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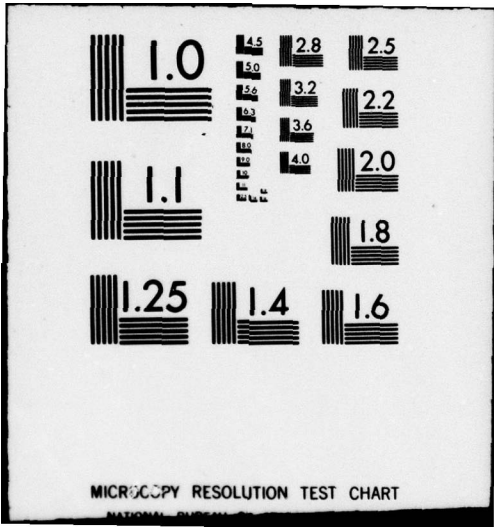
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**CONTROL OF JP-4 EMISSIONS FROM  
UNDERGROUND STORAGE TANKS**

**GORDON A. LEWANDOWSKI  
THOMAS B. STAUFFER  
ENVIRONMENTAL SCIENCES BRANCH**

**APRIL 1979  
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The South Coast Air Quality Management District, in southern California, is presently requiring controls on underground JP-4 tanks at March, Norton, and George AFB. It is expected that such controls may eventually be required at other Air Force installations. Therefore, an engineering study was undertaken to: (1) review the problem for Southern California and make recommendations where appropriate, and (2) determine the extent of the problem for the USAF as a whole. This report covers the first of these objectives. After visiting the above-		

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Block 20. Abstract (continued)

mentioned Air Force bases, and completing an engineering assessment of potential control strategies, low temperature refrigeration and recovery of condensed JP-4 vapors is recommended as the best control method.

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PREFACE

This report documents work performed during the period June 1978 through September 1978 under Program 62601F, Project 1900, Subtask 7002. The work was conducted by Dr Gordon Lewandowski, a Summer Faculty Research Fellow, and Mr Thomas Stauffer, Research Chemist. The basis of this technical report is Dr Lewandowski's final report for the Summer Faculty Program.

This report has been reviewed by the Information Officer (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

Effective 1 March 1979 CEEDO was inactivated and became the Engineering and Services Laboratory (ESL) a Directorate of the Air Force Engineering and Services Center located on Tyndall AFB Florida 32403.

This technical report has been reviewed and is approved for publication.

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## TABLE OF CONTENTS

Section	Title	Page
I	INTRODUCTION	1
II	AIR QUALITY REGULATIONS	2
III	JP-4 VAPOR COMPOSITIONS	4
IV	REFRIGERATION SYSTEMS	7
	A. Compression and Condensation of Vapors	7
	B. Low Temperature Condensation	7
V	ALTERNATIVE SYSTEMS	11
	A. Incineration	11
	B. Mono-Layer Vapor Suppression	11
	C. Carbon Adsorption	12
VI	RECOMMENDATIONS AND FUTURE DEVELOPMENT	13
	REFERENCES	14
	Appendix A	15
	Appendix B	16
	Appendix C	21
	Appendix D	23

LIST OF FIGURES

Figure	Title	Page
1	JP-4 Vapor Pressure Curve	3
2	Compression/Condensation System	8
3	Low Temperature Condensation System	9

LIST OF TABLES

Table	Title	Page
1	JP-4 Vapor Compositions	5
2	Degree of Vapor Saturation Versus Flammability Limits	6

## SECTION I

### INTRODUCTION

JP-4 underground storage tanks are used primarily to supply fuel hydrants along the operational apron at many USAF bases, although at some locations they are also used to fill tank trucks. This means that they must be located adjacent to, or on the operational apron, which places additional constraints on the methods available for vapor control (see Alternative Systems below).

The underground tanks are normally 50,000 gallon horizontal cylinders, about 12 ft in diameter by 60 ft long, with a vent pipe and submerged pump at one end, and various inspection hatches. They are filled, either by pump or gravity, from large bulk storage facilities where the fuel is initially brought on base. The bulk storage tanks generally have internal floating roofs, and are often far from the operational apron, which makes vapor balance impractical ("vapor balance" is where the vapors from the underground tanks would be returned to the vapor space above the bulk storage tanks, during filling operations).

## SECTION II

### AIR QUALITY REGULATIONS

Using Southern California as an example, any tanks larger than 40,000 gallons, containing volatile organics with a true vapor pressure of 1.5 psia or higher, must either: (a) install a floating roof, or (b) provide a vapor recovery system capable of achieving a 95 percent reduction in emissions (for the Mojave Desert, this has been modified to 90 percent). Underground JP-4 storage tanks at March, Norton, and George AFB fall under this regulation when the fuel temperature rises above 66°F, see Figure 1. Because the tanks are horizontal cylinders, floating roofs cannot be installed, and vapor recovery must be used.

At the present time March AFB has a condensation system for vapor control. However, this system only achieves a 20 percent reduction in vapor emissions (see below, Section IV. B, Low Temperature Condensation, for a discussion of this unit).

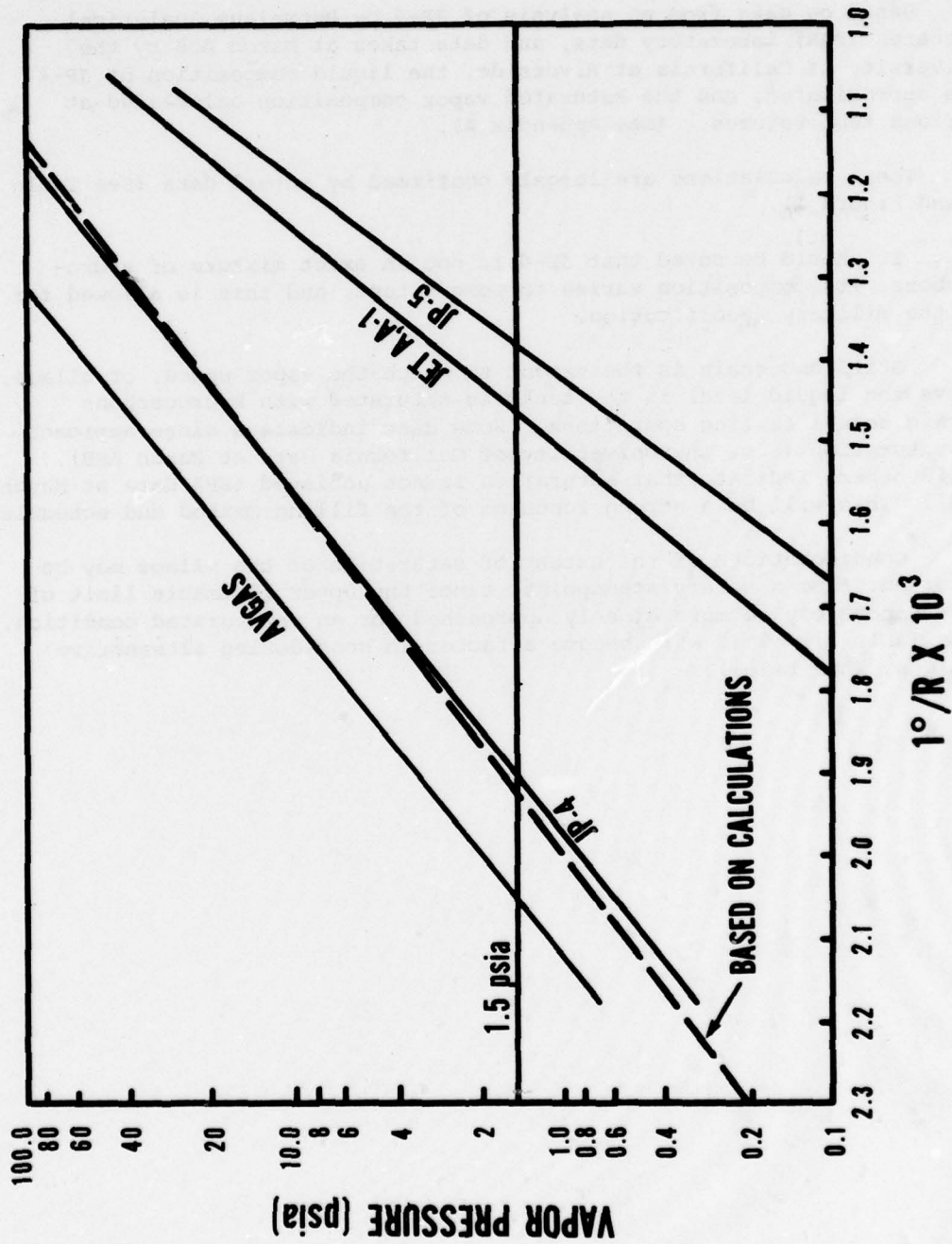


Figure 1. JP-4 Vapor Pressure Curve

### SECTION III

#### JP-4 VAPOR COMPOSITIONS

Based on data from an analysis of JP-4 by Petroleum Analytical Research (PAR) laboratory data, and data taken at March AFB by the University of California at Riverside, the liquid composition of JP-4 was approximated, and the saturated vapor composition calculated at various temperatures. (See Appendix A).

These calculations are largely confirmed by actual data (See Table 1 and Figure 1).

It should be noted that JP-4 is not an exact mixture of hydrocarbons. Its composition varies to some extent, and this is allowed for in the military specification.

Still uncertain is the extent to which the vapor space, or ullage, above the liquid level in the tanks is saturated with hydrocarbons during actual filling operations. Some data indicate a close approach to saturation (e.g. the University of California data at March AFB), while others indicate that saturation is not achieved (EPA data at March AFB). This will be a strong function of the filling method and schedule.

Considerations of the extent of saturation of the ullage may be important from a safety standpoint, since the upper flammable limit of JP-4 vapors may be more closely approached for an unsaturated condition, (see Table 2). This will become a factor in considering alternative designs, (see below).

TABLE 1. JP-4 Vapor Compositions

COMPOUNDS	JP-4 LIQUID MOLE FRACTIONS		VAPOR MOLE FRACTIONS				U of CA Data at March AFB
	%		@110°F	@70°F	%		
C2P	.00025*	.0025	.0010	.0007	.6	.0006	.0009
C3P	.0016*	.16	.0208	.0128	10.4	.0110	.0037
C4P	.0160*	1.6	.0800	.0432	35.3	.0352	.0371
n-C5P	.0100	4.0	.0130	.0062	22.9	.0048	.0095
i-C5P	.0300*	4.0	.0446	.0218		27.8	.0171
n-C6P	.0269	11.3	.0124	.0051	18.8	.0038	.0046
i-C6P	.0599	12.1	.0359	.0150		17.0	.0102
C6C	.0226	18.3	.0063	.0025	9.1	.0018	.0036
C6A	.0033		.0004	.0004		.0003	.0018
n-C7P	.0452	20.2	.0072	.0027	8.3	.0019	.0018
i-C7P	.0548	18.3	.0115	.0042		.0029	.0075
C7C	.0756		20.4	.0106	.0040	.0029	.0027
C7A	.0078	22.6		.0007	.0002	.0002	.0002
n-C8P	.0460		20.4	.0028	.0009	3.0	.0006
i-C8P	.0620	.0043		.0016	.0010		.0010
C8C	.0786	55.7%	.0031	.0010	100.1% <sup>++</sup>	.0008	.0012
C8A	.0169		.0005	.0002		.0001	.0006
	.5572	60.5%	.2556 <sup>+</sup>	.1225 <sup>+</sup>	99.4% <sup>++</sup>	.0952 <sup>+</sup>	.0942 <sup>+</sup>

C9 } Assumed to have a  
 C10 } Negligible Vapor  
 C11 } Contribution  
 C12 }  
 C13+ }

1.0000

\* Assumed (Compounds were not represented in PAR Data).  
 \*\* Modified PAR data, to account for light-ends representation.  
 + Total hydrocarbon mole fraction in vapor space.  
 ++ Percent breakdown of hydrocarbons.

TABLE 2. DEGREE OF VAPOR SATURATION  
 VERSUS FLAMMABILITY LIMITS

Source	Temperature	Volume Percent Hydrocarbon in Vapor Space	Flammability Limits (Volume % HC)
Calculated At Saturation	70°F	12.3	1.3 - 8.0
EPA Measurements at March AFB	76°F	8.9	

## SECTION IV

### REFRIGERATION SYSTEMS

Two types of refrigeration systems were investigated:

- A. Compression and condensation of vapors
- B. Low temperature condensation of vapors at atmospheric pressure on the surface of refrigeration coils.

#### A. Compression and Condensation of Vapors

This type of system could present serious safety problems, because it necessitates the compression of JP-4 vapors, whose concentration may lie within the flammable region. Such a system is shown schematically in Figure 2.

In order to minimize the safety hazard, a precompression spray chamber is needed to insure saturation of the vapors with JP-4. However, at fuel temperatures below about 50°F, no amount of saturation can bring the vapor composition above the flammable limit. In such cases, a detonation would occur in the compressor.

#### B. Low Temperature Condensation

This involves passing the JP-4 vapors over a cold refrigeration coil, and condensing out the hydrocarbons. The natural pressure of the vapor being forced out of the tank is sufficient to drive it across the coils and out the vent (maximum pressure drop is about 2" water column). No blowers or compressors are needed to motivate the vapor, and consequently, there is no ignition source in the vapor path.

This type of refrigeration system is diagrammed in Figure 3. It is compact, and relatively easy to operate. The only utility requirement is electricity, and the condensed JP-4 can be directly returned to a storage tank. Data from March where a condensation system is already installed (see below), indicates that fuel quality remains unchanged by introducing condensed vapors into the underground storage tanks.

Because the JP-4 vapors are not compressed, the refrigeration coil temperature must be very low. For 90-95 percent vapor recovery, the coil temperature will have to be about -100°F, or lower (See Appendix B for calculations). This temperature is supported by USAF data (Reference 1), and is necessitated by the dilution of the hydrocarbons with air (only 12 to 26 percent of the vent vapors is JP-4). In addition,

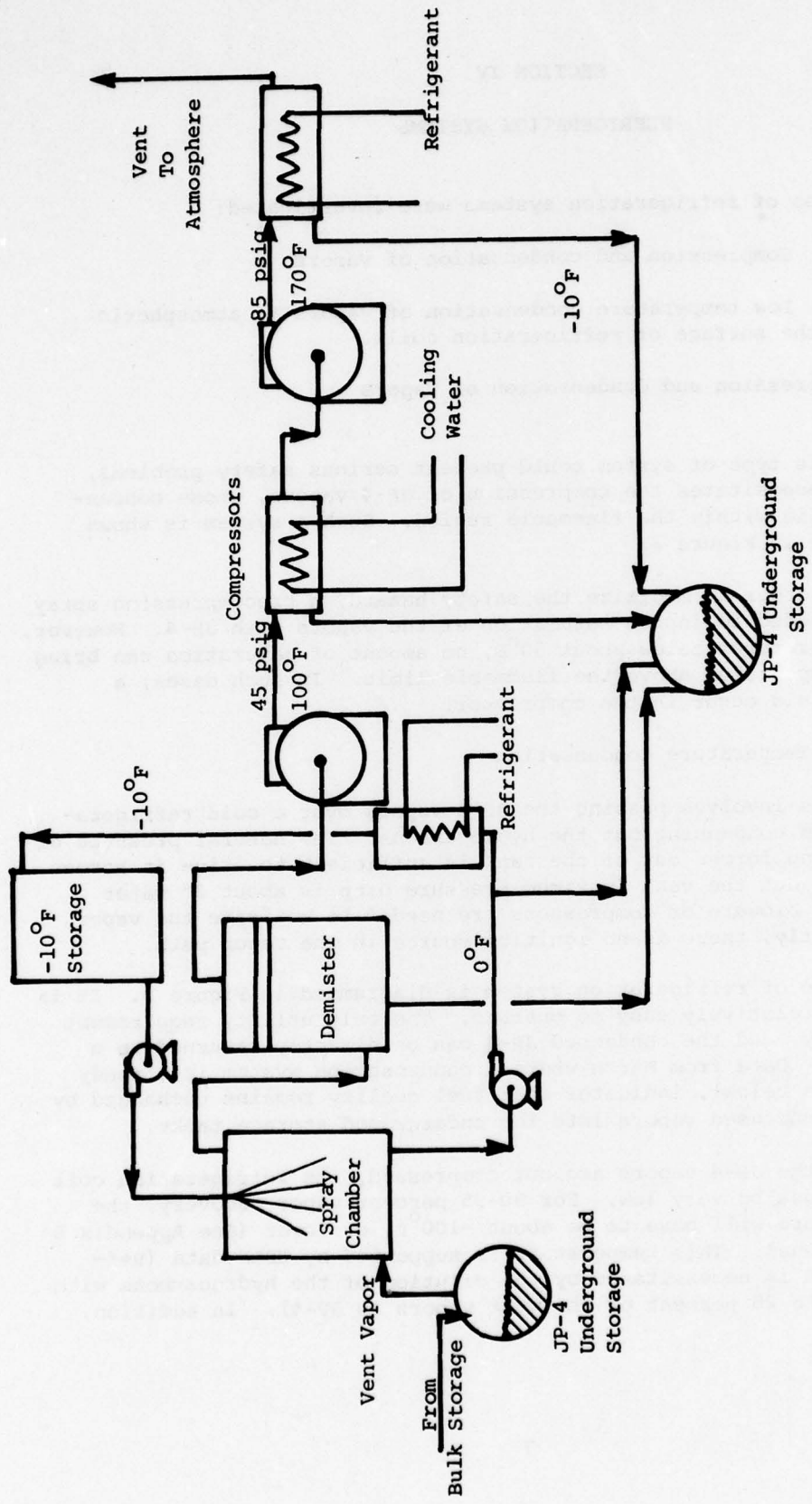


Figure 2. Compression/Condensation System

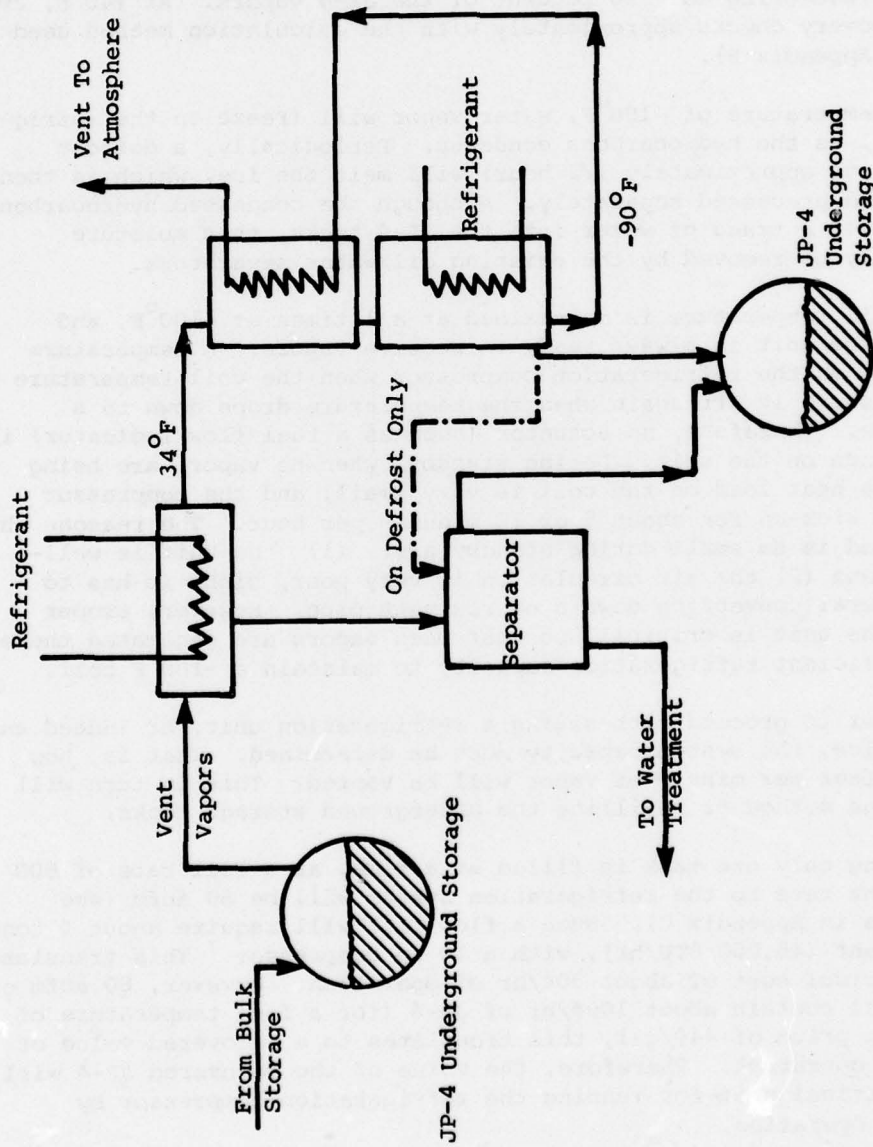


Figure 3. Low Temperature Condensation System

-100°F is in the typical range for 90 percent condensation of gasoline vapors, to which JP-4 is similar, and for which present-day commercial equipment is available. In fact, Edwards Engineering has 88 such units presently operating in the United States, and its model VC500, installed at the Southern Pacific Pipe Lines Terminal (in Sacramento, California), has been verified by the California Air Resources Board as achieving 97 percent vapor recovery at a gasoline loading rate of 305,000 gallons per day (Reference 2).

It should be noted that March AFB currently has a refrigeration unit (designed by the US Army Corps of Engineers) operating at about +40°F, and recovering only 20 percent of the JP-4 vapors. At +40°F, 20 percent recovery checks approximately with the calculation method used above (see Appendix B).

At a temperature of -100°F, water vapor will freeze on the refrigeration coil as the hydrocarbons condense. Periodically, a defrost cycle (lasting approximately 1/2 hour) will melt the ice, which is then collected and processed separately. Although the condensed hydrocarbons may carry over a trace of water into the JP-4 tanks, this moisture should easily be removed by the existing oil/water separators.

The coil temperature is maintained at all times at -100°F, and therefore, the unit is always ready to receive vapors. A temperature sensor turns on the refrigeration compressor when the coil temperature rises, and shuts it off again when the temperature drops down to a preset value. Therefore, no actuator (such as a fuel flow indicator) is needed to turn on the unit. During standby, when no vapors are being emitted, the heat load on the coil is very small, and the compressor should only kick-on for about 5 or 10 minutes per hour. The reasons why the heat load is so small during standby are: (1) the unit is well-insulated, and (2) the air circulation is very poor, since it has to rely on natural convection down a narrow vent pipe. However, proper sizing of the unit is critical, so that when vapors are generated there will be sufficient refrigeration capacity to maintain a -100°F coil.

In order to proceed with sizing a refrigeration unit, or indeed any control device, the system capacity must be determined. That is, how many cubic feet per minute of vapor will be vented? This in turn will depend on the method of refilling the underground storage tanks.

Assuming only one tank is filled at a time, at a fill rate of 600 gpm, the vent rate to the refrigeration system will be 80 acfm (see calculations in Appendix C). Such a flow rate will require about 4 tons of refrigerant (48,000 BTU/hr), with a 10 hp compressor. This translates to an electrical cost of about 30¢/hr of operation. However, 80 acfm of vent gas will contain about 100#/hr of JP-4 (for a fuel temperature of 70°F). At a price of 44¢/gal, this translates to a recovered value of \$8.46/hr of operation. Therefore, the value of the recovered JP-4 will exceed electrical cost for running the refrigeration compressor by \$8.16/hr of operation.

## SECTION V

### ALTERNATIVE SYSTEMS

#### A. Incineration

Incineration could theoretically provide a viable alternative to refrigeration/condensation systems. This would involve burning JP-4 vapors at temperatures ranging from about 600°F (for catalytic oxidation) to about 1400°F (for standard combustion). However, because of the proximity of the underground JP-4 tanks to the operational apron, a combustion source may be highly undesirable.

Instead, the vapors could be collected and piped far enough away from the apron to satisfy safety requirements, and the incinerator located at that distance. However, again because of proximity to the operational apron, underground vent lines may be required in many situations, which entails a high capital investment. For those locations where the underground tanks are in the middle of the apron (such as at March AFB), the runway would have to be ripped up to install such lines.

As a further safety consideration, the JP-4 vapors may have to be compressed, in order to force them through the combustion burners. However, because of uncertainty regarding the degree of saturation of the vapors (as mentioned above), they will have to be passed through a spray chamber prior to compression. Again, even presaturation will not be sufficient for fuel temperatures below about 50°F., when a detonation is likely to occur in the compressor.

Finally, since the JP-4 vapors are burned, there is no recovery value as with refrigeration. Although the vapors should be able to support combustion without auxiliary fuel (See Appendix D), an ignition source is always required, and possibly the combustion chamber will have to be maintained hot during periods when vapors are not being vented. Therefore, operating costs will be high compared to a refrigeration system.

#### B. Mono-Layer Vapor Suppression

A relatively new method of vapor suppression, still in the developmental stage, is to cover the surface of a volatile liquid (such as gasoline) with a monomolecular layer of high boiling point, low density, immiscible organic liquid. This has the effect of coating the gasoline surface, and suppressing its vapor pressure.

The major obstacle to utilization of this technique is the method of application of the mono-layer: i.e., getting an even coating. For JP-4 tanks, which have a submerged discharge pump, this would involve

a surface application each time the tank was emptied, and would be prohibitive from both an operational and cost standpoint. Furthermore, the mono-layer compound could contaminate the JP-4 unless tailored specifically for this application.

### C. Carbon Adsorption

A third alternative would be to adsorb the vented hydrocarbons on activated carbon. Conceivably, this would take the form of a 55 gallon drum, supplied by the carbon manufacturer, and attached to the end of the vent pipe. As the drum became saturated with adsorbed hydrocarbons, the manufacturer would replace it with a fresh drum.

However, as with incineration, this method prevents the recovery of any JP-4. Furthermore, using a "typical" loading for low molecular weight hydrocarbons of 0.1 lb/lb of activated carbon (Reference 3), the carbon usage would amount to about 1000 lb/hr of operation. This is far too excessive.

## SECTION VI

### RECOMMENDATIONS AND FUTURE DEVELOPMENT

1. A refrigeration unit using low temperature condensation should be purchased and evaluated for controlling JP-4 vapor.
2. In order to size a refrigeration unit, the vent rate, and therefore the schedule for refilling the JP-4 underground tanks, must be pinned down and adhered to.
3. After installation, the unit should be tested from winter through summer seasons, to insure operation over a wide fuel temperature range. Also, the capacity limits of the unit should be tested.

#### REFERENCES

1. "Analysis of Aeration Effluents of Fuel Tank Purging Fluids", pg 1, Aerospace Fuels Laboratory, Wright-Patterson AFB (January 1973).
2. "Source Test Report, Southern Pacific Pipe Lines' Vapor Recovery Systems for Gasoline Terminals", by the State of California Air Resources Board, Report No. C7-034 (July 1977).
3. "Control Characteristics of Carbon Beds for Gasoline Vapor Emissions", by M. J. Manos, et al, US EPA Publication No. EPA/600/277/057 (February, 1977).
4. R. H. Perry and C. H. Chilton, Chemical Engineers' Handbook, 5th ED, (1973).

APPENDIX A

CALCULATED JP-4 VAPOR COMPOSITIONS

The calculated vapor compositions were based on the following equation:

$$Y_i = K_i X_i$$

where  $Y_i$  = mole fraction of component  $i$  in the vapor

$X_i$  = mole fraction of component  $i$  in the liquid

$K_i$  = distribution coefficient, or "K factor", determined empirically, and a function of temperature.

The K factors for paraffins up to C9 were obtained from a DePriester nomograph. For all other hydrocarbons, the K factors were approximated using Raoult's Law:

$$K_i = \frac{P_i^0}{\pi}$$

where  $P_i^0$  = vapor pressure of component  $i$  at temperature  $T$  (Reference 4);

$\pi$  = total system pressure

This approximation can often result in serious errors: however, in the present case, these do not seem to be major, since good agreement was obtained with experimental values.

Neglecting the vapor contribution of C9+ (which will be negligible), mole fractions were calculated for each component in the vapor phase, and summed:

$\Sigma Y_i$  = total mole fraction of hydrocarbon in the vapor

$1 - \Sigma Y_i$  = mole fraction of air

(NOTE: Mole fraction is equivalent to volume fraction)

$\pi \Sigma Y_i$  = Total vapor pressure of JP-4

T	$\pi \Sigma Y_i$
59°F	1.40 psia
70°F	1.80 psia
110°F	3.76 psia

These are plotted in Figure 1 along with actual JP-4 vapor pressure data.

APPENDIX B

CALCULATED CONDENSATION TEMPERATURES FOR JP-4 VAPOR  
(at atmospheric pressure)

The following equations were used to determine the condensation temperature required for 90 percent removal of JP-4 vapors:

$$VY_i + LX_i = WZ_i \quad \text{material balance around component } i$$

$$V + L = W \quad \text{overall material balance}$$

where  $Z_i$  = initial mole fraction of  $i$  in the vapor  
 $Y_i$  = equilibrium mole fraction of  $i$  in the vapor  
 $X_i$  = equilibrium mole fraction of  $i$  in the liquid  
 $W$  = initial total amount of vapor  
 $V$  = final amount of vapor  
 $L$  = final amount of liquid

Dividing by  $W$ :

$$f_v Y_i + f_l X_i = Z_i$$

where  $f_v$  = vapor fraction =  $V/W$

$$f_l = \text{liquid fraction} = L/W$$

$$f_v + f_l = 1.0$$

\*NOTE:  $f_l$  = fraction of initial amount of vapor which condenses. Since most of the initial vapor is noncondensable,  $f_l$  will never be  $> .25$   
 Also, as in Appendix A:

$$Y_i = K_i X_i$$

$$f_v K_i X_i + (1 - f_v) X_i = Z_i$$

$$(1) \quad f_v (K_i - 1) + 1 \quad X_i = Z_i$$

$Z_i$  = vapor mole fractions given in Table I (a function of temperature)

Since all of the condensate is hydrocarbon (water has been ignored in this analysis),

$$\sum X_i = 1.0$$

Method of Solution

- a. Pick T (find K factors)
- b. Pick  $f_v$
- c. Use equation (1) to find  $X_i$
- d. See if  $\sum X_i = 1.0$

If not, return to (b), until correct  $f_v$  is calculated for a given temperature.

- e. When  $f_v$  is found, calculate  $Y_i = K_i X_i$
- f. Calculate average molecular weight of equilibrium vapor  $\overline{MW}$
- g. 
$$\left( \frac{\sum Y_i}{1 - \sum Y_i} \right) \left( \frac{\overline{MW}}{29} \right) = \frac{\text{lb hydrocarbon in vapor}}{\text{lb air}}$$

- h. Initially:

$$\left( \frac{\sum Z_i}{1 - \sum Z_i} \right) \left( \frac{70}{29} \right) = \frac{\text{lb hydrocarbon in vapor}}{\text{lb air}}$$

- i. Wt. percent of hydrocarbon condensed =

$$\left[ \frac{\left( \frac{\sum Z_i}{1 - \sum Z_i} \right) \left( \frac{70}{29} \right) \left( \frac{\sum Y_i}{1 - \sum Y_i} \right) \left( \frac{\overline{MW}}{29} \right)}{\left( \frac{\sum Z_i}{1 - \sum Z_i} \right) \left( \frac{70}{29} \right)} \right] = \left[ \left( 1 - \frac{\sum Y_i}{\sum Z_i} \right) \left( \frac{1 - \sum Z_i}{1 - \sum Y_i} \right) \left( \frac{\overline{MW}}{70} \right) \right]$$

The following pages show example calculations. The calculated weight percent condensation at 40° F checks approximately with the measured EPA results at March AFB and the final result is consistent with data taken by the Aerospace Fuels Laboratory at Wright-Patterson AFB.

NOTE: The calculation method is not accurate enough to distinguish between 90 percent and 95 percent recovery. Ninety five percent should only require about 10° F lower temperature.

RESULT: T = -90° F (vapor temperature)

To maintain a reasonable driving force for condensation, a -90° F vapor will require a -100° F coil.

@ 40°F

Compound	K <sub>i</sub>	f <sub>v</sub> = .9		Y <sub>i</sub>	Initially, Vapor Z <sub>i</sub> (@ 70°F)	Wt. Percent of Hydrocarbon Condensed
		X <sub>i</sub>	.99			
C2P	19.5	.00004	.00004	.00078	.0007	
C3P	5.1	.00273	.00256	.01290	.0128	
C4P	1.55	.02890	.02812	.04335	.0432	
n-C5P	.31	.01636	.01895	.00606	.0062	
i-C5P	.42	.04561	.05017	.02150	.0218	
n-C6P	.09	.02818	.04523	.00463	.0051	
i-C6P	.106	.07677	.11687	.01383	.0150	
C6C	.048	.01746	.03482	.00209	.0025	
C6A	.044	.00287	.00589	.00033	.0004	
n-C7P	.025	.02204	.05468	.00194	.0027	
i-C7P	.029	.03331	.07884	.00315	.0042	
C7C	.015	.03524	.10095	.00241	.0040	
C7A	.012	.00181	.00545	.00011	.0002	
n-C8P	.0076	.00842	.02777	.00039	.0009	
i-C8P	.0082	.01490	.04849	.00072	.0016	
C8C	.0055	.00953	.03294	.00036	.0010	
C8A	.0037	.00194	.00699	.00005	.0002	
		.34611	.65876	.1146	.1225	
						10 Percent Calculated 20 Percent Measured by EPA at March AFB (3)

MW = 68

\*Approximate solution, since C9+ compounds will contribute somewhat to the liquid mole fraction even though their values of Z<sub>i</sub> are very small.

@ -90°F

Compound	$K_i$		$X_i$		$Y_i$	(Initially, Vapor @ 70°F) $Z_i$	Wt. % of Condensed Hydro- carbon  90 Percent
	$f_v = .9$	$f_v = .88$	$f_v = .89$				
C2P	2.8	.0027	.0027	.0027	.00076	.0007	
C3P	.25	.03938	.03765	.03850	.00963	.0128	
C4P	.029	.34259	.29687	.31809	.00922	.0432	
n-C5P	-	.062	.05167	.05636	-	.0062	
i-C5P	-	.218	.18167	.19818	-	.0218	
n-C6P	-	.051	.04250	.04636	-	.0051	
i-C6P	-	.150	.12500	.13636	-	.0150	
C6C	-	.025	.02083	.02273	-	.0025	
C6A	-	.004	.00333	.00364	-	.0004	
n-C7P	-	.027	.02250	.02455	-	.0027	
i-C7P	-	.042	.03500	.03818	-	.0042	
C7C	-	.040	.03333	.03636	-	.0040	
C7A	-	.002	.00167	.00182	-	.0002	
n-C8P	-	.009	.00750	.00818	-	.0009	
i-C8P	-	.016	.01333	.01455	-	.0016	
C8C	-	.010	.00833	.00909	-	.0010	
C8A	-	.002	.00167	.00182	-	.0002	
		<u>1.04024</u>	<u>.88312</u>	<u>.95504*</u>	<u>.01961</u>	<u>.1225</u>	

Where data do not exist,  
 $K_i$  assumed to be 0 in  
equation (1).

\* Approximate solution, allowing for the condensation of  
some higher boiling components.

APPENDIX C

CALCULATION OF REQUIRED REFRIGERATION CAPACITY AND ELECTRICAL COST

At a fill rate of 600 gpm:

$$\text{Vent rate} = \text{fill rate} = 600 \frac{\text{gal}}{\text{min}} = 80 \text{ acfm}$$

$$\frac{7.48 \frac{\text{gal}}{\text{ft}^3}}{\text{ft}^3}$$

For vapors at 70°F, pounds of hydrocarbon emitted per hour is:

$$\left[ \frac{\left( \frac{.1225 \text{ lb moles HC}}{\text{lb mole vapor}} \right) \left( \frac{80 \text{ ft}^3 \text{ vapor}}{\text{min}} \right) \left( \frac{60 \text{ min}}{\text{hr}} \right) \left( \frac{70 \text{ lb HC}}{\text{lb mole HC}} \right)}{\left( \frac{359 \text{ ft}^3 \text{ vapor}}{\text{lb mole vapor}} \right) \left( \frac{530^\circ\text{R}}{492^\circ\text{R}} \right)} \right] = 106 \frac{\text{lb HC}}{\text{hr}}$$

The EPA measured 94 lb/hr at March AFB for vapors at 76°F, and a vent rate of 93 cfm.

Heat capacities for paraffins average about 0.55  $\frac{\text{BTU}}{\text{lb}^\circ\text{F}}$  (Reference 4).

Assuming an average value of 0.40  $\frac{\text{BTU}}{\text{lb}^\circ\text{F}}$  for the other hydrocarbons, the average heat capacity of JP-4 vapors is:

$$\left[ \left( \frac{0.55 \text{ BTU}}{\text{lb}^\circ\text{F}} \right) (0.932) + \left( \frac{0.40 \text{ BTU}}{\text{lb}^\circ\text{F}} \right) (0.068) \right] = 0.54 \frac{\text{BTU}}{\text{lb}^\circ\text{F}}$$

$$\left[ \left( \frac{0.54 \text{ BTU}}{\text{lb}^\circ\text{F}} \right) \left( \frac{70\#}{\text{lb mole}} \right) \right] = 38 \frac{\text{BTU}}{\text{lb mole } ^\circ\text{F}}$$

$$\text{Heat capacity of air} = \left[ \left( \frac{0.25 \text{ BTU}}{\text{lb}^\circ\text{F}} \right) \left( 29 \frac{\text{lb}}{\text{lb mole}} \right) \right] = 7.25 \frac{\text{BTU}}{\text{lb mole } ^\circ\text{F}}$$

Therefore, molar weighted average heat capacity of JP-4 vapors is:

$$\left[ (0.1225) \left( \frac{38 \text{ BTU}}{\text{lb mole } ^\circ\text{F}} \right) + (0.8775) \left( \frac{7.25 \text{ BTU}}{\text{lb mole } ^\circ\text{F}} \right) \right] = 11 \frac{\text{BTU}}{\text{lb mole } ^\circ\text{F}}$$

For a refrigeration temperature of  $-90^{\circ}\text{F}$ , the rate of sensible heat removal for a single storage tank is:

$$\left[ \frac{\left(80 \frac{\text{ft}^3}{\text{min}}\right) \left(60 \frac{\text{min}}{\text{hr}}\right) (70^{\circ}\text{F} - -90^{\circ}\text{F}) \left(11 \frac{\text{BTU}}{\text{lb mole } ^{\circ}\text{F}}\right)}{\left(359 \frac{\text{ft}^3}{\text{lb mole}}\right) \left(\frac{530^{\circ}\text{R}}{492^{\circ}\text{R}}\right)} \right] = 21845 \frac{\text{BTU}}{\text{hr}}$$

In addition, there is latent heat removal of:

$$(106 \text{ lb/hr}) \left(162 \frac{\text{BTU}}{\text{lb}}\right) = 17172 \text{ BTU/hr}$$

(where 162 BTU/lb is the approximate latent heat of the paraffinic hydrocarbons (Reference 4) in JP-4 vapors).

$$\text{Total heat removal required} = 39017 \frac{\text{BTU}}{\text{hr}}$$

Allowing for 20 percent heat leak, the required refrigeration capacity =

$$39017 \frac{\text{BTU}}{\text{hr}} \times 1.2 = 46820 \frac{\text{BTU}}{\text{hr}}$$

This corresponds to a 4 ton (48000 BTU/hr) refrigeration unit, for a single storage tank being filled at 600 gpm.

From Reference 4 (p.12-31), it would appear that Freon 13 (monochlorotrifluoromethane) would be a good refrigerant for this application, requiring a theoretical horsepower of about 1.2/ton of refrigerant.

$$\text{Total theoretical hp} = (1.2)4 = 4.8$$

which, with the compressor and motor inefficiency, will probably mean an effective power consumption of about 10 hp, or 7.5 KW. At an electrical cost of 4¢/KW/hr, this becomes 30¢/hr of operation.

APPENDIX D

HEAT OF COMBUSTION OF JP-4 VAPORS

Heats of combustion of paraffins are all about 19500  $\frac{\text{BTU}}{\text{lb HC}}$  (Reference 4),

and the vapors are all richer than the lower flammable limit. Therefore, theoretically, all that is required is an ignition source. However, the incinerator may have to be maintained hot even on standby, which will require auxiliary fuel.

Heat requirement:

$$\left[ \frac{\left( \frac{11 \text{ BTU}}{\text{lb mole } ^\circ\text{F}} \right) (600^\circ\text{F} - 70^\circ\text{F})}{\left( \frac{.1225 \text{ lb mole HC}}{\text{lb mole vapor}} \right) \left( \frac{70 \text{ lb HC}}{\text{lb mole}} \right)} \right] = \frac{680 \text{ BTU}}{\text{lb HC}} \quad \text{(for catalytic oxidation at } 600^\circ\text{F)}$$

OR

$$\frac{1706 \text{ BTU}}{\text{lb HC}} \quad \text{(for standard combustion @ about } 1400^\circ\text{F)}$$

Therefore, the heat contents of the vapors are more than sufficient to maintain combustion temperatures.

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USAFRCE/ER	1
HQ USAFE/DEPV/SGB	1
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63 ABG/DEEV	1
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