. As energy is added to the TSU, the thermocline moves downward thereby increasing the thermal charge of the system.

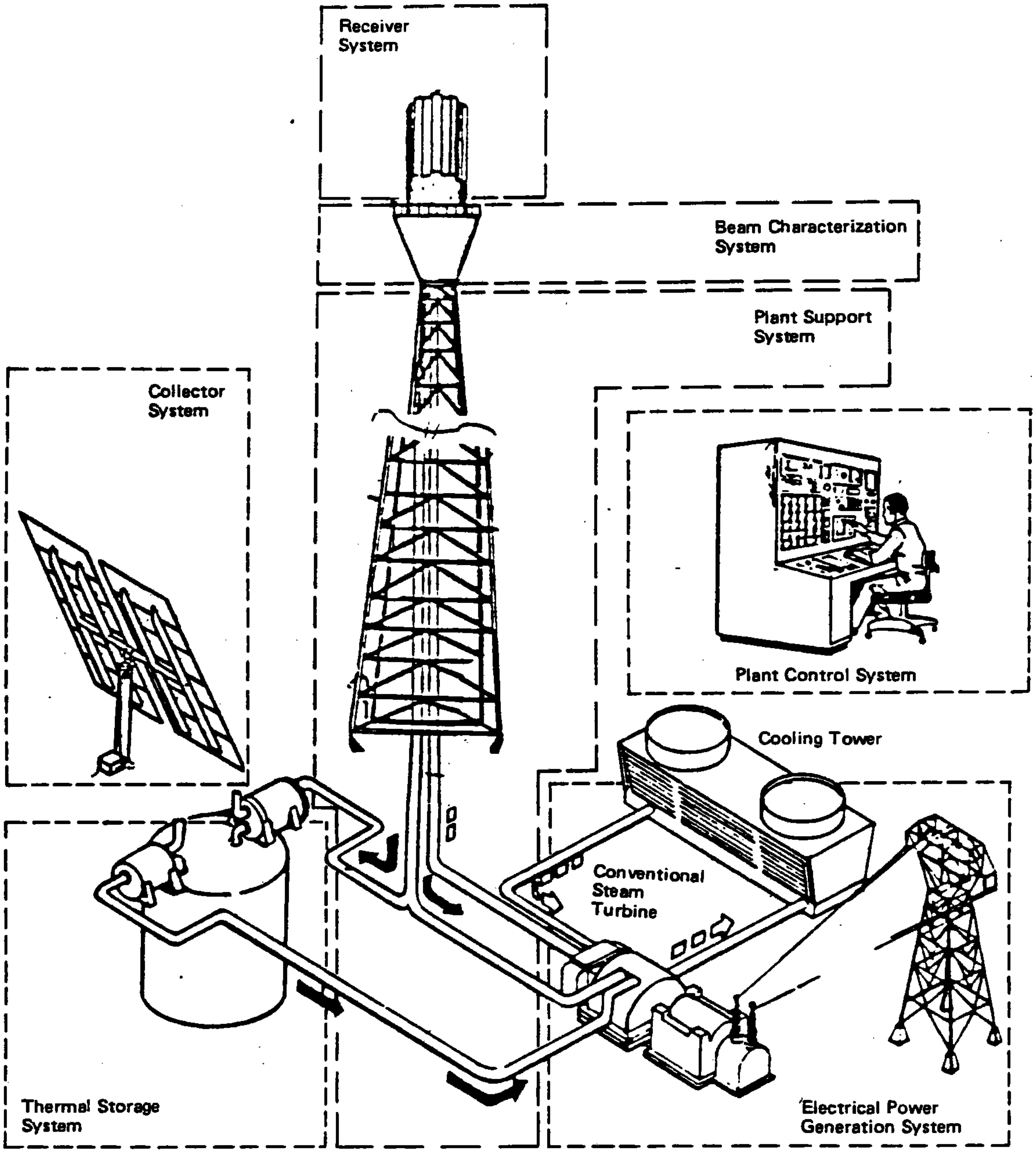
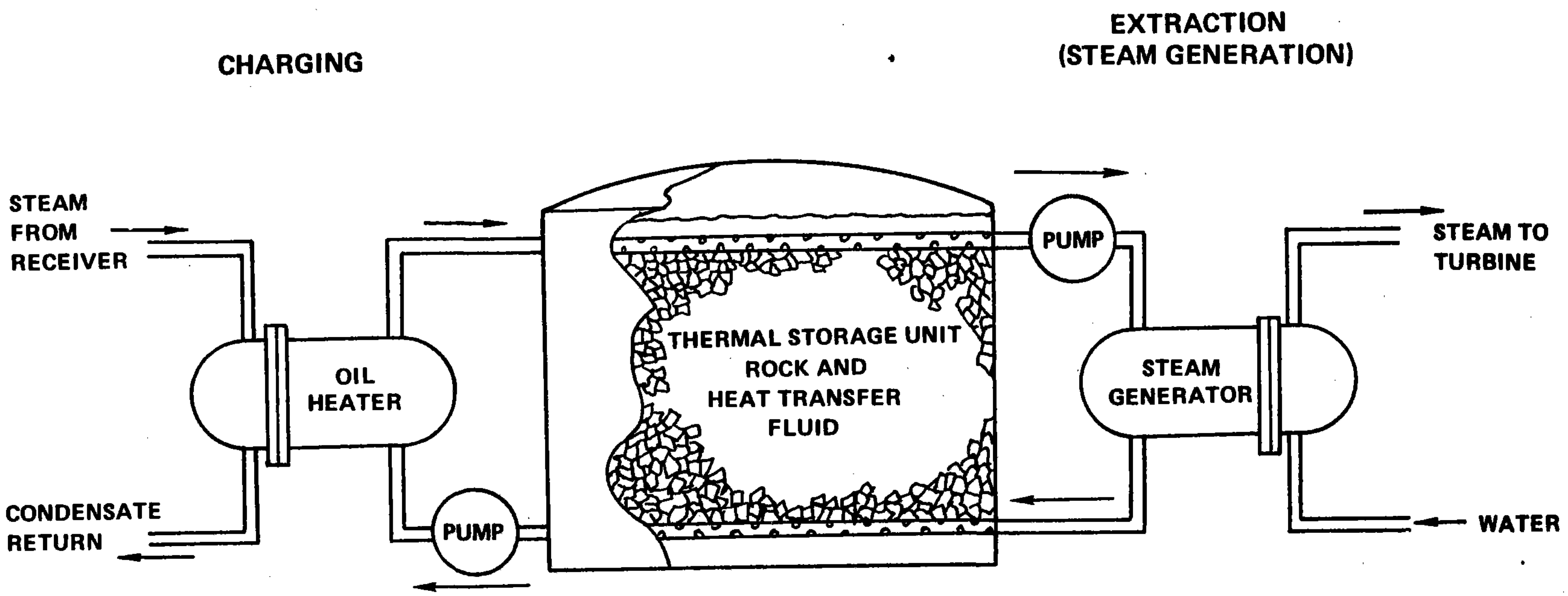


Figure 1. Pilot Plant System Schematic

FIGURE 2

SOLAR ONE THERMAL STORAGE SUBSYSTEM



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During the energy extraction process, high temperature Caloria is circulated to the steam generators either flowing directly from the outlet of the charging heat exchangers or from the top manifold in the TSU. The steam generators produce steam at a nominal condition of 420 psia and 530°F. Caloria leaves the steam generators at a nominal temperature of 425°F and flows to either the TSU bottom manifold where it is reintroduced into the tank or directly to the charging heat exchangers where it absorbs additional charging energy.

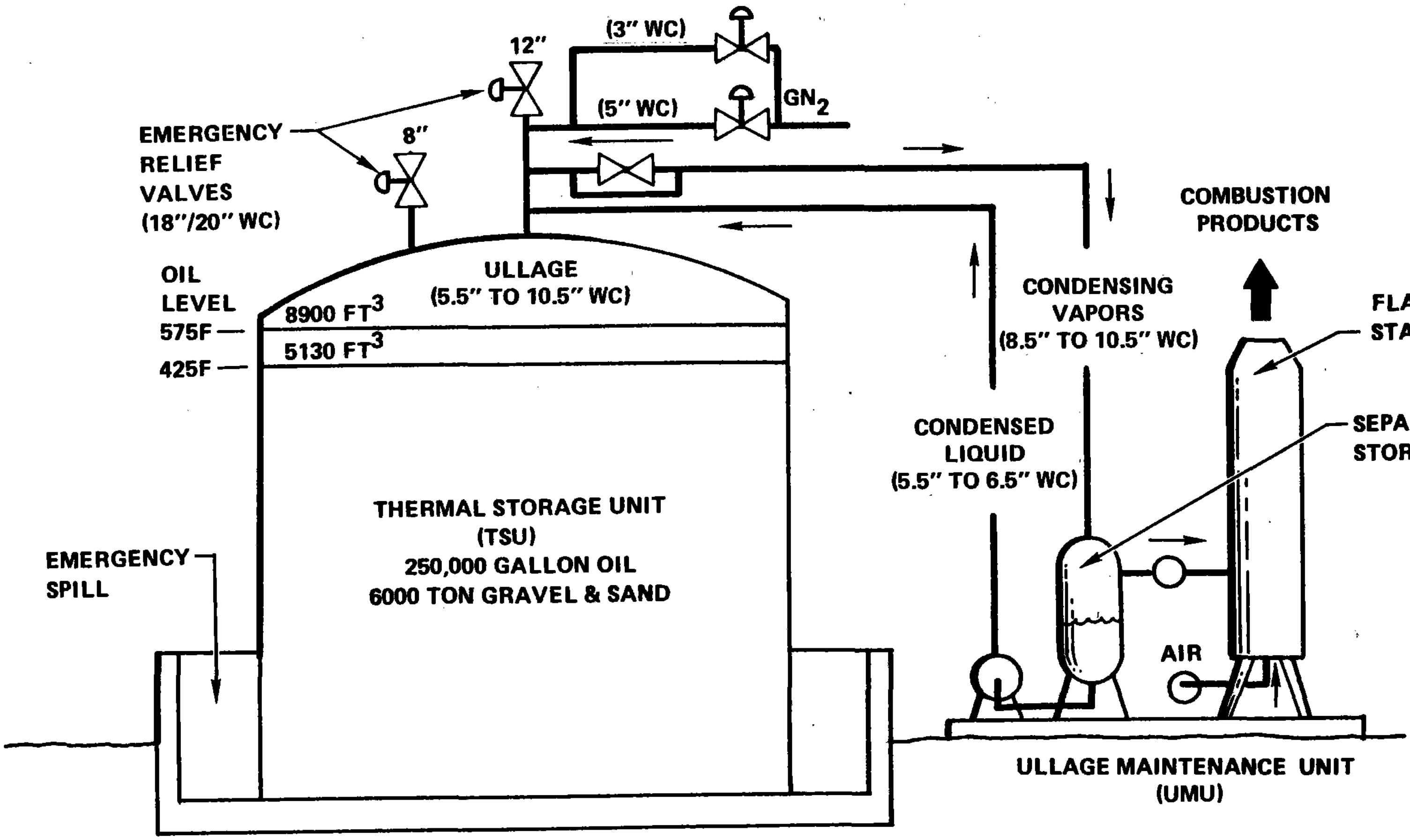
The Caloria introduced into the TSU bottom manifold flows upward through the sand/rock mixture. As the Caloria passes through the thermocline region, it absorbs heat from the high temperature rock and continues to flow upward until it passes out of the top of the tank at a nominal temperature of 575°F. During this period, the thermocline is moving toward the top of the TSU which results in a net energy extraction from the TSU. Charging and extraction functions for the TSU must be terminated when the thermocline begins to pass out of the bottom or top manifold respectively.

The ullage maintenance unit (UMU) (See Figure 3) controls the pressure in the TSU to a safe level and removes volatile degradation products generated by the Caloria at high temperature (See Table 1). The design ullage vapor flow rate (due to oil degradation plus volume change) is shown in Figure 4 and the expected daily vapor production is shown in Figure 5. The UMU also controls nitrogen flow to the TSU. At all times, the TSU is maintained at a slightly positive pressure to prevent air from leaking into the tank. The presence of oxygen in the tank will significantly increase the degradation rate of the Caloria and could produce a combustible mixture if sufficient free oxygen existed inside the TSU.

The configurational details of the UMU are shown in Figure 6, and a photo of the unit is shown in Figure 7. The remaining sections of this report describe the operation of the UMU, and provide analyses in support of these operational details.

FIGURE 3

THERMAL ENERGY STORAGE



- COMPLETELY ENCLOSED – OXYGEN FREE
- SLIGHT POSITIVE PRESSURE AT ALL TIMES
- CONDENSIBLE VAPORS RECYCLED
- NON CONDENSIBLES BURNED

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TABLE 1

CALORIA HT43 DEGRADATION PRODUCTS AT 575^{O}F

COMPONENT	MOLECULAR WEIGHT LB/LB$_{mole}$	VOL, %	BOILING PT °F
N_2	28	* 2.0	- 320
CO	28	2.4	- 312
CO_2	44	* 2.0	- 109
H_2	2	20.8	- 423
O_2	32	0.2	- 297
CH_4	16	20.5	- 263
C_2H_6	30	19.3	- 128
C_2H_4	28	0.5	- 155
C_3H_8	44	12.3	- 43.6
C_3H_6	42	2.0	- 57
n C_4H_{10}	58	8.1	31
i C_4H_{10}	58	2.4	31
n C_5H_{12}	72	6.0	97
i C_5H_{12}	72	0.4	82
H_2O	18	* 1.0	212
AVE	28.9	100	

* INERT CONSTITUENTS = 5%

FIGURE 4

ULLAGE VAPOR FLOW RATE

TOTAL OUTFLOW = OIL DEGRADATION + ULLAGE VOLUME CHANGE

MAXIMUM AT END OF CHARGING CYCLE

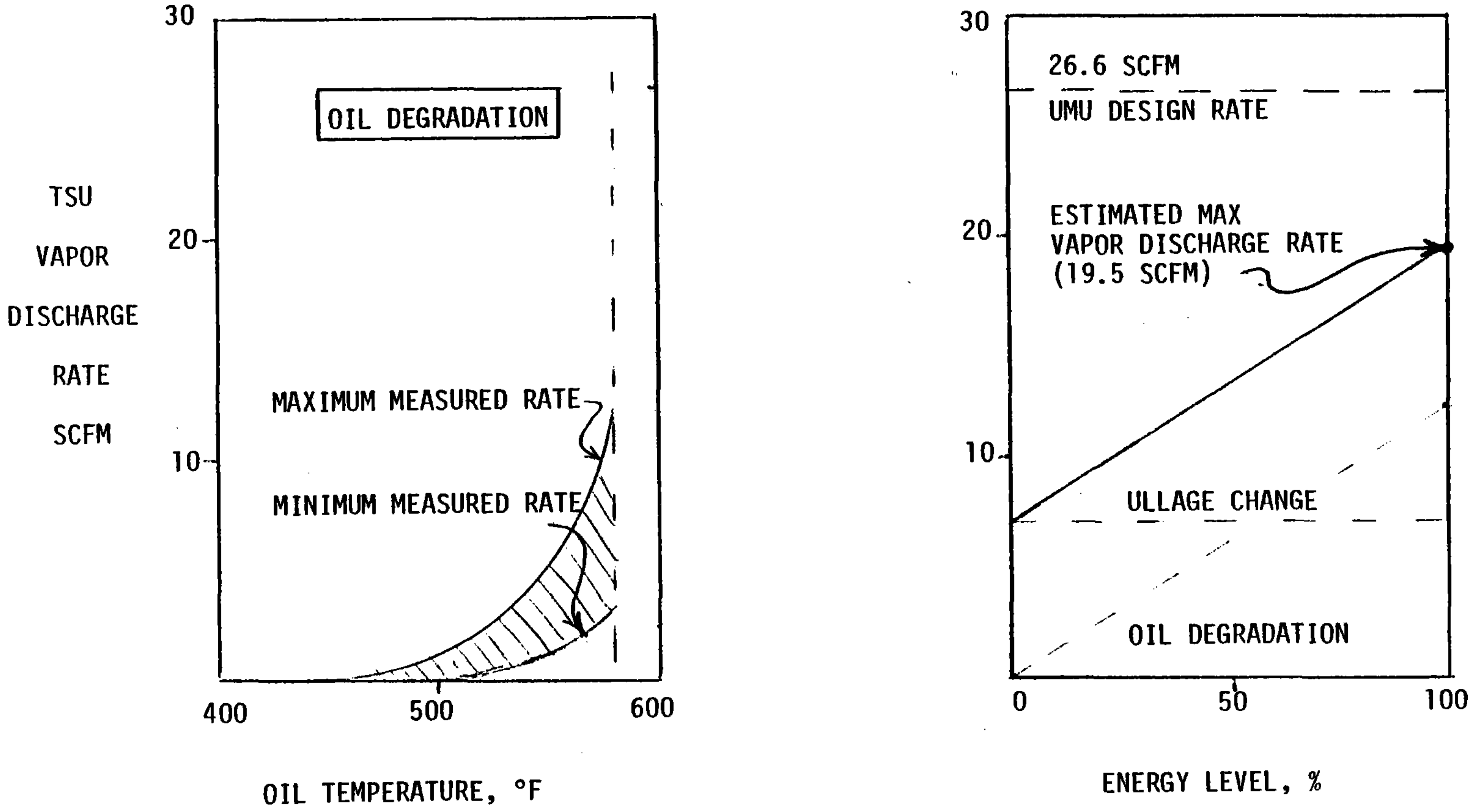


FIGURE 5
TSU DAILY FUEL VAPOR PRODUCTION

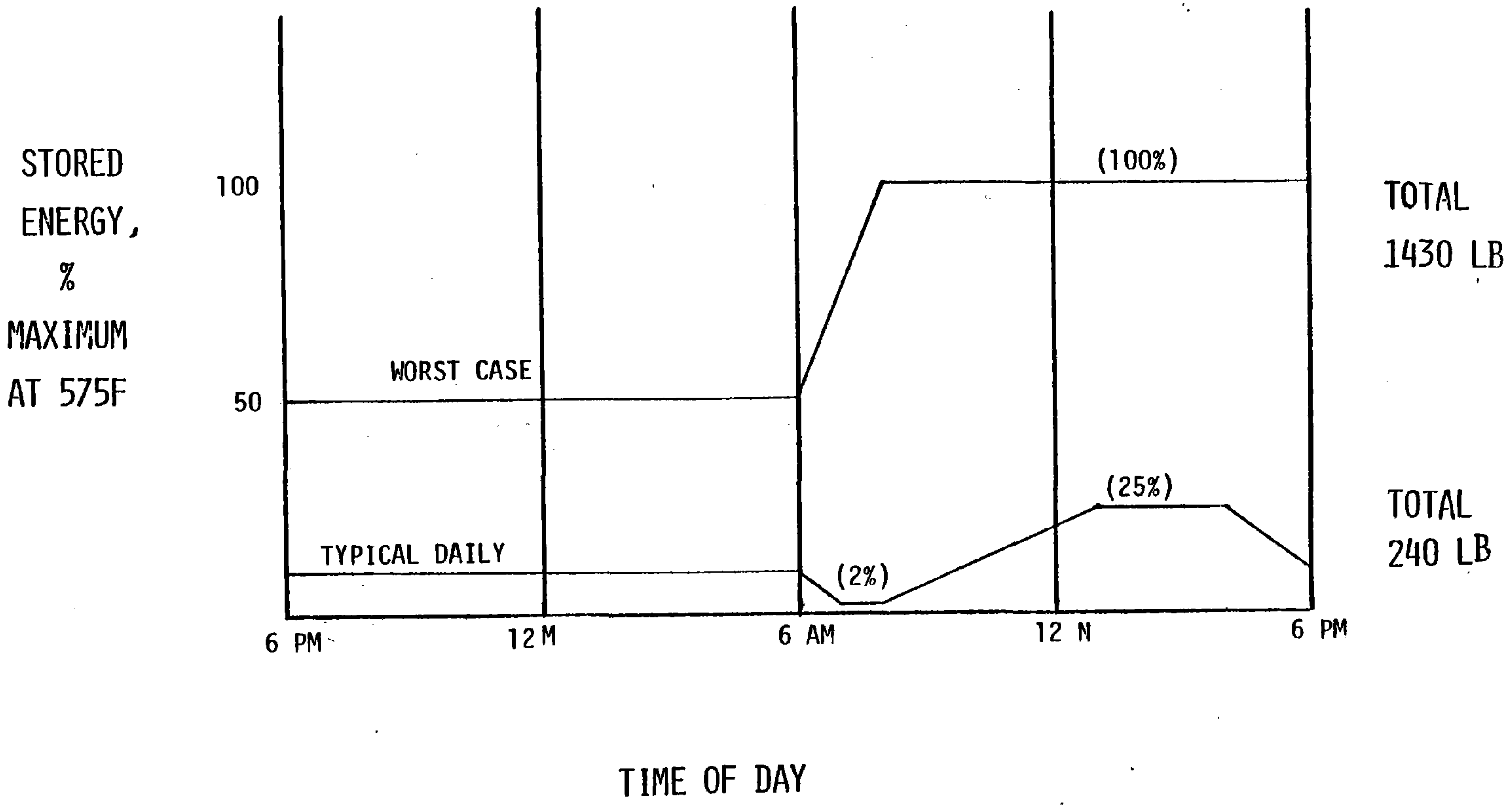
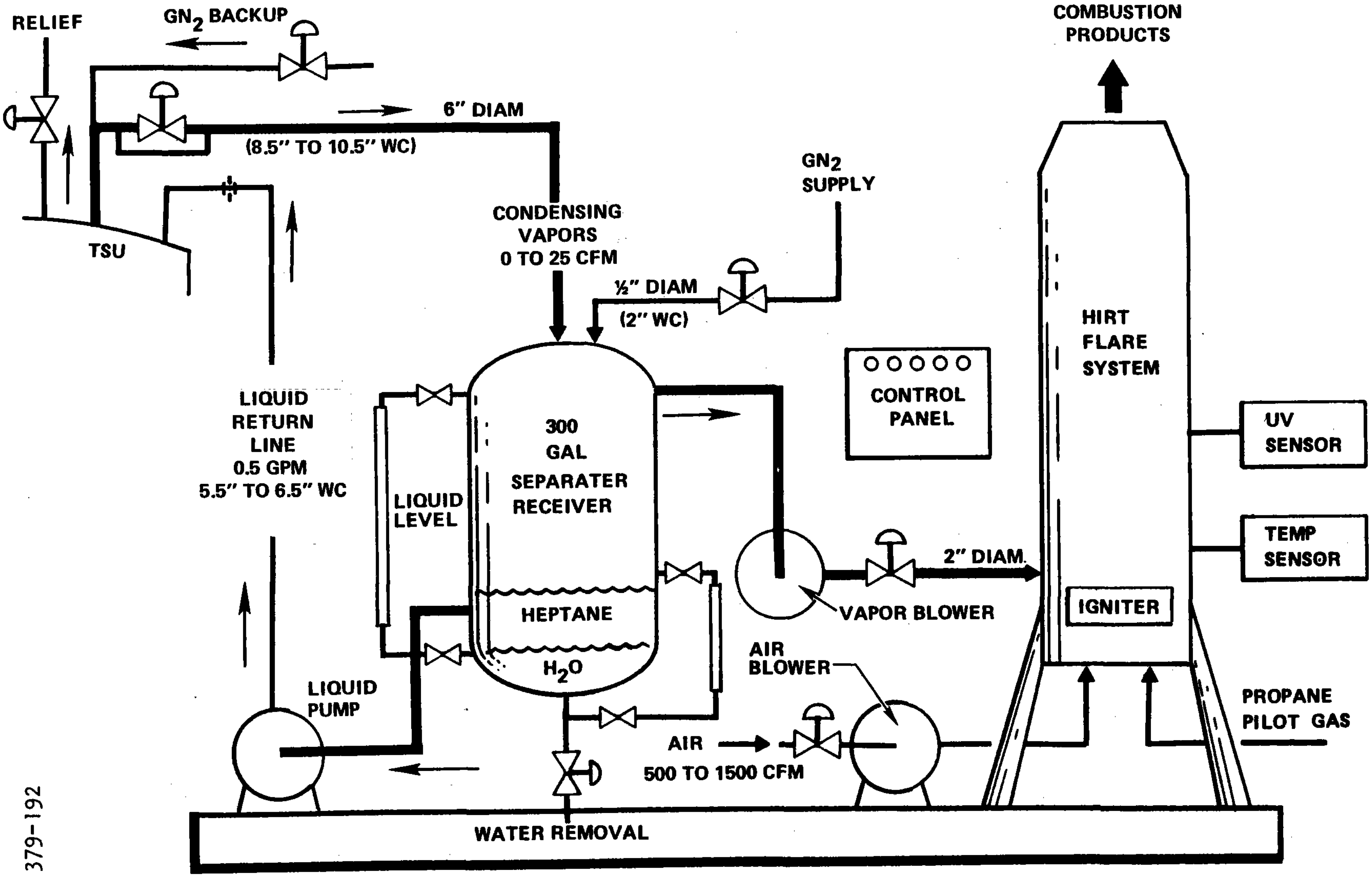


FIGURE 6

ULLAGE MAINTENANCE UNIT



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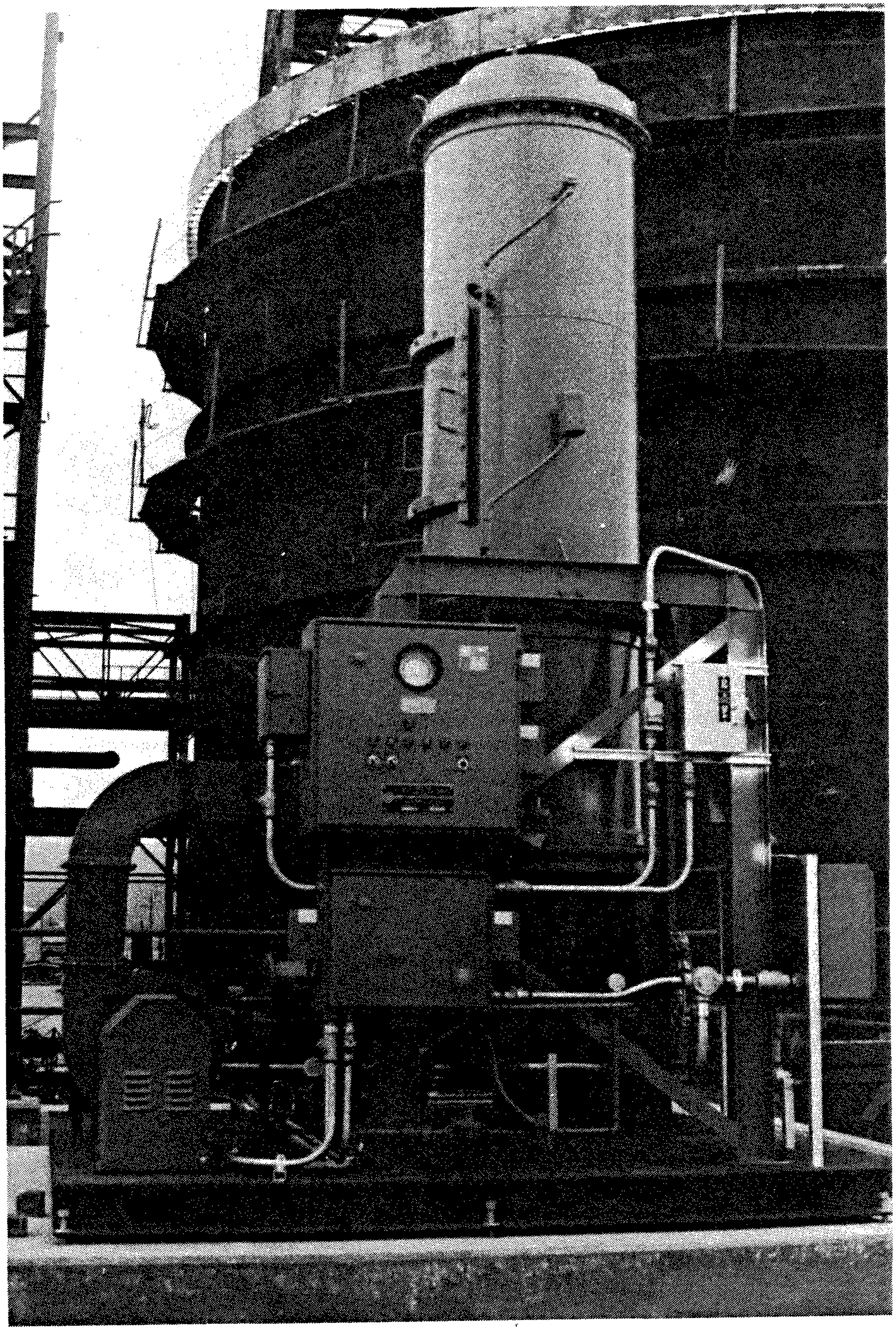

Internal Letter **Rockwell International**

Date: .28 July 1980 No: . IL 141-42-8352

TO: (Name, Organization, Internal Address)
.G. R. Morgan
.D/585-139 AA95

FROM: (Name, Organization, Internal Address, Phone)
.R. H. Morrison (4)
.D/585-141 AC35
.3431

Subject: .10 MWe Pilot Plant - Ullage Maintenance Unit (UMU), Description, Operation, and Analysis

SUMMARY

This memo contains a general description, operational description and analysis of the Ullage Maintenance Unit (UMU) which controls the venting, supply and disposal of the gas in the ullage space of the thermal storage unit (TSU).

The UMU provides an oxygen free environment in the ullage space of the TSU. Air, which can cause rapid deterioration of the heat transfer oil, is excluded by using non-oxygen bearing fuel vapors. Gaseous nitrogen is available for backup when necessary. Air is excluded by keeping the ullage space and UMU makeup system at a slight positive pressure, 7 to 11 inches of water, at all times. The oil level in the TSU changes continually as a result of heating and cooling during the charging and extraction cycles. The UMU compensates by removing and supplying gas to keep the ullage pressure in an established band. Fuel vapors, resulting from oil decomposition, that do not condense are disposed of through the UMU combustor/flare stack.

GENERAL DESCRIPTION

The UMU is a service unit to the TSU and provides the following 3 important functions:

1) Pressurization of the ullage space to a continuous and positive pressure, selected to be between 5.5 and 10.5-inches of water.
2) Venting or charging the ullage space with oxygen free gas to keep the pressure within the desired range as the liquid level changes during charging and extraction cycles.
3) Disposal of excess gas and water vapor through a combustion and drain system.

It is essential that the UMU retain the oxygen free integrity of the TSU ullage space at all time. The TSU is a sealed, closed system. Excess pressure will rupture the TSU. A pressure below atmospheric in the TSU may allow air to leak in and if too low will lead to collapse of the roof.

The UMU is contained in skid assembly SA311, Dwg, GA000-90907-M29, and is connected to the TSU ullage space by a 6" vapor line (6-UG-1-BBA), a 1" liquid line (1-HP-1-BBA) and numerous control lines. The UMU skid consists of a 300 gallon condensate storage and water separator, US; a pump to transfer liquid pressurant to the TSU, P308; a burner stack and associated blowers and controls to dispose of the waste gases; and a gaseous nitrogen supply (2-UC-2-BBA) that provides backup service when gas from the recirculating liquid phase system is inadequate to meet TSU pressure requirements.

The working fluid for pressurizing the TSU is heptane. It is stored in tank US as a liquid well below its boiling point of 209F. When returned to the TSU ullage space it vaporizes, since the ullage environment is at a temperature over 400F. When returning to tank US through line 6-UG-1-BBA the vapors condense. Tests have shown that the oil decomposition products of Caloria HT43 are a mixture of fuel vapors, some of which condense at room temperature and pressure. Thus the working fluid will be a mix of heptane and other hydrocarbon vapors. Condensed liquids remain in tank US and non-condensibles go to the burner stack through line 6-UG-1-BBA.

Waste gas blower FA-301 and air blower FA-302 provide a positive pressure to the burner stack where the fuel gases are mixed with air and burned. A pilot gas supply services a pilot flame to assure combustion at all mixture ratios. Pilot gas supply is from a pressure bottle on the UMU pad. Nitrogen for inert gas purging is supplied through line 1/2-N-4-BBD and is controlled by the flame safety control center through valve SOV-4009.

The ullage pump P-308 returns condensed liquid to the TSU through line 1-HP-1-BBA when the ullage volume is increasing. The liquid consisting of Heptane and some condensed fuel vapors revaporizes upon entering the TSU and fills the ullage space as needed.

Each day prior to operating in the extraction mode, the level of liquid in US will be checked using sight gage LG4020A, and makeup heptane will be added as necessary. Line 1-HP-2-BBA is the heptane fill line. Liquid heptane is delivered and stored on the UMU pad in 50 gallon barrels and transferred to the US storage container with a commercial, air or electrically powered, barrel pump.

Tank US, Figure 1, is a combined gas receiver, gas liquid separator and storage tank. Ullage gases and condensed vapors from the TSU enter near the top of the tank. The condensed vapors settle out and the non-condensible fraction is diverted to the burn stack. Approximately 120 gallons of heptane is required to fill the TSU ullage space during a complete extraction cycle. If none is lost the 120 gallons can be used repeatedly. However, it is expected that some will be lost and makeup heptane will be added as needed.

Tank US acting as a liquid gas separator provides an indication if water is leaking into the oil system. Water will be turned to steam which will ultimately find its way to the TSU ullage space and then into the UMU system. Steam will condense in the 6 inch vent line between the TSU and the UMU and settle to the bottom of US. Liquid level gage LG 4020B is placed in the lower region of the tank to monitor water level for drainage purposes. It is desirable that the water level remain below the connection to line 1-HP-2-BBA. Small amounts of water can be returned as a pressurizing gas for the ullage space in the TSU but repeated useage of large amounts of water may lead to oxidation of the oil. Water is drained from the bottom of the tank through manual control valve UHDV. A pad of nitrogen is available through valve PCV 4023. The pressure setting will be determined by the skid manufacturer in relation to the waste disposal system.

The gaseous nitrogen system serves as a backup and provides an independent, inert, positive pressure in the ullage space during activation before operating temperature conditions are reached. Gaseous nitrogen is supplied from the main supply at 130 psig through a 1-1/2 inch line and enters the UMU skid at interface U71. The gaseous nitrogen flows through a series of regulators, shutoff valves, and flowmeters, line UG-2-BBA, and into the TSU at interface U101. Final regulation into the TSU is by valve PCV-4006 and PCV-4007. The GN_2 system is completely mechanical. Line 1/2-UG-3-BBA provides sensing to valve PCV-4006 from TSU interface U111.

OPERATION

Reference drawing GA000-90907-M29

The UMU has 4 principal operating circuits. These are:

1. Vapor inlet and condensing
2. Condensate return
3. Waste gas disposal
4. Gaseous nitrogen supply

These fluid circuits are interconnected and controlled by a network of valves with signals from pressure sensors mounted on the TSU. Pressures, temperatures, liquid levels and flows are monitored with sight gages and electrical recording transducers.

Vapor Inlet and Condensing

During the charging mode the fluid level rises in the TSU (V303) and a high pressure signal opens valve AOV-4014 venting excess gases in the ullage space through line 6-UG-1-BBA to the receiver and storage vessel US. Condensible vapors collect in tank US and non-condensibles pass through into the waste gas disposal system through valve MOV-4015.

Condensate level in tank US is established by sight gage LG4020A and LG4020B. When the TSU is near or in the fully discharged state the water and excess condensate will be drained from tank US through valve UHDV and/or makeup heptane will be added to bring the condensate to the correct operating level (200 gallons of condensate). Heptane filling is through line 1-HP-2-BBA and valve UHIS-1. Heptane is stored in 50 gallon (type) barrels and is transferred to tank US through a portable electric or pneumatic barrel pump.

Condensate Return

During the extraction mode, and whenever more gas is needed in the TSU ullage space, a low pressure signal activates ullage pump P308 and condensate is injected into the TSU ullage space through line 1-HP-10BBA. The condensate vaporizes when heated to the operating temperature of the top of the TSU bed (500F or higher). The pump cycles on and off to meet the ullage gas demand. When the pump is off liquid is prevented from returning to Tank US by check valve UHCK. Isolation of the pump for maintenance is provided by valves UHIS-2 and USIS-3. Approximately 120 gallons of condensate is required to supply vapor during a full extraction.

Waste Gas Disposal

Gases and vapors that do not condense into tank US are transferred to the waste gas disposal system through line 6-UC-1-BBA and valve MOV-4015. Valve MOV-4015 actuates simultaneously with valve AOV-4014. Waste gas blower FA301 and air blower FA302 are synchronized with controls in the burner stack and pilot gas supply to provide controlled ignition and combustion of the waste gases.

Pilot gas supply is controlled through SOV-4016 and PCV-4012 to insure combustion during all operating conditions. The flow and ignition of waste and pilot gas is controlled through the flame safety control network that will be supplied by the manufacturer of the UMU skid assembly.

The principal purpose of burning the non-condensible gases is for safety and ease of disposal. Emission regulations do not require that every fuel molecule entering the system be burned. When the waste gas is mostly nitrogen it may be beyond the lean ignition limits and a mixture containing unburned fuel vapors may leave the stack. However, the pilot will operate at all times to insure that mixtures beyond the combustion lean limit will burn.

Gaseous Nitrogen Supply

Gaseous nitrogen at 130 ± 20 psig is supplied to the skid at interface U71. Valve PCV-4004 provides 1st stage regulation to 25 ± 5 psig. Final regulated pressure is controlled by PCV-4006 which is set for 5 in. WC and PCV-4007 set at 3 in. WC. Feedback of ullage gases to the GN_2 system is prevented by check valve UNCK-1. Valves PCV-4006 and PCV-4007 are externally sensed, spring loaded regulators that sense TSU ullage pressure.

Control

The operating set points for the UMU (and TSU) are shown in Figure 2. The "normal" operating range for the pressure in the TSU is between 5.5 and 10.5 inches water column (WC). Above 10.5 in. WC of pressure the UMU venting is activated to remove gases from the TSU. Below 5.5 in. WC pressure the UMU is activated to supply gas to the TSU.

When the ullage volume is decreasing and/or pressure is increasing, valves AOV-4014 and MOV-4015 are opened and the waste gas disposal system is activated. Ullage gas flows through line 6-UG-1-BBA into tank US. Vapors that can condense form liquid in the line and are tapped in tank US. Noncondensible vapors flow into the waste gas disposal system and out the burner stack.

If the pressure reaches 13 in. WC, the upper limit of the operating band, a high pressure alarm is activated and personnel are alerted to an excessive pressure condition.

As ullage pressure increases the redline unit terminates operation of the extraction and charging loops at 16 in. WC. At 18 in. WC low flow relief valve PSV-4018 opens. The high flow relief valve on the TSU opens at 20 in. WC. With decreasing pressure the ullage pump, P308, is activated at 5.5 in. WC. The low pressure alarm is activated at 5 in. WC. and the low flow GN_2 supply becomes active. The high flow GN_2 supply becomes active at 3 in. WC. Continually decreasing pressure activates the redline unit which shuts down the charging and extraction flow loops at 2 in. WC.

Instrumentation

Monitoring of the TSU is accomplished by remote sensors and in-situ sight gages. Sensors for control steps shown in Figure 2 are mounted on the thermal storage unit V303. Venting of the TSU is controlled by ullage pressure sensor PT4008 thru the ILS. The ILS is set to actuate the venting and waste gas disposal system at 10.5 in. WC. In the decreasing pressure mode it terminates venting at 8.5 in. WC. Control of liquid condensate flow to the TSU is also determined by PT-4008 thru the ILS. When pressure is decreasing the ILS activates the condensate pump at 5.5 in. WC. When increasing in pressure, operation is terminated at 6.5 in. WC. TSU ullage pressure is monitored in the control center by PT4008. Sight gage PI4013 provides reading of the TSU ullage pressure at the tank.

Gaseous nitrogen supply and operating pressures are monitored by sight gages PI 4003, PI 4005, and PI 4007. Pressure of gaseous nitrogen is monitored for the control center by PTX 4052.

Open/close position switches are provided for valves AOV-4014 and MOV-4015 for control center monitoring of these main venting valves.

Operation of components in the waste disposal system is controlled by the flame safety control subsystem. These will be interlocked in a manner that will assure safe operation at all times. The interlock network and operation will be established by the manufacturer of the UMU skid.

ANALYSIS

The analyses of the UMU gases, vapors, and liquid flows are contained in the following pages. Fifteen different sets of calculations have been included. Table 1 is a summary of the results of these calculations. Included are comments on the impact of specific calculated values on the sizing and operation of the UMU. The numbers in the left column refer to specific conditions in the calculations that follow. Discussions of techniques and assumptions are included with the calculations.

R. H. Morrison

R. H. Morrison
Valves & Controls

RHM:cc

REFERENCES: (1) Burolla, V.P.,"Prediction of Yearly Fluid Replenishment Rates for Hydrocarbon Fluids in Thermal Energy Storage Systems,"Sandia Laboratories, Report SAND79-8209, April 1979

(2) Hallet, R.W. and Gervais, R.L., "Central Receiver Solar Thermal Power System, Preliminary Design Report, Thermal Storage Subsystem," McDonnell Douglas Company, Report MDC G6776, October 1977

cc:	E. G. Spencer	AC35
	D. G. Landy	AC35
	J. G. Absalom	AA95
	A. Djordjevic	SS11

PREPARED BY: R. MORRISON	Rocketdyne Division Rockwell International	PAGE NO.
CHECKED BY:		REPORT NO.
DATE:	CONCEPTUAL SCHEMATIC OF HEPTANE TANK (US)	

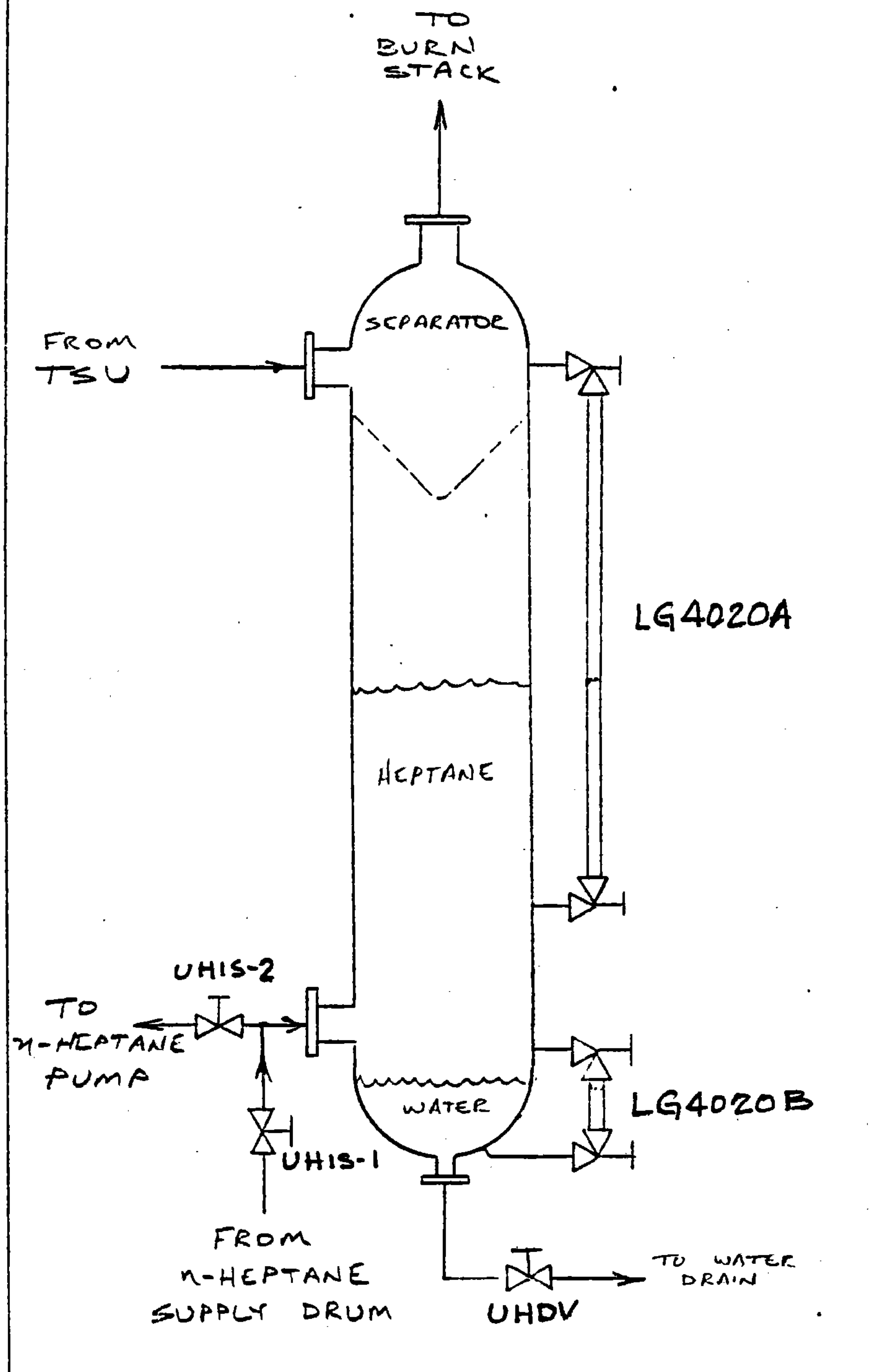

Figure 1

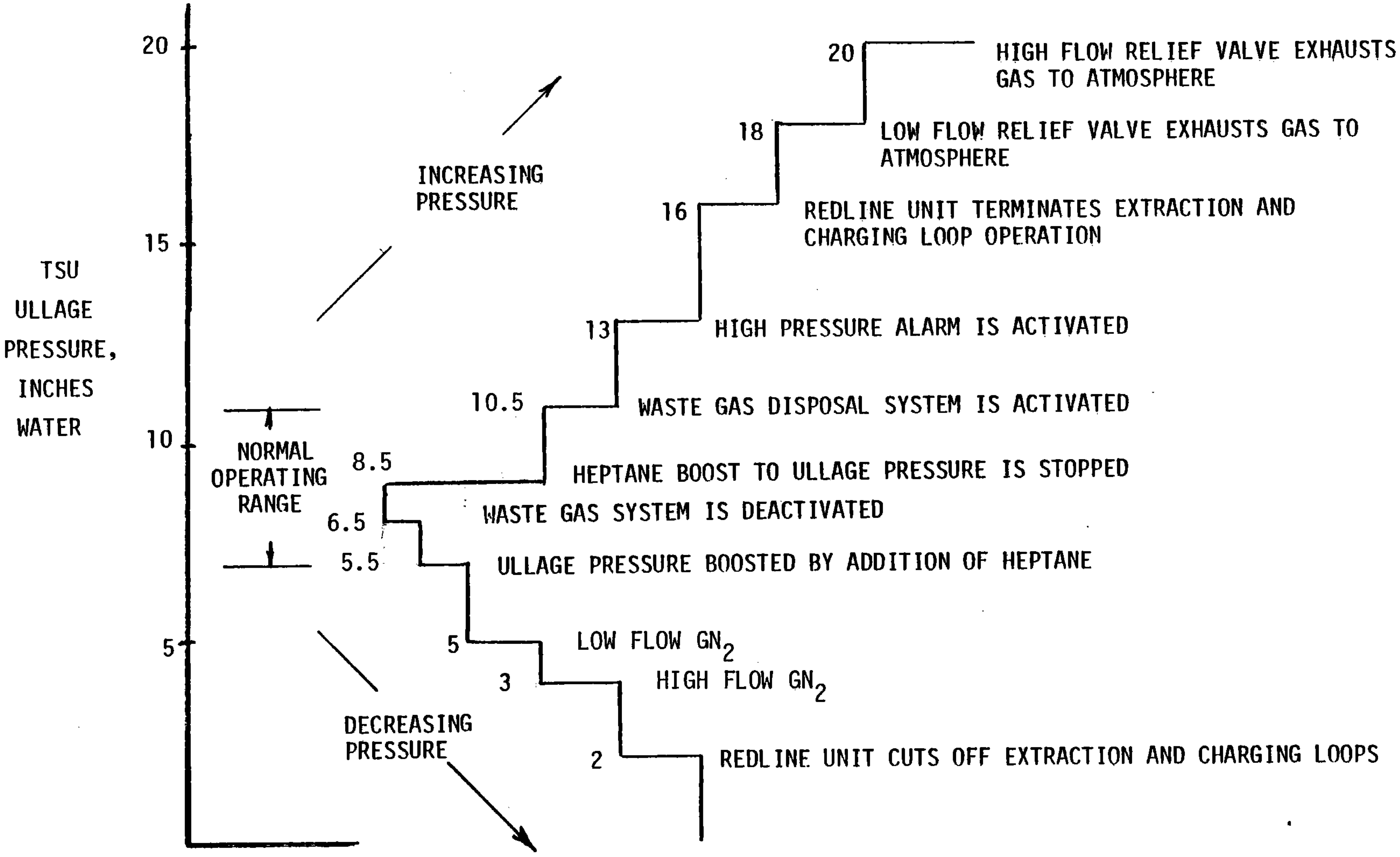

FIGURE 2. OPERATIONAL PRESSURE SETPOINTS FOR ULLAGE MAINTENANCE UNIT

TABLE 1. UMU DESIGN CALCULATIONS SUMMARY

NO.	DESCRIPTION	CALCULATED VALUE *	COMMENT
1	Max. rate of thermal contraction or expansion of HT43	741 ft^3/hr	Oil level rises and falls at a max. rate of 0.262 ft/hr
2	Density of oil degradation products at 580°F	0.0388 lb/ft^3	Based on vapor analysis from Reference 1
3	Max. rate of oil degradation product formation	1560 ft^3/hr	Based on tests from Reference 1 and 2
4	Max. flowrate of ullage gases out of TSU	2300 ft^3/hr	End of charging, 1 + 3
5	Max. flowrate of degradation products to burner	24.3 SCFM	Same as 4, no vapors condensing
6	Max. flowrate of Heptane leaving TSU	0.933 gpm	Beginning of charging, bed at 425 F
7	Max. flowrate of Heptane into TSU	0.356 gpm	Heptane pump flow selected to be 1.5 gpm
8	Volume of Heptane req'd for one day of operation	122 gal	Heptane tank capacity to be 300 gal.
9	Max. req'd flowrate of GN_2 req'd to back up Heptane	7.69 SCFM	GN_2 flow capacity selected to be 30 SCFM
10	Volume of GN_2 req'd for 1 day of operation	2640 SCFD	Based on 1 complete extraction, GN_2 only, no Heptane
11A	Drainage rate of 70°F TSU with 30 SCFM GN_2 supply	224 gpm	Density of GN_2 dependent on bed temperature
11B	Drainage rate of 425°F TSU with 30 SCFM GN_2 supply	367 gpm	
12A	Time to drain 70°F TSU	17.8 hrs	
12B	Time to drain 425°F TSU	12.9 hrs	
13A	Volume GN_2 to drain 70°F TSU	32,000 SCF	
13B	Volume GN_2 to drain 425°F TSU	23,000 SCF	

* Gallons refer to liquid state, ft^3 to gaseous state

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DATA SHEET

ULLAGE PRESSURE = 15.0 PSIA, STD. = 14.7 PSIA

CALORIA HT43

$\rho_{425^\circ F} = 44.91 \text{ lb/ft}^3$ $\quad \rho_{580^\circ F} = 40.85 \text{ LB/ft}^3$

TOTAL MASS = 1,709,000 LBS

$C_{p_{425}} = 0.61 \text{ BTU/lb°F}$ $\quad C_{p_{580}} = 0.69 \text{ BTU/lb°F}$

ROCK/SAND

$C_{p_{425}} = 0.23 \text{ BTU/lb°F}$ $\quad C_{p_{580}} = 0.25 \text{ BTU/lb°F}$

$\rho = 169. \text{ lb/ft}^3$

n-HEPTANE

$\rho_{70^\circ F} = \left(0.68376_{4}^{20}\right)(62.4) = 42.7 \text{ lb/ft}^3$

Z FACTOR RANGES FROM 0.95 to 1.0 IN OPERATING RANGE
ASSUME VAPOR BEHAVES AS PERFECT GAS. AT
15 PSIA AND GREATER THAN 100°F SUPERHEAT.

$$\rho_{391} = \frac{(15.0)(100.21)}{(10.73)(851)} = 0.1646 \text{ lb/ft}^3$$

$$\rho_{425} = 0.1646\left(\frac{851}{885}\right) = 0.1583 \text{ lb/ft}^3$$

$$\rho_{580} = 0.1646\left(\frac{851}{1090}\right) = 0.1347 \text{ lb/ft}^3$$

GASEOUS NITROGEN

$\rho_{LN_2} = 50.4 \text{ lb/ft}^3$
(-320°F)

$$\rho_{70^\circ F,\,STANDARD} = \frac{(14.7)(28.02)}{(10.73)(530)} = 0.0724 \text{ LB/ft}^3$$

$$\rho_{425^\circ F} = \frac{(15)(28.02)}{(10.73)(885)} = 0.0443 \text{ LB/ft}^3$$

$$\rho_{580^\circ F} = \frac{(15)(28.02)}{(10.73)(1090)} = 0.0377 \text{ LB/ft}^3$$

$C_{p_{GN_2}} = 0.24 \text{ BTU/lb°R}$

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1. WHAT IS THE MAXIMUM RATE OF VOLUME CHANGE IN THE ULLAGE SPACE DUE THERMAL CONTRACTION AND EXPANSION OF FLUID?

DISCUSSION: THE TSU CAN FULLY CHARGE OR FULLY DISCHARGE AT ITS MAXIMUM RATE OF FLOW IN FOUR HOURS. ASSUME THAT IN THIS TIME ALL OF THE ROCKS & SAND BETWEEN THE UPPER & LOWER MANIFOLD CHANGE TEMPERATURE FROM 580 TO 425 AND VICE VERSA. ALSO, A NET QUANTITY OF OIL EQUAL TO THAT OCCUPYING THE VOID SPACE IN THE BED AT 425°F UNDERGOES THE SAME CHANGE. ALL FLOWING OIL GOES INTO THE ROCK/SAND (I.E. THERE IS NO OPERATION IN WHICH HOT OIL ENTERS THE UPPER MANIFOLD WITHOUT SIMULTANEOUS COOLING OF OTHER OIL AT SOME POINT IN THE TSU).

GIVEN: FROM TSS ANALYSIS REPORT (4-12)

VOID SPACE IN ROCK/SAND BED = 28,373 ft^3

VOID SPACE IN 10¾" GRADED BED ABOVE LOWER MANIFOLD = 836 ft^3

VOID SPACE IN 6½" OF ROCK ABOVE BOTTOM OF UPPER MANIFOLD = 589 ft^3

29,798 ft^3

TOTAL VOID SPACE IN ACTIVE PORTION OF TSU = 29,800 ft^3

TIME = 4 HRS

DENSITY OF 580 °F OIL = 40.85 lb/ft³
DENSITY OF 475 °F OIL : 44.91 lb/ft³

<u>CALCULATION:</u>

$$\dot{V} = \frac{M_{OIL}\,(lb)}{t\,(hr)}\left(\frac{1}{\rho_1}-\frac{1}{\rho_2}\right)\frac{(ft^3)}{(lb)}$$

$$M_{OIL} = \rho_{OIL} V_{VOID} = 44.91\left(\frac{lb}{ft^3}\right) 29{,}800\ (ft^3)$$

$$M_{OIL} = 1.34 \times 10^6 \ lb$$

$$\dot{V} = \frac{1.34\times10^6}{4}\left(\frac{1}{40.85}-\frac{1}{44.91}\right)$$

$$\dot{V} = 741 \ \frac{ft^3}{hr}$$

<u>CONCLUSION:</u> THE MAXIMUM RATE OF VOLUME CHANGE DUE TO THERMAL EXPANSION OR CONTRACTION OCCURS DURING MAX. FLOWRATE CONDITIONS IN CHARGING OR EXTRACTION AND IS NO GREATER THAN 741 FT³/HR IN EITHER CASE.

THIS CALCULATION IS CONSERVATIVE BECAUSE DURING THE ACTUAL CHARGING AND EXTRACTION CYCLES, THE CYCLE IS TERMINATED BEFORE THE ENTIRE BED IS BROUGHT TO TEMPERATURE.

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2. DETERMINE THE DENSITY OF THE OIL DEGRADATION PRODUCTS.

<u>ASSUME</u>: GAS BEHAVES AS AN IDEAL SOLUTION
WITH PERFECT GAS PROPERTIES,
ULLAGE PRESSURE = 15.0 PSIA

GIVEN:

COMPONENT	M.W. (LB/LBmole)	VOL %	BOILING PT. (°F)
N_2	28	2.0	-320
CO	28	2.4	-312
CO_2	44	2.0	-109
H_2	2	20.8	-423
O_2	32	0.2	-297
CH_4	16	20.5	-263
C_2H_6	30	19.3	-128
C_2H_4	28	0.5	-155
C_3H_8	44	12.3	-43.6
C_3H_6	42	2.0	-54
$n\text{-}C_4H_{10}$	58	8.1	31
$i\text{-}C_4H_{10}$	58	2.4	31
$n\text{-}C_5H_{12}$	72	6.0	97
$i\text{-}C_5H_{12}$	72	0.4	82
H_2O	18	1.0	212
TOTAL		99.9	

CALCULATION: $\text{AVG. M.W.} = \sum \frac{\text{LBmole COMPONENT}}{\text{LBmole TOTAL}} \; \frac{\text{LB COMPONENT}}{\text{LBmole COMPONENT}}$

$$\frac{\text{LBmole COMPONENT}}{\text{LBmole TOTAL}} = \frac{\text{VOL. COMPONENT}}{\text{VOL. TOTAL}} = \frac{\text{VOL \%}}{100}$$

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$$\text{M.W. COMPONENT} = \frac{\text{LB COMPONENT}}{\text{LB MOLE COMPONENT}}$$

$$\text{AVG. M.W.} = \sum \left(\frac{\text{VOL\%}}{100}\right)(\text{M.W. COMPONENT})$$

COMPONENT	$\frac{\text{VOL\%}}{100}$	$\frac{\text{VOL\%}}{100}$ (M.W.)
N_2	0.020	0.560
CO	0.024	0.672
CO_2	0.020	0.880
H_2	0.208	0.416
O_2	0.002	0.064
CH_4	0.205	3.280
C_2H_6	0.193	5.790
C_2H_4	0.005	0.140
C_3H_8	0.123	5.412
C_3H_6	0.020	0.840
$n\text{-}C_4H_{10}$	0.081	4.698
$i\text{-}C_4H_{10}$	0.024	1.392
$n\text{-}C_5H_{12}$	0.060	4.320
$i\text{-}C_5H_{12}$	0.004	0.288
H_2O	0.010	0.180
TOTAL		28.9

DENSITY IS A FUNCTION OF TEMPERATURE. ACCORDING TO THE TSS ANALYSIS REPORT (pg. 4-67) THE TEMPERATURE OF THE CEILING VARIES FROM 440°F AT THE WALL TO 282 °F 1.45 ft. RADIALLY INWARD AT A FLUID SURFACE TEMPERATURE OF 500°F

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ASSUME AN AVERAGE ULLAGE TEMPERATURE OF $\frac{500 + 282}{2} = 391\ °F$

$$\rho_{D.P.\ 391°F} = \frac{(15.0)\ PSIA\ LB_{mol}\ °R\ (28.9)\ LB}{(10.73)\ PSIA\ Ft^3\ LBMOL\ (851)\ °R}$$

$$\rho_{D.P.\ 391°F} = 0.0475\ LB/Ft^3$$

AT MAX. TEMP. (580°F)

$$\rho_{D.P.} = \frac{(15.0)(28.9)}{(10.73)(1090)} = 0.0388$$

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3. DETERMINE THE MAXIMUM RATE OF OIL DEGRADATION PRODUCT FORMATION.

DISCUSSION: THE MAXIMUM RATE OF DEGRADATION PRODUCT FORMATION OCCURS WHEN THE MAXIMUM QUANTITY OF OIL IS AT ITS MAXIMUM TEMPERATURE

ASSUME: ALL THE OIL IN THE TSU IS AT 580 °F.

GIVEN: RATE OF PRODUCT FORMATION IN BED AT 580 °F = 0.000092 LB/LB_{OIL} HR = R_1

RATE OF PRODUCT FORMATION ABOVE BED AT 580 °F = 0.00001375 LB/LB_{OIL} HR = R_2

TOTAL VOID SPACE IN BED = 32,084 Ft^3

TOTAL MASS OF OIL = 1,704,000 LB

DENSITY OF OIL AT 580 °F = 40.85 $\frac{LB}{Ft^3}$

DENSITY OF DEGRADATION PRODUCTS AT 580 °F = 0.0388 $\frac{LB}{Ft^3}$

CALCULATIONS:

M_1 = MASS OF OIL IN BED

$M_1 = (32{,}084\ Ft^3)(40.85\ LB/Ft^3) = 1.311 \times 10^6\ LB$

M_2 = MASS OF OIL ABOVE BED

$M_2 = (1.704 - 1.311) \times 10^6 = 0.393 \times 10^6\ LB$

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$M_1R_1 + M_2R_2 =$ RATE OF DEGRADATION PRODUCT FORMATION $= \dot{M}$

$$\dot{M} = (1.311 \times 10^{6})(4.2 \times 10^{-5}) + (0.393 \times 10^{6})(1.375 \times 10^{-5})$$

$$\dot{m} = 55.062 + 5.409 = 60.47 \ \frac{LB}{HR}$$

$$\dot{V} = \frac{\dot{m}}{\rho} = \frac{60.47 \ LB}{HR} \ \frac{FT^3}{0.0388 \ LB} = 1559 \ \frac{FT^3}{HR}$$

$$\frac{\dot{M}}{M} = \frac{60.47}{1,704,000} = 0.0000353 \ LB/LB \ HR$$

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4. DETERMINE THE MAXIMUM FLOWRATE OF ULLAGE GASES OUT OF THE TSU.

DISCUSSION: THE MAXIMUM FLOWRATE OF ULLAGE GASES OUT OF THE TSU OCCURS NEAR THE END OF THE CHARGING CYCLE WHEN THE MAXIMUM RATE OF DEGRADATION PRODUCT FORMATION COMBINES WITH THE MAXIMUM RATE OF ULLAGE CONTRACTION DUE TO THERMAL EXPANSION OF THE CALORIA HT43.

GIVEN:

MAX. RATE OF DEGRADATION PRODUCT FORMATION $= 1559 \frac{Ft^3}{HR}$

MAX. RATE OF ULLAGE CONTRACTION $= 741 \frac{Ft^3}{HR}$

CALCULATIONS:

MAX RATE OF ULLAGE GAS FLOW OUT OF TSU $= 1559 + 741 = 2300 \frac{Ft^3}{HR}$

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5. DETERMINE THE MAXIMUM FLOWRATE OF DEGRADATION PRODUCTS TO BURNER.

DISCUSSION: IF THE TSU IS ALLOWED TO SIT FOR A LONG PERIOD OF TIME WITH SOME MINIMUM QUANTITY OF ITS CONTENTS ABOVE 580 °F, DEGRADATION PRODUCTS WILL EVENTUALLY OCCUPY ALL OF THE ULLAGE SPACE. NEARLY ALL OF THE n-HEPTANE WILL HAVE BEEN REMOVED BY THE PERIODIC PURGES NECESSARY TO MAINTAIN ULLAGE PRESSURE. IF CHARGING IS THEN RESTARTED AND BROUGHT TO ITS MAXIMUM FLOWRATE THEN THE MAXIMUM FLOWRATE OF DEGRADATION PRODUCTS OUT OUT OF THE ULLAGE SPACE IS EQUAL TO THE MAXIMUM FLOWRATE OF ULLAGE GASES.

ASSUME: FLOWRATE AND ENVIRONMENTAL CONDITIONS IN THE WORST CASE ARE SUCH THAT NO PART OF THE DEGRADATION PRODUCTS ARE ABLE TO CONDENSE BEFORE REACHING THE BURNER.

GIVEN: THE MAXIMUM FLOWRATE OF ULLAGE GASES $= 2300 \frac{Ft^3}{HR}$

DENSITY OF D.P. $= 0.0475 \; {}^{LB}/_{Ft^3}$

CALCULATION:

$$\rho_{D.P.\ @\ STD.} = \frac{PM}{RT} = \frac{(14.7)(28.9)}{(10.73)(530)} = 0.075 \frac{LB}{Ft^3}$$

14.7 PSIA
70 °F

$$\dot{V}_{STD} = \dot{V}_{580°F} \cdot \frac{\rho_{580°}}{\rho_{STD}}$$

$$\dot{V}_{STD} = 2300 \frac{Ft^3}{HR} \left(\frac{0.0475}{0.075}\right) \frac{HR}{60\ MIN.}$$

$$\dot{V}_{STD} = 24.3 \text{ SCFM}$$

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6. DETERMINE THE MAXIMUM FLOWRATE OF n-HEPTANE OUT OF TSU.

DISCUSSION: AT 425°F THE RATE OF DEGRADATION PRODUCT FORMATION IS NEGLIGIBLE. ASSUMING THE TANK HAS BEEN BROUGHT TO 425°F AND HAS REMAINED AT THAT TEMPERATURE FOR A LONG PERIOD OF TIME, THE ULLAGE SPACE WILL BE FILLED WITH ONLY n-HEPTANE VAPORS. FURTHERMORE, THE AVERAGE TEMPERATURE OF THE ULLAGE SPACE WILL DROP BY 75° FROM THAT WHEN THE TOP LAYER OF OIL IS AT 500°F. THE NEW AVERAGE TEMPERATURE IS 249°F. SOME n-HEPTANE MAY EVEN BE CONDENSING ON THE ROOF. WHEN CHARGING IS AGAIN STARTED, AT ITS MAXIMUM FLOWRATE, THE HEPTANE VAPORS WILL BE FORCED OUT OF THE TANK BY THERMAL EXPANSION OF THE FLUID. ASSUME ALSO THAT THE AVERAGE TEMPERATURE OF THE ULLAGE GASES RISES AT A MAXIMUM RATE OF 75°/1/4 HR. = 5°/MIN. THE MAXIMUM FLOW OF n-HEPTANE OCCURS WHEN THE MAXIMUM RISE IN ULLAGE GAS TEMPERATURE IS OCCURING.

GIVEN: RATE OF FLUID VOLUME CHANGE = 791 ft³/HR

$$\rho_{n\text{-HEPTANE @ 244°F}} \; 0.1696 \frac{(851)}{(704)} \quad 0.1990 \text{ lb/ft}^3$$

$$\rho_{n\text{-HEPTANE @ 249°F}} - 0.1646 \frac{(851)}{709} \quad 0.1976 \text{ lb/ft}^3$$

ROOF EDGE HEIGHT - 425°F FLUID HEIGHT = 31 INCHES

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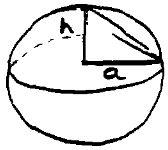
TANK DIAMETER = 60 ft.

ROOF IS A SEGMENT OF A SPHERE WITH AN 18" RISE FROM TANK EDGE TO CENTER & SPHERICAL RADIUS OF 301.58 Ft.

CALCULATION:

ULLAGE VOLUME

VOLUME OF DOME ROOF = VOLUME OF ZONE AND SEGMENT OF ONE BASE



R = RADIUS OF SPHERE

$$V = \frac{1}{3}\pi h^2(3R-h)$$

$$h = \frac{18}{12}\ \text{ft}$$

$$R = 301.58\ \text{ft}$$

$$V = \frac{1}{3}\pi\left(\frac{18}{12}\right)^2\left(3(301.58)-\frac{18}{12}\right)$$

$$V = 2128\ \text{ft}^3$$

VOLUME OF CYLINDER FROM FLUID SURFACE TO EDGE OF ROOF.

$$V = \frac{\pi D^2}{4}h = \frac{\pi(60)^2}{4}\left(\frac{31}{12}\right) = 7{,}304\ \text{ft}^3$$

MAXIMUM ULLAGE VOLUME = 9,432 ft^3

CHANGE IN VOLUME DUE TO HEATING OF GASES

$$m_1 = \rho_1 V_1 = \left(0.1990\ \frac{\text{lb}}{\text{ft}^3}\right)\left(9432\ \text{ft}^3\right) = 1877\ \text{lb}$$

$$m_2 = \rho_2 V_2 = \left(0.1976\ \frac{\text{lb}}{\text{ft}^3}\right)\left(9432\ \text{ft}^3\right) = 1864\ \text{lb}$$

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$$\Delta m = 1877 - 1869 = 13 \text{ lb}$$

$$\dot{m} = \left(\frac{13 \text{ lb}}{5 \text{ min}} \right) \left(\frac{60 \text{ min}}{\text{hr}} \right) = 156 \text{ lb/hr}$$

$$\rho_{avg} = 0.1983 \text{ lb/ft}^3$$

$$\Delta V = 156 \frac{\text{lb}}{\text{hr}} \; \frac{\text{ft}^3}{0.1983 \text{ lb}} = 787 \frac{\text{ft}^3}{\text{hr}}$$

TOTAL FLOWRATE OF ULLAGE GASES OUT OF TSU

$$\dot{Q} = 741 + 787 = 1528 \text{ ft}^3/\text{hr}$$

THE FIRST n-Heptane FLOWING OUT OF THE TSU WILL BE AT THE TEMPERATURE OF THE ROOF ≈ 210 °F

$$\rho = \frac{(15.0)(100.21)}{(10.73)(670°\text{F})} = 0.2091 \text{ lb/ft}^3$$

LIQUID FLOW BACK TO UMU

$$\left(1528 \frac{\text{ft}^3}{\text{hr}}\right) \left(\frac{0.2091}{42.7} \right) = 7.482 \frac{\text{ft}^3}{\text{hr}}$$

$$Q = \left(7.482 \frac{\text{ft}^3}{\text{hr}}\right) \frac{7.48052}{60 \text{ MIN.}} \frac{\text{HR GAL}}{\text{FT}^3}$$

$$Q = 0.933 \text{ GPM}$$

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7. DETERMINE THE MAXIMUM FLOWRATE OF n-HEPTANE NECESSARY TO COMPENSATE FOR THERMAL CONTRACTION.

DISCUSSION: AT THE BEGINNING OF THE EXTRACTION CYCLE PRODUCTION OF DEGRADATION PRODUCTS IN THE ECD COMPENSATES FOR THERMAL CONTRACTION. THE MAXIMUM REQUIRED FLOW OF n-HEPTANE OCCURS NEAR THE END OF THE EXTRACTION CYCLE WHEN THERMAL CONTRACTION OF THE HT43 IS STILL AT ITS MAXIMUM RATE AND NO DEGRADATION PRODUCTS ARE BEING FORMED.

ASSUME: AVG. TEMP. OF ULLAGE SPACE IS 391 °F

GIVEN:

$$\rho_{N\text{-}HEPTANE\ 391°F} = 0.1696\ lb/ft^3$$

$$\rho_{N\text{-}HEPTANE\ 70°F} = 42.7\ lb/ft^3$$

CONTRACTION RATE OF ULLAGE: 741 FT³/HR

CALCULATION:

$$\dot{V}_{70°F} = \dot{V}_{244°F}\frac{\rho_{244°F}}{\rho_{70°F}} = 741\frac{(0.1696)}{(42.7)} = 2.856\ \frac{ft^3}{hr}$$

$$Q = 2.856\ \frac{\cancel{ft^3}}{\cancel{hr}}\ \frac{7.48052\ GAL\ \cancel{hr}}{\cancel{Ft^3}\ \ 60\ min.}$$

$$Q = 0.356\ GPM$$

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8. DETERMINE THE VOLUME OF N-HEPTANE NECESSARY FOR 1 DAY OF OPERATION.

DISCUSSION: MAXIMUM HEPTANE REQUIREMENT IS BASED ON THE ASSUMPTION THAT NO MORE WILL BE REQUIRED THAN IS NECESSARY TO FILL THE CHANGE IN ULLAGE VOLUME FROM THE FULLY CHARGED TO THE FULLY DISCHARGED CONDITION

ASSUME: THE CHANGE IN FLUID LEVEL IS 18" (NEARLY ALL OF FLUID GOES FROM 580°F TO 425 °F) AND THERE IS NO CONTRIBUTION FROM DEGRADATION PRODUCT FORMATION. TOP LAYER OF FLUID IS AT 500 °F, AVG. ULLAGE TEMP. IS 391 °F

GIVEN

$\rho_{N\text{-}HEPTANE\ 70°F}$: 42.7 lb/ft³

$\rho_{N\text{-}HEPTANE\ 391°F}$ = 0.1696 lb/ft³

CALCULATION:

$$\Delta V = \frac{\pi D^2}{4} h = \frac{\pi (60)^2}{4} \frac{18}{12} = 4241 \text{ Ft}^3$$

$$V_{70°F} = \Delta V \frac{\rho_{391}}{\rho_{70}} = 4241\left(\frac{0.1696}{42.7}\right) = 16.35 \text{ Ft}^3$$

$$V = (16.35 \text{ Ft}^3)\left(7.48052 \frac{\text{GAL}}{\text{Ft}^3}\right) = 122 \text{ GAL.}$$

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9. DETERMINE THE MAXIMUM FLOWRATE OF GN_2 NECESSARY TO BACK-UP THE n-HEPTANE ULLAGE MAINTENANCE SYSTEM

GIVEN: VOLUME FLOW REQUIREMENT = 741 $\frac{ft^3}{hr}$

$$\rho_{GN_2\ STD} = 0.0724\ LB/Ft^3$$

$$\rho_{GN_2\ 391} = 0.0724\left(\frac{530}{851}\right) = 0.0451\ \frac{LB}{ft^3}$$

CALCULATION:

$$\dot{V}_{STD} = \dot{V}_1 \frac{\rho_1}{\rho_{STD}} = 741\left(\frac{0.0451}{0.0724}\right) = 461.6\ \frac{ft^3}{hr}$$

$$\dot{V} = \frac{461.6}{60} = 7.69\ \text{SCFM}$$

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10. DETERMINE THE VOLUME OF LN_2 NECESSARY FOR 1 DAY OPERATION

ASSUME: FULL EXTRACTION OCCURS ONCE IN A DAY WITH NITROGEN REQUIRED ONLY TO FILL THE CHANGE IN ULLAGE VOLUME BETWEEN FULL CHARGE AND FULL DISCHARGE. AVG. TEMP. IS 391 °F IN ULLAGE SPACE

GIVEN: CHANGE IN ULLAGE VOLUME = 4241 Ft^3

$\rho_{GN_2\ STD.} = 0.0724\ LB/Ft^3$

$\rho_{GN_2\ 391} = 0.0951\ LB/Ft^3$

$\rho_{LN_2} = 50.4\ LB/Ft^3$

$$V_{STD} = V_1 \frac{\rho_1}{\rho_{STD}} = 4241\ Ft^3\ \frac{0.0951}{0.0779}$$

$$V_{STD} = 2642\ SCF$$

$$V_{LN_2} = V_{STD} \frac{\rho_{STD}}{\rho_{LN_2}} = 2692 \left(\frac{.0724}{50.4}\right)$$

$$V_{LN_2} = 3.80\ ft^3\ (7.48052)\ \frac{gal}{ft^3}$$

V_{LN_2} = 28.4 gallons LN_2

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11. DETERMINE THE RATE THAT OIL MAY BE REMOVED FROM THE TSS ASSUMING A MAXIMUM FLOWRATE OF $GN_2 = 30$ SCFM WITH OIL AT BOTH 70°F & 425°F

ASSUME: GN_2 IN THE PORE SPACE OF THE ROCK/SAND BED IS AT THE SAME TEMPERATURE AS THE ROCK/SAND BED. ALSO, THE TEMPERATURE PROFILE OF THE TANK REMAINS CONSTANT THROUGHOUT THE DRAINING PROCEDURE.

GIVEN: $\rho_{GN_2\,70°F} = 0.0724 \ LB/Ft^3$

$\rho_{GN_2\,425} = 0.0443 \ LB/Ft^3$

$$\dot{V}_{70°F} = 30 \frac{Ft^3}{MIN} \ \frac{7.48052 \ GAL}{Ft^3} = 224. \ GPM$$

$$\dot{V}_{425°F} = 30 \frac{Ft^3}{MIN} \left(\frac{0.0724}{0.0443}\right) \frac{7.48052 \ GAL}{MIN}$$

$$\dot{V}_{425°F} = 367 \ GPM$$

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12. DETERMINE THE TIME REQUIRED TO EMPTY THE TSU WHEN THE OIL IS AT 70°F AND WHEN IT IS AT 425°F

<u>GIVEN:</u> $\rho_{OIL\ 70°F} = 53.1\ LB/Ft^3$

$\rho_{OIL\ 425°F} = 44.91\ LB/Ft^3$

$M_{OIL} = 1,700,000\ LB$

$\dot{V}_{OIL\ 70°F} : 224\ GPM$

$\dot{V}_{OIL\ 425°F} : 367\ GPM$

$$V_{70°F} = \frac{(1,700,000)LB\ Ft^3}{(53.1)LB} \frac{(7.48052)GAL}{Ft^3}$$

$$V_{70°F} : 239,500\ GAL.$$

$$t = \frac{V}{\dot{V}} = \frac{239,500\ GAL}{224\ GPM} \frac{hr}{60 min}$$

$$t_{70°F} = 17.8\ hrs.$$

$$V_{425} = \frac{1,700,000}{(44.91)}(7.48052) = 283,200\ GAL.$$

$$t = \frac{V}{\dot{V}} = \frac{283,200}{(367)(60)} = 12.9\ hrs.$$

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13. DETERMINE THE MAXIMUM VOLUME OF GN_2 NECESSARY TO EMPTY THE THERMAL STORAGE UNIT, IN EXCESS OF THAT REQUIRED FOR NORMAL ULLAGE MAINTENANCE

GIVEN: VOLUME OF 70°F OIL TO BE DISPLACED = 239,500 GAL.

VOLUME OF 425°F OIL TO BE DISPLACED = 283,200 GAL.

$\rho_{GN_2\ 70°F} = 0.0724$ LB/FT³

$\rho_{GN_2\ 425°F} = 0.0443$ LB/FT³

$\rho_{LN_2} = 50.4$ LB/FT³

CALCULATIONS:

$$V_{LN_2} = V_{OIL\ 70°F} \frac{\rho_{GN_2\ 70°F}}{\rho_{LN_2}} = 239{,}500\left(\frac{0.0724}{50.4}\right)$$

$V_{LN_2} = 344$ GAL. FOR 70°F TSU

$V_{STD} = 32{,}016 \sim 32{,}000$ SCF

$V_{LN_2} = 283{,}200\left(\frac{.0443}{50.4}\right) = 249$ GAL. FOR 425°F TSU

$V_{STD} = 37{,}858 \; \frac{.0443}{.0724} = 23{,}000$ SCF.

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$T_c = 540.2$ K

$T = 282 - 580$ °F

$= 412.09 - 577.6$ °K

$P_c = 27.0$ ATM

$P = 1.02$ ATM

$\omega = 0.351$

$T_R = 0.763 - 1.070$

$P_R = 0.038$

USE GENERALIZED VIRIAL COEFFICIENTS (1.)

$$Z = 1 + \frac{BP}{RT} = 1 + \left(\frac{BP_c}{RT_c}\right)\frac{P_r}{T_r}$$

$$\frac{BP_c}{RT_c} = B^0 + \omega B^1$$

$$B^0 = 0.083 - \frac{0.422}{T_r^{1.6}}$$

$T_r: 0.763$ $T = 282$°F $B^0 = -.5675$

$T_r: 1.070$ $T = 580$°F $B^0 = -.2957$

$$B^1 = 0.139 - \frac{0.172}{T_r^{4.2}}$$

$T_r = 0.763$ $T = 282$°F $B^1 = -.3967$

$T_r = 1.070$ $T = 580$°F $B^1 = .0095$

1.) REF. INTRODUCTION TO CHEMICAL ENGINEERING THERMODYNAMICS, 3RD EDITION, SMITH AND VAN NESS, 1959, pg. 87

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$$\left(\frac{BP_c}{RT_c}\right)_{282°F} = -.5675 + (.351)(-.3967)$$
$$= -.7067$$

$$\left(\frac{BP_c}{RT_c}\right)_{580°F} = -.2957 + (.351)(.0095)$$
$$= -.2929$$

$$Z_{282°F} = 1 - .7067\left(\frac{0.038}{0.763}\right) = 0.965$$

$$Z_{580°F} = 1 - 0.2929\left(\frac{0.038}{0.763}\right) = 0.985$$

ASSUMPTIONS: n-Heptane is relatively non-polar and non-associating

$$\rho_{282} = \frac{PM}{ZRT} = \frac{(15.0)(100.21)}{(10.73)(742)(.965)} = 0.196 \ \frac{lb}{ft^3}$$

$$\rho_{580} = \frac{(15.0)(100.21)}{(10.73)(1040)(.985)} = 0.137 \ \frac{lb}{ft^3}$$

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REF. PETROLEUM REFINERY ENGINEERING, 3RD EDITION, W. L. NELSON, McGRAW-HILL BOOK CO., INC., 1949, pp. 581-585

Cracking may be described as a first order reaction if the decomposition is limited to a low conversion per pass (< 20 to 25 %)

$$K_1 = \frac{1}{t} \ln \frac{a}{a-x} \quad \text{or} \quad = \frac{1}{t} \ln \frac{100}{100-x}$$

K_1 = reaction velocity constant (Fig. 220)

t = time, sec.

a = % of material in feedstock

for a pure feedstock $a = 100$

x = percentage of material that disappears during the reaction time, t.

for heptane x is a mole (gas volume percentage)

$$e^{K_1 t} = \frac{100}{100-x}$$

$$x = 100 - \frac{100}{e^{K_1 t}}$$

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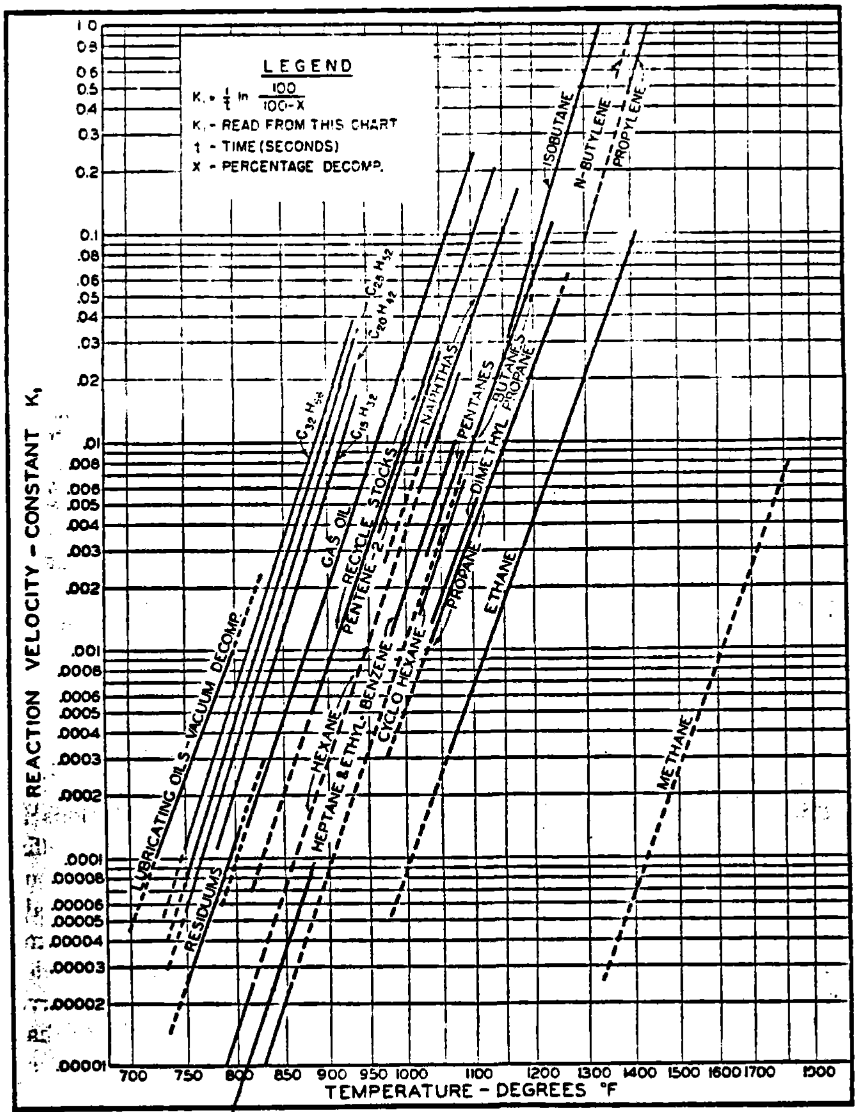

Fig. 220.—Reaction velocity constants for the decomposition of hydrocarbons and petroleum fractions into gasoline (except as noted in the text).

T= 1050 K = .006

T= 1000 K = .002

T= 850 K = .00004

$K_1 \approx 7.55 \times 10^{-75} T^{23.8}$

PREPARED BY: R. MORRISON

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DATE: 7-28-80

Rocketdyne Division
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n HEPTANE CRACKING RATE

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FOR CONSERVATISM - ASSUME ALL HEPTANE AT TEMPERATURE OF TOP LAYER OF FLUID -

ASSUME: TOP LAYER OF FLUID ~ 580°F
24 HRS / DAY.

$$K_{1\,(T=580°F)} = 4.5 \times 10^{-9}$$

$$24 \times 3600 = 8.64 \times 10^{4} \text{ sec}$$

$$X = 100 - \frac{100}{e^{(4.5\times10^{-9})(8.64\times10^{4})}}$$

$$X = 0.039 \%$$

CRACKING RATE OF HEPTANE SHOULD BE MUCH LESS THAN 0.1% / DAY.

10 MW PILOT PLANT
THERMAL STORAGE SYSTEM
ULLAGE MAINTENANCE UNIT
SUPPORTING DETAILED ANALYSIS

ROCKETDYNE

26 NOVEMBER 1980

REV. 1: 26 FEBRUARY 1981

FOREWORD

This document contains supporting detail analysis for the thermal storage unit (TSU) and ullage maintenance unit (UMU). This material provides supplementary information for the supporting detailed analysis dated 8/6/80.

Included are relief valve calculations for the TSU, nitrogen supply line size to the TSU from the UMU, heptane supply line size to the TSU from the UMU, the vent line routed from the TSU to the UMU, and the heptane concentration in the ullage space of the TSU.

Revision 1 includes the relief valve calculations for tank US on the UMU skid, p. 57 & 58, and a summary sheet for the TSU relief valve sizing, p. 1A.

Questions concerning the contents should be addressed to:

Art Moore
or (213) 884 - 3324
Dick Morgan

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PREPARED BY: W. KNIPPEL	Rocketdyne Division Rockwell International	PAGE NO. 1
CHECKED BY: K. YEO	SOLAR	REPORT NO.
DATE: 23 FEB 80	TSU RELIEF VALVES	

SUMMARY

STORAGE AND VENTING OF CALORIA HT 43.

CALCULATIONS PRESENTED HEREIN DETERMINE THE SIZE AND CAPACITY OF THE VENT VALVES SELECTED. THE APPLICATION OF THE VENT VALVES WILL MINIMIZE THE PROBLEMS THAT COULD OCCUR IN THE EVENT OF OVER FILLING, THERMAL CHANGE, EQUIPMENT MALFUNCTION OR EXTERNAL FIRE. IN NORMAL OPERATION THE ULLAGE MAINTENANCE UNIT WILL PROVIDE LEADOFF OF FLAMMABLE VAPORS TO A CONDENSER AND FLARE FOR SAFE DISPOSAL. VENT VALVE SELECTION IS BASED UPON REQUIREMENTS OUTLINED IN THE AMERICAN PETROLEUM INSTITUTE BULLETIN RP-2000.

FORM R 152-R-2 REV. 10-73

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REVIEW OF CALCU.

TOTAL RATE OF EMERGENCY VENTING REQUIRED FOR FIRE EXPOSURE VERSUS WETTED SURFACE AREA, REF. TABLE 2, PAR. 1.5.2, API STANDARD 2000

WETTED AREA = $60\pi 30$ = 5655 SQ FT

VENTING REQ'D, V = 742,000 CFH, FROM TABLE

FLOW CAPACITY OF RELIEF, REF. NFC, PARA. 2-2.5.9 (b) $CFH = 1667\, C_f A \sqrt{P_t - P_a}$

$$C_f = \frac{293{,}000}{1667\sqrt{6}\ 113.1} = 0.634$$ REF. 12" GROTH VALVE

$$C_f = \frac{133{,}000}{1667\sqrt{6}\ 50.03} = 0.651$$ REF 8" GROTH VALVE

$$CFH_{12''\,GROTH} = 1667(0.634)(113.1)\sqrt{20} = 534567$$

$$CFH_{8''\,GROTH} = 1667(0.651)(50.03)\sqrt{20} = 242808$$

TOTAL VENT CAPACITY AVAIL. 777375 CFH

777375 > 742000 CFH

ALSO $CFH = V \frac{1337}{L\sqrt{M}}$ REF. NFC, PARA. 2-2.5.5

$$CFH = \frac{742{,}000(1337)}{65.3\sqrt{415}} = 745758 < 777375$$

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STORED PRODUCT, EXXON CALORIA HT43

* MOLECULAR WEIGHT, 415

* HEAT OF VAPORIZATION, 65.3 $\frac{BTU}{LB}$ @ B.P. OF 800°F.

FLASH POINT 400°F.

AUTOIGNITION TEMPERATURE 759°F

TYPE OF VESSEL VERTICAL CYLINDER

OIL CAPACITY 254 000 GALLONS (W/ROCK)

DIA. OF VESSEL 60'-0

HEIGHT OF VESSEL 44'-0

WORKING PRESSURE 10 TO 12 INCHES W.C.

DESIGN PRESSURE 20.0 INCHES W.C.

LOW FLOW RELIEF SETTING 18.0 INCHES W.C.

HIGH FLOW RELIEF SETTING 20.0 INCHES W.C.

OPERATING TEMPERATURE 580°F.

HIGH PRESSURE/VOLUME RATE 1,330,000 SCFH (NO INSULATION)

HIGH PRESSURE/VOLUME RATE 99,750 SCFH (INSULATED)

GROTH EQUIPMENT CORP, HOUSTON TEXAS, HERB PARKER 713-675-6151

EXXON CRIS BYLOW 552-5595 * INFO REC'D PHONE

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DATE: 17 JAN 80	TSU RELIEF VALVE	

DETERMINE INDIVIDUAL RELIEVING RATES

1. INADVERTENT VALVE OR PUMP FLOW INLET MAXᴹ

1.28×10^6 LB/HR @ 575°F

$$1.28 \times 10^6 \frac{\text{LBS}}{\text{HR}} \times \frac{\text{CU FT}}{41.0 \text{ LBS}} = 31219.5 \text{ CFH} = 520 \text{SCFM}$$

2. STEAM GENERATION RATE IN TSU, WATER LEAK ETC

$$32 \frac{\text{MW}}{(\text{DAY})} \times \frac{\text{DAY}}{20 \text{ HR}} \times 0.05688 \frac{\text{BTU}}{\text{MIN WATT}} \times \frac{\text{LB OF STEAM}}{1000 \text{ BTU}} =$$

91 LBS OF STEAM/MIN OR $26.8 \frac{\text{CU FT}}{\text{LB}} \times \frac{60 \text{ MIN}}{\text{HR}} \times \frac{91 \text{ LBS}}{\text{MIN}} =$

146,328 CFH $\quad$ $1.517 \frac{\text{LBS}}{\text{SEC}}$

3. FIRE

REF. API 2000

$A = 60\pi \times 30 = 5655$ SQFT

$\text{CFH} = 1107 A^{0.82}$

CFH = 1,321,729

ALSO $\quad \text{CFH} = \frac{V(1,337)}{L\sqrt{M}}$

$$\text{CFH} = \frac{1,321,729\ (1337)}{65.3\sqrt{415}} = 1,328,424$$

USE CFH = 1,330,000 FOR LARGE EMERGENCY RELIEF

CFH = 1330000 (.075) = 99750 (INSULATION FACTOR)

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4. STEAM LEAK

$65,500 \text{ LBS}/\text{HR} \times 26.8 \frac{\text{CU FT}}{\text{LB}} = 1,755,400 \text{ CFH}$

I. PRESSURE DROP THRU HIGH FLOW RELIEF SYSTEM IS 20 INCHES W.C., FLOW (2.) $= 1.517 \frac{\text{LBS}}{\text{SEC}}$.

ASSUME 12" GROTH VALVE & 4'-0 LG PIPE

REF. CRANE, PIPE LOSS

$$\Delta p = f\frac{L}{DP}\left[\frac{w}{0.525Yd^2}\right]^2$$

$$Re = 22716\frac{w}{d\mu} = \frac{22716(1.517)}{(12)0.0205} = 140,082$$

$$f = 0.0138$$

$$\Delta p = 0.0138\left(\frac{4}{1}\right)\frac{26.8}{1}\left[\frac{1.517}{0.525(1)(12)^2}\right]^2(27.72)$$

$$\Delta p = 0.0165 \text{ INCHES W.C.}$$

ENTRY LOSS

$k = 0.5$ REF. CRANE

$$\Delta p = k\bar{V}\left[\frac{w}{0.525Yd^2}\right]^2$$

$$\Delta p = 0.5(26.8)\left[\frac{1.517}{0.525(1)144}\right]^2(27.72) = .1496 \text{ INCHES W.C.}$$

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SOLAR

TSU RELIEF VALVE.

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ORIFICE LOSS

$$\Delta p = \left[\frac{w}{0.525 Y d^2 C}\right]^2 \bar{V}_1$$

$$\Delta p = \left[\frac{1.5167}{0.525(1)(144)(.59)}\right]^2 (26.8)\ 27.72$$

$$\Delta p = 0.86 \text{ INCHES W.C.}$$ OK

II. HIGH FLOW RELIEF SYSTEM, FLOW (3.) = 99,705 CFH

$$\rho_1 = \frac{MP}{10.72T} = \frac{415\ (14)}{10.72(1040)} = 0.5211 \frac{\text{LBS}}{\text{CUFT}}$$ CALORIA

$$\rho_2 = \frac{29}{415}\rho_1 = 0.0364 \frac{\text{LBS}}{\text{CU FT}}$$ AIR

$S_G = 14.309$ VALVE SET = 11.54 OZ/SQ IN

12" GROTH VALVE CAPACITY FROM CHART = 542 000 SCFH

$$\frac{542000}{(14.309)^{\frac{1}{2}}}\left(\frac{520}{1040}\right)^{\frac{1}{2}} = 101,316 \text{ CFH} > 99705 \text{ REQ'D}$$

OK

III. LOW FLOW RELIEF SYSTEM

FLOW = 65.5 LBS/HR (ULLAGE MAINT. SYS.) HEPTANE

$$\rho_1 = \frac{MP}{10.72} = \frac{100.20\ (14)}{10.72(1040)} = 0.1258 \frac{\text{LBS}}{\text{CUFT}}$$

$$S_G = \frac{.1258}{.0364} = 3.46$$ VALVE SET = 10.39 OZ/SQIN

8" GROTH VALVE CAPACITY = 235000 SCFH

$$\frac{235000}{(3.46)^{\frac{1}{2}}}\left(\frac{520}{1040}\right)^{\frac{1}{2}} = 89334 \text{ CFH} > 520 \text{ CFH (HEPTANE)}$$

ASSUME 8" PLUS 12" RELIEF CAPACITY ALLOW FOR INCREASE OF TEMP. ABOVE 580°F FOR FIRE.

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FLOW CAPACITY OF 12 INCH GROTH FLAME ARRESTOR

@ 10.39 OZ/SQ IN IS 200,000 SCFH

$$\frac{200{,}000}{(3.46)^{1/2}}\left(\frac{520}{1040}\right)^{\frac{1}{2}} = 76{,}029 \text{ CFH (HEPTANE)}$$

NOTE FINAL VALVE SELECTION OF GROTH RELIEF HAS INCREASED CAPACITY ABOVE THOSE SPECIFIED HEREIN. (17 OCT 80 W.O.K.)

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DATE: 11 NOV 80	ULLAGE MAINTENANCE SYSTEM	

THERMAL STORAGE UNIT VENT PIPE

SUMMARY

CALCULATIONS ATTACHED WERE MADE TO DETERMINE THE HEAT TRANSFER CAPACITY OF THE PIPE LINE PROVIDED TO VENT THE THERMAL STORAGE UNIT TO THE ULLAGE MAINTENANCE SYSTEM. THE PIPE LINE PROVIDES ABOUT 200 LINEAL FEET OF AIR COOLED STEEL PIPE SURFACE. THE UMU DISPOSES OF THE NON-CONDENSIBLE FRACTION OF WASTE PRODUCT LEAVING THE TSU AND COLLECTS AND RETURNS CONDENSIBLES TO THE TSU. THIS PIPE LINE PROVIDES THE COOLING REQUIRED BY THE CONDENSIBLES. THE PRESSURE LOSS CALCULATED ILLUSTRATES THAT THE POSITIVE PRESSURE WITHIN THE TSU WILL ADEQUATELY DISCHARGE THE GASES AND VAPOR. A BLOWER FURNISHED ON THE UMU SKID WILL MAINTAIN A CONSTANT FLOW TO THE FLARE SYSTEM.

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DATE: 26 SEPT 79	HEAT TRANSFER, 6" DIA PIPE LINE	

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GIVEN DATA

1. THERMAL STORAGE UNIT OPERATING TEMP.

DAILY CYCLE 425° TO 580°F.

2. MAXIMUM FLOW RATE OF ULLAGE GAS $= 2300 \frac{CUFT}{HR}$

3. LENGTH OF 6" DIA PIPE, AIR COOLED, 200 FT

4. MAXIMUM AMBIENT TEMP. OF STEEL PIPE ASSUMED TO BE 140°F

5. DENSITY OF ULLAGE GAS @ 580°F = 0.0388 LB/CUFT

$$\text{MAXIMUM } \Delta T = T_{g1} - T_{g2} = 580 - 150 = 430°F.$$

$$\text{AVERAGE TEMP OF GAS} = \frac{580 + 150}{2} = 365°F$$

$$\rho = \frac{580+460}{365+460}(0.0388) = 0.04891 \frac{LBS}{CUFT}$$

$$Q = 2300 \frac{CU\,FT}{HR} \times 0.04891 \frac{LBS}{CUFT} \times 1.170 \frac{BTU}{LB} \times 430°F =$$

$$56595 \frac{BTU}{HR}$$

SURFACE AREA OF PIPE = 200(1.73) = 346 SQFT

LMTD

ASSUME AIR ENTERS @ TEMP. OF 120° AND LV 130°F

ASSUME GAS ENTERS @ 580° AND LV @ 150°F

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△, 3250 △, 2021 △1, 2027 △1

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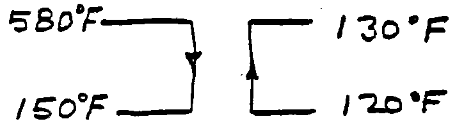
REV 11 NOV 80

LMTD,



$$LMTD = \frac{450 - 30}{LOG_E \frac{450}{30}} = \frac{420}{2.708} = 155°F$$

AREA OF PIPE 200 × 1.73 = 346 SQ FT

$$U = \frac{Q}{A \times LMTD} = \frac{56595}{346 \times 155°} = 1.055 \frac{BTU}{SQ FT HR-°F}$$ REQUIRED

REF. ASHREA CHART "U" AVAILABE $\leq 3.94 \frac{BTU}{SQ\ FT-HR-°F}$

CHECK PRESSURE DROP

$$Re = 22716 \frac{8\rho}{d\mu}$$ REF. CRANE TECH. BUL. 410

$$Re = 22716 \frac{2300\ (0.04891)}{3600\ (6.065)\ 0.013898}$$

$Re = 8421$ $f = 0.032$

$$\Delta p = f \frac{L}{D}\left(\frac{1}{\rho}\right)\left[\frac{w}{0.525\, Y d^2}\right]^2 \qquad w = \frac{2300(0.04891)}{3600}$$

$\frac{L}{D} \approx$ (12) 90° EL + 1 CHECK + 1 VALVE = 460 K = 14.72

K ≈ (3) ENTRANCE (3) EXIT K = (1.5) 3 = 4.5

$\frac{L}{D} \approx$ PIPE = 400 K = 12.80

K = 32.02

$$\Delta p = 32.02\left(\frac{1}{0.04891}\right)\left[\frac{0.03125}{0.525(1)(36.78)}\right]^2 = 0.001714\ PSI$$

$= 0.0475$ IN H_2O

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PROPERTIES OF UMU WASTE PRODUCT, TEMP = 391°F

		M.W.	VOL%	C_p BTU/FT^3·°F	μ CENTIPOSE
	H_2	2	20.8	3.50	0.0120
	N_2	28	2.0	0.252	0.0247
	CO	28	2.4	0.252	0.0247
	CO_2	44	2.0	0.240	0.0214
	O_2	32	0.2	0.233	0.0275
METHANE	CH_4	16	20.5	0.670	0.0155
ETHANE	C_2H_6	30	19.3	0.600	0.0140
ETHYLENE	C_2H_4	28	0.5	0.540	0.0150
PROPANE	C_3H_8	44	12.3	0.534	0.0118
PROPYLENE	C_3H_6	42	2.0	0.473	0.0128
ISOBUTANE	$n\,C_4H_{10}$	58	8.1	0.535	0.0128
	$i\,C_4H_{10}$	58	2.4	0.535	0.0128
PENTANE	$n\,C_5H_{12}$	72	6.0	0.529	0.0102
	$i\,C_5H_{12}$	72	0.4	0.529	0.0102
	H_2O	18	1.0	0.4650	0.0160

$C_{p\,AVE.} = 1.1700$ $\mu_{AVE.} = 0.013898$

REF. TEMA

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THERMAL STORAGE UNIT CONDENSATE RETURN

SUMMARY

THE UMU DISPOSES OF THE NON-CONDENSIBLE FRACTION OF WASTE AND COLLECTS AND RETURNS THE CONDENSIBLES TO THE TSU. A 1.5 GPM CAPACITY PUMP RETURNS THE CONDENSATE FROM THE RECEIVER ON THE UMU SKID VIA A 1½ IN. DIA. PIPE LINE APPROXIMATELY 200 FEET LONG. THE ATTACHED CALCULATIONS WERE MADE TO DETERMINE THE PRESSURE LOSS OF THE PIPE LINE. THE PUMP TO BE FURNISHED ON THE UMU SKID WILL PROVIDE A 1.5 GPM FLOW AGAINST A TOTAL HEAD OF 100 FEET. THE CALCULATED HEAD IS 25½ FEET AND IS THEREFORE ADEQUATE.

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ULLAGE MAINTENANCE SYSTEM
TSU HEPTANE RETURN

GIVEN:

1- MAXIMUM FLOW RATE OF HEPTANE INTO TSU = 0.356 GPM (REQ'D)

2- PUMP FLOW RATE OF HEPTANE = 1.5 GPM

3- LENGTH OF PIPE = 200 LINEAL FEET, 1½" DIA.

4- (16) 90° ELBOWS, (1) REDUCER, 1½" DIA.

5- ELEVATION IS 40 FEET

6- LENGTH OF PIPE = 10 LINEAL FEET, 1" DIA

7- (4) 90° ELBOWS, (1) TEE, (1) CHECK, (1) VALVE, 1" DIA

VELOCITY IN $1\frac{1}{2}$" DIA PIPE

$$V = \frac{1.5\text{ GAL}}{\text{MIN.}} \times \frac{\text{CU FT}}{7.48\text{ GAL}} \times \frac{1}{0.01414\text{ SQFT}} \times \frac{\text{MIN}}{60\text{ SEC}} = 0.24\text{ FPS}$$

VELOCITY IN 1" DIA PIPE

$$V = \frac{1.5\text{ GAL}}{\text{MIN.}} \times \frac{\text{CU FT}}{7.48\text{ GAL}} \times \frac{1}{0.0060\text{ SQFT}} \times \frac{\text{MIN}}{60\text{ SEC}} = 0.56\text{ FPS}$$

$$R_E = 123.9 \frac{d v \rho}{\mu}$$ TEMP = 150°F HEPTANE

$$R_{E\,1\frac{1}{2}\text{ IN PIPE}} = 123.9 \frac{(1.610)(0.24)\,39.87}{0.28} = 6817$$

$$R_{E\,1\text{ IN PIPE}} = 123.9 \frac{(1.049)(0.56)\,39.87}{0.28} = 10364$$

$$f_{1\frac{1}{2}} = 0.035$$

$$f_1 = 0.033$$

REF. CRANE TECH. BUL. 410, TEMA

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ULLAGE MAINTENANCE SYSTEM
TSU HEPTANE RETURN

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$1\frac{1}{2}$ IN. DIA., K

$K = f\frac{L}{D} = 0.035\frac{(200)}{0.1342} = 52.16$ (PIPE)

(16) 90° EL $30 \times 16 \times 0.035 = 16.80$

(1) REDUCER $K = 0.25$

$K_{1\frac{1}{2}''\text{TOTAL}} = 69.21$

$$\Delta p = \left[\frac{Q}{236 d^2}\right]^2 K \rho = \left[\frac{1.5}{236(2.59)}\right]^2 (69.21)(39.87) = 0.0166 \text{ PSI}$$

1 IN. DIA., K

PIPE $K = 0.033\frac{(10)}{0.0874} = 3.78$

(4) 90° EL $= 30 \times 4 \times 0.033 = 3.96$

VALVES (2) $= 100 \times 0.033 = 3.30$
TEE (1) $= 20 \times 0.033 = 0.66$
$K_{1''\text{TOTAL}} = 11.7$

$$\Delta p = \left[\frac{1.5}{236(1.1)}\right]^2 (11.7)(39.87) = 0.0156 \text{ PSI}$$

40' ELEVATION

$40 \times 0.433103 \times \frac{39.87}{62.4} = 11.069$ PSI

TOTAL $\Delta p = 11.10$ PSI

REF. ROCKETDYNE IL 141-42-8352, DRAWING NO. 40P7005132020 △1, 3250 △1, 2021 △1, 2027 △1

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THEMAL STORAGE UNIT NITROGEN SUPPLY

SUMMARY

THE ULLAGE MAINTENANCE UNIT PROVIDES AN OXYGEN FREE ULLAGE GAS OVER THE TSU HEAT TRANSFER OIL. AIR IS EXCLUDED FROM THE ULLAGE SPACE IN THE TSU BY MAINTAINING A SLIGHT POSITIVE PRESSURE WITH VAPORS RESULTING FROM OIL DECOMPOSITION OR AN EMERGENCY BACKUP SUPPLY OF GASEOUS NITROGEN. THE ATTACHED CALCULATIONS ILLUSTRATE THE FLOW AND PRESSURE LOSS IN THE 2 INCH PIPE SUPPLY LINE OF GN_2. THE UPSTREAM PRESSURE REGULATOR FURNISHED ON THE UMU SKID LOCATED AT THE INLET TO THE SUPPLY WILL BE SET TO REGULATE THE DOWNSTREAM PRESSURE AT 25 PSIG. THIS PRESSURE AT THE PIPE INLET IS ADEQUATE COMPARED TO 2½ PSI PRESSURE LOSS CALCULATED AND GN_2 FLOW TO THE TSU WILL EXCEED THE MINIMUM REQUIRED 30 SCFM.

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GIVEN:

1- GN_2 REQUIRED FLOW CAPACITY = 30 SCFM MINIMUM

2- ACTIVATION PRESSURE = 3.5 IN. W.C. IN TSU

3- DEACTIVATE @ 7.0 IN. W.C. IN TSU

4- 2 IN DIA PIPE LINE, 200 FT LG

5- (16) 90° ELBOWS, 2 IN. DIA.

6- (1) 2 IN TO 1 IN REDUCER

7- (1) VALVE, 1 IN. DIA.

8- 1" PIPE, 10 FT LG

9- UP STREAM LINE PRESSURE 3 TO 13 PSIG

ASSUME MINIMUM FLOW = 50 SCFM

$$w = \frac{50\ \text{CU FT}}{\text{MIN}} \times 0.07274 \frac{\text{LBS}}{\text{CU FT}} \times \frac{\text{MIN}}{60\ \text{SEC}} = 0.0606 \frac{\text{LBS}}{\text{SEC}}$$

$$Re = 22716 \frac{w}{d\mu}$$

$$Re_{1\,IN,DIA} = \frac{22716\ (0.0606)}{(1.049)\ 0.0175} = 74988 \qquad f = 0.025$$

$$Re_{2\,IN.DIA} = \frac{22716\ (0.0606)}{(2.067)\ 0.0175} = 38056 \qquad f = 0.025$$

REF. CRANE TECH. BUL. 410, ROCKETDYNE IL 141-42-8352,

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PREPARED BY: W. O. KNIPPEL
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ULLAGE MAINTENANCE SYSTEM
GN_2 SUPPLY

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K, 2 IN. DIA

$K = f\frac{L}{D} = \frac{0.025(200)}{0.1722} = 29.04$ (PIPE)

(16) 90° EL $30 \times 16 \times 0.025 = 12.0$

(1) REDUCER $K = 0.33$

$K_{2'' \, TOTAL} = 41.37$ $Y = 0.925$ $\frac{\Delta}{P_1'} = 0.23$ (ASSUMED)

$$\Delta p = K\frac{1}{\rho}\left[\frac{w}{0.525 Y d^2}\right]^2$$

$$\Delta p_{2'' \, DIA} = \frac{41.37}{0.07274}\left[\frac{0.0606}{0.525(0.925)4.272}\right]^2$$

$\Delta p_{2'' \, DIA} = 0.485$ PSI

K, 1 IN DIA

$K = f\frac{L}{D} = \frac{0.025(10)}{0.0874} = 2.86$ (PIPE)

$K = 0.025(340) = 8.5$ (GLOBE VALVE)

$$\Delta p_{1'' \, DIA} = \frac{11.36}{0.07274}\left[\frac{0.0606}{0.525(0.925)\,1.10}\right]^2$$

$\Delta p_{1'' \, DIA} = 2.01$

TOTAL $\Delta p = 2.495$ PSI

Internal Letter

Rockwell International

Date. . 4 November 1980

No: . IL 141-42-8458

TO: (Name. Organization. Internal Address)
. D. G. Landy
. D/585-141
. AC35

FROM: (Name. Organization, Internal Address, Phone)
. R. H. Morrison
. D/585-141
. AC35
. 3232

Subject: . 10 MWe PILOT PLANT - HEPTANE CONCENTRATION IN ULLAGE SPACE OF TSU

References:
1) IL 141-43-8352, "10 MWe Pilot Plant - Ullage Maintenance Unit (UMU), Description, Operation, and Analysis", R. H. Morrison to G. R. Morgan.
2) Lipscomb, T. G., Correspondence, Exxon Co. USA., Houston, 25 September 1980.

INTRODUCTION

Attached to this letter (Appendix A) is the analysis of heptane concentration in the ullage space of the TSU. This analysis has been performed to assist definition of the requirements for a system to monitor the oxygen concentration in the TSU ullage space.

SUMMARY OF RESULTS

Heptane concentration vs. time of day and the corresponding thermal charge in the TSU are depicted in Figs. 1A and 1B. The lower curve in Fig. 1A shows the heptane concentration when the rate of oil degradation (fresh oil) is at the maximum reported in Ref. 1. The heptane concentration varies from 5 to 26 percent by mass. The upper curve shows heptane concentration when the rate of oil degradation (weathered oil) is one half the maximum. In this case the heptane concentration varies from 32 to 55 percent by mass.

The thermal charge cycle of Fig. 1B is a nominal cycle assumed as the basis for this analysis. A charge of 0 percent corresponds to the condition when all of the rock/sand bed and the oil in its void space are at 425°F. The TSU is at 100 percent charge when all of the rock/sand bed and the oil in its void space are at 580°F. The thermocline between hot and cold oil is assumed to have negligible thickness. The TSU is charged in four hours from 9 AM to 1 PM and discharged in 4 hours from 5 PM to 9 PM.

DISCUSSION

The assumptions and data used in the solution of this problem are presented in Appendix A. The primary source of data and operating characteristics was Ref. 1. The heptane concentration vs. time of day is described by the curves in Fig. 1A

DISCUSSION (CONT'D)

after at least four days of continuous operation with the TSU undergoing the assumed thermal cycle described by Fig. 1B. This cycle represents ideal system operation but not necessarily normal system operation. Extremes in system operation can be envisioned (Ref. 1) where heptane concentration in the TSU ullage space will reach 100 percent or 0 percent.

The rationale for selecting a minimum oil degradation rate equal to one-half the maximum was based on data received in Ref. 2. No experimental data on the rate of oil degradation in weathered oil was available. Observation suggests, however, that weathered oil will degrade at a slower rate than fresh oil as evidenced by the lower vapor pressure. The vapor pressure of weathered oil has been reported to be approximately one-half that of fresh oil, therefore a minimum oil degradation rate of one-half has been assumed for the purposes of this calculation.

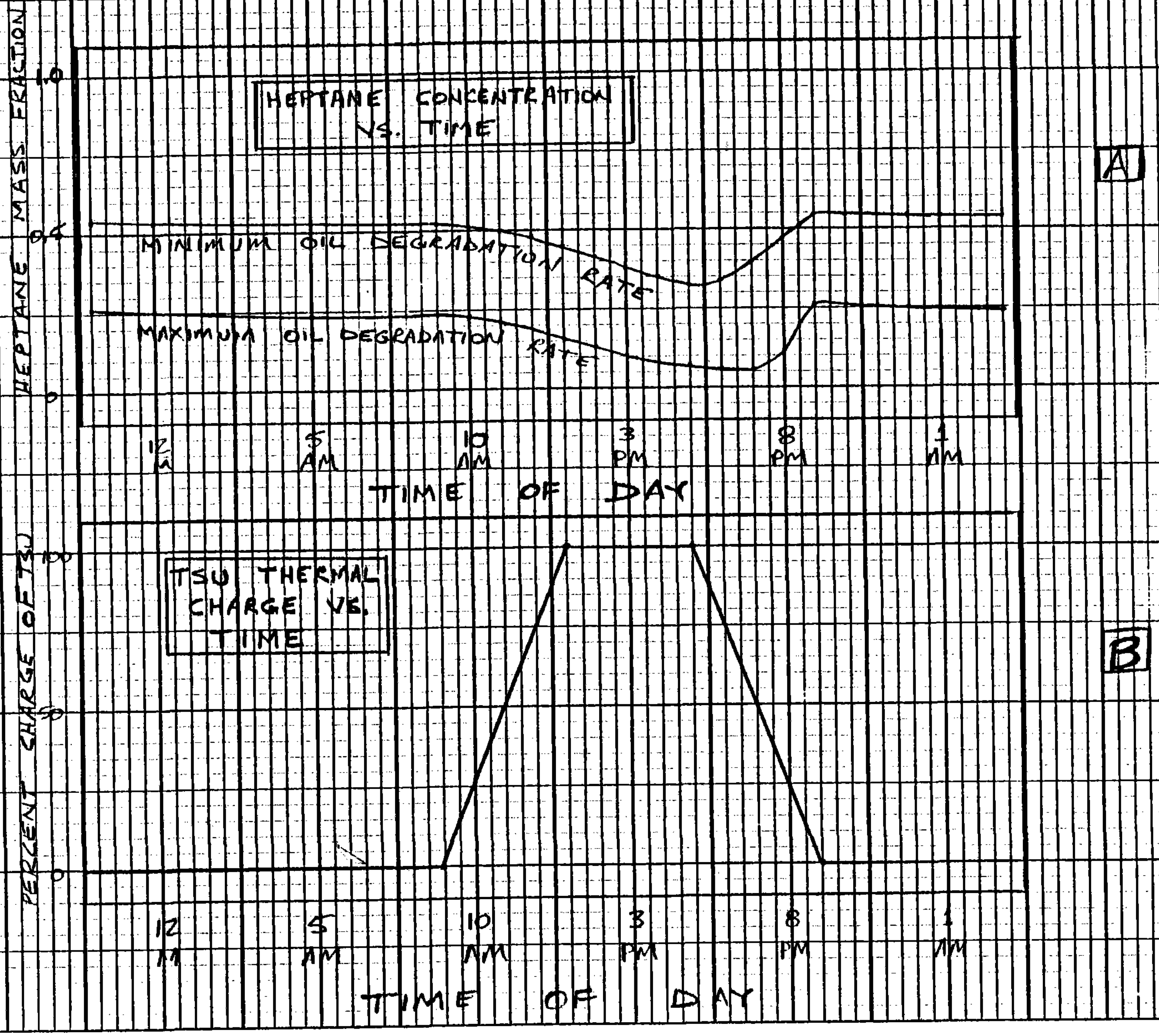
R. H. Morrison

R. H. Morrison
Valves & Controls

lw

cc:	E. G. Spencer	AC35
	G. F. Tellier	AC35
	G. R. Morgan	AA95
	J. G. Absalom	AA95
	A. E. Moore	AA95

FIGURE 1


HEPTANE CONCENTRATION VS. TIME
A
HEPTANE MASS FRACTION
1.0
0.6
0
MINIMUM OIL DEGRADATION RATE
MAXIMUM OIL DEGRADATION RATE
12 M
5 AM
10 AM
3 PM
8 PM
1 AM
TIME OF DAY
TSU THERMAL CHARGE VS. TIME
B
PERCENT CHARGE OF TSU
100
50
0
12 M
5 AM
10 AM
3 PM
8 PM
1 AM
TIME OF DAY

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APPENDIX A

FORM R 152-R-2 REV. 10-73

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DETERMINE: CONCENTRATION OF n-HEPTANE (C_7) AS A FUNCTION OF TIME IN THE ULLAGE SPACE.

ASSUME: THE INITIAL CONCENTRATION OF C_7 IN THE ULLAGE SPACE IS ZERO

ALL OF THE OIL IN THE ROCK BED OF THE TANK IS AT 425 °F IN THE FULLY DISCHARGED STATE.

NO HEAT IS LOST THROUGH THE WALLS OF THE TANK.

ALL OF THE OIL ABOVE THE ROCK BED IS ALWAYS AT 580°F

ALL OF THE OIL IN THE TANK IS AT 580 °F IN THE FULLY CHARGED STATE

THE THERMOCLINE HAS NO THICKNESS → ie. ALL OIL IN THE TANK IS EITHER AT 425 °F OR 580°F

FORM R 152-R-2 REV. 10-73

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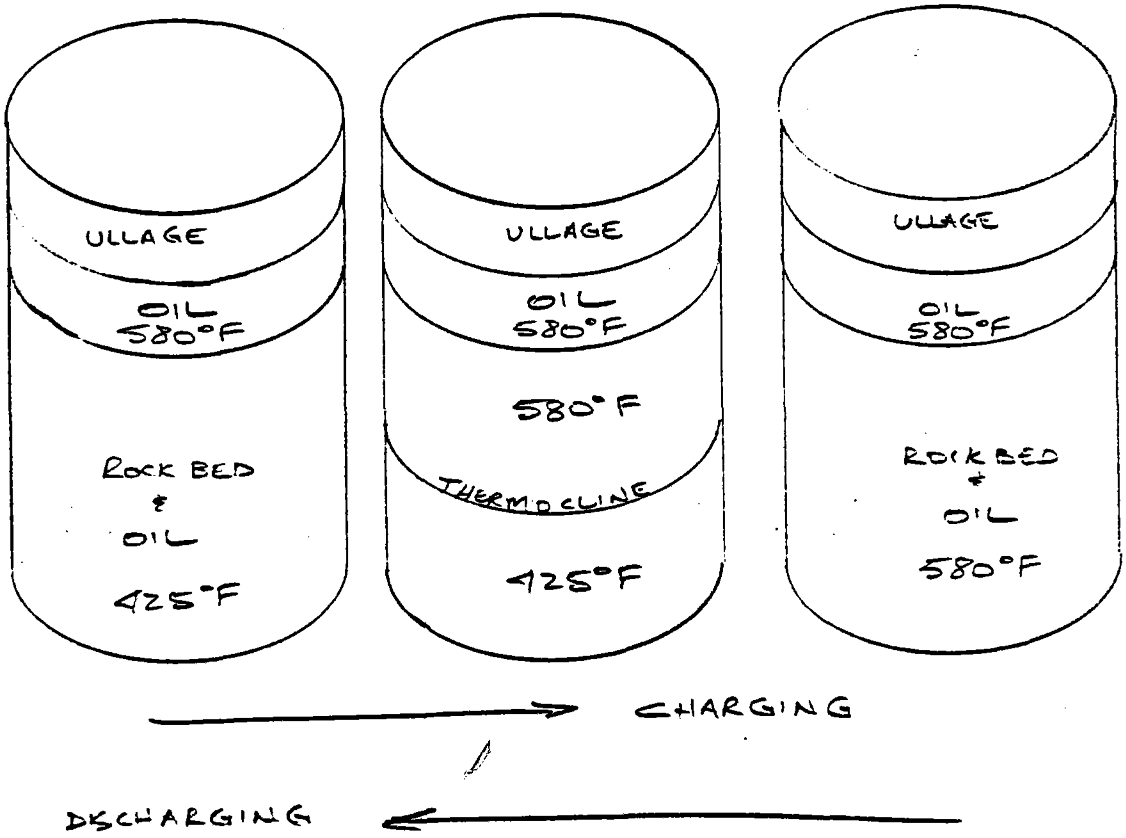
ASSUME : - CONT. -



EACH CHARGING AND DISCHARGING CYCLE REQUIRES 4 HRS.

AVG. DAY → START CHARGING AT 9 AM.
STOP CHARGING AT 1 PM.

START DISCHARGING AT 5 PM
STOP DISCHARGING AT 9PM

ASSUME: - CONT. -

C_7 AND DEGRADATION PRODUCTS (GAS) BEHAVE AS AN IDEAL GAS AT THE AVERAGE TEMPERATURE AND PRESSURE OF THE UMU

THE AVERAGE MOLECULAR WEIGHT OF THE GAS IS 28.9 LB/LBMOL.

ULLAGE PRESSURE IS MAINTAINED CONSTANT AT ITS AVERAGE VALUE

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<u>GIVEN</u>: OIL DEGRADATION RATE AT 580 °F:
IN ROCK BED = 42×10^{-6} LB/LB-HR = $R_{GAS\ RB}$
ABOVE ROCK BED = 13.75×10^{-6} LB/LB-HR = $R_{GAS\ ARB}$

OIL DEGRADATION RATE AT 425 °F = 0

EXPANSION AND CONTRACTION RATE OF OIL DURING 4 HR. CHARGING AND DISCHARGING PERIOD = 741 Ft^3/HR = ΔV

TOTAL MASS OF OIL IN TSU = M_{OIL}
M_{OIL} = 1,640,000 LBS.

DENSITY OF OIL AT 580 °F = $\rho_{580°F} = 40.85 \frac{LB}{Ft^3}$

DENSITY OF OIL AT 425 °F = $\rho_{425°F} = 44.91 \frac{LB}{Ft^3}$

VOLUME OF VOID SPACE IN ROCK BED = V_V
V_V = 29,800 Ft^3

AVERAGE TEMP OF ULLAGE SPACE = (CENTER CEILING TEMP + CENTER OIL SURFACE TEMP.)/2 = (282 + 580)/2 = 431 °F

AVERAGE ULLAGE PRESSURE = P
P = 9 in. W.C. = 0.325 PSIG = 14.13 PSIA
P_{ATM} = 13.8 PSIA.

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GIVEN: — CONT. —

SPECIFIC GAS CONSTANT OF GASEOUS

$G = 1546$ (ft lbf/lbmol °R)/100 lb/lbmol)

$R_G = 15.46$ ft/°R

SPECIFIC GAS CONSTANT OF THE GAS = R_{GAS}

$R_{GAS} = 1546/28.9 = 53.49$ ft/°R

VOLUME OF ULLAGE SPACE WHEN ALL OIL IS 425°F = $V_{U_{425}} = 9432$ ft³

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CALCULATION:

FROM 9 P.M. TO 5 P.M. (NEXT DAY), NO C_7 NEED EVER BE ADDED TO THE ULLAGE SPACE. THE OIL NEVER CONTRACTS AND THERE IS ALWAYS A POSITIVE RATE OF FORMATION OF GAS.

FROM 5 P.M. TO 9 P.M. THE OIL IS CONTRACTING AND THE ULLAGE SPACE IS EXPANDING. ALSO, THE RATE OF GAS FORMATION IS DECREASING. AT SOME POINT THE RATE OF GAS FORMATION BECOMES INSUFFICIENT TO COMPENSATE FOR THE EXPANSION OF THE ULLAGE SPACE. AT THIS POINT PRESSURE DROPS AND C_7 MUST BE ADDED TO THE ULLAGE SPACE TO MAINTAIN PRESSURE.

LET F = FRACTION OF ROCK BED AT 425°F

9 P.M. TO 9 A.M. : $F = 1$

9 A.M. TO 1 P.M. : $F = 1 - \frac{1}{4}t$ t (hours)

1 P.M. TO 5 P.M. : $F = 0$

5 P.M. TO 9 P.M. : $F = \frac{1}{4}t$

LET $m_{B,580}$ = MASS OF OIL IN BED AT 580°F

$$m_{B,580} = (1-F)\,V_v\,\rho_{580} = (1-F)(29800)(40.85)\ lb_m$$

LET m_A = MASS OF OIL ABOVE ROCK BED

$$m_A = 1{,}640{,}000 - F(29{,}800)(44.91) - (1-F)(29{,}800)(40.85)$$

$$m_A = 1{,}640{,}000 - 29800\,[44.91\,F + (1-F)(40.85)]$$

$$m_A = 1{,}640{,}000 - 29800\,[40.85 + F\,(44.91 - 40.85)]$$

$$m_A = 1{,}640{,}000 - 29{,}800\,[40.85 + 4.06\,F]$$

$$m_A = 422{,}670 - 120{,}988\,F$$

$$m_{B,580} = (1-F)\,1{,}217{,}330$$

RATE OF DEGRADATION PRODUCT FORMATION

$$R = R_{GAS\,RB}\,m_{B,580} + R_{GAS\,ABB}\,m_A$$

$$R = (1-F)(1{,}217{,}330)(42\times10^{-6}) + (422{,}670 - 120{,}988\,F)(13.75\times10^{-6})$$

9 P.M. TO 9 AM. $F=1$ $R = 4.148$ lb/hr

9 A.M. TO 1 P.M. $F = 1 - \frac{1}{4}t$

$$R = \left(1-1+\tfrac{1}{4}t\right)(1{,}217{,}330)(42\times10^{-6}) + \left(422{,}670 - 120988 + 120{,}988\left(\tfrac{1}{4}\right)t\right)(13.75\times10^{-6})$$

$$R = 4.148 + 13.198\,t$$

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1 PM. TO 5 P.M. $F = 0$ $R = 56.940$ lb/hr

5 PM TO 9 PM $F = 1/4t$

$$R = (1 - 1/4t)(1,217,330)(42\times10^{-6}) +$$

$$+ \left(422670 - \frac{120,988}{4}t\right)(13.75\times10^{-6})$$

$$R = 56.940 - 13.198t$$

ULLAGE VOLUME FROM 9 P.M. TO 9 A.M. $= V_{UMAX}$

TOTAL TANK VOID VOLUME − VOLUME OF OIL ABOVE BED − VOLUME OF BED VOID SPACE

$$V_{UMAX} = \left(V_{U\,925} + \frac{M_T}{44.91}\right) - \frac{M_{A,F=1}}{40.85} - 29800$$

$$V_{UMAX} = \left(9432 + \frac{1,640,000}{44.91}\right) - \frac{301682}{40.85} - 29800$$

$$V_{UMAX} = 8769 \text{ ft}^3$$

ULLAGE VOLUME FROM 1 PM TO 5 PM V_{UMIN}

$$V_{UMIN} = \left(V_{U\,925} \pm \frac{M_T}{44.91}\right) - \frac{M_{A,F=0}}{40.85} - 29800$$

$$V_{UMIN} = \left(9432 + \frac{1690000}{44.91}\right) - \frac{422,670}{40.85} - 29800$$

$$V_{UMIN} = 5803 \text{ ft}^3$$

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ULLAGE VOLUME FROM 9 A.M. TO 1 P.M.

$$V_{U_{DEC.}} = 8764 - 740.3\,t \qquad t\ (\text{hours})$$

ULLAGE VOLUME FROM 5PM TO 9PM.

$$V_{U_{INC.}} = 5803 + 740.3\,t$$

CONSIDER THE TIME INTERVAL FROM 9 PM TO 9AM

$$V = V_{U_{MAX}} = 8769\ \text{Ft}^3$$

$$Q = 4.148\ \text{lb/hr}$$

CHOOSE A TIME INCREMENT, Δt, SUCH THAT

$$C_{C_7} = \left.\frac{m_{C_7}}{m_T}\right|_{t=t_0} \approx \left.\frac{m_{C_7}}{m_T}\right|_{t=t_0+\Delta t}$$

$m_{C_{7_0}}$ is known

m_{GAS_0} is known

LET PRESSURE INCREASE OVER TIME INTERVAL, FIND NEW CONCENTRATION, C_1. ASSUME GAS AT CONCENTRATION C_1 IS RELEASED UNTIL SET POINT PRESSURE IS REACHED. DETERMINE NEW MASSES OF C_7 AND GAS IN ULLAGE SPACE

FORM R 152-R-2 REV. 10-73

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$\rightarrow \quad M_{GAS_1} = m_{GAS_0} + \dot{R}\,\Delta t$

$\rightarrow \quad m_{C7_1} = m_{C7_0}$

$R_{C7} = 15.46 \text{ ft}/{}^\circ R$

$R_{GAS} = 53.49 \text{ ft}/{}^\circ R$

$$\rightarrow \quad R_{mix} = \frac{(m_{GAS_1})(53.99) + (m_{C7_1})(15.46)}{(m_{GAS_1} + m_{C7_1})}$$

$$P_{mix} = 14.13 \text{ PSIA} = \frac{M_T R_{mix} T_{mix}}{144 \; V}$$

$$\rightarrow \quad M_T = \frac{(14.13)(8764)(144)}{R_{mix}\;(891)} \; \frac{\text{lb}}{\text{in}^2} \; \frac{\text{ft}^3\,\text{in}^2}{\text{ft}^2\;{}^\circ R} \; \frac{{}^\circ R}{\text{ft}}$$

$\rightarrow \quad \Delta M_{UMU} = m_{GAS_1} + m_{C7_1} - m_T$

$\Delta M_{UMU} = M_{GAS_0} + \dot{R}\,\Delta t + m_{C7_0} - m_T$

$$\rightarrow \quad M_{GAS_2} = M_{GAS_0} + \dot{R}\,\Delta t - \frac{m_{GAS_1}}{m_{GAS_1} + m_{C7_1}} \Delta M_{UMU}$$

$$\rightarrow \quad M_{C7_2} = M_{C7_0} - \frac{M_{C7_1}}{m_{GAS_1} + M_{C7_1}} \Delta M_{UMU}$$

NEXT TIME INCREMENT →

M_{C7_0} = M_{C7_2} from previous increment
M_{GAS_0} = M_{GAS_2} from previous increment

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CONCENTRATION OF C_7 AT THE END OF EACH TIME INCREMENT

$$= C_{C7} = \frac{M_{C7_2}}{M_{C7_2} + M_{GAS_2}}$$

CONSIDER TIME INTERVAL FROM 9 A.M. TO 1 P.M.

$$V = V_{U\,DEL} = 8764 - 740.3t$$

$$R = 4.148 + 13.198\,t$$

M_{C7_0} is known

M_{GAS_0} is known

$$M_{GAS_1} = M_{GAS_0} + R\,\Delta t$$

$$M_{C7_1} = M_{C7_0}$$

$$R_{mix} = \frac{(M_{GAS_1})(53.49) + (M_{C7_1})(15.46)}{(M_{GAS_1} + M_{C7_1})}$$

$$M_T = \frac{(14.13)(8764 - 740.3t)(144)}{R_{mix}\;(891)}$$

$$\Delta M_{UMU} = M_{GAS_1} + M_{C7_1} - M_T$$

PREPARED BY: F. [illegible]

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$$M_{GAS_2} = M_{GAS_1} - \frac{M_{GAS_1}}{M_{GAS_1} - M_{C7_1}} \Delta M_{UMU}$$

$$M_{C7_2} = M_{C7_0} - \frac{M_{C7_1}}{M_{GAS_1} + M_{C7_1}} \Delta M_{UMU}$$

$$C_{C7} = \frac{M_{C7_2}}{M_{C7_2} + M_{GAS_2}}$$

$$M_{C7_2} \longrightarrow M_{C7_0}$$

$$M_{GAS_2} \longrightarrow M_{GAS_0}$$

RETURN → decrement time

CONSIDER TIME INTERVAL FROM 1 AM. TO 5 P.M.

$V = V_{UMIN} = 5803 \text{ Ft}^3$

$R = 56.940$ lb/hr

M_{C7_0} is known

M_{GAS_0} is known

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$$M_{GAS_1} = M_{GAS_0} + R_1 \Delta t$$

$$M_{C7_1} = M_{C7_0}$$

$$R_{mix} = \frac{(M_{GAS_1})(53.49) + (M_{C7_1})(15.46)}{(M_{GAS_1} + M_{C7_1})}$$

$$m_T = \frac{(19.13)(5803)(144)}{R_{mix}\,(891)}$$

$$\Delta M_{UMU} = M_{GAS_1} + M_{C7_1} - M_T$$

$$M_{GAS_2} = M_{GAS_1} - \frac{M_{GAS_1}}{M_{GAS_1} + M_{C7_1}} \Delta M_{UMU}$$

$$M_{C7_2} = M_{C7_0} - \frac{M_{C7_1}}{M_{GAS_1} + M_{C7_1}} \Delta M_{UMU}$$

$$C_{C7} = \frac{M_{C7_2}}{M_{C7_2} + M_{GAS_2}}$$

$$M_{C7_2} \rightarrow M_{C7_0}$$

$$M_{GAS_2} \rightarrow M_{GAS_0}$$

increment time

RETURN

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CONSIDER TIME INTERVAL FROM 5 P.M. TO 9 A.M.

$$V = V_{u\,inc.} = 5803 + 740.3\,t$$

$$\mathcal{R} = 56.94 - 13.198\,t$$

AT SOME POINT DURING THIS TIME INTERVAL $\mathcal{R}$ BECOMES INSUFFICIENT TO MAINTAIN P

M_{C7_0} is known

M_{GAS_0} is known

$$M_{GAS_1} = M_{GAS_0} + \mathcal{R}\,\Delta t$$

$$M_{C7_1} = M_{C7_0}$$

$$R_{mix} = \frac{(M_{GAS_1})(53.49) + (M_{C7_1})(15.46)}{(M_{GAS_1} + M_{C7_1})}$$

$$M_T = \frac{(14.13)(5803 + 740.3\,t)(144)}{R_{mix}\,(891)}$$

$$\Delta M_{UMU} = M_{GAS_1} + M_{C7_1} - M_T$$

IF ΔM_{UMU} IS NEGATIVE, HEPTANE MUST BE ADDED → GO TO $\boxed{A}$

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$$M_{GAS_2} = M_{GAS_1} - \frac{M_{GAS_1}}{M_{GAS_1} + M_{C7_1}} \Delta M_{UMU}$$

$$M_{C7_2} = M_{C7_0} - \frac{M_{C7_1}}{M_{GAS_1} + M_{C7_1}} \Delta M_{UMU}$$

$$C_{C7} = \frac{M_{C7_2}}{M_{C7_2} + M_{GAS_2}}$$

$M_{C7_2} \rightarrow M_{C7_0}$

$M_{GAS_2} \rightarrow M_{GAS_0}$

RETURN → decrement Time

$\boxed{A}$

$$P_T = P_{GAS} + P_{C7}$$

$P_T = 14.13$ PSIA

$$P_{GAS} = \frac{M_{GAS_1}\,(53.49)(891)}{144\,(5803 + 740.3t}$$

$$P_{C7} = P_T - P_{GAS}$$

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$$P_{C_7} = \frac{M_{C_7}(15.46)(891)}{144\,(5803+740\,t)}$$

$$M_{C7_2} = \left[14.13 - \frac{M_{GAS_1}(53.49)(891)}{(144)(5803+740t)}\right] \times$$

$$\times \left[\frac{144\,(5803+740t)}{(15.46)\,(891)}\right]$$

$$M_{GAS_2} = M_{GAS_1}$$

$$C_{C_7} = \frac{M_{C7_2}}{M_{GAS_2} + M_{C7_2}}$$

$$M_{C7_2} \longrightarrow M_{C7_0}$$

$$M_{GAS_2} \rightarrow M_{GAS_0}$$

RETURN → decrement time

$$M_{C7_0} = 0$$

$$M_{GAS_0} = \frac{14.13\,(144)(8997)}{(53.49)(891)} = 362.76 \text{ lbs.}$$

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DETERMINE: CONCENTRATION OF N-HEPTANE (C_7) AS A FUNCTION OF TIME IN THE ULLAGE SPACE WHEN THE RATE OF DEGRADATION PRODUCT FORMATION IS 1/2 THE MAXIMUM RATE.

GIVEN: SAME AS BEFORE EXCEPT:

OIL DEGRADATION RATE AT 580°F:
IN ROCK BED = 21×10^{-6} LB/LB-HR = $R_{GAS\ RB}$
ABOVE ROCK BED = 6.875×10^{-6} LB/LB-HR = $R_{GAS\ ABB}$

CALCULATION: SAME AS BEFORE EXCEPT

RATE OF DEGRADATION PRODUCT FORMATION

$$R = R_{GAS\ R.B.}\, m_{B,580} + R_{GAS\ ABB}\, m_A$$

$$R = (1-F)(1{,}217{,}330)(21\times10^{-6}) + (422{,}670 - 120{,}988\,F)(6.875\times10^{-6})$$

9 P.M. TO 9 A.M. $F=1$ $R = 2.074$ LB/HR

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9 AM TO 1 P.M . $F = 1 - \frac{1}{4}t$

$$R = (1 - 1 + \tfrac{1}{4}t)(1{,}217{,}330)(21 \times 10^{-6}) +$$

$$+ \left(422{,}670 - 120988 + \frac{120988}{4}t\right) 6875 \times 10^{-6}$$

$$R = 2.079 + 6.599t$$

1 P.M. TO 5 P.M. $F = 0$ $R = 28.470$

5 P.M. TO 9 P.M. $F = \frac{1}{4}t$ $R = 28.470 - 6.599t$

FORM R 152-R-2 REV. 10-73

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PROGRAM NAME:

STEP	DESCRIPTION	ENTER	PRESS	READ	PRINT	
					VALUE	LABEL
1	ENTER PROGRAM		CMS			
2	ENTER TIME INCREMENT IN HRS. TO BE USED IN CALCULATION (0.1)	Δt (HR.)	A'	Δt		
3	ENTER TIME INCREMENT BETWEEN DATA PRINTOUTS IN HOURS (0.5)	Δt (HR) PRINT	B'	-		
4	ENTER INITIAL MASS OF GAS LBS (365.611)	M_{GAS_0} (LBS)	C'	M_{GAS_0}		
5	ENTER INITIAL MASS OF HEPTANE, LBS (0)	M_{C_7} (LBS)	D'	M_{C_7} (LBS)		
6	START CALCULATING PRESS A TO START AT 5 P.M. PRESS B TO START AT 9 P.M. PRESS C TO START AT 9 AM PRESS D TO START AT 1 P.M.		A		t (hrs) C	
7	STOP		R/S			

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00		0
01		1
02		2
03		3
04	$M_{GAS_{0,2}}$ (lb)	4
05	$M_{CT_{0,2}}$ (lb)	5
06	M_{GAS_1} (lb)	6
07	M_{CT_1} (lb)	7
08	Q (lb/hr)	8
09	Δt (hr)	9
10	R_{mix} (ft/°R)	0
11	M_t (lb)	1
12	V (ft^3)	2
13	ΔM_{UMU} (lb)	3
14	C_{GAS_2} (lb/lb_T)	4
15	C_{CT_2} (lb/lb_T)	5
16	$M_{CT_1} + M_{GAS_1}$ (lb)	6
17	Δt PRINT (HR)	7
18	# Δt BETWEEN PRINTS	8
19	t (HR)	9
20	t_{TOTAL}	0
1		1
2		2
3		3
4		4
5		5
6		6
7		7
8		8
9		9

PREPARED BY: K. MORRISON	PAGE NO. A 21
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Rocketdyne Division
Rockwell International

0	LBL	5PM TO 9AM	0	=	0	SUBR
1	A		1	STO	1	PRT
2	CLR		2	08	2	4
3	STO		3	5	3	x≷t
4	19		4	8	4	RCL
5	LBL		5	0	5	19
6	—		6	3	6	INV
7	0		7	+	7	x=t
8	x≷t		8	7	8	—
9	RCL		9	4	9	GTO B
0	09		0	0	0	LBL
1	SUM		1	.	1	√x
2	19		2	3	2	SUBR
3	SUM		3	×	3	x≷t
4	20		4	RCL	4	SUBR
5	5	Z	5	19	5	PRT
6	6	8	6	=	6	4
7	.	.	7	STO	7	x≷t
8	9	4	8	12	8	RCL
9	4	7	9	SUBR	9	19
0	—	—	0	RCL	0	INV
1	1	6	1	SUBR	1	x=t
2	3	.	2	SUM	2	—
3	.	5	3	RCL	3	NOP
4	1	9	4	13	4	
5	9	4	5	INV	5	
6	8	0	6	x≷t	6	
7	×		7	√x	7	
8	RCL		8	SUBR	8	
9	19		9	STO	9	

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PREPARED BY: K. Morrison	Rocketdyne Division Rockwell International	PAGE NO. A22
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0	LBL	9AM to 9AM	0	RCL
1	B		1	SBR
2	CLR		2	SUM
3	STO		3	SBR
4	19		4	STO
5	1		5	SBR
6	2		6	PRT
7	x⇌t		7	RCL
8	LBL		8	19
9	+		9	INV
0	RCL		0	x=t
1	09		1	+
2	SUM		2	NOP
3	19		3	
4	SUM		4	
5	20		5	
6	4	2	6	
7	.		7	
8	1	0	8	
9	4	7	9	
0	8	4	0	
1	STO		1	
2	08		2	
3	8		3	
4	7		4	
5	6		5	
6	4		6	
7	STO		7	
8	12		8	
9	SBR		9	

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PREPARED BY:	
CHECKED BY:	
DATE:	10-28-80

Rocketdyne Division
Rockwell International

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0	LBL	9AM – 1PM
1	C	
2	RCL	
3	STO	
4	19	
5	4	
6	x⇄t	
7	LBL	
8	x	
9	RCL	
0	09	
1	SUM	
2	19	
3	SUM	
4	20	
5	9	2
6	.	.
7	1	0
8	4	7
9	8	4
0	+	+
1	1	6
2	3	.
3	.	5
4	1	9
5	9	9
6	8	0
7	x	
8	RCL	
9	19	

0	=		
1	STO		
2	08		
3	x		
4	-		
5	6		
6	4		
7	—		
~~8~~	7		
~~9~~	4		
~~0~~	0		
~~1~~	.		
~~2~~	3		
3	√		
4	RCL		
5	19		
6	=		
7	STO		
8	12		
9	SUBR		
0	RCL	0	x=t
1	SUBR	1	X
2	SUM	2	NOP
3	SUBR	3	
4	STO	4	
5	SUBR	5	
6	PRT	6	
7	RCL	—	
8	19	8	
9	INV	9	

PREPARED BY: [illegible]	Rocketdyne Division Rockwell International	PAGE NO. A29	
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DATE: 10. 28. 80			

0	LBL	1PM TO 5PM	0	SUBR
1	D		1	SUM
2	CLR		2	SUBR
3	STO		3	STO
4	19		4	SUBR
5	4		5	RET
6	xZt		6	RCL
7	LBL		7	19
8	÷		8	INV
9	RCL		9	x=t
0	09		0	÷
1	SUM		1	NOP
2	19		2	GTO
3	SUM		3	A
4	20		4	
5	5	2	5	
6	6	8	6	
7	.	.	7	
8	9	4	8	
9	4	7	9	
0	STO		0	
1	08		1	
~~2~~	5		2	
~~3~~	8		3	
~~4~~	0		4	
~~5~~	3		5	
6	STO		6	
7	12		7	
8	SUBR		8	
9	RCL		9	

PREPARED BY: R. Morrison	Rocketdyne Division Rockwell International	PAGE NO. A25	
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SUBROUTINE RCL

$M_{GAS_1} = M_{GAS_0} + \dot{R}\Delta t$

$M_{GT_1} = M_{GT_0}$

```
0  LEL
1  RCL
2  RCL
3  04
4  +
5  RCL
6  08
7  ×
8  RCL
9  09
0  =
1  STO
2  06
3  RCL
4  05
5  STO
6  07
7  INV
8  SER
9
0
1
2
3  -
4
5
6
7
8
9
```

SUBROUTINE SUM

$$R_{mix} = \frac{\left[(M_{GAS_1})(53.49) + (M_{GT_1})(1546)\right]}{(M_{gas} + M_{GT_1})}$$

$$M_T = \frac{(14.13)(V)(144)}{R_{mix}\,(391)}$$

$\Delta M_{UMU} = M_{GAS_1} + M_{GT_1} - M_T$

```
0  LBL
1  SUM
2  RCL
3  06
4  ×
5  5
6  3
7  .
8  4
9  9
0  +
1  RCL
2  07
3  ×
4  1
5  5
6  .
7  4
8  6
9  =
0  ÷
1  (
2  RCL
3  06
4  +
5  RCL
6  07
7  )
8  =
9  STO
```

PREPARED BY: R. MORRISON
CHECKED BY:
DATE: 10-28-80

Rocketdyne Division
Rockwell International

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0	10	0	LBL	SUBROUTINE
1	RCL	1	STO	STO
2	12	2	RCL	$C_{GAS_2} = \frac{M_{GAS_1}}{M_{GAS_1}+M_{C7_1}}$
3	×	3	06	
4	2	4	+	
5	.	5	RCL	$C_{C7_2} = \frac{M_{C7_1}}{M_{C7_1}+M_{GAS_1}}$
6	2	6	07	
7	8	7	=	
8	3	8	STO	$M_{GAS_2} = M_{GAS_1}$
9	6	9	16	
0	4	0	1/x	$- C_{GAS_2} \Delta M_{UMO}$
1	÷	1	×	
2	RCL	2	RCL	$M_{C7_2} = M_{C7_1}$
3	10	3	06	
4	=	4	=	$- C_{C7_1} \Delta M_{UMO}$
5	STO	5	STO	
6	11	6	14	
7	RCL	7	RCL	
8	06	8	07	
9	+	9	÷	
0	RCL	0	RCL	
1	07	1	16	
2	−	2	=	
3	RCL	3	STO	
4	11	4	15	
5	=	5	RCL	
6	STO	6	06	
7	13	7	−	
8	INV	8	RCL	
9	SUBR	9	14	

PREPARED BY: E. Morrison	PAGE NO. A27
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Rocketdyne Division
Rockwell International

0	Y	0	LBL	SUBROUTINE
1	RCL	1	XZt	XZt
2	13	2	1	
3	=	3	4	$M_{CH_{4_2}} = \Big[14.13 -$
4	STO	4	.	
5	09	5	1	$- \dfrac{M_{GAS_1} (330.97)}{V} \Big]$
6	RCL	6	3	
7	07	7	−	$\times\ 0.010459\ V$
8	−	8	RCL	
9	RCL	9	06	$C_{CH_4} = \dfrac{M_{CH_4}}{M_{CH_4} + M_{GAS_2}}$
0	15	0	Y	
1	×	1	3	
2	RCL	2	3	$C_{GAS_2} = \dfrac{M_{GAS_2}}{M_{CH_4} + M_{GAS_2}}$
3	13	3	0	
4	=	4	.	
5	STO	5	9	
6	05	6	7	
7	INV	7	÷	
8	SUBR.	8	RCL	
9		9	12	
0		0	=	
1		1	Y	
2		2	.	
3		3	0	
4		4	1	
5		5	0	
6		6	4	
7		7	5	
8		8	9	
9		9	X	

PREPARED BY: F. Morrison	Rocketdyne Division Rockwell International	PAGE NO. A28
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0	RCL	0	STO
1	12	1	15
2	=	2	INV
3	STO	3	SUBR.
4	05	4	
5	RCL	5	
6	06	6	
7	STO	7	
8	04	8	
9	RCL	9	
0	04	0	
1	÷	1	
2	(	2	
3	RCL	3	
4	04	4	
5	+	5	
6	RCL	6	
7	05	7	
8	)	8	
9	STO	9	
0	16	0	
1	=	1	
2	STO	2	
3	14	3	
4	RCL	4	
5	05	5	
6	÷	6	
7	RCL	7	
8	16	8	
9	=	9	

PREPARED BY: R. MORRISON	Rocketdyne Division Rockwell International	PAGE NO. A 29	
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DATE:			

0	LBL	0	LBL SUBROUTINE
1	A'	1	PRT PRINT
2	STO	2	DSZ
3	09	3	0
4	R/S	4	CLR
5		5	RCL
6		6	20
7		7	PRT
8	LBL	8	RCL
9	B'	9	15
0	STO	0	PRT ← ADV
1	17	1	RCL
2	×	2	18
3	RCL	3	STO
4	09	4	00
5	1/x	5	LBL
6	=	6	CLR
7	STO	7	INV
8	18	8	SUBR
9	STO	9	
0	00	0	
1	R/S	1	
2		2	
3		3	
4	LBL	4	LBL
5	C'	5	D'
6	STO	6	STO
7	09	7	05
8	R/S	8	R/S
9		9	

HIGH RATE OF DEGRADATION PRODUCT FORMATION

A 30

```
        0.   5 PM
        0.

      0.5
       0.

       1.
       0.

      1.5
       0.

        2.
.0011681073

      2.5
.0271596725

       3.
.0802433399

      3.5
.1511075685

        4.   9 PM
.2313477751

      4.5
.2302789154

        5.
.2292140225

      5.5
.2281530988

        6.
.2270961384

      6.5
.2260431353

        7.
.2249940833

      7.5
.2239489763

        8.
0.222907808
```

```
       8.5
0.221870572

        9.
0.220837262

      9.5
.2198078715

      10.
.2187823939

     10.5
.2177608226

      11.
.2167431509

     11.5
.2157293721

      12.
.2147194793

     12.5
.2137134656

      13.
.2127113241

     13.5
.2117130478

      14.
.2107186295

     14.5
.2097280621

      15.
.2087413385

     15.5
.2077584512

      16.   9 AM
.2067793931
```

```
     16.5
.2048397622

      17.
.2012125431

     17.5
.1958210442

      18.
.1886193487

     18.5
.1796013161

      19.
.1688108076

     19.5
0.156332673

      20.   1PM
.1424037264

     20.5
.1285070114

      21.
.1158422393

     21.5
.1043237343

      22.
.0938672497

     22.5
.0843909089

      23.
.-----------

     23.5
.0680675136

      24.   5 PM
.0610745917
```

HIGH RATE OF DEGRADATION PRODUCT FORMATION

A 31

24.5	0.055317068	
25.	.0509590017	
25.5	.0476666802	
26.	.0462872352	
26.5	0.068610994	
27.	.1168889712	
27.5	.1825766425	
28.	.2578267222	9 P.M.
28.5	.2566622405	
29.	.2555018435	
29.5	.2543455323	
30.	.2531933031	
30.5	.2520451518	
31.	.2509010743	
31.5	.2497610665	
32.	.2486251241	
32.5	.2474932427	
33.	.2463654179	
33.5	.2452416451	
34.	.2441219197	
34.5	.2430062369	
35.	.2418945919	
35.5	.2407869797	
36.	.2396833955	
36.5	.2385838341	
37.	.2374882903	
37.5	.2363967589	
38.	.2353092345	
38.5	.2342257117	
39.	0.233146185	
39.5	.2320706488	
40.	.2309990974	9 A.M.
40.5	.2288756213	
41.	~~0.224902442~~	
41.5	.2189915024	
42.	.2110862395	
42.5	.2011714762	
43.	.1892849587	
43.5	.1755301511	
44.	.1600893618	1 P.M.
44.5	.1446642717	
45.	.1305698347	
45.5	0.117720491	
46.	.1060305689	
46.5	.0954155418	
47.	.0857931095	
47.5	0.077084024	
48.	.0692126906	5 P.M.

A 32

HIGH RATE OF DEGRADATION PRODUCT FORMATION

```
       48.5
 .0627237508

        49.
 .0578071252

       49.5
 .0540900195

        50.
 .0523800238

       50.5
 .0742219776

        51.
 .1218635013

       51.5
 .1868612677

        52.
 .2614425768

       52.5
 .2602654642

        53.
 .2590924474

       53.5
 .2579235277

        54.
 .[illegible]
```

9 P.M.

A 33

LOW RATE OF DEGRADATION PRODUCT FORMATION

```
0.0   5PM
0
         0.5                  8.5                    16.5
 .0280131122          0.419472029             .4057445744

          1.                   9.                     17.
 .0748667627          0.41[illegible]         .----------

         1.5                  9.5                    17.5
 .1302162237          .4178425825             .3981975972

          2.                  10.                     18.
 .1900455656          .4170292312             .3920187319

         2.5                 10.5                    18.5
 .2513663682          .4162167967             .3840770301

          3.                  11.                     19.
 .3120932926          .4154052804             .3742501197

         3.5                 11.5                    19.5
 .3708623768          .----------             .3624166588

          4.                  12.                     20.
 .4268494883  9 PM    .4137850088             .3484609682  1 PM

         4.5                 12.5                    20.5
 .4260261631          .4129762566             .3337019648

          5.                  13.                     21.
 .4252037331          .4121684289             .31[illegible]

         5.5                 13.5                    21.5
 .4243822035          .4113615271             .3054966674

          6.                  14.                     22.
 0.423561576          .4105555527             .---------

         6.5                 14.5                    22.5
 .4227418524          .4097506073             .2790552435

          7.                  15.                     23.
 .4219230343          .4089463923             .2664955728

         7.5                 15.5                    23.5
 .4211051232          .4081432092             0.254373649

          8.                  16.  9 AM              24.  5PM
 .4202881209          .4073409594             .2426857309
```

A34

LOW RATE OF DEGRADATION PRODUCT FORMATION

```
          24.5
 .2535281547

           25.
 .2763288043

          25.5
 .3078557753

           26.
 0.345209017

          26.5
 .3862410792

           27.
 .4288878049

          27.5
 .4718668258

           28.     9PM
 .5142124331

          28.5
 .5133088909

           29.
 .5124060205

          29.5
 .5115038287

           30.
 .5106023182

          30.5
 .5097014918

           31.
 .5088013521

          31.5
 .5079019018

           32.
 .5070031435
```

```
          32.5
 .5061050798

           33.
 .5052077135

          33.5
 .5043110472

           34.
 .5034150834

          34.5
 .5025198248

           35.
 0.501625274

          35.5
 .5007314335

           36.
 0.499838306

          36.5
 0.498945894

           37.
 .4980542001

          37.5
 .4971632268

           38.
 .4962729767

          38.5
 .4953834523

           39.
 .4944946562

          39.5
 .4936065908
                   9AM
           40.
 .4927192586
```

```
          40.5
 .4909526807

           41.
 .4876179458

          41.5
 .4825850603

           42.
 .----------

          42.5
 .4668575418

           43.
 .4558569399

          43.5
 0.44254937

           44.     1PM
 0.426769237

          44.5
 [illegible]

           45.
 .3935834445

          45.5
 .3775954382

           46.
 .3620247737

          46.5
 .3468797245

           47.
 .3321667682

          47.5
 .3178906495

           48.     5PM
 .3040544536
```

A35

LOW RATE OF DEGRADATION PRODUCT FORMATION

```
        48.5
.3103541508

         49.
0.328032485

        49.5
.3542789884

         50.
.3865374428

        50.5
.4226439416

         51.
0.460667515

        51.5
0.499886337

         52.   9PM
.5387348835

        52.5
0.537814223

         53.
0.536094158

        53.5
.5359746959

         54.
.5350558396

        54.5
0.534137592

         55.
.5332199561

        55.5
.5323029347

         56.
.5313865308
```

```
        56.5
.5304101412

         57.
.5295555868

        57.5
.5286410526

         58.
.5277271473

        58.5
.5268138739

         59.
.5259012351

        59.5
.5249892338

         60.
.5240778729

        60.5
.5231671551

         61.
.5222570833

        61.5
.5213476602

         62.
.5204388888

        62.5
.5195307716

         63.
.5186233117

        63.5
.5177165115   9AM

         64.
.5168103741
```

```
        64.5
.5150061008

         65.
0.511599279

        65.5
.5064552945

         66.
0.499428622

        66.5
.4903627165

         67.
.4790906448

        67.5
0.465436891

         68.   1PM
.4492209649

        68.5
.4319364997

         69.
.4150288706

        69.5
.3985124451

         70.
.3823998024

        70.5
.3667016299

         71.
.3514267563

        71.5
.3365821976

         72.   5 PM
.3221732166
```

LOW RATE OF DEGRADATION PRODUCT FORMATION

```
        72.5
.3272107841

         73.
.3434437435

        73.5
.3681790142

         74.
.3989476172

        74.5
.4336435817

         75.
.4705691424

        75.5
.5084181214

         76.     9 PM
.5462269207

        76.5
.5453015022

         77.
.5443766551
```

PREPARED BY: W.O. KNIPPEL	Rocketdyne Division Rockwell International	PAGE NO. 1 OF 2
CHECKED BY: K. YEO.		REPORT NO.
DATE: 18 FEB 81	SOLAR ULLAGE MAINTENANCE UNIT	

CONDENSATE RECOVERY TANK
300 GAL. 50 PSIG

SUMMARY

THE ATTACHED CALCULATIONS WERE MADE TO ASCERTAIN THE RELIEF VALVE CAPACITY REQUIREMENT OF THE TANK IN THE EVENT OF FIRE ON THE SKID. THE TANK IS PIPED TO A SYSTEM CONTAINING A BLOWER DESIGNED TO OPERATE AT 5 PSIG MAXIMUM. A NITROGEN SUPPLY TO THE TANK IS NOT A CONSIDERATION SINCE FIRE ACCOUNTS FOR THE MAXIMUM FLOW THRU A RELIEF. A 4" RELIEF VALVE IS RECOMMENDED TO ACCOMMODATE THE RELIEF CAPACITY REQUIREMENTS AS SPECIFIED BY API STANDARD 2000 AND NFC. THE RELIEF VALVE SHALL BE LOCATED IN THE 6" PIPE LINE ROUTED BETWEEN THE TSU AND THE RECOVERY TANK AT A SAFE ELEVATION FOR RELIEF VALVE DISCHARGE.

REV
1

PREPARED BY: W.O. KNIPPEL	**Rocketdyne Division** Rockwell International	PAGE NO. 2 OF 2
CHECKED BY: K. YEO	SOLAR	REPORT NO.
DATE: 18 FEB 81	ULLAGE MAINTENANCE UNIT	

CONDENSATE RECOVERY TANK

RELIEF VALVE SIZING (REF API STANDARD 2000)

$Q = 20{,}000\ A$ (APPENDIX)

$A = 75$ SQ FT

$Q = 1{,}500{,}000$ BTU/HR

$SCFH = \frac{70.5\,Q}{L\sqrt{M}}$ (FREE AIR, 14.7PSIA @ 60°F).

$SCFH = \frac{70.5(1{,}500{,}000)}{133\sqrt{100}}$ (HEPTANE)

$SCFH = 79511$ (AIR).

USE 4" GROTH MODEL 2301, SET TO OPEN AT 5 PSIG PRESSURE, REMAIN CLOSED WITH VACUUM, STAINLESS STEEL TRIM, VITON SEAT, CARBON STEEL BASE AND COVER 4"-150LB FLANGE

REV. 1

APPENDIX A

UMU OPERATING MANUAL

APPENDIX A

UMU OPERATING MANUAL

The UMU provides an oxygen free environment in the ullage space of the TSU. Air, which can cause deterioration of the heat transfer oil, is excluded by using non-oxygen-bearing fuel vapors. Gaseous nitrogen is available for backup when necessary. Air is excluded by keeping the ullage space and UMU makeup system at a slight positive pressure, 5.5 to 10.5-inches of water, at all times. The oil level in the TSU changes continually as a result of heating and cooling during the charging and extraction cycles. The UMU compensates by removing and supplying gas to keep the ullage pressure in an established band. Fuel vapors, resulting from oil decomposition, that do not condense are disposed of through the UMU combustor.

GENERAL DESCRIPTION

The UMU is a service unit for the TSU and provides the following two functions:

1) Pressurization of the ullage space to a continuous and positive pressure, selected to be between 5.5 and 10.5-inches of water, by adding or removing oxygen free gas to keep the pressure within the desired range as the liquid level changes during TSU charging and extraction cycles.
2) Disposal of excess gas and water vapor through a combustion and drain system.

It is essential that the UMU retain the oxygen free integrity of the TSU ullage space at all times. The TSU is a sealed, closed system. Excess pressure will result in operation of the TSU relief valves. A pressure below atmospheric in the TSU may allow air to leak in and, if too low, will lead to the collapse of the roof. The UMU is contained in skid assembly SA311, and is connected to the TSU ullage space by a 6-inch vapor line (6-UG-1-BBA), a 1-inch liquid line (1-HP-1-BBA) and a 2-inch nitrogen line (2-N-5-BBA). The UMU skid consists of a 300 gallon condensate storage and water separator tank; a pump to transfer liquid pressurant to the TSU; a burner stack and associated blowers and controls to dispose of combustible gases; and a gaseous nitrogen supply that provides TSU pressurant when gas from the condensate system is inadequate to meet TSU pressure requirements.

The working fluid for pressurizing the TSU is a mixture of heptane and other hydrocarbon vapors. It is stored in the tank TK-302 as a liquid well below its boiling point. When returned to the TSU ullage space it vaporizes, since the ullage environment is at a temperature above 400°F. When returned to tank TK-302 through line 6-UG-1-BBA the vapors condense. Tests have shown that the oil decomposition products of Caloria HT43 are a mixture of fuel vapors, some of which condense at room temperature and pressure. Condensed liquids remain in tank TK-302 and non-condensibles go to the burner stack through line 6-UG-1-BBA.

Waste gas blower FA-301 and air blower FA-302 provide a positive pressure to the burner stack where the fuel gases are mixed with air and are burned. A pilot gas supply services a pilot flame to assure combustion at all mixture ratios. Pilot gas supply is from a pressure bottle on the UMU pad.

The ullage pump P-308 returns condensed liquid to the TSU through line 1-HP-1-BBA when the ullage volume is increasing. The liquid consisting of Heptane and some condensed fuel vapors revaporizes upon entering the TSU and fills the ullage space as needed.

Each day at the end of the charging mode, the level of liquid in TK-302 shall be checked using sight gage LG4020A, and makeup heptane shall be added as necessary. Line 1/2-inch-HP-2-BBA is the heptane fill line. Liquid heptane is delivered and stored on the UMU pad in 50 gallon barrels and transferred to the U S storage container with a commercial, air or electrically powered barrel pump.

Tank TK-302 is a combined gas receiver, gas-liquid separator and storage tank. Ullage gases and condensed vapors from the TSU enter near the top of the tank. The condensed vapors settle out and the non condensible fraction is diverted to the burn stack. Approximately 120 gallons of condensate or heptane is required to fill the TSU ullage space during a complete extraction cycle. If none is lost, the 120 gallons can be used repeatedly. However, it is expected that some will be lost and makeup condensate or heptane will be added as needed.

Tank TK-302, acting as a liquid-gas separator, provides an indication if water is leaking into the oil system. Water will be turned to steam, which will ultimately find its way to the TSU ullage space and then into the UMU system. Steam will condense in the 6-inch vent line between the TSU and the UMU and settle to the bottom of TK-302. Liquid level gage LG4020B is placed in the lower region of the tank to monitor water level for drainage purposes. It is desirable that the water level remain below the connection to line 1-HP-2-BBA. Small amounts of water can be returned as a pressurizing gas for the ullage space in the TSU but repeated usage of large amounts of water may lead to oxidation of the oil. Water is drained from the bottom of the tank through manual control valve UHDV.

Nitrogen is available through pressure regulator PCV-4023 to maintain a positive pressure in V-304 to prevent condensate flashing into vapor. A gaseous nitrogen system serves as a UMU backup and provides an independent source of inert pressurant for the TSU ullage space.

OPERATION

Reference Drawings

UMU Skid Assembly	GA000-90907-M8
Skid Assembly SA-311 Flow Diagram	GA000-90907-M77
UMU Electrical Diagram	GA000-90907-E20
UMU Termination Boxes	GA000-90907-E17

The UMU has four (4) principal operating circuits. These are:

(1) Vapor inlet and condensing (storage vessel)
(2) Condensate return
(3) Waste gas disposal (thermal oxidizer)
(4) Gaseous nitrogen supply

These fluid circuits are interconnected and controlled by a network of valves with signals from pressure switches mounted on the TSU. Pressures, temperatures, liquid levels and flows are monitored with sight gages and electrical recording transducers.

Powering of the UMU

The operation of the UMU can start after the unit is powered. To power the UMU, the following actions are required:

(1) The main UMU power switch has to be in the ON position.

(2) Breakers 10 and 12 in LP4 (Building 712) in ON position.

(3) The thermal oxidizer power switch has to be in the ON position. This will be indicated by the lit POWER lamp on the thermal oxidizer control panel.

(4) The ullage pump disconnect switch has to be in the ON position.

When these five switches are in the ON position all circuits of the UMU are ready for operation.

In addition to the above, the AUTO-MANUAL switch on the thermal oxidizer control panel shall be turned to AUTO.

Vapor Inlet and Condensing

During the charging mode the fluid level in the TSU (V303) rises. At the same time, due to the high temperature, a certain amount of oil vapors are being released from the oil into the ullage space. The combination of those two factors causes the pressure in the ullage space to increase. When the pressure in the TSU reaches 10.5-inches H_2O on PI-4008, the ILS closes the circuit, energizing the solenoid valve SOV-4014 in the instrument air supply line to valve AOV-4014 and the relay ICR in the control system of the thermal oxidizer. Subsequently, valve AOV-4014 opens, venting gases from the ullage space of the TSU, through line 6-inch-UG-1-BBA, to the UMU tank TK-302. Condensible vapors condense in the 6-inch line and collect in the UMU tank, while non-condensible gases (fumes) pass through the tank into the thermal oxidizer. (Non-condensible gases passing through the thermal oxidizer will be referred to as fumes). Limit switches mounted on valve AOV-4014 transmit signals to the master controller, indicating whether the valve is open or closed.

The level of the condensate in the UMU tank can be monitored at the sight gage LG-4020A. Gage LG-4020B shows the level of water in the tank if there is an accumulation of water.

The volume of condensate in the UMU tank required to maintain the ullage pressure in the TSU during the transition from the fully charged (with heat) to the fully discharged state of the TSU, has been calculated to be 122 gallons. This figure has to be verified in the field. Upon verification a scale shall be fastened to the sight gage LG-4020A. The scale shall be graduated in such a manner to show the maximum volume of condensate required for the transition from the fully charged to the fully discharged TSU with increments of 1/10 of the maximum volume, down to zero volume. The scale shall be set in such a way that the point of zero volume coincides with the level of the lower connection of sight gage LG-4020A. This will then coincide with the midpoint of gage LG-4020B. The level of the condensate has to be checked every evening after the end of the charging cycle. The condensate level in the UMU tank shall correspond to the state of the TSU heat charging, i.e., for maximum TSU charging, the UMU tank shall contain the maximum volume of condensate; for 40% TSU charging the UMU tank shall contain 40% condensate. If the condensate is below the required level, heptane shall be pumped to the UMU tank from one of the barrels located at the pad adjacent to the UMU. Heptane is added through valve UHIS-1 located at the east side of the UMU. In order to prevent air from entering the UMU tank during the adding of heptane, the following procedure shall be used:

(1) Place pump suction hose into heptane barrel and make sure that the hose is submerged in heptane. Make sure that air can enter the heptane barrel.

(2) Attach hose from pump discharge to valve UHIS-1.

(3) Open valve UHIS-1. Wait one minute (or as long as required) for the condensate from the tank to displace the air in the hoses and the pump.

(4) Start the pump. Observe the sight gage LG-4020A and add only the amount of heptane required. Stop pump before the heptane level in the barrel drops below the suction hose inlet to prevent pumping air.

(5) After the required level of condensate in the UMU tank is reached, close valve UHIS-1 and stop the pump

If the presence of water is observed in the UMU tank, the water shall be drained before the reading of the condensate tank is made.

An appreciable amount of water will be noticeable in the UMU tank by a dividing line in the sight gage separating water and the lighter hydrocarbon liquids. Water shall be drained as soon as such a dividing line appears in the lower sight gage LG-4020B. Water shall be drained by opening the valve UHDV and observing the water level in the sight gage LG-4020B. After the water level reaches the lowest point of the sight gage LG-4020B, another 30 gallons of water shall be drained. Those 30 gallons of water are accumulated in the tank below the lowest level of the sight gage LG-4020B.

If, during the normal course of plant operation an unusually high water volume is observed in the UMU tank, the heat exchangers in the thermal storage subsystem shall be checked for leakage between the steam/water and the oil side.

Waste Gas Disposal

Fumes that do not condense in the UMU tank TK-302 are transferred to the thermal oxidizer system, through line 6-inch-UG-2-BBA. The operation of the thermal oxidizer system is controlled by the pressure transmitter PI-4008 located on the TSU and the ILS. In the automatic mode of the thermal oxidizer operation, the ILS closes the circuit when the pressure in the TSU rises to 10.5-inch H_2O, opening the valve AOV-4014 and energizing relay 1CR in the thermal oxidizer control system. In the manual mode of operation the setting of the AUTO-MANUAL switch on MANUAL performs the same action as the closing of the circuit by the ILS. After relay 1CR becomes energized, the following steps will take place:

(1) The air fan FA-302, and timer 1TDR (set at 2 minutes) and the purge timers (set at 30 seconds) are energized. The purging of the burner starts, indicated by the lit amber light tagged PURGING.

(2) At the end of 30 seconds, if the pressure switches PS-4037, PS-4038 and PS-4039 are closed, the solenoid valve SOV-4016 will open, allowing the flow of propane to the pilot burner, and the ignition rod will ignite the pilot. The pilot lamp will light.

(3) After the pilot flame proves and valve AOV-4014 is open, the pressure in the line downstream of the fume blower reaches 8-inches H_2O, and the pressure switch PS-4034 closes. If the fume high pressure switch PS-4033 and the high limit burner flame temperature switch TS-4035 are closed (which should normally be the case) the fume blower FA-301 will start and the valve MOV-4015 will open, allowing the flow of

fumes to the main burner. The proper fume pressure will be indicated by the lit FUME PRESSURE lamp. The normal burner temperature will be indicated by the lit TEMP NORMAL lamp. The burner temperature is displayed on the dial of the temperature controller.

The proving of the pilot flame is done by means of the pilot flame rod. Limit switches mounted on valve MOV-4015 transmit signals to the master controller, indicating whether the valve is open or closed.

(4) Upon ignition of the fumes in the main burner, the dilution air damper which has remained at its low flow position, goes under control of the temperature controller TC-4031 which senses the stack temperature through thermocouple TE-4031. The proving of the flame in the main burner is done by means of the UV detector BE-4030.

(5) All the above steps should occur within 33 seconds. If all steps take place within that time period, the burner will continue its normal operation. If not, after 48 seconds an override circuit opens MOV-4015 and starts fume blower FA-301 (without ignition) to assure venting of the TSU.

The vapors coming from the TSU may, under certain conditions, contain a high proportion of nitrogen. This will happen if the make up gas to the TSU during the preceding extraction cycle was provided from the standby nitrogen supply. If the proportion of nitrogen in the fumes flowing to the burner exceeds a certain level the flame in the main burner will go out. When this happens the UV detector BE-4030 will activate the audible alarm and light the red BURNER OUT lamp. Simultaneously an alarm signal will be sent to the master controller, indicating that there is no flame in the burner. This signal will require a visual inspection of the unit in order to determine whether the reason for the absence of flame is caused by a malfunction of the system or by a lack of combustible gases in the fumes. To silence the alarm the ALARM SILENCE button has to be depressed.

The indication that the lack of flame in the burner is caused by an absence of combustibles in the fumes will be as follows:

(1) The PILOT lamp will be on. (The pilot flame, once lighted, will be on as long as the propane supply is normal and the relay 1CR is energized). With the PILOT lamp lit, the LIMITS NORMAL lamp has

also to be lit. These two lamps, if lit, indicate that the flow of propane is normal, that the air blower is running, and that the pilot flame is on.

(2) The FUME PRESSURE lamp will be lit, indicating that there is a flow of fumes to the burner.

(3) The TEMP NORMAL lamp will be lit, indicating that no overtemperature condition in the stack has taken place.

If it is found that the lack of combustibles is the cause for the "burner out" alarm, no further action is required except the silencing of the audible alarm. If during the same charging cycle the content of combustible gases becomes high enough, the fumes will be ignited by the pilot flame. This will cancel the alarm signal to the master controller, and turn off the red BURNER OUT lamp.

It is, however, necessary to examine the cause for the high content of nitrogen in the TSU vapors. The two major groups of possible causes are the malfunction of the condensate return system and the misadjustment of the pressure regulating valves in the nitrogen supply system. If the "burner out" alarm is caused by a malfunction in the system as indicated by the lamps on the control panels or by some other indication, the cause shall be determined and rectifying actions shall be implemented immediately. If the malfunction is of a nature that requires more than several minutes to rectify, action shall be taken immediately to discharge the heat from the TSU.

A detailed analysis of malfunctions of the UMU and of corresponding troubleshooting actions is given in a separate section of this manual.

When the pressure in the TSU ullage space drops to 8.5-inches H_2O on the pressure transducer PI-4008, the ILS breaks the circuit, de-energizing relay 1CR and closing the solenoid valve SOV-4014. This will cause the valve AOV-4014 to close, and the de-energizing of relay 1CR will end the operation of the thermal oxidizer. The air fan and the fume blower will stop, and the valves SOV-4016 and MOV-4015 will close. As a result the pilot flame and the main flame will be extinguished and all lamps on the thermal oxidizer control panel, with the exception of the POWER lamp, will be off.

Condensate Return

During the TSU extraction mode the temperature of the oil in the TSU will drop, resulting in a decrease of the volume of oil. During those periods and whenever the pressure in the ullage space of the TSU drops, make-up gas has to be added to the TSU from the UMU.

The primary source of the make-up gas is the condensate return circuit, consisting of the ullage pump P-308 and an assortment of valves and controls. The condensate pump from tank TK-302 into the TSU ullage space vaporizes when heated to the operating temperature at the top of the TSU bed, thus increasing the pressure in the ullage space. The condensate return is controlled by the ILS through transducer PI-4008 located at the top of the TSU. When the pressure in the ullage space of the TSU drops to 5.5-inches H_2O, the ILS closes the circuit and energizes the pump contactor. After 30 seconds, if the flow switch TS-4024 has not sent a flow signal to the ILS the pump will shut off and a "no flow" alarm will occur. A disconnect switch built in to the pump circuit has to be in the ON position for the pump to operate.

When the TSU ullage pressure increases to 6.5-inches H_2O, the ILS de-energizes the pump contactor, and the pumping stops. When the pump is off, liquid is prevented from returning to the tank by the check valve UHCK. Isolation of the pump for maintenance is provided by valves UHIS-2 and UHIS-3.

Nitrogen Supply

If the condensate return system cannot supply the required amount of make up gas to the TSU, the pressure in the TSU ullage space will gradually decrease. When the pressure drops below 5-inches H_2O, the nitrogen pressure regulator PCV-4006 will open, and when below 3-inches H_2O, PCV-4007 will open allowing the flow of nitrogen to the TSU through line 2-inches-N-5-BBA (PCV-4006 and PCV-4007 are located off the UMU skid).

Nitrogen is supplied to the UMU from the GN_2 supply tank at a pressure of 125 ± 20 psig. The GN_2 inlet pressure is indicated by gage PI-4003. Nitrogen pressure regulator PCV-4004 provides first stage regulation at 25 ± 5 psig. This pressure is maintained at all times in the line downstream of pressure regulator PCV-4004, and is indicated by gage PI-4005.

Line one-half-inch-N-4-BBD supplies nitrogen to the UMU tank TK-302 when the pressure in the UMU tank drops below 2-inches H_2O. Pressure regulator PCV-4023 which is set at 2-inches H_2O regulates the pressure of the supplied nitrogen which is indicated by gage PI-4017.

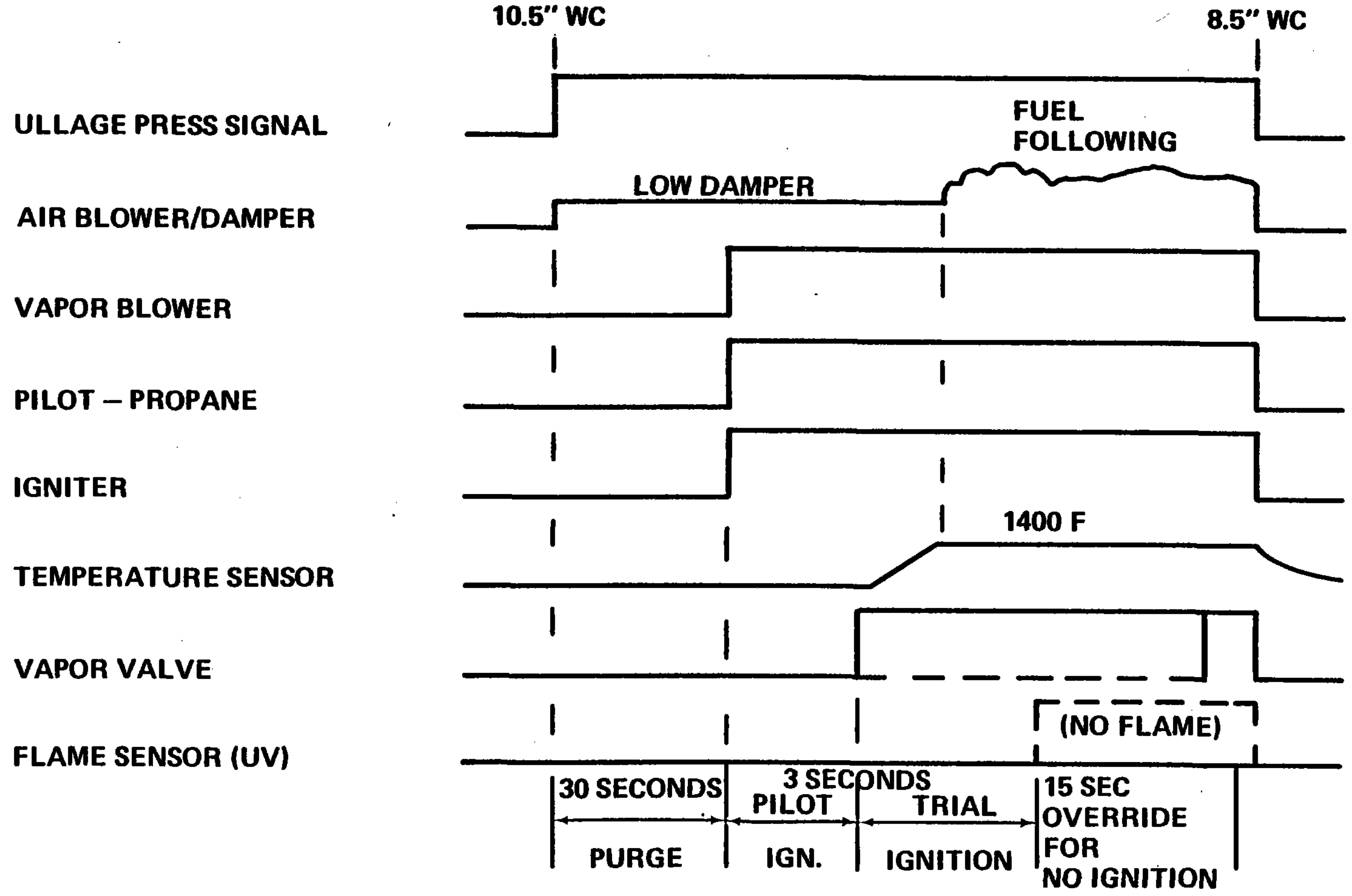
Pressure transmitter PTX-4052 transmits the pressure of nitrogen in line 1-inch-N-2-BBA to the master controller. A temperature transmitter TEX-4051 and a flow transmitter are also available to provide information regarding the nitrogen temperature and flow condition.

SETTING OF CONTROL INSTRUMENTATION UMU & TSU

INSTRUMENT	TAG NO.	FUNCTION	SETTING	REMARKS
Pressure Control Valve	PCV-4004	Main nitrogen pressure regulator	25 psig	
Pressure Control Valve	PCV-4023	Nitrogen make-up to UMU Tank Pressure Regulator	2" H_2O	
Pressure Control Valve	PCV-4009	First stage propane pressure regulator	6 psig	
Pressure Control Valve	PCV-4012	Second stage propane pressure regulator	4 to 8 oz/sq.in.	Field adjustment required to obtain pilot flame that will prove
Pressure Control Valve	PCV-4006	Primary nitrogen press. regulator	5" H_2O	Located off UMU in pipeline to TSU
Pressure Control Valve	PCV-4007	Secondary nitrogen press. regulator	3" H_2O	Located off UMU in pipeline to TSU
Pressure switch	PS-4001	Low pressure switch in main nitrogen line	60 psig	
Pressure switch	PS-4033	Fume high pressure switch	32" H_2O	
Pressure Switch	PS-4034	Fume low pressure switch	8" H_2O	
Pressure switch	PS-4037	Low Combustion air pressure switch	0.2" H_2O	
Pressure switch	PS-4038	Low pilot gas pressure switch	1.5 psig	
Pressure switch	PS-4039	High pilot gas pressure switch	10 psig	
Pressure transducer	PI-4008 + ILS	Controls operation of UMU pump P-308	Makes at 5.5" H_2O Breaks at 6.5" H_2O	This transducer is lo at the top of t

INSTRUMENT	TAG NO.	FUNCTION	SETTING	REMARKS
Pressure transducer	PI-4008 + ILS	Controls operation of UMU Burner Assembly	Makes at 10.5" H_2O Breaks at 8.5" H_2O	
Temperature switch	TS-4035	High limit burner flame temperature switch	1550°F	
Temperature Controller	TC-4031	Burner flame temperature control	1400	
Flame safeguard purge timer	———	Controls the purge period	30 seconds	
1 Timer/TDR	———	Allows burner to run before main flame proves	2 minutes	
MOV-4015 override timer 3 TDR	———	Open MOV-4015 to vent TSU if no flame (plus turn on FA-301)	48 seconds	

UMU VENTING AND FLARING SEQUENCE



APPENDIX B

MISCELLANEOUS

DESIGN DATA

APPENDIX B

MISCELLANEOUS DESIGN DATA

CALORIA PROPERTIES

1. Vapor Pressure: The vapor pressure of both fresh and weathered (1000 hours at 581°F) Caloria HT-43, as recently measured by Exxon, are shown in the attached figure.

2. Normal Boiling Point: Caloria HT-43 is a complex mixture of petroleum hydrocarbons, and as such has no discrete boiling point. Rather, various components fractionate (distill) across the temperature range of 700°F to 1000°F.

3. Density: The density of Caloria HT-43 varies linearly from 7.10 lb/gal at 75°F to 5.48 lb/gal at 575°F.

4. Other Properties: Other properties of Caloria HT-43 are discussed in the attached brochure and OSHA Data Sheets. Note that the vapor pressure shown in the brochure is in error.

SYSTEM FLOWRATES

The maximum Caloria flowrate in the system is 210,000 gallons per hour. The flowrate varies from zero to the maximum in a random manner in response to solar insolation and load transients; an approximate average flowrate is, perhaps, 100,000 gallons per hour.

TANK DATA

1. TSU Tank: The TSU Tank is 60 feet in diameter by 44 feet in height and cost approximately $1,750,000.

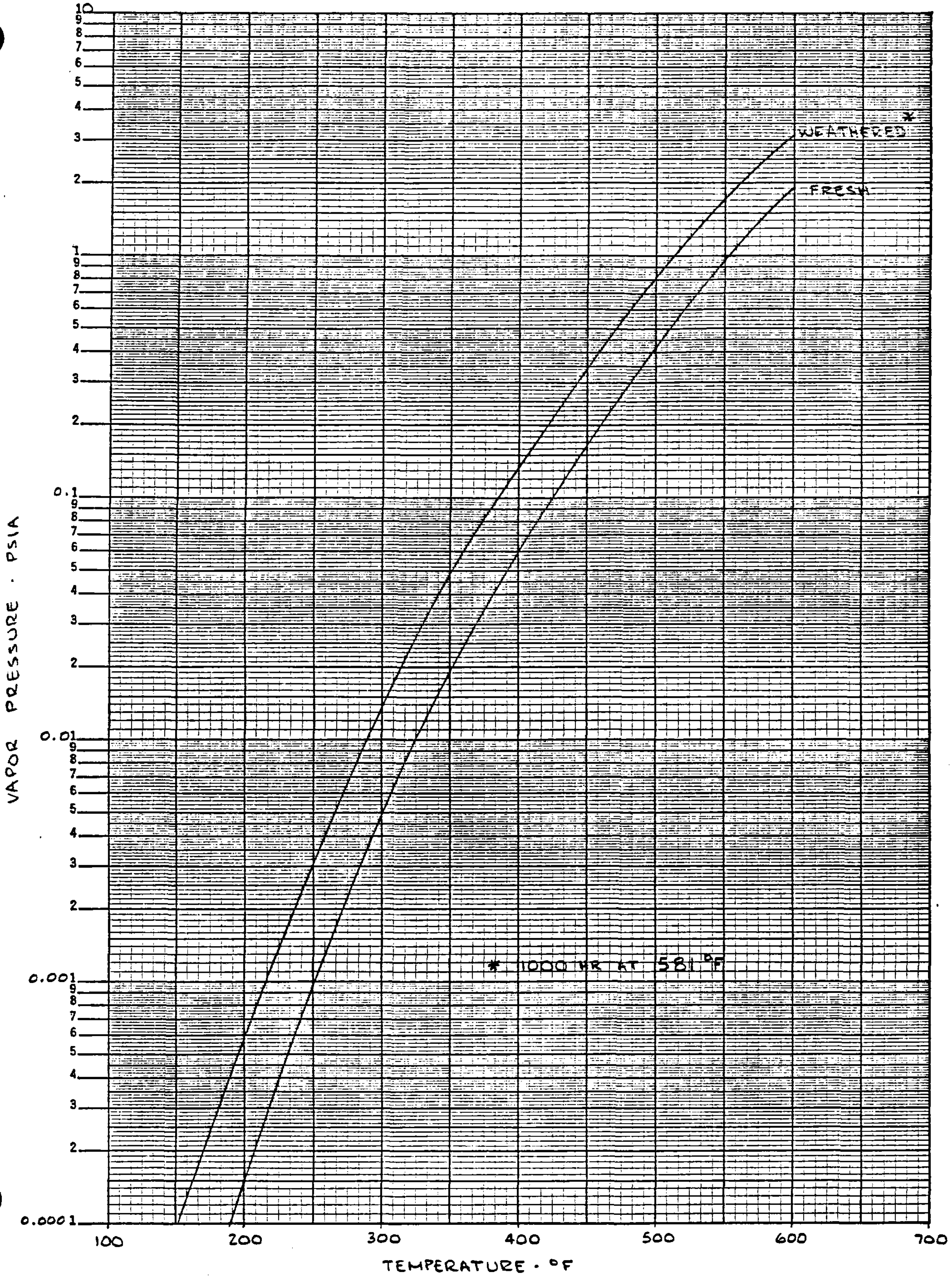
2. Caloria Make-up Tank: The Caloria Make-up Tank is 14 feet in diameter by 10 feet in height and cost approximately $30,000.

ULLAGE MAINTENANCE UNIT (UMU) DATA

1. UMU Stack Dimensions: The UMU Thermal Oxidizer (burner) stack outlet is 2 feet in diameter and is 23 feet above grade.

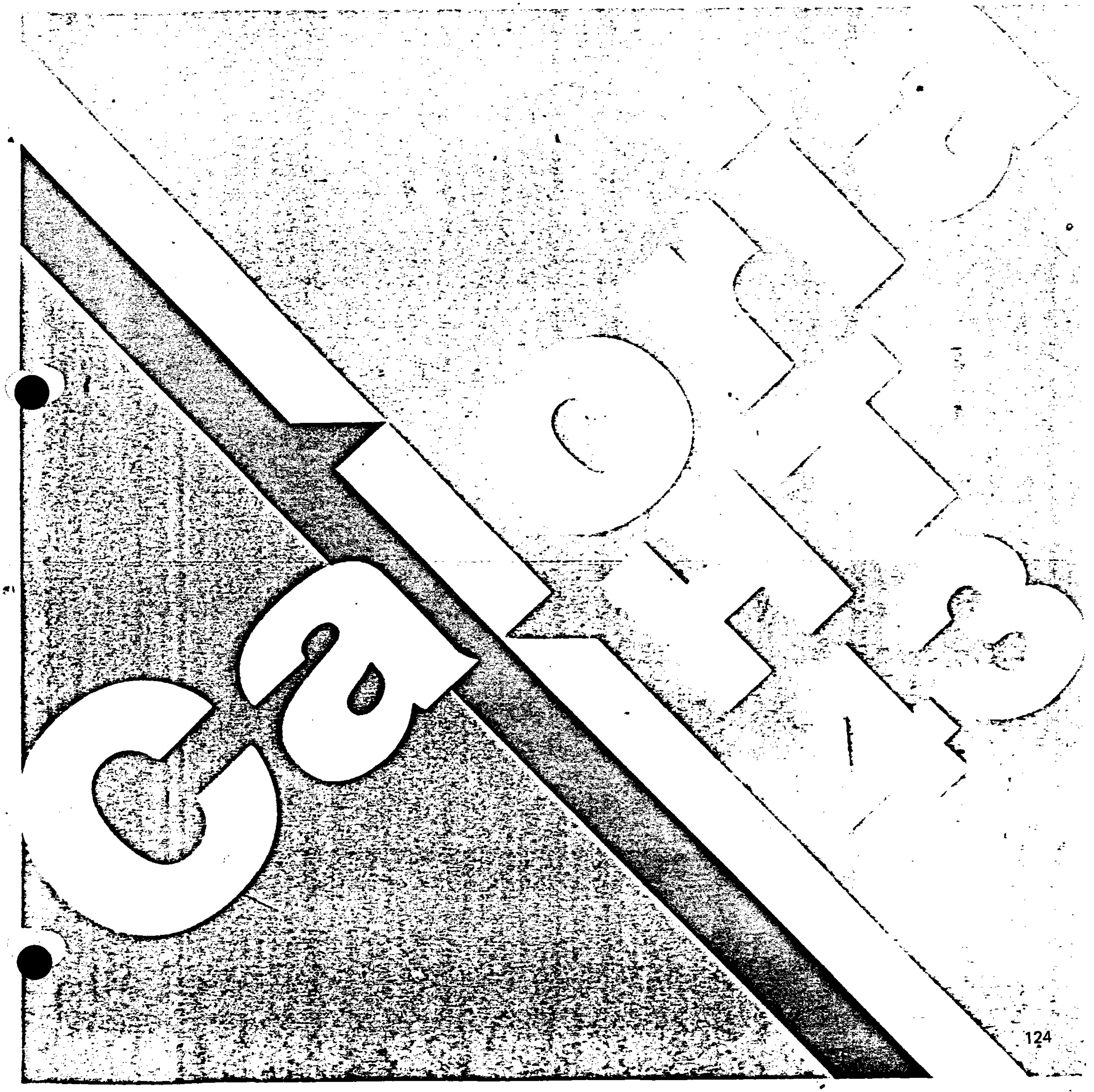
2. UMU Stack Gas: The flow rate of the exhaust gas from the UMU Thermal Oxidizer stack is 5770 ACFM of 800°F gas. This is equivalent to a stack exhaust velocity of 30 feet per second.

VAPOR PRESSURE · CALORIA HT-43

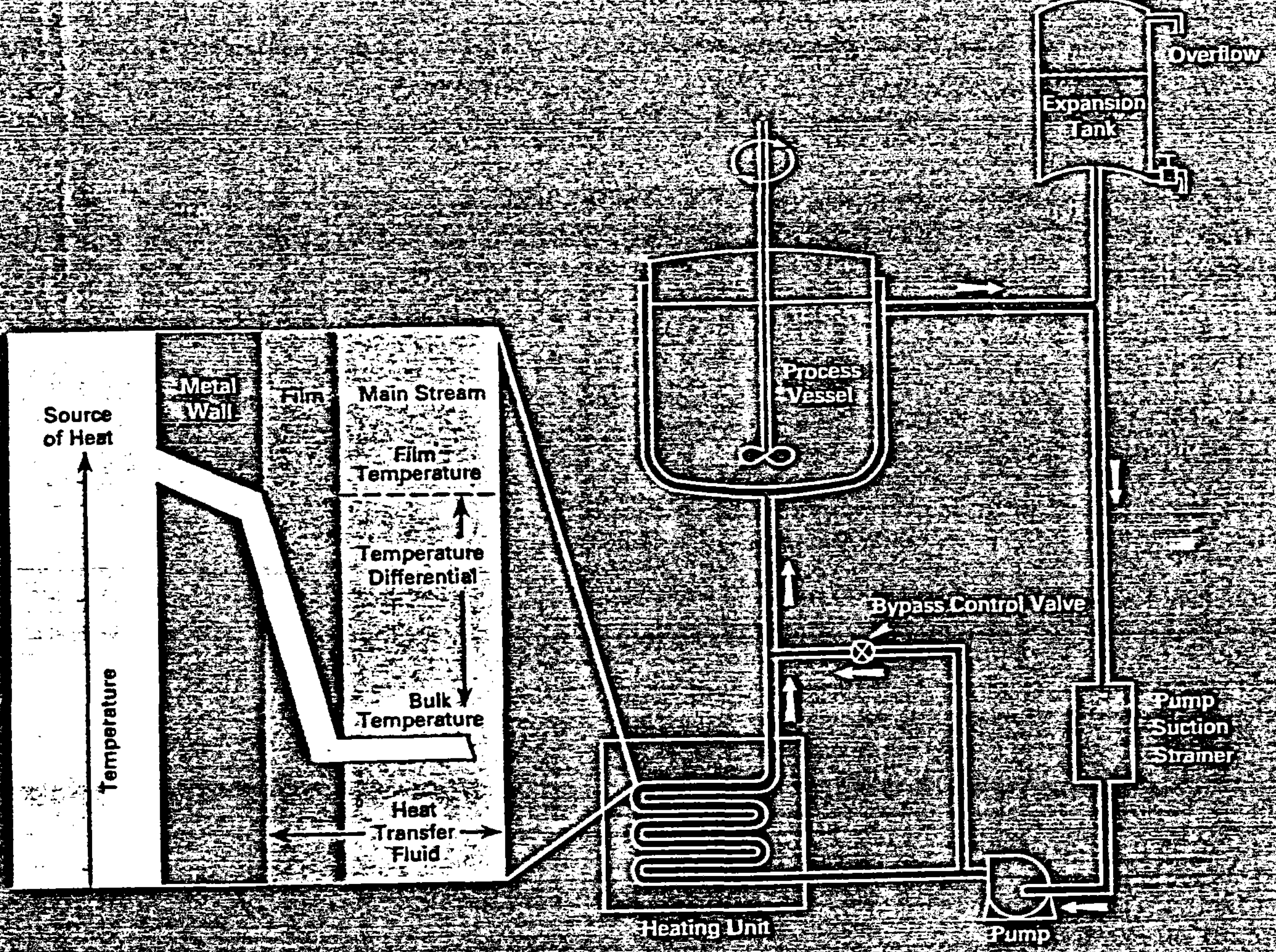


* 1000 HR AT 581 °F

EXXON



Caloria HT 43



Lubetex DG-2C

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CALORIA HT 43

Caloria HT 43 is a heat-transfer fluid that provides excellent performance in a wide variety of applications. Caloria HT 43 is a petroleum-base heat-transfer fluid formulated from a highly stable paraffinic base stock fortified with a high-temperature oxidation inhibitor.

FLUID TEMPERATURES

In the operation of any heat-transfer system, a wide range of fluid temperatures exists between the hottest and the coolest areas. When fluid temperatures are considered, therefore, it is important to identify them and to recognize their relationship to one another.

Next to the wall of the heating tube or coil is a layer of heat-transfer fluid that is distinct from the main stream (see illustration). Clinging to the surface of the tube, this layer flows more slowly than the main stream. Its slower speed and its proximity to the heat source raise its temperature to a higher level. In fact, this temperature—the maximum film (skin) temperature—may be far above the bulk temperature, the overall fluid temperature of the flowing system. Thus, the film temperature may exceed the maximum operating temperature for which the fluid is recommended. Since fluid life is shortened by overheating, this temperature differential must be taken into consideration.

The differential between maximum film temperature and bulk temperature depends primarily on flow velocity. Flow velocity, in turn, depends on the design of the installation and the flow properties of the fluid. In the evaluation of any heat-transfer fluid, therefore, its heat resistance should be related to the characteristics of the installation in which it is to be used. Unless the fluid is rated on a bulk-temperature basis allowing a reasonable margin for a higher film temperature, and unless the equipment is so designed and operated that this margin is not exceeded, the fluid may be overheated. By the same token, the fluid must have adequate flow properties—not only under normal operating conditions, but during low-temperature start-up, when it is relatively thick and sluggish.

THERMAL STABILITY

One of the most vital properties of a heat-transfer fluid is, of course, its resistance to heat. This includes resistance to oxidation at high temperatures and to thermal cracking, two forms of chemical decomposition to which organic compounds are commonly subject. Thermal cracking is the high-temperature breakdown of the fluid into fractions that are wholly undesirable from a heat-transfer standpoint. Some fractions form heavy, sluggish tars that may eventually break down into coke. The coke may in turn deposit on the heating coils, producing an insulating effect and thus interfering with the circulation required for efficient heat transfer. Other petroleum fractions are high in volatility, increasing the vapor pressure of the fluid and lowering its flash point. Fractions of this type are conducive to fire hazard and evaporation loss.

Caloria HT 43 heat-transfer fluid is manufactured from petroleum stocks produced by a special refining method. Since thermally unstable components are separated and removed by this treatment, the resulting product has exceptional resistance to thermal decomposition.

OXIDATION STABILITY

Base stocks used in the manufacture of Caloria HT 43 are selected for good oxidation stability, a characteristic that is further improved by selected refining techniques and the addition of an oxidation inhibitor. With these advantages, Caloria HT 43 is especially resistant to the formation of oxidation sludges that may otherwise insulate the coil against efficient heat transfer and may also cause obstructions to fluid flow.

LOW VOLATILITY

Another essential high-temperature property is low volatility—low vapor pressure and high flash point. The low vapor pressure of Caloria HT 43 (Figure 1) helps to eliminate vapor lock in circulating pumps; and reduces the possibility of cavitation, which is destructive to centrifugal pump blades. The low vapor pressure of Caloria HT 43 throughout the normal operating range also prevents the buildup of excessive pressure in closed systems. It also minimizes evaporation loss in open systems. In open systems operated at moderately high temperature, some evaporation loss can occur. This will result in a weathering effect which effectively reduces the vapor pressure to a still lower, equilibrium value as illustrated in Figure 1.

The low volatility and high flash point of CALORIA HT 43 are due to its excellent distillation characteristics. (Figure 2). The characteristic high flash point of this heat-transfer fluid permits higher expansion tank temperatures than common with many other fluids.

LOW-TEMPERATURE PERFORMANCE

The effectiveness of a heat-transfer fluid depends upon its low-temperature performance as well as its high-temperature performance. With a typical pour point of −9°C (15°F), CALORIA HT 43 has good pumpability in cold-weather start-ups, thereby diminishing the likelihood of hot spots—dangerously high fluid temperatures at the heater. The oil's low-temperature fluidity is a function of its high viscosity index—typically 115. This exceptionally high value gives CALORIA HT 43 greater resistance to changes in viscosity with varying temperatures, as illustrated in Figure 3.

HEATING EFFICIENCY

CALORIA HT 43 has the ability not only to resist heat, but to transfer it efficiently. Its viscosity characteristics are such that it provides a high rate of circulation under a wide range of operating temperatures. Other properties enable CALORIA HT 43 to transmit full heating loads rapidly. High specific heat gives CALORIA HT 43 the capacity to supply or remove the large amount of heat that efficient operation requires (Figure 4). High thermal conductivity enables it to transfer heat efficiently (Figure 5). These properties contribute not only to fuel economy, but to more even heat distribution and longer equipment life.

COMPATIBILITY

CALORIA HT 43 is compatible with other petroleum heat-transfer fluids and, if necessary, can be added to them as make-up. This is not recommended, however, for fluids that are in poor condition. The mixing of a new petroleum oil with one that has deteriorated may cause the precipitation of sludges particularly at elevated temperatures—and will accelerate degradation of fresh oil. Adding of other petroleum fluids to CALORIA HT 43 is also feasible, though it can be expected that performance will be modified in proportion of the amount of added material.

THERMAL EXPANSION

All petroleum oils expand upon heating, and it is desirable to be able to predict the volume expansion of the oil to permit proper design of the expansion tank. In Figure 6, the volume of oil at a specific temperature relative to its volume at standard temperature is given. From this figure the increase in volume with an increase in temperature can be estimated.

APPLICATION—OPEN SYSTEM

CALORIA HT 43 gives good performance in open systems—where the fluid is exposed to air—provided the oil does not exceed 316°C (600°F) bulk temperature or 191°C (375°F) at the point of exposure to air.

If the 191°C temperature level will be exceeded, the Exxon representative should be consulted for alternate recommendations. For exposures above 191°C, the heat-transfer fluid should be chosen on the basis of flash point, to provide the lowest viscosity oil with a flash point at least 14°C (25°F) above the exposure temperature to prevent a fire hazard.

It should be recognized that at temperatures appreciably above 66°C (150°F), even the finest petroleum oils are subject to significant oxidation when exposed to air—the higher the temperature, the shorter the service life of the oil.

APPLICATION—CLOSED SYSTEM

CALORIA HT 43 heat-transfer fluid is recommended for service in closed, inert-gas blanketed systems, involving a maximum film temperature at the heater surface of 360°C (680°F). On the basis of a typical temperature drop of 44°C (80°F) across the fluid film adjacent to the heater surface, this permits a maximum bulk temperature of 316°C (600°F).

SAFETY

With its low volatility and high flash point, CALORIA HT 43 offers a reasonable degree of safety. When used as recommended in both open and closed systems that are mechanically sound, the danger of fire or explosion is minimized. Like petroleum products in general, however, the fluid will burn if subjected to the proper combinations of high temperature, oxygen, and source of ignition.

CALORIA HT 43 presents no special toxicity hazards and can be handled with the simple precautions ordinarily observed with lubricating oils. "Work Safely—Personal Care" cards suitable for mounting throughout a plant are available from the Exxon representative.

TYPICAL INSPECTIONS

The values shown here are representative of current production. Some are controlled by manufacturing specifications, while others are not. All of them may vary within modest ranges.

Gravity, °API	33.2
Density at 15°C, g(cm)$^{-3}$	0.8587
Color, ASTM	L1.0
Viscosity, cSt at 40°C	29.6
cSt at 100°C	5.4
SSU at 100°F	153
SSU at 210°F	44.4
Viscosity index	115
Flash point, COC, °C	204
°F	400
Pour point, °C	−9
°F	15
Rotary bomb oxidation life 150°C, minutes	115
Phenol, mass %	0.002
Saturates, mass % (ASTM D 2007)	91.0
Conradson carbon, mass %	0.003
Aniline point, °C	109.8
°F	229.7

Sulphur % ND .2

Ash

No Heavy metals

RA 10/23/82

Tom Lipscomb Exxon, Houston Texas 713-656-5318

$1.75 /gal

Figure 1
Vapor Pressure of Caloria HT 43
(Calculated)

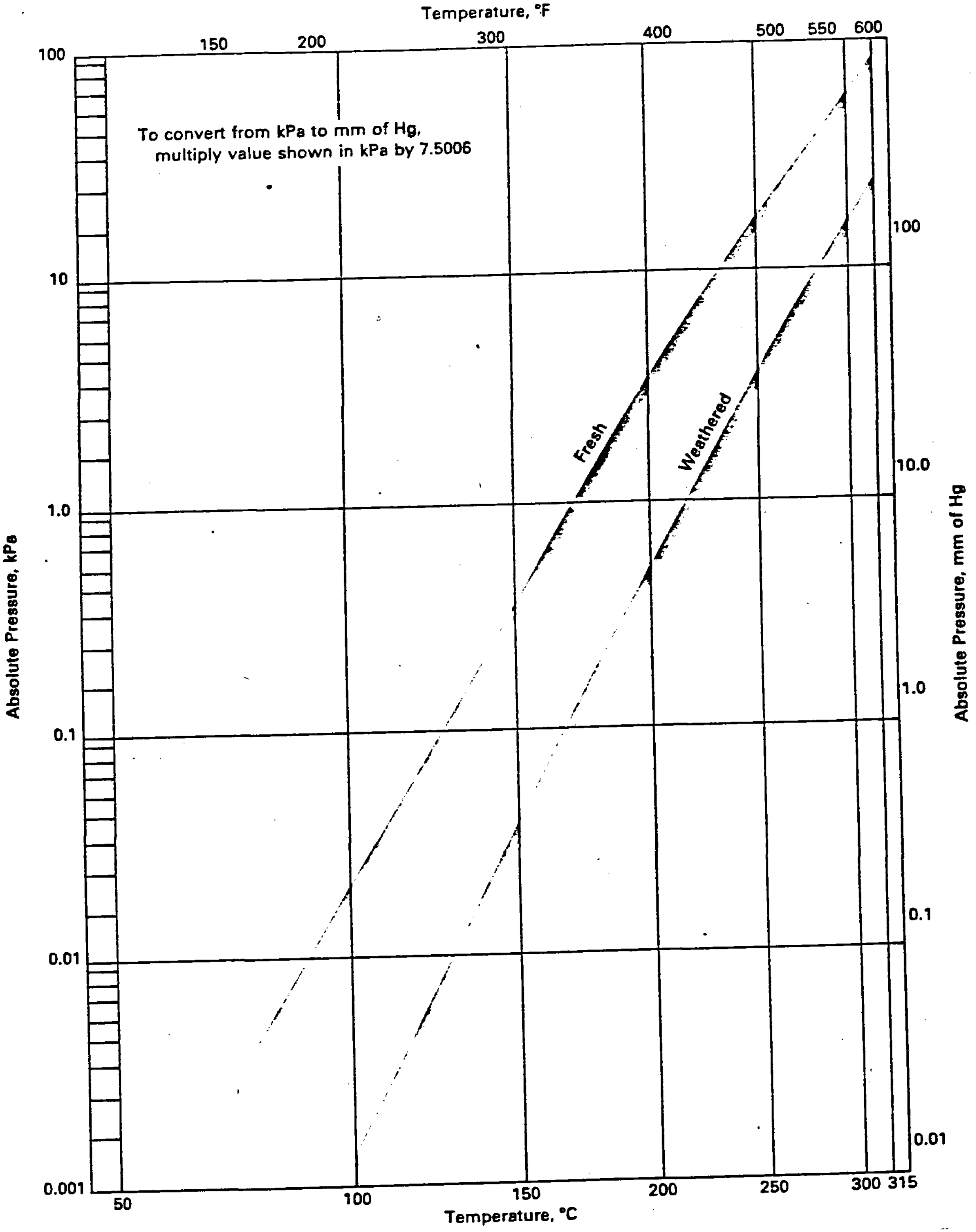


Figure 2
Distillation of Caloria HT 43
(Gas Chromatograph)

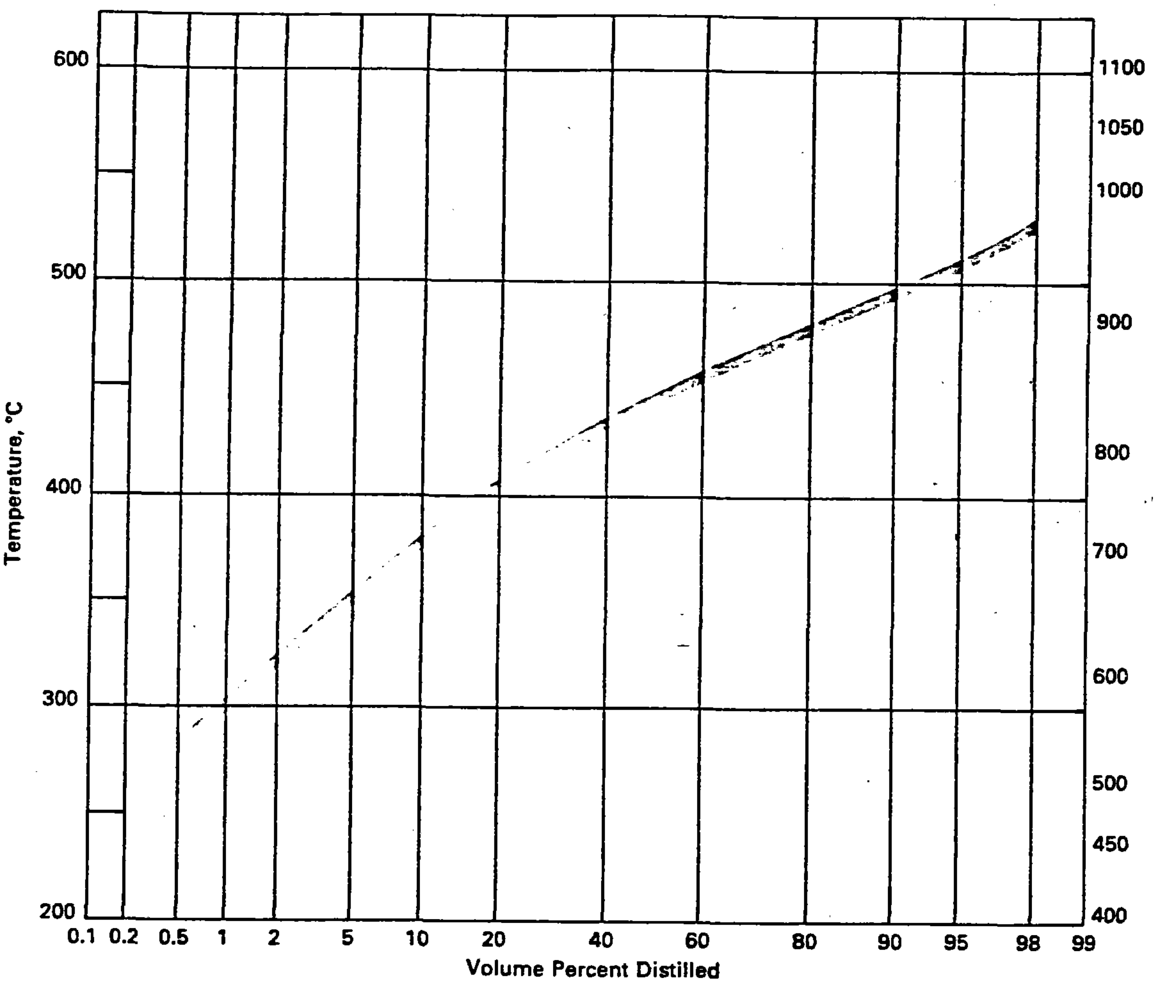


Figure 3
Viscosity-Temperature Relationship
of Caloria HT 43

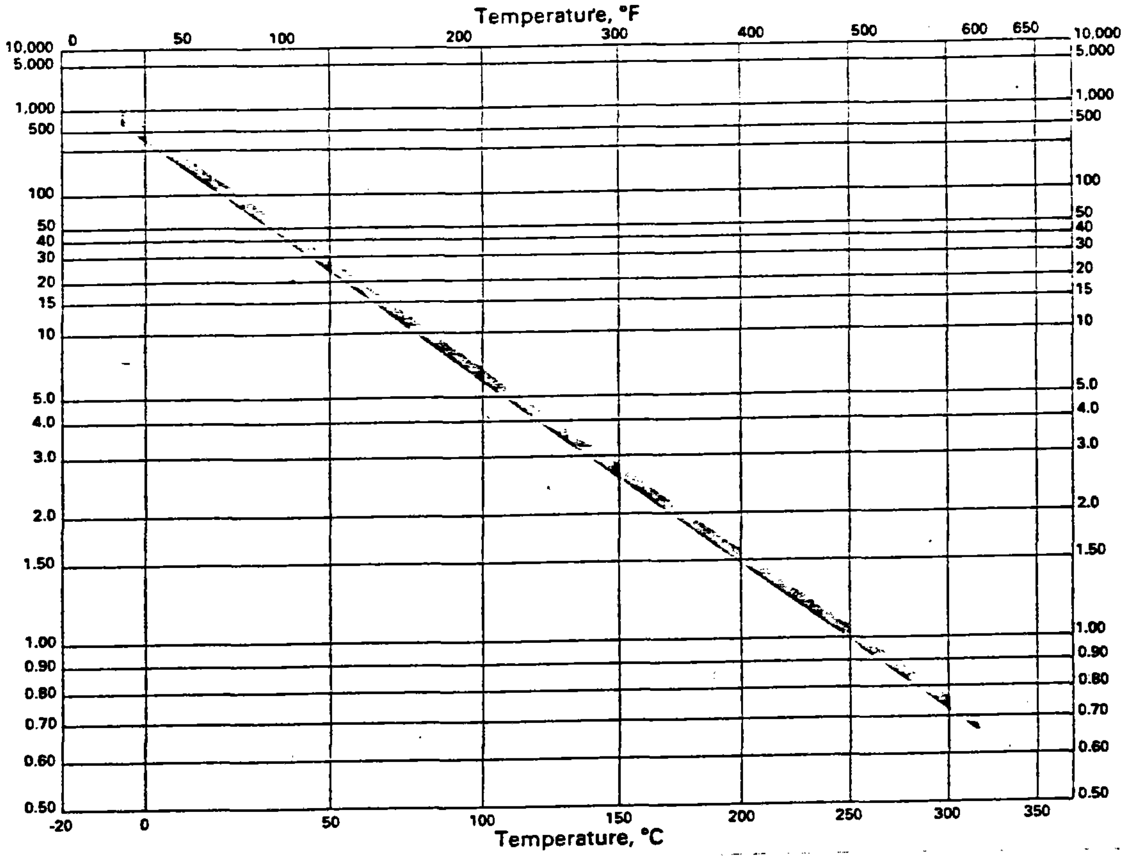


Figure 4
Specific Heat of Caloria HT 43

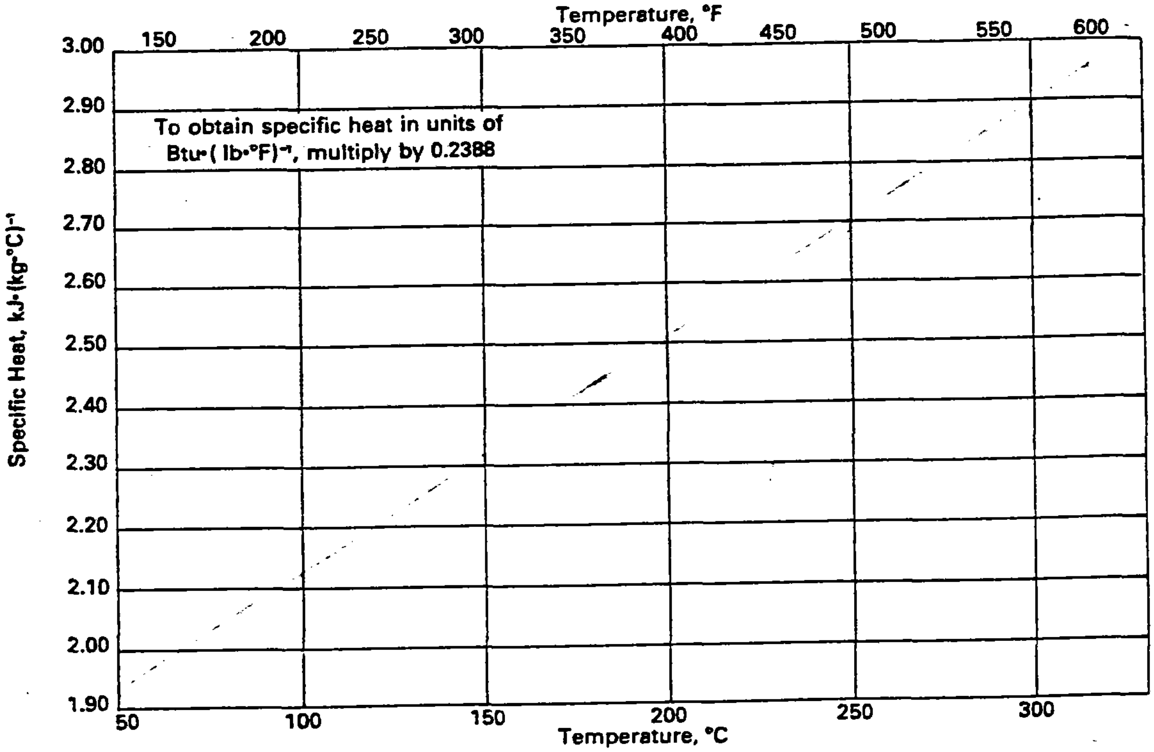


Figure 5
Thermal Conductivity of Caloria HT 43

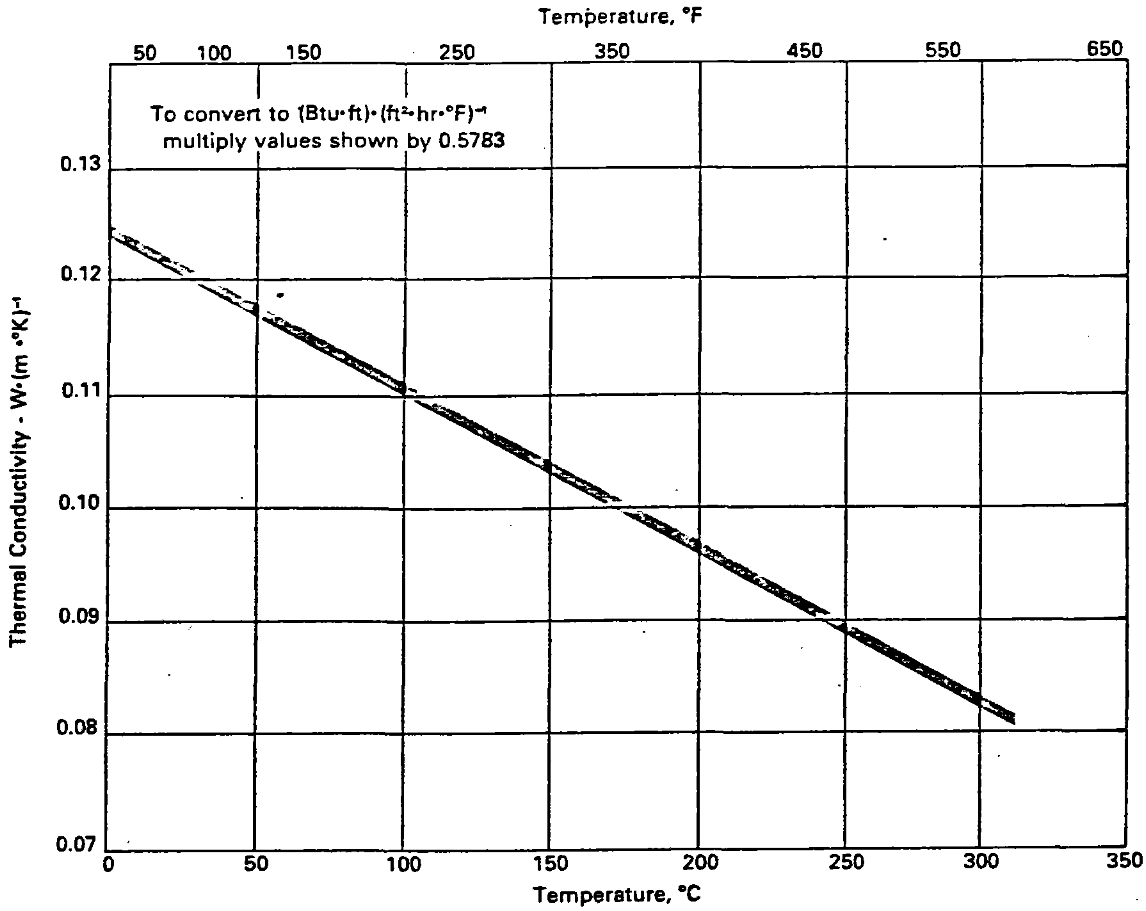
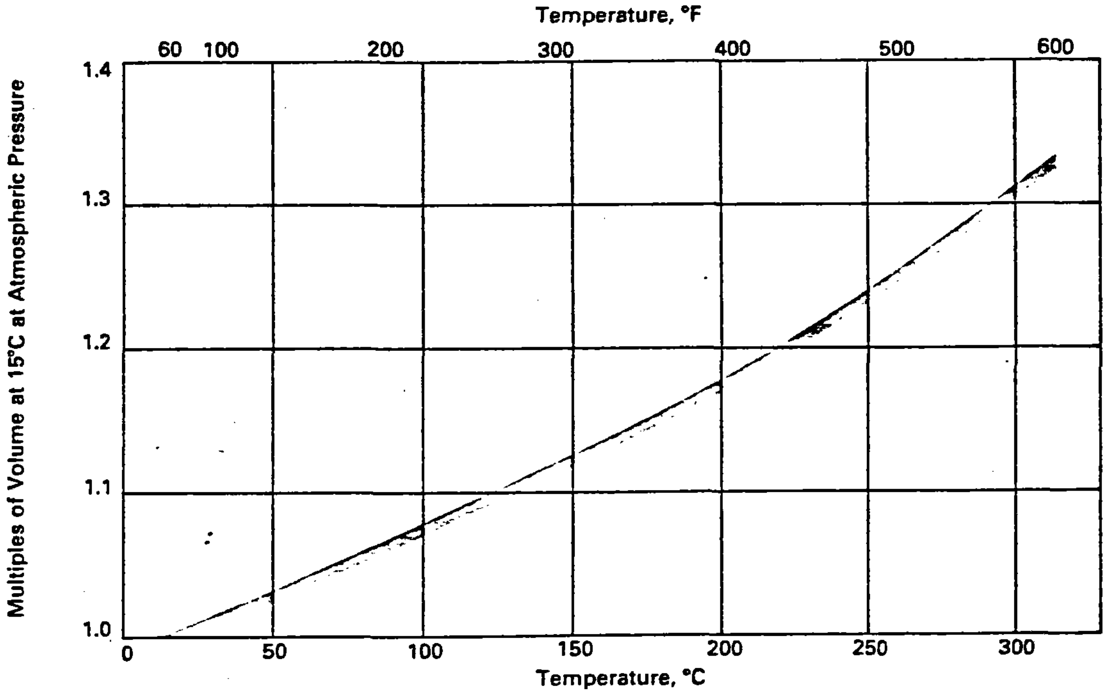


Figure 6
Thermal Expansion of Caloria HT 43



EXXON COMPANY U.S.A.
A DIVISION OF EXXON CORPORATION

CALORIA HT 43

Form No. OSHA-20
4/16/79
Supersedes issue
of 1/2/73
DG-2C

U.S. DEPARTMENT OF LABOR
OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION
MATERIAL SAFETY DATA SHEET

SECTION I

MANUFACTURER'S NAME Exxon Company, U.S.A.	EMERGENCY TELEPHONE NO. (713) 656-3424
ADDRESS *(Number, Street, City, State and ZIP Code)* P. O. Box 2180 Houston, Texas 77001	
CHEMICAL NAME AND SYNONYMS Heat Transfer Fluid	TRADE NAME AND SYNONYMS CALORIA HT 43
CHEMICAL FAMILY Petroleum Hydrocarbon	FORMULA Complex mixture of petroleum hydrocarbons and selected additives.

SECTION II HAZARDOUS INGREDIENTS

	%	TLV (UNITS)

SECTION III PHYSICAL DATA

BOILING RANGE IBP - FBP	700-1000°F	SPECIFIC GRAVITY (H_2O=1)	0.86
VAPOR PRESSURE (mm Hg.) @ 20°C	< 0.01	PERCENT VOLATILE BY VOLUME (%)	Negligible
VAPOR DENSITY (AIR=1)	> 15	EVAPORATION RATE (n - BUTYL ACETATE=1)	< 0.01
SOLUBILITY IN WATER	Negligible		

APPEARANCE AND ODOR
Light-colored, low viscosity fluid, Very mild hydrocarbon odor.

SECTION IV FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method Used)	FLAMMABLE OR EXPLOSIVE LIMITS (PERCENT BY VOLUME IN AIR)	LOWER LIMIT	UPPER LIMIT
Cleveland Open Cup 400°F		1%	6%

EXTINGUISHING MEDIA
Foam, dry chemical, CO_2, or water fog or spray.

SPECIAL FIRE FIGHTING PROCEDURES
Use air-supplied breathing equipment for enclosed areas.
Cool exposed containers with water spray. Avoid breathing vapor or fumes.

UNUSUAL FIRE AND EXPLOSION HAZARDS
Do not mix or store with strong oxidants like liquid chlorine or concentrated oxygen.

SECTION V HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE
5 mg/m^3 for oil mist in air. (OSHA Regulation 29 CFR 1910.1000)

EFFECTS OF OVEREXPOSURE

Prolonged or repeated skin contact may cause mild skin irritation.

EMERGENCY AND FIRST AID PROCEDURES

In case of skin contact, wash thoroughly with soap and warm water. If splashed into the eyes, flush with clear water for 15 minutes or until irritation subsides.

SECTION VI REACTIVITY DATA

STABILITY	UNSTABLE		CONDITIONS TO AVOID
	STABLE	X	

INCOMPATABILITY *(Materials to avoid)*
Strong oxidants like: liquid chlorine, concentrated oxygen, sodium or calcium hypochlorite

HAZARDOUS DECOMPOSITION PRODUCTS
Fumes, smoke, carbon monoxide, and sulfur oxides, in the case of incomplete combustion.

HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID
	WILL NOT OCCUR	X	

SECTION VII SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Recover free liquid. Add absorbent (sand, earth, sawdust, etc.) to spill area. Keep petroleum products out of sewers and watercourses by diking or impounding. Advise authorities if product has entered or may enter sewers, watercourses or extensive land ar

WASTE DISPOSAL METHOD

Assure conformity with applicable disposal regulations. Dispose of absorbed material at approved waste disposal site or facility.

SECTION VIII SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION *(Specify type)* Normally not needed. Use supplied-air respiratory protectio in confined or enclosed spaces.

VENTILATION	LOCAL EXHAUST Use local exhaust to capture fumes and vapors.	SPECIAL Provide greater than 60 fpm hood face velocity for confined spaces.
	MECHANICAL *(General)*	OTHER

PROTECTIVE GLOVES Use chemical resistant gloves if needed to avoid prolonged skin contact.	EYE PROTECTION Use splash goggles or face shield when eye contact may occur.

OTHER PROTECTIVE EQUIPMENT Use chemical resistant apron or other clothing if needed to avoid prolonged skin contact.

SECTION IX SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING & STORING

Keep containers closed when not in use. Do not handle or store near heat, sparks, flame or strong oxidants.

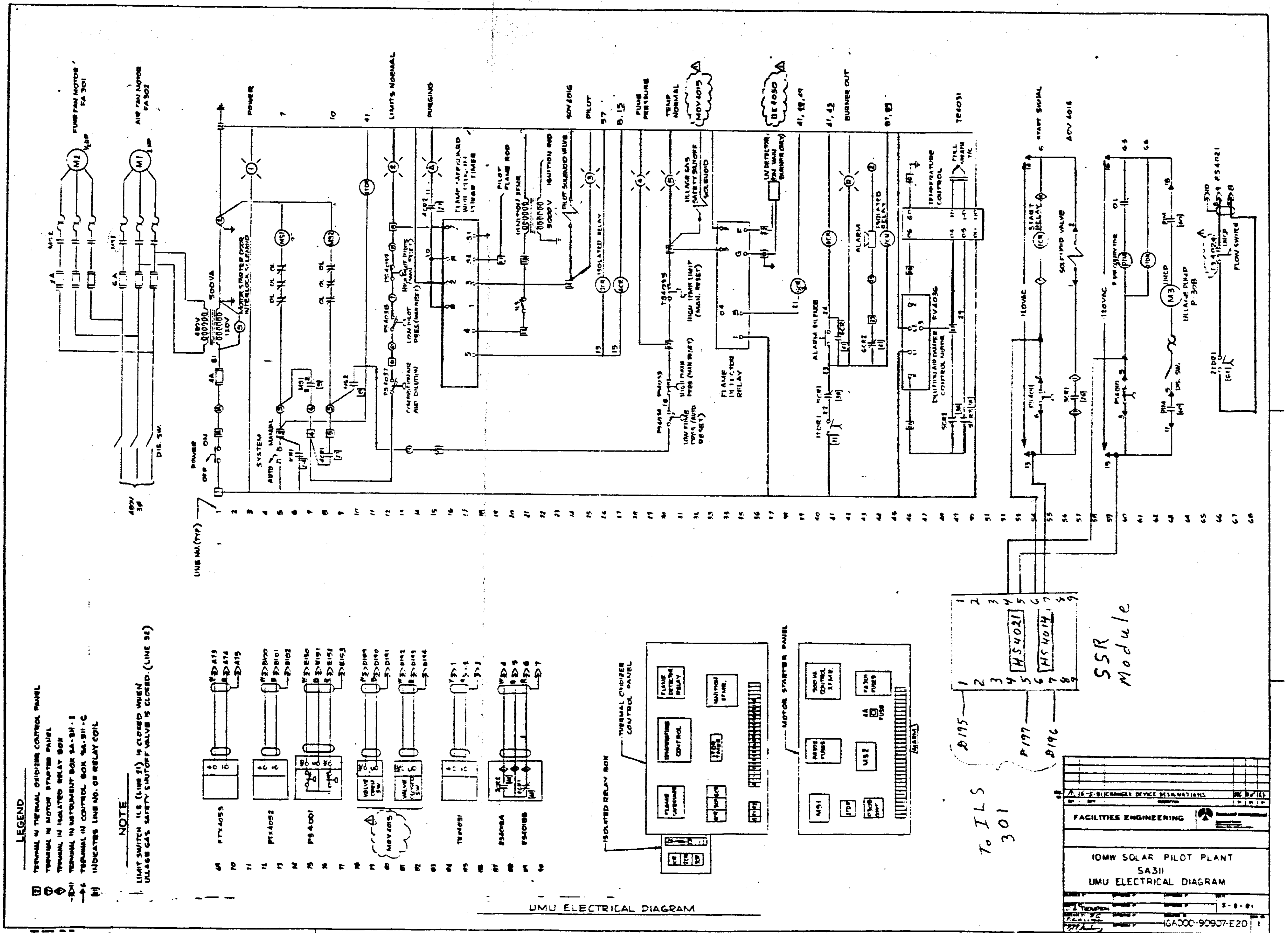
OTHER PRECAUTIONS
Avoid breathing oil mist. Remove oil-soaked clothing and launder before re-use. Discarc oil-soaked shoes. Wash skin thoroughly with soap and water after handling.

FOR ADDITIONAL INFORMATION ON HEALTH EFFECTS CONTACT:

Director of Industrial Hygiene
(713) 656-2443

FOR OTHER PRODUCT INFORMATION CONTA

Manager, Marketing Technical Services
(713) 656-4929



LEGEND

- [?] TERMINAL IN THERMAL OXIDIZER CONTROL PANEL
- (?) TERMINAL IN MOTOR STARTER PANEL
- ◇ TERMINAL IN ISOLATED RELAY BOX
- →B11 TERMINAL IN INSTRUMENT BOX SA-311-I
- →6 TERMINAL IN CONTROL BOX SA-311-C
- [1] INDICATES LINE NO. OF RELAY COIL

NOTE

1. LIMIT SWITCH ILS (LINE 21) IS CLOSED WHEN ULLAGE GAS SAFETY SHUTOFF VALVE IS CLOSED. (LINE 52)

⚠ 16-5-81 CHANGED DEVICE DESIGNATIONS

FACILITIES ENGINEERING

10MW SOLAR PILOT PLANT
SA311
UMU ELECTRICAL DIAGRAM

J. A. THOMPSON

5-8-81

1GA000-90907-E20

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RELEASE