

CATALOGED BY WCOSI-3

TI-22,005

WADC TECHNICAL REPORT 54-19

PART II

AD0093139

DO NOT DESTROY
RETURN TO
TECHNICAL DOCUMENT
CONTROL SECTION
WCOSI-3

FILE COPY

AD-93139

SEMITRAILER MOUNTED OXYGEN OR NITROGEN GENERATING AND CHARGING PLANT

Part 2. Final Report

S. L. FELDHAN

AIR PRODUCTS, INCORPORATED

MARCH 1956

Statement A
Approved for Public Release

20050713261

WRIGHT AIR DEVELOPMENT CENTER

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified requesters may obtain copies of this report from the ASTIA Document Service Center, Knott Building, Dayton 2, Ohio.

Copies of WADC Technical Reports and Technical Notes should not be returned to the Wright Air Development Center unless return is required by security considerations, contractual obligations, or notice on a specific document.

SEMITRAILER MOUNTED OXYGEN OR NITROGEN GENERATING AND CHARGING PLANT

Part 2. Final Report

S. L. FELDHAN

AIR PRODUCTS, INCORPORATED

MARCH 1956

**EQUIPMENT LABORATORY
CONTRACT No. AF 33(600)-19855**

**WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO**

FOREWORD

This technical report was prepared by Air Products, Incorporated, Allentown, Pennsylvania on Contract No. AF33(600)-19855, dated June 9, 1952; supplemental agreement No. 1, dated March 2, 1953; revision No. 1, dated May 15, 1953. Work was administered under the direction of C. R. Anderson and F. E. Pavlis, Vice-presidents in charge of Engineering, and executed by P. G. Foust, Chief Project Engineer, H. W. Farrow, Senior Engineer, and S. L. Feldhan, Project Engineer.

This is the final technical report to be issued on this project. Two previous reports have been issued, which are: a Design Study, dated July, 1953, and a Test Report, dated April, 1955.

Included among those who cooperated in this project were G. F. Brestovansky, J. V. Fetterman, C. J. Schilling, and L. L. Volland of Air Products, Incorporated.

ABSTRACT

Design of a mobile generator capable of producing two tons per day of high purity liquid oxygen or liquid nitrogen and capable of compressing the entire production capacity to 4000 PSIG is described. The flows of the operating cycle are pictured and discussed. Material and heat balances are calculated on the basis of theory and past experience gained from the fabrication of more than 500 oxygen generators, both mobile and stationary, of high and low purity type. Specifications for the equipment components are listed.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER:

for *R. Lutton* *RAE/USAF*

S. T. SMITH
Colonel, USAF
Chief, Equipment Laboratory

CONTENTS

<u>SECTION</u>		<u>PAGE</u>
	Foreword	ii
	Abstract	iii
	Introduction	vi
I	Description	1
II	Cycle of Air Separation	11
III	Thermodynamic Calculations	15
IV	Electric Power and Control	44
V	Equipment Specifications	51
VI	Fabrication	93

LIST OF ILLUSTRATIONS

<u>FIG. NO.</u>	<u>SEC. NO.</u>		<u>PAGE</u>
1	I	Flowsheet - Oxygen Production	9 & 10
2	I	Flowsheet - Nitrogen Production	9 & 10
3	IV	A.C. Control Panel	45
4	IV	A.C. Wiring Diagram	46 & 47
5	IV	D.C. Control Box Assembly	49
6	V	Generator Layout	52 & 53
7	V	Oxygen or Nitrogen Generating and Charging Plant	54
8	V	Air Compressor (Sectional View)	59 & 60
9	V	Oxygen or Nitrogen Generating and Charging Plant (Curb Side View)	66
10	V	Oxygen or Nitrogen Generating and Charging Plant (Air Compressor Section)	67
11	V	Transmission Assembly (Sectional View)	69 & 70
12	V	Switch Valve Assembly	75
13	V	Expansion Turbine (Sectional View)	83
14	V	Product Pump Motor (Sectional View)	86
15	V	Controls, Front of Cold Compartment	89
16	V	Controls, Rear of Cold Compartment	90

INTRODUCTION AND SUMMARY

To obtain the desired production of two tons per day of 99.5 percent pure liquid oxygen, or two tons per day of 99.0 percent pure liquid nitrogen, an air feed of approximately 1000 standard cubic feet per minute is used. This indicates a liquid oxygen recovery by weight of 4.29 percent or a liquid nitrogen recovery by weight of 3.7 percent. To operate the unit, three diesel engines supply approximately 330 HP, which result in a ratio of approximately 1.1 pounds of liquid oxygen produced per pound of diesel fuel burned. A temperature approach of approximately 8°F shall be expected at the air inlet end of the heat exchanger between incoming air and effluent products. The estimated heat infiltration from ambient surroundings into the air separator shall be 1.5 BTU per pound of air feed. It is estimated that the loss of air from the heat exchanger during the reversals, which occur every 10 minutes, shall be 3 percent of the total input. The semitrailer shall be approximately 32'-0" long, 9'-6" wide, and 12'-0" high.

SECTION I

DESCRIPTION

General

This technical report describes the design and manufacture of the Air Products, Incorporated, Model IGEON-2T Mobile Oxygen-Nitrogen Generating Plant. The Generator is installed in a van-type semitrailer adaptable for towing by a standard type M-52, 5-ton truck-tractor. The generating plant is equipped with three diesel engines which serve as prime movers for the three air compressors. The Generator is composed of four main groups and their auxiliaries. The four groups are: Power Plant Group, Air Compressor Group, Liquefaction and Separation Group, and Product Pumping Group. All groups are designed to meet the requirements of compactness and ease of mobility, installation, and operation.

Generator Capacity

With an air compressor intake of one atmosphere, an ambient temperature of 21°C (70°F) and a relative humidity of 50 percent, the Model IGEON-2T Oxygen-Nitrogen Generating Plant is designed to produce:

- a. 2 tons per day of subcooled liquid oxygen having a purity of 99.5 percent at a pressure of about 0 PSIG.

or

- b. 2000 SCFH (measured at 21°C (70°F) and one atmosphere) of gaseous oxygen having a purity of 99.5 percent at a pressure up to 4000 PSIG.

or

- c. 2 tons per day of liquid nitrogen having a purity of 99.0 percent at a pressure of about 0 PSIG.

or

- d. 2000 SCFH of gaseous nitrogen having a purity of 99.0 percent at a pressure up to 4000 PSIG.

Since the oxygen and nitrogen products result from the distillation of liquid air, they may be considered to be absolutely free of moisture.

Generating Plant Component Assemblies

The following is a brief description of component assemblies which comprise the Model IGEON-2T Mobile Oxygen-Nitrogen Generating Plant.

Air Filter

The air is filtered through a dry panel type air filter, attached to the underside of the trailer. Two bonded glass filtering elements are mounted in a lightweight steel duct which is attached to the first stage air compressor.

Air Compressor

The air compressor consists of blowers connected in series into three stages. Each compression stage consists of a separate three-lobe, rotary, positive displacement, axial flow, horizontal, heavy duty blower coupled to its individual diesel prime mover. Because of the design of the blowers, the air passing through them does not contact any of the compressor lubricant and is therefore oil-free.

Intercoolers and Aftercoolers

The oil-free air leaving each stage of compression is cooled in an extended surface type aluminum heat exchanger by a stream of outside air. Coupled to the shaft of each blower is an all-steel fan with standard steel shaft, which supplies outside air at about two inches of water pressure and ambient temperature to the cooler. Outside air enters the suction of the fans through screened openings and is discharged through openings in the trailer roof.

The first stage intercooler and the third stage aftercooler contain coils in which the high pressure oxygen and nitrogen liquid products are vaporized at pressures up to 4000 PSIG by means of hot outgoing air.

Diesel Engines

The power plant is composed of three identical, 2 cycle, 6 cylinder, radiator-cooled, diesel engines. The blowers and inter-and-aftercooler fans of each stage are direct-driven in tandem by these engines. In addition, a 31.3 KVA, 120/208 volt, 3 phase, 60 cycle electrical generator is belt-driven by the second stage diesel engine. The engines are started electrically and have incorporated an air heater for cold weather starting.

Diesel Engine Transmission

This unit consists of a 14" double plate dry-disc Rockford, over center clutch bolted to the engine flywheel, and an in-line, non-shifting, overspeed transmission which is bolted, in turn, to the clutch assembly. By means of a suitable selection of transmission gears, each of the three diesel engine output drive shafts will have a different rotating speed, although the diesels themselves are operating at about 1800 RPM.

Air Switch Valve

The air switch valve is of the cylindrical type with five valve ports, four valve seats, and a stem with two valve discs. As the stem slides back and forth in the valve cylinder, the discs contact alternate valve seats. The valve stem is actuated by a double-acting compressed air cylinder whose operation is controlled by a four-way solenoid air valve.

Air Cylinder

The air cylinder is of the non-rotating, double-acting type, without cushioning, whose rod end is flange-mounted to three supports extending out from the switch-valve body.

Solenoid Valve

The air solenoid valve mounted on the air cylinder is a complete packaged unit consisting of a four-way directional slide valve, solenoid controls, and piston speed regulators. This valve differs from the conventional solenoid valve in that the air is used to do the work of shifting the slide valve. The solenoids in the valve act as triggers, which release and direct incoming air against a piston, which, in turn, shifts the slide valve.

Interval Timer

A synchronous motor-driven cam-type interval timer, which can be set for a 5 or 10 minute interval, energizes the air solenoid valve. Electrical controls for the switch valve include a master "OFF", "AUTOMATIC", "MANUAL" selector switch, an interval selector switch, and "IN" and "OUT" manual push buttons. Further details and instructions on the timer and controls will be found in the electrical section of this manual.

Air Separator

The air separator includes most of the equipment which operates at low temperatures, and which is involved in the cooling, liquefaction, and distillation of the air. This equipment is suitably insulated in a compartment which extends the full width of the trailer frame.

Heat Exchanger

Three heat exchanger sections of the extended surface type serve for interchange of heat between the warm incoming air and the cold effluent by-product leaving the distillation column. The third heat exchanger section serves to partially liquefy the air before it enters the distillation equipment.

Check Valves

Two check valves, piped in parallel, are located in the air and effluent by-product circuits between the second and third heat exchanger sections. Whenever the air switch valve operates on the up-stream side of the heat exchangers, the check valves automatically reverse the flow of air and effluent by-product on the down-stream side.

Phase Separator

The phase separator is a cylindrical vessel located in the flow circuit between the heat exchanger and the distillation columns, in which gravity separation of the partially liquefied air into a gaseous and a liquid phase is effected.

Expansion Turbine

The expansion turbine is mounted and insulated in a framework in the forward section of the trailer. The turbine is designed for an inlet pressure of about 97 PSIG and a discharge pressure of about 6 PSIG, and operates at a speed of about 20,000 RPM. The energy developed by the turbine is absorbed through a centrifugal blower forcing air against a back pressure.

Expansion Valves

The Generator is provided with six expansion valves, designated as the air expansion (A1-A and A1-B), the oxygen expansion valve (O1), the nitrogen expansion valves (N1-A and N1-B), and the subcooler nitrogen expansion valve (N116). The functions of these valves are described in the Cycle of Air Separation, Section II of this report.

Oxygen Distillation Column

In this column, crude liquid oxygen is separated into high purity liquid oxygen and a nitrogen-rich gaseous by-product. The distillation equipment consists of a low pressure column mounted above a high pressure condenser. The condenser serves to vaporize pure oxygen in the bottom of the low pressure column above it and to condense the nitrogen.

High Pressure Condenser

Nitrogen-rich air leaving the phase separator enters the high pressure condenser where it is condensed as a nitrogen-rich liquid. Condensation is effected by high purity, low temperature liquid oxygen, produced in the low pressure column which surrounds the condenser tubes. The nitrogen-rich liquid which drops to the bottom of the condenser is expanded through the nitrogen expansion valve (N1-A) into the top of the low pressure column to aid in the oxygen distillation process.

Low Pressure Column

This column effects the separation of oxygen from air by the process of distillation to produce a high purity liquefied product. The column contains a series of bubble-cap pans on which the descending liquid comes into intimate contact with the ascending vapor resulting from the vaporization of pure liquid oxygen in the condenser. The intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more volatile constituent, nitrogen, and a condensation of the less volatile constituent, oxygen.

Hydrocarbon Adsorber

Before the crude liquid oxygen, leaving the phase separator, enters the oxygen or nitrogen distillation column, it flows through a silica-gel hydrocarbon adsorber. Any traces of acetylene and other hydrocarbons, which entered the equipment as impurities in the air feed, will be adsorbed by the silica-gel so that no hazardous accumulation of hydrocarbons can occur in the distillation columns. The adsorbent can be reactivated by passing a warm stream of nitrogen through it to vaporize and purge the hydrocarbon impurities.

Nitrogen Distillation Column

In this column a crude oxygen-nitrogen mixture is separated into high purity liquid nitrogen and an effluent gaseous by-product. The distillation equipment consists of a high pressure condenser mounted above a high pressure column. The condenser serves to vaporize an oxygen-rich air mixture in the top of the high pressure column and to condense pure nitrogen.

High Pressure Column

Nitrogen-rich air leaving the phase separator enters the high pressure column

which contains a series of bubble-cap pans. The descending liquid comes into intimate contact with the ascending nitrogen-rich vapor. The intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more volatile constituent, nitrogen, and a condensation of the less volatile constituent, oxygen. The oxygen-rich liquid which drops to the bottom of the high pressure column is expanded through the nitrogen expansion valve (N1-B) into the top of the high pressure condenser to aid in the distillation process.

High Pressure Condenser

Condensation of the high purity gaseous nitrogen is effected by the low temperature oxygen-rich liquid, expanded from high pressure column pressure, which surrounds the condenser tubes.

Indicating Instruments

Indicating instruments connected with the operation of the air separator include pressure gages, liquid level gages, and an indicating pyrometer. All of these instruments are mounted on a control panel on the wall of the insulating compartment which encloses the air separator.

Pressure Gages

A final air pressure to plant gage, high pressure and low pressure column gages for oxygen product, and high pressure and low pressure column gages for nitrogen product are mounted on an instrument panel located on the front wall of the cold compartment. Each of these gages is provided with a shut-off valve that may be throttled to eliminate excessive vibration of the gage mechanism, or closed completely if the gage must be removed during operation.

The condenser pressure gages indicate the pressure of the nitrogen-rich air in the condensers. For all practical purposes, these gages will indicate normally a pressure about 20 PSIG less than that of the final air pressure to the plant. Because of this, the gages have an important function in indicating to the operator when the circuit between the air compressor and the condensers is becoming clogged. An accumulation of snow or ice in the circuit will be evidenced by an increasing difference in pressure between the air compressor discharge and these gages.

The low pressure column gage indicates the pressure in the low pressure column. For all practical purposes this gage also indicates the discharge pressure of the oxygen and nitrogen expansion valves, the expansion turbine, and the inlet pressure to the oxygen product pump. The low pressure column pressure is the pressure required to force the oxygen product out of the distillation column and either to the oxygen product pump or to the atmosphere.

The high pressure column gage indicates the inlet pressure to the nitrogen expansion valves, the expansion turbine, and nitrogen product pump.

Liquid Level Gages

For the proper operation of the Generator, it is necessary to know the levels of the liquids in the phase separator, high pressure condensers, low pressure column, and the high pressure column. All of these levels are indicated by differential pressure gages. The liquid level gages must be kept gas tight to read correctly.

Temperature Indicator

A temperature indicator (pyrometer) of the potentiometer type, connected with copperconstantan thermocouples, is provided for measuring certain important temperatures. One rotary switch permits the operator to select the temperature point to be measured.

It is necessary to keep a constant check on the temperature of the air leaving the heat exchanger and the temperatures of the air entering and leaving the expansion turbine in order to be able to operate efficiently. The expansion turbine temperatures also serve to indicate when the turbine needs maintenance and repair.

Purity Test Sets

For efficient operation of the Generator, it is necessary to constantly check the composition of the oxygen and nitrogen products. Product purities are determined by means of two chemical test sets which are installed in a common cabinet.

Oxygen and Nitrogen Test Set

The oxygen purity measurement is based on the chemical reaction between the oxygen in a measured sample of product and a highly activated form of copper contained in a water solution of ammonium hydroxide. The nitrogen purity measurement is based on the chemical reaction between nitrogen in a measured sample of product and a caustic solution of pyrogallol. The test set includes glassware and rubber connecting tubing. Because the strength of the solutions are depleted by chemical action during purity determination, it is necessary to add fresh chemicals at regular intervals.

Product Subcooler

Liquid oxygen and nitrogen when withdrawn at atmospheric pressure will "flash" resulting in the loss of a small amount of liquid product. To minimize this loss, an extended surface type heat exchanger is included so that the liquid product is subcooled by effluent air several degrees before expansion. However, the liquid nitrogen product is approximately the same temperature as the effluent air, so that it is necessary to expand a very small fraction of the liquid nitrogen through N116 valve in order to obtain a temperature sufficient to subcool the remaining liquid product.

Oxygen-Nitrogen Compressing System

The oxygen-nitrogen compressing system includes the exclusive Air Products, Incorporated liquid pumps and low and high pressure filters. The pumps are of the horizontal, reciprocating plunger type with effective thermal features. The pumps are provided with thermal breaks that allow the mechanical elements outside the insulation jacket to operate at atmospheric temperature while the pump cylinder within the jacket is at the temperature of the liquid oxygen and nitrogen being pumped.

The pump is operated by a crank and connecting rod mechanism, which is driven by an electric motor through a gear reduction. The pump mechanism together with the electric motor and the gear reduction, form a compact assembly, which is attached to the insulating jacket that encloses the distillation column and heat exchanger. The rate at which the liquid product is pumped is controlled by varying the pump stroke.

Electrical Equipment

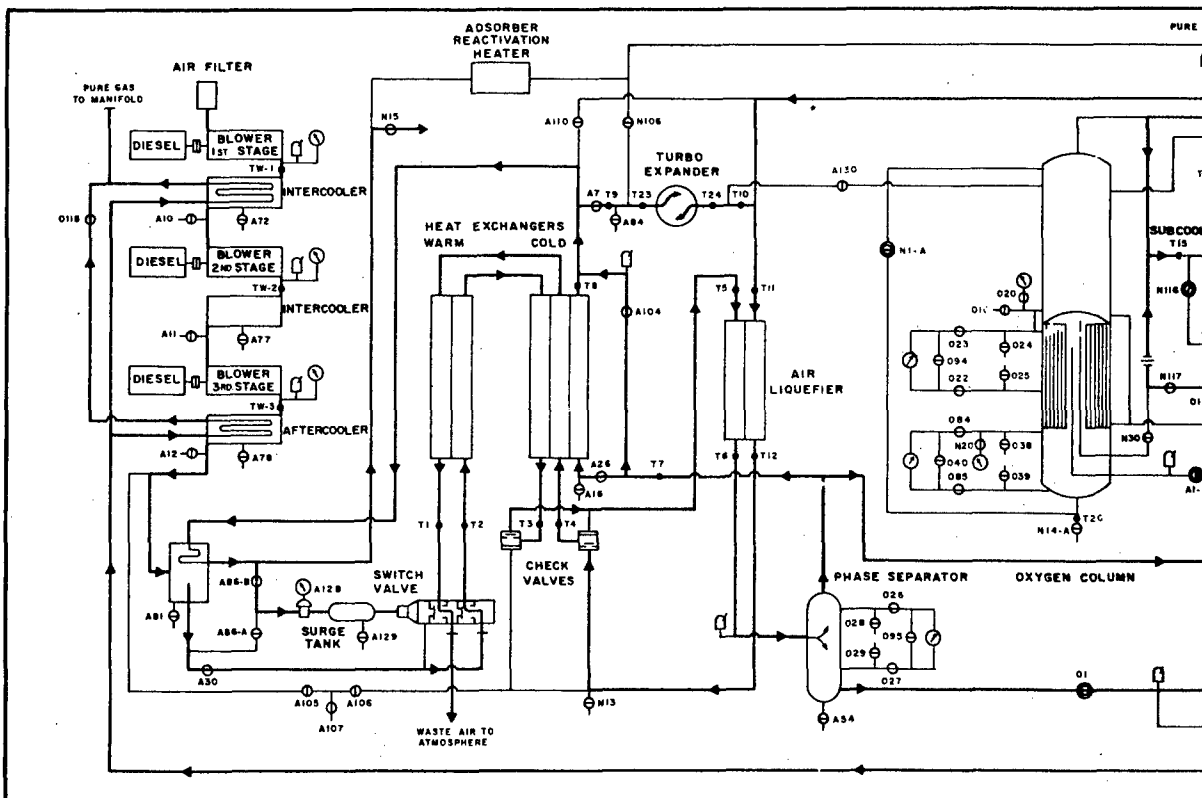
The electrical system of the Model LGEON-2T Oxygen-Nitrogen Generator is entirely self-contained. The system operates on 3 phase, 60 cycle, alternating current available as 208 volts between phase wires, and 120 volts between any phase wire and the neutral or ground of the four wire system. In addition, a direct current 24 volt system is used to start and control the diesel engines.

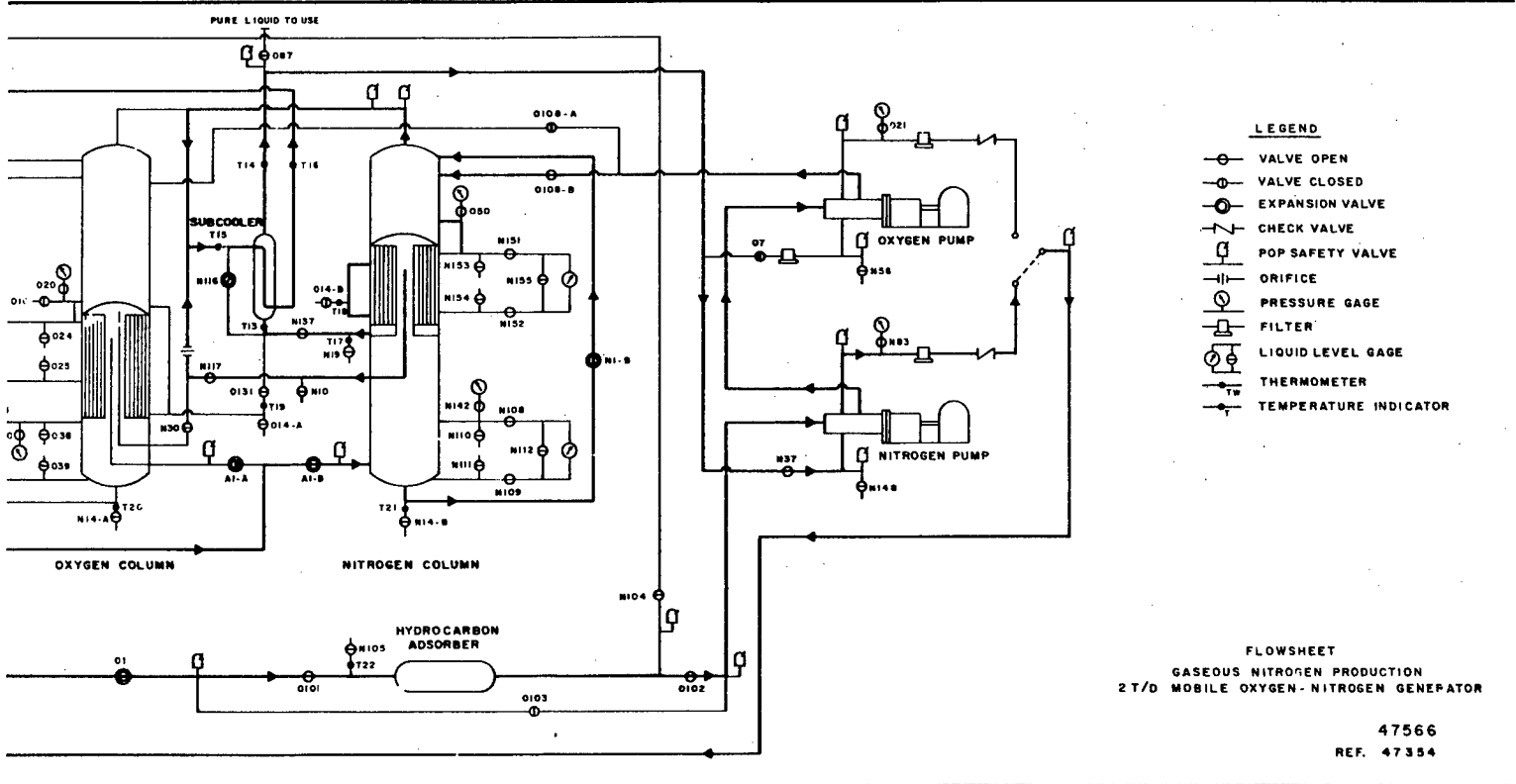
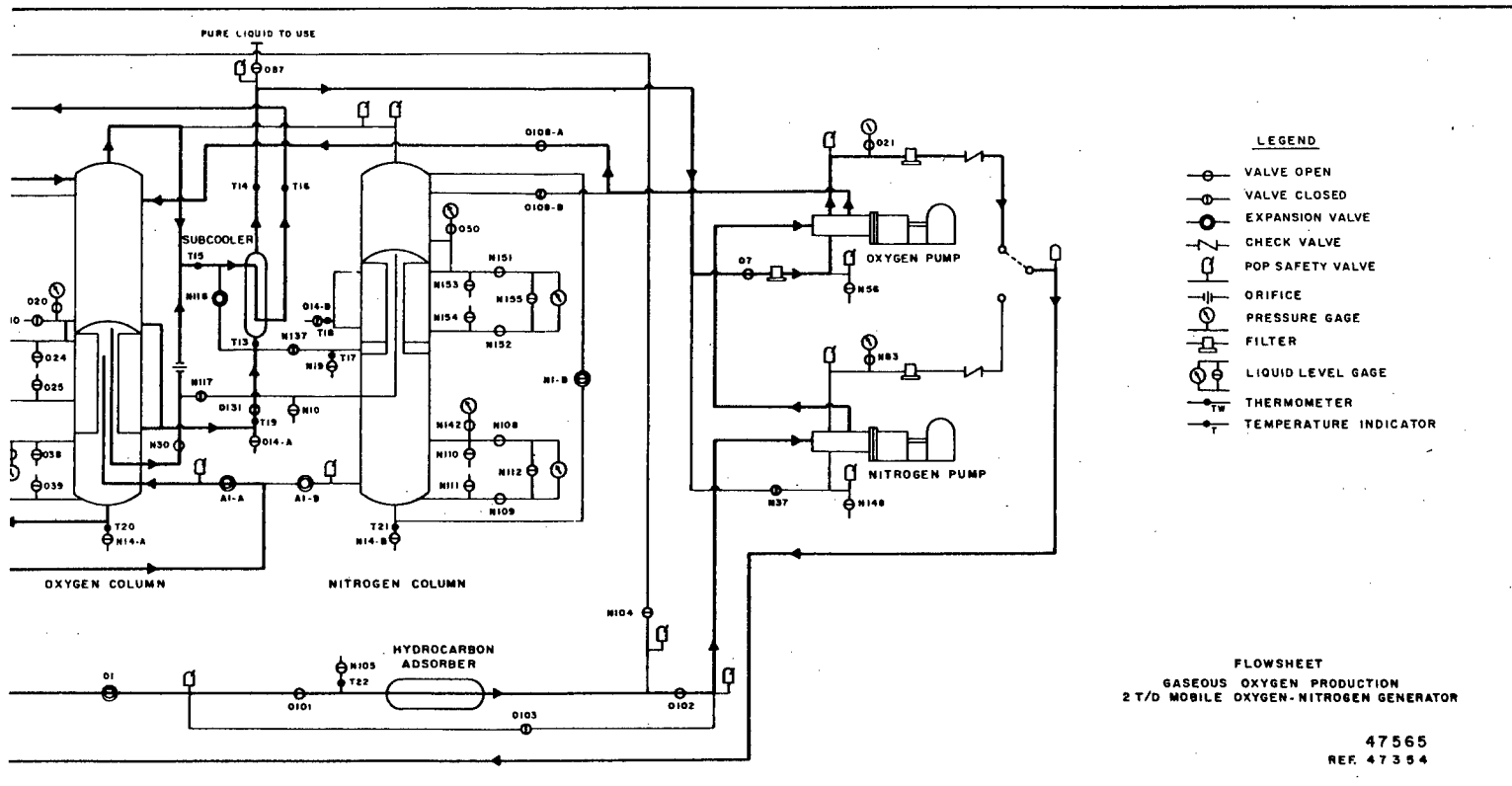
The alternating current system is comprised of one power generator, an electrical control center, a hydrocarbon adsorber reactivation heater, oxygen and nitrogen high pressure pumps and controls. The direct current system consists of two 24 volt generators used alternately, two automatic voltage regulators, an engine control center, and a 24 volt battery bank.

The lighting system consists of dome fixtures operating from either the alternating current generator or the 24 volt direct current battery bank.

All components are discussed in detail in the Equipment Specifications, Section V of this report. The following items will be covered in the Equipment Specifications, Section V:

1. Manufacturing Specifications
2. Size, Weight, and Type of Construction





SECTION II

CYCLE OF AIR SEPARATION

General

The cycles of air separation for this Generator are pictured on two Air Products, Incorporated Flow Diagrams, numbers 47565 and 47566. Each will illustrate a phase of operation and will herein be referred to as Figure 1 and 2. The liquid product is produced by the distillation of liquid air into pure oxygen or nitrogen depending on requirements. Atmospheric air which forms the raw material is filtered, compressed, freed of water vapor and carbon dioxide in reversing heat exchangers, and then liquefied by a combination of cooling and expansion. The pure product which results from the distillation of the liquid air is drawn off as a liquid at column operating pressure or is fed as a liquid into special pumps which compress the product to any pressure up to 4000 PSIA. The cold high pressure liquid product leaving the pump is warmed in a heat exchanger, and flows as a gas into cylinders or into some other receiver. Since this product is the result of distillation of liquid air, it can be considered absolutely dry for all conditions of use.

It is necessary to remove the water vapor and carbon dioxide contents from the air inasmuch as these impurities, if not removed, would in a relatively short period of time "freeze out" at the sub-zero temperatures involved and thus plug lines and render the Generator inoperative.

Detailed Description

Atmospheric air is drawn through mechanical filters to remove any foreign matter which may be injurious to the equipment, and is then fed to an oil-free air compressor where its pressure is elevated to 100 PSIG. The air compressor is a three stage unit, each stage consisting of a rotary blower which is direct-driven by a diesel engine through a suitable transmission. Some moisture and also heat of compression is removed from the air in air cooled inter-and-aftercoolers and condensate traps. The high pressure air is then fed to the heat exchanger through a switch valve. This valve switches or reverses, at preset ten minute intervals, the heat exchanger passes for the incoming, high pressure air and the effluent, low pressure, waste air such that, the passes which were high pressure air passes for the previous ten minutes then become effluent, waste air passes for the next ten minutes, and vice-versa. The remaining moistures, and also carbon dioxide, in the high pressure air are deposited in the heat exchanger at the different temperature levels which are in equilibrium with the vapor pressures and concentrations of the moisture and carbon dioxide. These deposits are made in the two passes alternately. While a deposit is being made in one pass, the deposit in the other pass is being "cleaned up" through the absorptive capacity of the dry, low pressure, effluent, waste air.

After leaving the heat exchanger, the high pressure air, which is then a saturated vapor, enters the air liquefier. The liquefier is an extension of the heat exchanger surface, and in it, liquefaction of a portion of the incoming air is effected. This portion is the amount of liquefaction necessary to keep the cycle operating, and it is equivalent to: (1) the amount of liquid withdrawn as the final product, plus (2) the amount of liquid which is vaporized as a result of the influx

of heat into the Generator from the ambient surroundings, plus (3) the amount of liquid which is lost as a result of the expansion from high pressure air pressure to column operating pressure, the pressure at which the liquid product is withdrawn.

The partially liquefied, high pressure air then enters the phase separator, where its liquid and vapor phases are divided and directed into different streams.

The liquid stream is expanded to approximately 6 PSIG after which it is passed through a silica-gel type hydrocarbon adsorber. In the adsorber, removal of the hydrocarbon content is accomplished to prevent their accumulation to dangerous concentrations in the distillation column. After every 150 hours or more of operation, the adsorber is reactivated by means of an electrically heated stream of hot dry air which absorbs the hydrocarbons and carries them off to atmosphere. This air is tapped from the air supply to the turbo expander.

After the adsorber the liquid stream is fed to the sub-cooling jackets of the liquid product pumps to prevent vaporization of the pure liquid product when the pump is operating, and thus keep the pump efficiency high. The stream is then directed to the low pressure section of either the nitrogen or oxygen column depending on the final product required.

The vapor phase is further divided into two streams. One of these, representing 75 percent of the total air feed, passes through the cold section of the heat exchanger from the cold end to the warmer end, and then feeds the turbo expander. The exhaust from the expander joins the effluent waste air stream which leaves the column and enters the air liquefier.

In the case of producing oxygen, the other vapor stream from the phase separator is expanded through a valve from high pressure air pressure to high pressure column pressure, which is approximately 89 PSIA. This vapor enters the high pressure column and is fed directly into the condenser where all of it is condensed by the product liquid oxygen which surrounds the tubes on the low pressure column side of the condenser. The resulting liquid is expanded to low pressure column pressure and introduced into the low pressure column at the top as reflux. In order to prevent rare, inert gases such as neon, etc., which are found in the air, and which are not capable of being condensed by the liquid oxygen, from blanketing the condenser tube surfaces and thus impair their efficiencies, a stream is drawn off from the dome of the condenser and expanded into the effluent waste air stream which leaves the column. This non-condensable offtake, although very effective in accomplishing its purpose, is so very small in magnitude that it does not enter into the calculations for the material and heat balance.

The low pressure column contains a number of bubble-cap pans of conventional design, which are fed at the proper points by the expanded liquid from the incoming high pressure air, and the expanded liquid from the high pressure column. The liquid descending on these pans comes into intimate contact with the ascending vapors resulting from the column feeds as well as the vapors from the boiling oxygen which surrounds the tubes of the condenser. This intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more volatile constituent, nitrogen, and a condensation of the less volatile constituent, oxygen. Sufficient pans are included in the low pressure column to insure that the liquid withdrawn from the bottom is 99.5 percent pure oxygen. Because the boiling point of argon is closer to the boiling point of oxygen than it is to the boiling point of nitrogen, it appears in the column in the vicinity of the oxygen and shows up as the 0.5 percent impurity in the product oxygen.

Since there is only one product, oxygen, withdrawn from the column, the remaining oxygen and argon and all of the nitrogen leave the column at the top as a saturated vapor. This vapor passes through the oxygen subcooler where it subcools the product oxygen to prevent or reduce "flash" losses resulting from later expansion. After passing through the subcooler, it combines with the turbo expander exhaust and enters the air liquefier where it liquefies a portion of the incoming high pressure air. From the air liquefier it passes through the heat exchanger where it both cools the incoming air to saturation temperature, and absorbs the moisture and carbon dioxide which were deposited by the incoming air during the preceding ten minute switch period. It finally exhausts to atmosphere through the switch valve.

The product liquid oxygen is withdrawn from the bottom of the low pressure column. It passes through the subcooler where it is subcooled by the effluent waste air to prevent or reduce "flash" losses resulting from expansion into the reciprocating oxygen pump, or into an external receiver through valve 087. In the pump, its pressure is elevated to 4000 PSIG and it is discharged through a heat exchanger or vaporizer in the discharge air stream of the first stage intercooler and third stage aftercooler where it is warmed to ambient temperature.

In the case of producing nitrogen, the other vapor stream from the phase separator is expanded through a valve from high pressure air pressure to high pressure column pressure, which is approximately 52.2 PSIA. The vapor enters the high pressure nitrogen column which contains a number of bubble-cap pans of conventional design. The ascending vapor comes into intimate contact with liquid descending on the pans. This intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more volatile constituent, nitrogen, and a condensation of the less volatile constituent, oxygen, which is expanded into the low pressure column. The ascending vapor enters the condenser where it is condensed to a liquid nitrogen product by the crude oxygen product which surrounds the tubes on the low pressure column side of the condenser. As in the case of oxygen production, a small non-condensable stream is removed from the dome of the condenser to prevent blanketing of the condenser surface.

The low pressure column consists essentially of a condenser and shell. The expanded crude oxygen from the high pressure column and the expanded liquid stream from the product pump jackets are introduced into the low pressure column side of the condenser. These streams are vaporized by the condensing nitrogen in the high pressure column and the resulting vapor passes through several entrainment trays above the condenser in the low pressure column.

The waste vapor from the low pressure column passes through the subcooler. After passing through the subcooler, it combines with the turbo expander exhaust and enters the air liquefier where it liquefies a portion of the incoming high pressure air. From the air liquefier it passes through the heat exchanger where it both cools the incoming air to saturation temperature, and absorbs the moisture and carbon dioxide which were deposited by the incoming air during the preceding ten minute switch period. It finally exhausts to atmosphere through the switch valve.

The product liquid nitrogen is withdrawn from the bottom of the condenser. It passes through the subcooler into the reciprocating nitrogen pump, or into an external receiver through valve 087. In the pump its pressure is elevated to 4000 PSIA and it is discharged through a heat exchanger or vaporizer in the discharge air stream of the first stage intercooler and third stage aftercooler where it is

warmed to ambient temperature.

Pressure gages, liquid level gages, and temperature indicators are located throughout the system as necessary to serve as operating aids. In addition, all circuits in the cycle are protected against excess pressure by means of pop safety valves.

After 150 hours or more of operation, accumulation of moisture and carbon dioxide deposits may require that the Generator be defrosted or derimed. To accomplish this, numerous outlets are provided at desired locations to vent the defrost air to the atmosphere.

Should ambient air penetrate the air separator insulation jacket, its moisture content would be deposited upon the cold surfaces of the components and also upon the cold fiberglass insulation. To prevent this, the insulation jacket is put under a slight positive pressure by means of a small stream of dry, nitrogen-rich air which is tapped from the turbo expander supply line and warmed in a coil inside of the condensate trap.

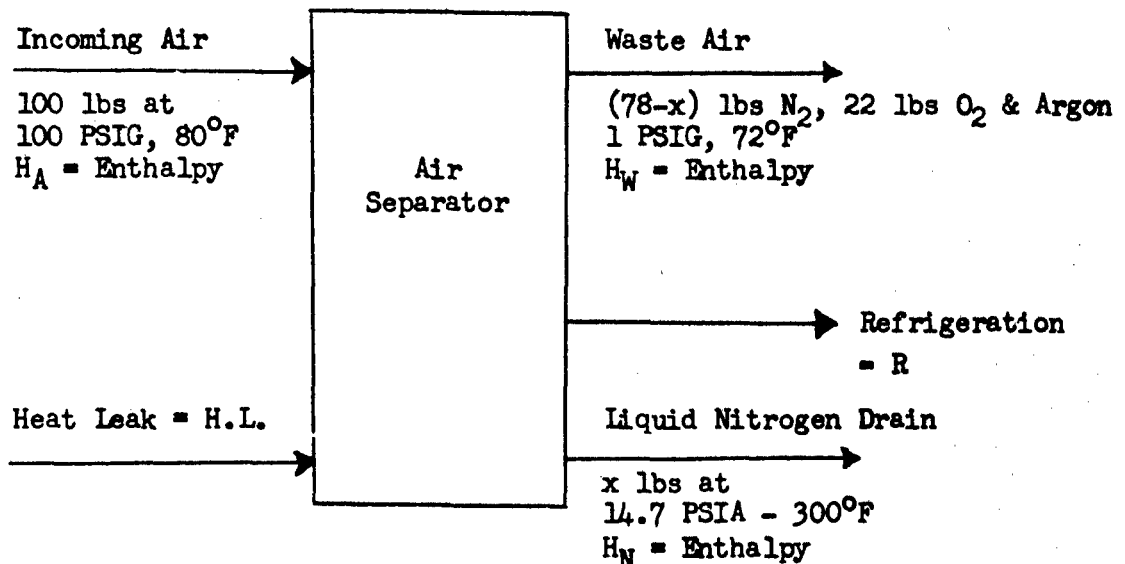
SECTION III

THERMODYNAMIC CALCULATIONS

The sources of thermodynamic data for this report were: Miller & Sullivan, United States Bureau of Mines, Mollier Charts of 1928, and V. C. Williams, Northwestern University.

The material balance of this cycle is based upon the following composition of atmospheric air: 21 percent oxygen, 78 percent nitrogen, and 1 percent argon.

The term "standard cubic feet per minute", abbreviated SCFM, as used in this report means one cubic foot of gas at the standard conditions of 70°F and 14.7 PSIA.



Liquid Nitrogen Generator Heat Balance

Refrigeration, R

The refrigeration available results from the expansion of approximately 75 percent of the incoming air from 112 PSIA to 21 PSIA. For the expander to have an adiabatic efficiency of 72 percent, the assumed inlet temperature is -240°F.

$$\begin{aligned}
 H_1 &= \text{Enthalpy at Inlet Conditions 112 PSIA } -240^\circ\text{F} \\
 &= 104.50 \text{ BTU/lb.}
 \end{aligned}$$

$$\begin{aligned}
 H_o \text{ isen} &= \text{Enthalpy at Expander Exhaust for 100 percent Expander Efficiency} \\
 &= 35.58 \text{ BTU/lb.}
 \end{aligned}$$

$$\begin{aligned}
 H_o \text{ act} &= \text{Enthalpy at Actual Exhaust Conditions} \\
 &= 90.93 \text{ BTU/lb.}
 \end{aligned}$$

$$\begin{aligned}
 \text{Efficiency} &= \frac{H_1 - H_o \text{ act}}{H_1 - H_o \text{ isen}} \times 100 \\
 &= \frac{104.5 - 90.93}{104.5 - 85.58} \times 100 = 71.72\%
 \end{aligned}$$

This checks the anticipated value

$$\begin{aligned}
 R &= H_1 - H_o \text{ act} \\
 &= 104.5 - 90.93 \\
 &= 13.57 \text{ BTU/lb.}
 \end{aligned}$$

Since only 75% of the incoming air is to be expanded

$$\begin{aligned}
 R &= 0.75 \times 13.57 \\
 &= 10.18 \text{ BTU/lb.}
 \end{aligned}$$

For 100 lbs.

$$R = 1018 \text{ BTU}$$

Enthalpy of Incoming Air, H_A

At the conditions of 100 PSIG and 80°F, the heat content of 100 lbs. of entering air will be

$$H_A = 18,430 \text{ BTU}$$

Enthalpy of Liquid Nitrogen, H_N

At the conditions of 14.7 PSIA and -298°F, the enthalpy of liquid nitrogen is (equivalent of 3.55 ATM SAT.)

$$H_N = 12.02 \text{ BTU/lb.}$$

For x lbs., the heat content will be

$$H_N = 12.02 \times$$

Heat Leak, H.L.

The anticipated heat leak is taken as

$$H.L. = 1.5 \text{ BTU/lb. or } 150 \text{ BTU for } 100 \text{ lbs.}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 1 PSIG and 72°F, the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents

The enthalpy of nitrogen at these conditions is

$$H_N = 183.5 \text{ BTU/lb.}$$

Since 78-x pounds of N_2 are exhausted as waste in this case

$$H_N = 183.50 (78-x)$$

$$H_N = 14,313 - 183.5x \text{ BTU}$$

The enthalpy of the oxygen under these conditions is

$$H_O = 181.20 \text{ BTU/lb.}$$

Since all oxygen is waste

$$H_O = 22 \times 181.20$$

$$H_O = 3,986 \text{ BTU}$$

$$H_W = H_N + H_O$$

$$= 14,313 - 183.5x + 3986$$

$$H_W = 18,299 - 183.5x$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. = H_W + R + H_N$$

$$18,430 + 150 = 18,299 - 183.5x + 12.02x + 1018$$

$$x = 4.30 \text{ lbs. } N_2 \text{ produced per 100 lbs. Air}$$

Since it is impossible to get sufficient subcooling 14.0 percent of the liquid nitrogen produced will "flash"

The air required for 2 tons per day liquid production is

$$Q = 2 \text{ (Tons/Day)} \times 2000 \frac{(\text{lbs})}{(\text{Ton})} \times \frac{1 \text{ (Days)}}{24 \text{ (Hr)}} \times \frac{1 \text{ (Hr)}}{60 \text{ (Min)}} \times \frac{1 \text{ (CuFt)}}{0.075 \text{ (lbs)}} \times$$

$$\frac{1}{0.0430} \times \frac{1}{0.86}$$

$$Q = 1002 \text{ Assuming a 3\% reversal loss}$$

$$Q = 1032 \text{ Say } 1035 \text{ SCFM}$$

GENERATOR MATERIAL BALANCE

Point 1-N Standard Intake Conditions for Air Compressor

Pressure 14.7 PSIA

Temperature 70°F

Fluid State Superheated Vapor

Fluid Flow Rate

$$\begin{aligned} W_1 &= 1035 \times 0.075 \times 60 \times \frac{1}{28.9} \\ &= 161.16 \frac{\text{lb - Mols}}{\text{Hr.}} \end{aligned}$$

Composition Flow x Concentration = Composition

$$W_{O_2} = 0.21 \times 161.16$$

$$= 33.84 \text{ Mols/Hr}$$

$$W_{N_2} = 0.78 \times 161.16$$

$$= 125.71 \text{ Mols/Hr}$$

$$W_A = 0.01 \times 161.16$$

$$= 1.61 \text{ Mols/Hr}$$

Enthalpy

At 14.7 PSIA and 70°F

$$H_1 = 182.74 \text{ BTU/lb}$$

Point 2-N Discharge for Air Compressor

Pressure 114.7 PSIA

Temperature 80°F

Fluid State Superheated Vapor

Fluid Flow Rate

The 3 percent switch loss is eliminated for the purpose of calculating a heat balance.

$$W_2 = 156.02 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 32.76 \text{ Mols/Hr}$$

$$W_{N_2} = 121.70 \text{ Mols/Hr}$$

$$W_A = 1.56 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and 80°F

$$H_2 = 184.30 \text{ BTU/lb}$$

Point 3-N High Pressure Air Leaving Heat Exchanger

Pressure 114.7 PSIA

Temperature -272°F

The air leaving the exchanger will be a saturated vapor at 114.7 PSIA.

Fluid State Saturated Vapor

Fluid Flow Rate

$$W_3 = 156.02 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 32.76 \text{ Mols/Hr}$$

$$W_{N_2} = 121.70 \text{ Mols/Hr}$$

$$W_A = 1.56 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_3 = 95.79 \text{ BTU/lb}$$

Point 4-N High Pressure Air Leaving Air Liquefier

Pressure 114.7 PSIA

Temperature -272°F

Fluid State

The liquid requirement of the air entering the liquefier is the sum of the liquid equivalent of the product takeoff, the liquid equivalent of the heat loss, and the

liquid equivalent of the expansion loss.

Product Liquid Equivalent

The latent heat of nitrogen at 52.2 PSIA is

$$H = 78.00 \text{ BTU/lb}$$

On the basis of 4.3% recovery

$$H = 3.35 \text{ BTU/lb}$$

Heat Loss Liquid Equivalent

$$H_{H.L.} = 1.5 \text{ BTU/lb}$$

Expansion Loss Liquid Equivalent

The enthalpy drop at saturated vapor conditions resulting from the expansion of incoming air from 114.7 PSIA to 21 PSIA is

$$\begin{aligned} H_{Exp} &= 95.79 - 90.93 \\ &= 4.86 \text{ BTU/lb} \end{aligned}$$

Since only 25% of the incoming air is to be expanded

$$H_{Exp} = 0.25 \times 4.86$$

$$H_{Exp} = 1.22 \text{ BTU/lb}$$

The total liquid requirement enthalpy drop is

$$\begin{aligned} H &= H_{T.O.} + H_{H.L.} + H_{Exp} \\ &= 3.35 + 1.50 + 1.22 \\ &= 6.07 \text{ BTU/lb} \end{aligned}$$

The latent heat of vaporization of air at 114.7 PSIA

$$\begin{aligned} L.H. &= 95.79 - 22.61 \\ &= 73.18 \text{ BTU/lb} \end{aligned}$$

$$\text{Liquid Requirement} = H/L.H. \times 100$$

$$\begin{aligned} \text{Liquid Requirement} &= 6.07/73.18 \times 100 \\ &= 8.29\% \end{aligned}$$

Hence the fluid state will be 8.29% liquid and 91.71% vapor

Composition

Same as Point 3

$$W_{O_2} = 32.76 \text{ Mols/Hr}$$

$$W_{N_2} = 121.70 \text{ Mols/Hr}$$

$$W_A = 1.56 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_4 = 89.72 \text{ BTU/lb}$$

Point 5-N High Pressure Air Leaving the Phase Separator and Entering the Expansion Valve

Entering the 7.8 atmosphere equilibrium curve for oxygen and nitrogen at -272°F or 104.3°K for 21 mol percent oxygen

Total Mols = Mols Liquid + Mols Vapor

$$0.21 = 0.0829 (0.366) + 0.9171 (0.196)$$

$$0.21 = 0.0303 + 0.1798$$

$$0.21 = 0.2101$$

$$\text{Mols Oxygen Vapor} = 0.1798 \times 156.02$$

$$W_{O_2} = 28.04 \text{ Mols/Hr}$$

$$\text{Mols Oxygen Liquid} = 0.0303 \times 156.02$$

$$W_{O_2} = 4.72 \text{ Mols/Hr}$$

The amount of air entering the phase separator which is expanded into the high pressure column through the A1 expansion valves is

$$100 - 75 - 8.29 = 16.71\%$$

Pressure

114.7 PSIA

Temperature

-272°F

Fluid State

Saturated Vapor

Fluid Flow Rate

$$W_5 = 0.1671 \times 156.02$$

$$= 26.07 \text{ Mols/Hr}$$

Composition

$$\begin{aligned}W_{O_2} &= 26.07 \times 0.196 \\ &= 5.11 \text{ Mols/Hr}\end{aligned}$$

$$\begin{aligned}W_A &= 1/21 \times 5.11 \\ &= 0.24\end{aligned}$$

$$\begin{aligned}W_{N_2} &= 26.07 - 5.11 - 0.24 \\ &= 20.72 \text{ Mols/Hr}\end{aligned}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_5 = 95.79 \text{ BTU/lb}$$

Point 6-N High Pressure Air Entering High Pressure Nitrogen Column

Pressure 52.2 PSIA

Temperature -282.5°F

Fluid State Superheated Vapor

Fluid Flow Rate Same as Point 5

$$W_6 = 26.07 \text{ Mols/Hr}$$

Composition Same as Point 5

$$W_{O_2} = 5.11 \text{ Mols/Hr}$$

$$W_{N_2} = 20.72 \text{ Mols/Hr}$$

$$W_A = 0.24 \text{ Mols/Hr}$$

Enthalpy

At 52.2 PSIA and -282.5°F

$$H_6 = 95.79 \text{ BTU/lb}$$

Point 7-N High Pressure Air Leaving Phase Separator and Entering Cold Heat Exchanger

The pressure and temperature are the same as Point 5 with the flow and composition proportional to the division of the total vapor phase leaving the phase separator.

Pressure 114.7 PSIA
Temperature -272°F
Fluid State Saturated Vapor
Fluid Flow Rate

$$W_7 = 0.75 \times 156.02$$
$$= 117.02 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = \text{Total } O_2 \text{ Vapor leaving separator - Oxygen to Column}$$

$$W_{O_2} = 28.04 - 5.11$$
$$= 22.93 \text{ Mols/Hr}$$

$$W_A = 1/21 \times 22.93$$
$$= 1.09 \text{ Mols/Hr}$$

$$W_{N_2} = 117.02 - 1.09 - 22.93$$
$$= 93.00 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_7 = 95.79 \text{ BTU/lb}$$

Point 8-N High Pressure Air Entering Turbo Expander

Stream 7 in passing through the heat exchanger will undergo a slight pressure drop and rise in temperature. This warm-up will increase the expander efficiency.

Pressure 112 PSIA
Temperature -240°F
Fluid State Superheated Vapor
Fluid Flow Rate Same as Point 7
 $W_8 = 117.02 \text{ Mols/Hr}$
Composition Same as Point 7
 $W_{O_2} = 22.93 \text{ Mols/Hr}$

$$W_{N2} = 93.00 \text{ Mols/Hr}$$

$$W_A = 1.09 \text{ Mols/Hr}$$

Enthalpy

At 112 PSIA and -240°F

$$H_8 = 104.50 \text{ BTU/lb}$$

Point 9-N Low Pressure Air Leaving the Expander and Feeding the Low Pressure Column

No flow is demanded through Point 9 since the only purpose of such a flow is to give advantage to the low pressure column in so far as oxygen production is concerned.

Point 10-N Expander Exhaust Stream into Air Liquefier

Pressure 21 PSIA

Temperature -306°F

Fluid State Saturated Vapor

Fluid Flow Rate Same as Point 8

$$W_{10} = 117.02 \text{ Mols/Hr}$$

Composition Same as Point 8

$$W_{O2} = 22.93 \text{ Mols/Hr}$$

$$W_{N2} = 93.00 \text{ Mols/Hr}$$

$$W_A = 1.09 \text{ Mols/Hr}$$

Enthalpy 90.93 BTU/lb

Point 11-N Air Stream Feeding Air Liquefier

Pressure 21 PSIA

Temperature -306°F

Fluid State Saturated Vapor

Fluid Flow Rate

The flow will be stream 4 minus the product take-off

$$W_{11} = 156.02 - 2 \times 2000 / 0.86 \times 28 \times 24$$

$$W_{11} = 149.10 \text{ Mols/Hr}$$

Composition

Referring to compositions at Point 14, Point 6, and Point 10.

$$W_{O_2} = 5.11 + 4.72 + 22.93 - 0.04$$

$$= 32.72 \text{ Mols/Hr}$$

$$W_{N_2} = 20.72 + 7.99 + 93.00 - 6.84$$

$$= 114.87 \text{ Mols/Hr}$$

$$W_A = 0.24 + 0.22 + 1.09 - 0.04$$

$$= 1.51 \text{ Mols/Hr}$$

Enthalpy

Combination of Points 19 and 10

$$= \frac{90.93 \times 117.02 + 91.10 \times 32.08}{149.10}$$

$$= 90.97 \text{ BTU/lb}$$

Point 12-N Air Leaving Air Liquefier and Entering Cold Heat Exchanger

Pressure

19 PSIA

Temperature

All of the latent heat of the liquefied air is taken by this stream.

$$(95.79 - 89.72) \quad 156.02/149.10 = 6.34$$

$$6.34 + 90.97 = 97.31 \text{ BTU/lb}$$

$$T_{12} = -283.6^\circ\text{F}$$

Fluid State

Superheated Vapor

Fluid Flow Rate

Same as Point 11

$$W_{12} = 149.10 \text{ Mols/Hr}$$

Composition

Same as Point 11

$$W_{O_2} = 32.72 \text{ Mols/Hr}$$

$$W_{N_2} = 114.87 \text{ Mols/Hr}$$

$$W_A = 1.51 \text{ Mols/Hr}$$

Enthalpy

At 19 PSIA and -283.6°F , the enthalpy is

$$H_{12} = 97.31 \text{ BTU/Hr}$$

Point 13-N Waste Air Leaving Warm Heat Exchanger

Pressure 14.7 PSIA

Temperature 72°F

Fluid State Superheated Vapor

Fluid Flow Rate Same as Point 12

$$W_{13} = 149.10 \text{ Mols/Hr}$$

Composition Same as Point 12

$$W_{O_2} = 32.72 \text{ Mols/Hr}$$

$$W_{N_2} = 114.87 \text{ Mols/Hr}$$

$$W_A = 1.51 \text{ Mols/Hr}$$

Enthalpy

At 14.7 PSIA and 72°F

$$H_{13} = 182.97 \text{ BTU/lb}$$

Point 14-N High Pressure Liquid Leaving Phase Separator

Pressure 114.7 PSIA

Temperature -275.6°F

Fluid State Saturated Liquid

Fluid Flow Rate

$$\begin{aligned} W_{14} &= 0.0829 \times 156.02 \\ &= 12.93 \text{ Mols/Hr} \end{aligned}$$

Composition

$$W_{O_2} = 4.72 \text{ Mols/Hr}$$

$$W_A = 4.72 \times 1/21$$

$$W_A = 0.22 \text{ Mols/Hr}$$

$$W_{N2} = 12.93 - 0.22 - 4.72$$

$$W_{N2} = 7.99 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -275.6°F

$$H_{14} = 22.55 \text{ BTU/lb}$$

Point 15-N Low Pressure Air Leaving Expansion Valve and Entering Low Pressure Column

The liquid air is expanded to the pressure at the top of the low pressure column at constant enthalpy.

Pressure 21 PSIA

Temperature -304.3°F

Fluid State

The expansion of saturated liquid from 114.7 PSIA to 21 PSIA results in

79.05% Liquid

20.95% Vapor

Fluid Flow Rate Same as Point 14

$$W_{15} = 12.93 \text{ Mols/Hr}$$

Composition

$$W_{O2} = 4.72 \text{ Mols/Hr}$$

$$W_{N2} = 7.99 \text{ Mols/Hr}$$

$$W_A = 0.22$$

Enthalpy

At 21 PSIA and -304.3°F

$$H_{15} = 22.55 \text{ BTU/lb}$$

Point 16 Liquid Air Leaving High Pressure Column

This is the result of liquefaction of Stream 6 minus the product take-off.

Pressure 52.2 PSIA

Temperature -291.9°F

Fluid State

Saturated Liquid

Fluid Flow Rate

$$W_{16} = 26.07 - 6.92 = 19.15 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 5.11 - 0.005 \times \frac{2000 \times 2}{24 \times 28 \times .86} = 5.07 \text{ Mols/Hr}$$

$$W_{N_2} = 20.72 - 6.84 = 13.88$$

$$W_A = 0.24 - 0.04 = 0.20$$

Enthalpy

At 52.2 PSIA and -291.9°F

$$H_{16} = 12.77 \text{ BTU/lb}$$

Point 17 Liquid Air Entering Low Pressure Column

Pressure

21 PSIA

Temperature

-304.3°F

Fluid State

Liquid and Vapor

The expansion of 52.2 PSIA saturated liquid to 21 PSIA results in 90.40% liquid and 9.60% vapor.

Fluid Flow Rate

Same as Point 16

$$W_{17} = 19.15 \text{ Mols/Hr}$$

Composition

Same as Point 16

$$W_{O_2} = 5.07 \text{ Mols/Hr}$$

$$W_{N_2} = 13.88 \text{ Mols/Hr}$$

$$W_A = 0.20 \text{ Mols/Hr}$$

Enthalpy

At 21 PSIA and -304.3°F

$$H_{17} = 12.77 \text{ BTU/lb}$$

Point 18 Waste Air Leaving Low Pressure Column

The waste air leaving the low pressure column will be saturated vapor at the pressure at the top of the column.

Pressure 21.5 PSIA
 Temperature -304.3°F
 Fluid State Saturated Vapor
 Fluid Flow Rate

Stream 18 equals stream 19 which equals stream 4 minus stream 10 minus the product take-off.

$$W_{18} = 156.02 - 117.02 - \frac{2 \times 2000}{24 \times 28} \times \frac{1}{0.84} \text{ (Due to product flash)}$$

$$W_{18} = 32.08 \text{ Mols/Hr}$$

Composition

Stream 15 + stream 17

$$W_{O_2} = 5.07 + 4.72 = 9.79 \text{ Mols/Hr}$$

$$W_{N_2} = 7.99 + 13.88 = 21.87 \text{ Mols/Hr}$$

$$W_A = 0.22 + 0.20 = 0.42 \text{ Mols/Hr}$$

Enthalpy

At 21 PSIA and -304.3°F

$$H_{18} = 91.10 \text{ BTU/lb}$$

Point 19-N Waste Air Leaving Subcooler (Same as Point 18)

Pressure 21 PSIA
 Temperature -304.3°F
 Fluid State Saturated Vapor
 Fluid Flow Rate Same as Point 18

$$W_{19} = 32.08 \text{ Mols/Hr}$$

Composition Same as Point 18

$$W_{O_2} = 9.79 \text{ Mols/Hr}$$

$$W_{N_2} = 21.87 \text{ Mols/Hr}$$

$$W_A = 0.42 \text{ Mols/Hr}$$

Enthalpy (As shown)

$$H_{19} = 91.10 \text{ BTU/lb}$$

Point 20 Liquid Nitrogen Entering Subcooler

Pressure 52.2 PSIA
Temperature -298°F
Fluid State Saturated Liquid
Fluid Flow Rate

$$W = \frac{2 \times 2000}{24 \times 0.86 \times 28}$$

$$W_{20} = 6.92 \text{ Mols/Hr}$$

Composition

$$W_{N2} = 6.92 \times 0.99 = 6.84 \text{ Mols/Hr}$$

$$W_{O2} = 0.04 \text{ Mols/Hr}$$

$$W_A = 0.04 \text{ Mols/Hr}$$

It is assumed that the impurity is equally divided between oxygen and argon.

Enthalpy

At 52.2 PSIA and -298°F

$$H_{20} = 12.02 \text{ BTU/lb}$$

Point 21-N Liquid Nitrogen Take-off

Pressure 14.7 PSIA
Temperature -298°F
Fluid State 14% Vapor
86% Liquid

Fluid Flow Rate

$$W_{21} = 6.92 \text{ Mols/Hr}$$

Composition

$$W_{N2} = 6.84 \text{ Mols/Hr}$$

$$W_{O2} = 0.04 \text{ Mols/Hr}$$

$$W_A = 0.04 \text{ Mols/Hr}$$

Vapor

$$W = 0.97 \text{ Mols/Hr}$$

Liquid

$$W = 5.95 \text{ Mols/Hr}$$

Enthalpy

At 14.7 PSIA and -298°F

$$H = 12.02 \text{ BTU/lb}$$

Summary

The conditions calculated for the various points in the flow diagram are summarized below:

Pt.No.	Pressure Temp.		Composition (lb Mols/hr)				Phase	Enthalpy BTU/lb	Total Heat BTU/hr
	(PSIA)	(°F)	O ₂	N ₂	A	Total			
1-N	14.7	70	33.84	125.71	1.61	161.16	Vapor	182.74	851,116
2-N	114.7	80	32.76	121.70	1.56	156.02	Vapor	184.30	831,005
3-N	114.7	-272	32.76	121.70	1.56	156.02	Vapor	95.79	431,915
4-N	114.7	-272	32.76	121.70	1.56	156.02	Liq & Vap	89.72	404,546
5-N	114.7	-272	5.11	20.72	0.24	26.07	Vapor	95.79	72,170
6-N	52.2	-282.5	5.11	20.72	0.24	26.07	Vapor	95.79	72,170
7-N	114.7	-272	22.93	93.00	1.09	117.02	Vapor	95.79	323,950
8-N	112.0	-240	22.93	93.00	1.09	117.02	Vapor	104.50	353,406
10-N	21.0	-306	22.93	93.00	1.09	117.02	Vapor	90.93	307,514
11-N	21.0	-306	32.72	114.87	1.51	149.10	Vapor	90.97	392,545
12-N	19.0	-283.6	32.72	114.87	1.51	149.10	Vapor	97.31	419,914
13-N	14.7	72	32.72	114.87	1.51	149.10	Vapor	182.97	789,548
14-N	114.7	-275.6	4.72	7.99	0.22	12.93	Liquid	22.55	8,426
15-N	21.5	-304.3	4.72	7.99	0.22	12.93	Liq & Vap	22.55	8,426
16	52.2	-291.9	5.07	13.88	0.20	19.15	Liquid	12.77	7,067
17	21.5	-304.3	5.07	13.88	0.20	19.15	Liq & Vap	12.77	7,067
18	21.5	-304.3	9.79	21.87	0.42	32.08	Vapor	91.10	85,031
19-N	21.0	-304.3	9.79	21.87	0.42	32.08	Vapor	91.10	85,031
20	52.2	-298	0.04	6.84	0.04	6.92	Liquid	12.02	2,329
21-N	14.7	-298	0.04	6.84	0.04	6.92	Liq & Vap	12.02	2,329

Heat Balance

For any heat balance $Q_{in} = Q_{out}$ where $Q = W(\text{lbs/hr}) \times H(\text{BTU/lb})$

Heat Exchanger Balance

$Q_{in} = Q_2 + Q_7 + Q_{12}$ where Q_2 is corrected to allow for the loss due to reversal

$$= 831,005 + 323,950 + 419,914$$

$$= 1,574,869$$

$$Q_{out} = Q_3 + Q_8 + Q_{13}$$

$$= 431,915 + 353,406 + 789,548$$

$$= 1,574,869$$

Air Liquefier Balance

$$Q_{in} = Q_3 + Q_{11}$$

$$= 431,915 + 392,545$$

$$= 824,460$$

$$Q_{out} = Q_4 + Q_{12}$$

$$= 404,546 + 419,914$$

$$= 824,460$$

Phase Separator Heat Balance

$$Q_{in} = Q_4$$

$$= 404,546$$

$$Q_{out} = Q_5 + Q_7 + Q_{14}$$

$$= 72,170 + 323,950 + 8,426$$

$$= 404,546$$

Turbo Expander Heat Balance

$$Q_{in} = Q_8$$

$$= 353,406$$

$$Q_{out} = Q_{10} + Q_{work}$$

$$= 307,514 + Q_W$$

$$Q_{\text{work}} = 353,406 - 307,514$$

$$= 45,892$$

or

$$= 18.04 \text{ H.P.}$$

Distillation Column Heat Balance

$$Q_{\text{in}} = Q_6 + Q_{15} + Q_{\text{Heat Leak}}$$

$$= 72,170 + 8,426 + (156.02 \times 1.5 \times 28.9)$$

$$= 87,360$$

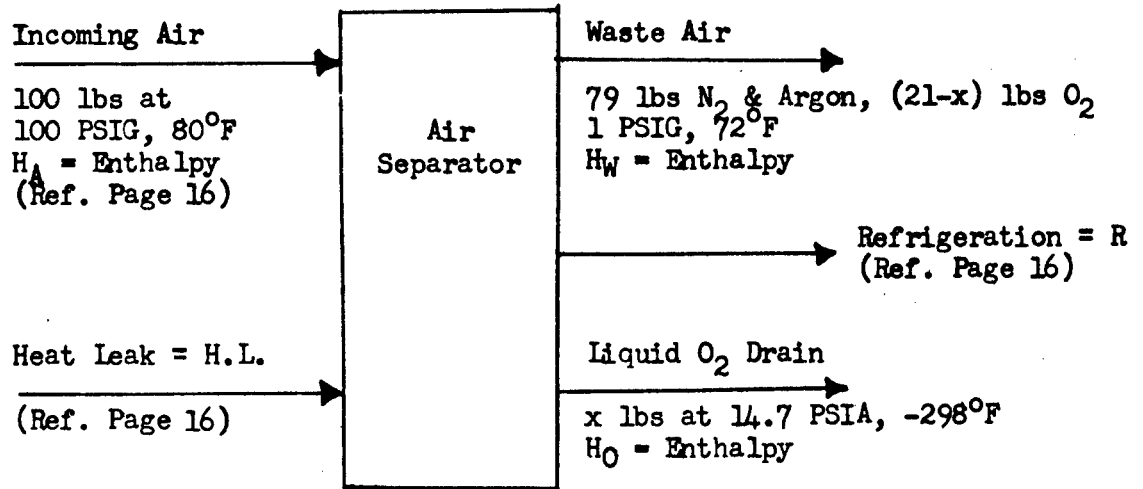
$$Q_{\text{out}} = Q_{18} + Q_{20}$$

$$= 85,031 + 2,329$$

$$= 87,360$$

Overall Heat Balance

Liquid Oxygen Production



Liquid Oxygen Generator Heat Balance

Enthalpy of the Liquid O_2 Drained, H_O

At the conditions of 14.7 PSIA and -298°F, the enthalpy of the liquid O_2 is

$$H_O = 8.89 \text{ BTU/lb}$$

For x lbs. drained

$$H_O = 8.89x \text{ BTU}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 1 PSIG and 72°F, the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents.

The enthalpy of nitrogen at these conditions is

$$H_{NW} = 183.5 \text{ BTU/lb}$$

All of the nitrogen contained in the intake air will be waste thus

$$H_{NW} = 183.5 \times 79 = 14,497 \text{ BTU}$$

The enthalpy of oxygen at these conditions is

$$H_{OW} = 181.2 \text{ BTU/lb}$$

The oxygen contained in the waste air will be

$$(21 - x) \text{ lbs/100 lbs of Air Feed}$$

$$H_{OW} = 181.2 (21 - x)$$

$$= 3805 - 181.2x \text{ BTU}$$

$$H_W = H_{NW} + H_{OW} = 14,497 + 3,805 - 181.2x$$

$$H_W = 18,302 - 181.2x \text{ BTU}$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. = H_W + R + H_O$$

$$18,430 + 150 = 18,302 - 181.2x + 1,018 + 8.89x$$

$$740 = 172.31x$$

$$x = 4.29 \text{ lbs O}_2/100 \text{ lbs Air Feed}$$

This indicates a 4.29% recovery by weight. For two tons per day, the required air intake will be

$$Q = 2 \frac{\text{Tons}}{\text{Days}} \times \frac{2000 \text{ lbs}}{1 \text{ Ton}} \times \frac{1}{24 \text{ hr}} \times \frac{1 \text{ Days}}{24 \text{ hr}} \times \frac{1 \text{ hrs}}{60 \text{ Min}} \times \frac{1}{0.075} \frac{\text{Cu Ft}}{\text{lb}} \times \frac{1}{0.0429}$$

$$Q = 863 \text{ SCFM}$$

Assuming a 3% loss during reversal

$$0.03 \times 863 = 25.9$$

$$Q = 863 + 25.9 = 889 \text{ say } 890 \text{ SCFM}$$

Since the expander requires 750 SCFM and the compressors are capable of 1000 SCFM

$$Q = 1000$$

$$\frac{1000 \times 24 \times 60 \times 0.075 \times 0.0429}{2000}$$

$$\text{Production} = 2.32 \text{ T/D}$$

$$Q \text{ including Reversal Loss} = 1030 \text{ SCFM}$$

Summary: Liquid Oxygen Production

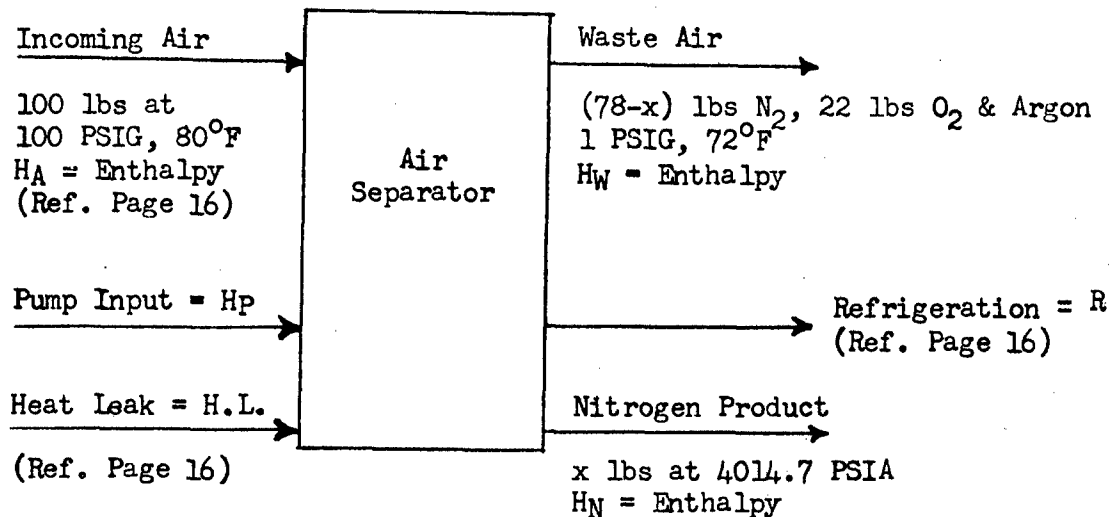
As in the liquid nitrogen cycle, the following points are the result of the thermodynamic analysis:

Pt.No.	Pressure Temp.		Composition (lb Mols/hr)				Phase	Enthalpy BTU/lb	Total Heat BTU/hr
	(PSIA)	(°F)	O ₂	N ₂	A	Total			
*1-0	14.7	70	32.70	121.45	1.56	155.71	Vapor	182.74	822,333
2-0	114.7	80	32.70	121.45	1.56	155.71	Vapor	184.30	829,354
3-0	114.7	-272	32.70	121.45	1.56	155.71	Vapor	95.79	431,039
4-0	114.7	-272	32.70	121.45	1.56	155.71	Liq & Vap	89.22	401,492
5-0	114.7	-272	4.86	19.85	0.23	24.94	Vapor	95.79	69,095
22	89	-276	4.86	19.85	0.23	24.94	Vapor	95.79	69,095
7-0	114.7	-272	22.77	92.93	1.08	116.78	Vapor	95.79	323,286
8-0	112.0	-240	22.77	92.93	1.08	116.78	Vapor	104.5	352,681
10-0	21	-306	22.77	92.93	1.08	116.78	Vapor	90.93	306,883
11-0	21	-305	26.69	121.45	1.53	149.67	Vapor	90.56	390,149
12-0	19	-281	26.69	121.45	1.53	149.67	Vapor	97.45	419,696
13-0	14.7	72	26.69	121.45	1.53	149.67	Vapor	182.97	788,598
14-0	114.7	-275.6	5.10	8.64	0.24	13.98	Liquid	22.55	9,111
15-0	21	-304.3	5.10	8.64	0.24	13.98	Liq & Vap	22.55	9,111
23	89	-282	4.86	19.85	0.23	24.94	Liquid	19.18	13,824
24	21	-304.3	4.86	19.85	0.23	24.94	Liq & Vap	19.18	13,824
25	21	-311.5	3.92	28.52	0.45	32.89	Vapor	86.96	82,757
19-0	21	-305.0	3.92	28.52	0.45	32.89	Vapor	87.48	83,248
26	21	-291	6.01	0.00	0.03	6.04	Liquid	11.43	2,209
21-0	14.7	-298	6.01	0.00	0.03	6.04	Liquid	8.89	1,718

NOTE: 3% Reversal Loss not included in Point 1 Tabulation

Overall Heat Balance

Gaseous Nitrogen Production



Gaseous Nitrogen Heat Balance

Enthalpy of the Liquid N_2 Pumped, H_N

At the condition of 4014.7 PSIA, the enthalpy of the pumped nitrogen is

$$H_N = 12.02 \text{ BTU/lb}$$

For x lbs pumped

$$H_N = 12.02x \text{ BTU}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 1 PSIG and 72°F, the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents.

$$H_{NW} = 183.5 \text{ BTU/lb}$$

The nitrogen contained in the waste air will be (78 - x) lbs/100 lbs of Air Feed thus

$$\begin{aligned} H_{NW} &= (78 - x) 183.5 \\ &= 14,313 - 183.5x \end{aligned}$$

The enthalpy of oxygen at these conditions is

$$H_{OW} = 181.2 \text{ BTU/lb}$$

All of the oxygen contained in the intake air will be waste hence

$$H_{OW} = 181.2 \times 22$$

$$= 3,986 \text{ BTU}$$

$$H_W = H_{NW} + H_{OW} = 14,313 - 183.5x + 3,986$$

$$H_W = 18,299 - 183.5x$$

Pump Input

It is estimated that the pump input to the circuit is 2 H.P. or

$$2 \frac{(\text{HP})}{(1)} \times 2544 \frac{(\text{BTU})}{(\text{HP-hr})} \times \frac{1}{166.6} \frac{(\text{hrs})}{(\text{lb N}_2)} = 30.53 \text{ BTU/lb N}_2$$

Since there are to be x lbs of nitrogen pumped per 100 lbs of Air Feed

$$\text{HP} = 30.53x \text{ BTU}$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. + H_P = H_W + R + H_N$$

$$18,430 + 150 + 30.53x = 18,299 - 183.5x + 1,018 + 12.02x$$

$$18,580 + 30.53x = 19,317 - 171.48x$$

$$202.01x = 737$$

$$x = 3.65 \text{ lbs N}_2 / 100 \text{ lbs Air Feed}$$

This indicates a 3.65% recovery by weight. For two tons per day the required air intake will be

$$Q = 2 \frac{\text{Tons}}{\text{Day}} \times \frac{2000 \text{ lbs}}{1 \text{ Ton}} \times \frac{1 \text{ Days}}{24 \text{ hr.}} \times \frac{1 \text{ hrs}}{60 \text{ Min}} \times \frac{1}{0.075} \frac{\text{Cu Ft}}{\text{lb}} \times \frac{1}{0.0365}$$

$$Q = 1015 \text{ SCFM}$$

Since 3% is assumed to be Reversal Loss

$$0.03 \times 1015 = 30$$

$$\text{Total Air Required} = 1045 \text{ SCFM}$$

Summary: Gaseous Nitrogen Production

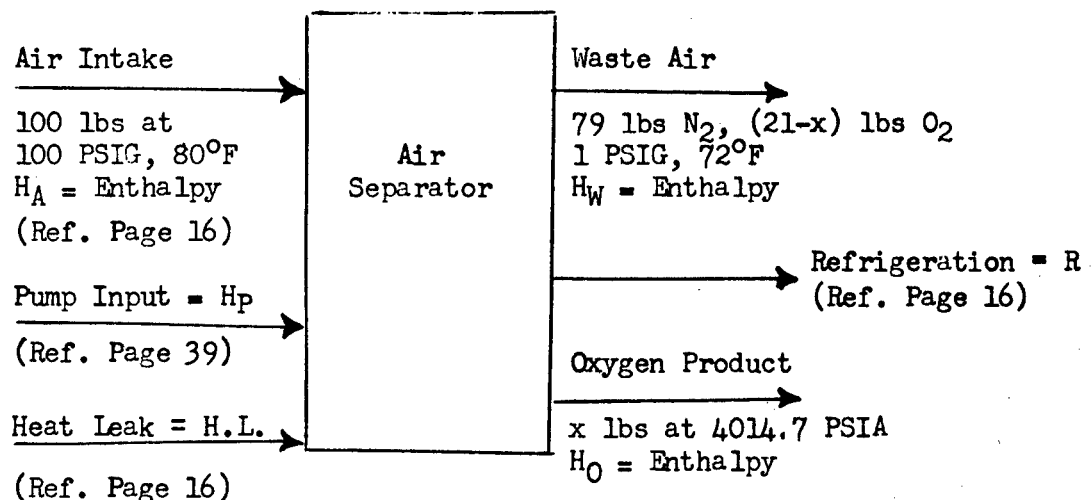
As in the liquid nitrogen cycle, the following points are the result of the thermodynamic analysis:

Pt.No.	Pressure Temp.		Composition (lb Mols/hr)				Phase	Enthalpy BTU/lb	Total Heat BTU/hr
	(PSIA)	(°F)	O ₂	N ₂	A	Total			
*1-PN	14.7	70	33.19	123.27	1.58	158.04	Vapor	182.74	859,355
2-PN	114.7	80	33.19	123.27	1.58	158.04	Vapor	184.30	841,764
3-PN	114.7	-272	33.19	123.27	1.58	158.04	Vapor	95.82	437,624
4-PN	114.7	-272	33.19	123.27	1.58	158.04	Liq & Vap	89.14	407,123
5-PN	114.7	-272	4.86	19.99	0.23	25.08	Vapor	95.82	69,451
6-PN	52.2	-282.5	4.86	19.99	0.23	25.08	Vapor	95.82	69,451
7-PN	114.7	-272	23.05	94.38	1.10	118.53	Vapor	95.82	328,268
8-PN	112.0	-240	23.05	94.38	1.10	118.53	Vapor	104.56	358,183
10-PN	21.0	-307	23.05	94.38	1.10	118.53	Vapor	90.80	311,070
11-PN	21.0	-306	33.16	117.38	1.55	152.09	Vapor	90.96	399,804
12-PN	19.0	-280	33.16	117.38	1.55	152.09	Vapor	97.90	430,305
13-PN	14.7	72	33.16	117.38	1.55	152.09	Vapor	183.04	804,530
14-PN	114.7	-275.6	5.27	8.91	0.25	14.43	Liquid	22.55	9,404
15-PN	21.0	-304.3	5.27	8.91	0.25	14.43	Liq & Vap	22.55	9,404
27	21.0	-304.3	5.27	8.91	0.25	14.43	Liq & Vap	34.75	14,492
16-PN	52.2	-291.9	4.83	14.10	0.20	19.13	Liquid	12.77	7,060
17-PN	21.0	-304.3	4.83	14.10	0.20	19.13	Liq & Vap	12.77	7,060
18-PN	21.0	-304.3	10.10	23.01	0.45	33.56	Vapor	91.49	88,734
20-PN	114.7	-298	0.03	5.89	0.03	5.95	Liquid	12.02	2,060
29	114.7	-298	0.03	5.89	0.03	5.95	Liquid	12.02	2,060
30	4014.7	-298	0.03	5.89	0.03	5.95	Vapor	12.02	2,060

NOTE: 3% Reversal Loss not included in Point 1 Tabulation

Overall Heat Balance

Gaseous Oxygen Production



Gaseous Oxygen Heat Balance

Enthalpy of the Liquid O_2 Pumped, H_O

At the conditions of 4014.7 PSIA, the enthalpy of the pumped liquid is

$$H_O = 8.89 \text{ BTU/lb}$$

For x lbs pumped

$$H_O = 8.89x \text{ BTU}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 72°F and 1 PSIG, the enthalpy of the effluent waste air equals the sum of the enthalpies of the constituents.

The enthalpy of nitrogen under these conditions is

$$H_{NW} = 183.5 \text{ BTU/lb}$$

All of the nitrogen contained in the intake air will be waste thus

$$H_{NW} = 183.5 \times 79 = 14,497 \text{ BTU}$$

The enthalpy of oxygen under these conditions is

$$H_{OW} = 181.2 \text{ BTU/lb}$$

The oxygen contained in the waste air will be

$(21 - x)$ lbs/100 lbs of Air Feed hence

$$H_{OW} = 181.2 (21 - x)$$

$$= 3,805 - 181.2x$$

$$H_W = H_{NW} + H_{OW} = 14,497 + 3,805 - 181.2x$$

$$H_W = 18,302 - 181.2x \text{ BTU}$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. + H_P = H_W + R + H_O$$

$$18,430 + 150 + 30.53x = 18,302 - 181.2x + 1,018 + 8.89x$$

$$740 = 203.74x$$

$$x = 3.63 \text{ lbs } O_2/100 \text{ lbs Air Feed or a } 3.63\% \text{ by weight recovery}$$

The required air intake for two tons per day will be

$$Q = \frac{2 \text{ Tons}}{\text{Day}} \times \frac{2000 \text{ lbs}}{1 \text{ Ton}} \times \frac{1 \text{ Days}}{24 \text{ hr}} \times \frac{1 \text{ hrs}}{60 \text{ Min}} \times \frac{1}{0.075} \frac{\text{Cu Ft}}{\text{lb}} \times \frac{1}{0.0363}$$

$$= 1020 \text{ SCFM}$$

Assuming 3% Loss upon Reversal

$$Q = 1050 \text{ SCFM}$$

Summary: Gaseous Oxygen Production

As in the liquid nitrogen cycle, the following points are the result of the thermodynamic analysis:

Pt.No.	Pressure Temp.		Composition (lb Mols/hr)				Phase	Enthalpy BTU/lb	Total Heat BTU/hr
	(PSIA)	(°F)	O ₂	N ₂	A	Total			
*1-PO	14.7	70	33.35	123.88	1.59	158.82	Vapor	182.74	838,758
2-PO	114.7	80	33.35	123.88	1.59	158.82	Vapor	184.30	845,918
3-PO	114.7	-272	33.35	123.88	1.59	158.82	Vapor	95.79	439,666
4-PO	114.7	-272	33.35	123.88	1.59	158.82	Liq & Vap	88.11	404,433
5-PO	114.7	-272	4.43	18.40	0.21	23.04	Vapor	95.79	63,782
22-PO	89	-276	4.43	18.40	0.21	23.04	Vapor	95.79	63,782
7-PO	114.7	-272	22.89	95.14	1.09	119.12	Vapor	95.79	329,764
8-PO	112	-240	22.89	95.14	1.09	119.12	Vapor	104.50	359,748
10-PO	21	-306	22.89	95.14	1.09	119.12	Vapor	90.93	313,033
11-PO	21	-305	28.17	123.88	1.56	153.61	Vapor	90.02	398,193
12-PO	21	-281	28.17	123.88	1.56	153.61	Vapor	97.98	433,426
13-PO	14.7	72	28.17	123.88	1.56	153.61	Vapor	182.97	809,694
14-PO	114.7	-275.6	6.03	10.34	0.29	16.66	Liquid	22.55	10,887
15-PO	21	-304.3	6.03	10.34	0.29	16.66	Liq & Vap	22.55	10,887
28	21	-304.3	6.03	10.34	0.29	16.66	Liq & Vap	33.11	15,942
23-PO	89	-282	4.43	18.40	0.21	23.04	Liquid	19.18	12,771
24-PO	21	-304.3	4.43	18.40	0.21	23.04	Liq & Vap	19.18	12,771
25-PO	21	-311.5	5.28	28.74	0.47	34.49	Vapor	87.71	84,703
19-PO	21	-305	5.28	28.74	0.47	34.49	Vapor	88.14	85,127
26-PO	21	-291	5.18	0.00	0.03	5.21	Liquid	11.43	1,906
31	21	-298	5.18	0.00	0.03	5.21	Liquid	8.89	1,482
32	4014.7	-298	5.18	0.00	0.03	5.21	Vapor	8.89	1,482

NOTE: 3% Reversal Loss not included in Point 1 Tabulation

SECTION IV

ELECTRIC POWER AND CONTROL

Alternating Current Generator

The alternating current generator is a 208 volt, 3 phase with neutral, 33.3 KW generator belt-driven from the second stage diesel engine and is located in the drop section of the trailer. The generator has a 3 phase "Y" connected (star) alternating current stator and a direct current field rotor supplied through slip rings and carbon brushes with direct current generated in an exciter housed on the rear of the same frame. Both the generator rotor and the exciter armature are directly connected to the same shaft. The exciter has an armature and commutator with two carbon brushes. The alternating current generator runs whenever the second stage diesel engine is running and the clutch is engaged. It generates electric power only when it is connected to the voltage regulator circuits in the electrical control center by turning the proper switches.

Electrical Control Center

The electrical control center is located on the left side of the operator's compartment (when viewed facing the rear of the trailer; ref. to Figure No. 3, A.C. Control Panel). It is divided into three major sections, namely - the upper section is the temperature indicator; the middle section is the electrical control section; and the bottom section is the power distribution section.

a. Temperature Indicator Section

The temperature indicating section has on its panel a pyrometer, a pyrometer selector switch, a pyrometer grounding switch, and a red button the top right side marked "Emergency Stop". This closes the air intake butterfly valves on all three diesel engines simultaneously, causing the three engines to stop almost immediately.

b. Electrical Control Section

The electrical control section has mounted on its face a switch valve timer control and transformer starters for the liquid oxygen and nitrogen pumps, a reactivation heater pilot light, and a reactivation heater contactor.

c. Power Distribution Section

The lower portion of the control center has mounted on its face five single-pole magnetic type circuit breaker push button switches with name plates identifying the circuits they control. If any of the circuits experience a severe overload or a short circuit, the circuit breaker will automatically disconnect the circuit. There is also included in this section a voltmeter and an ammeter.

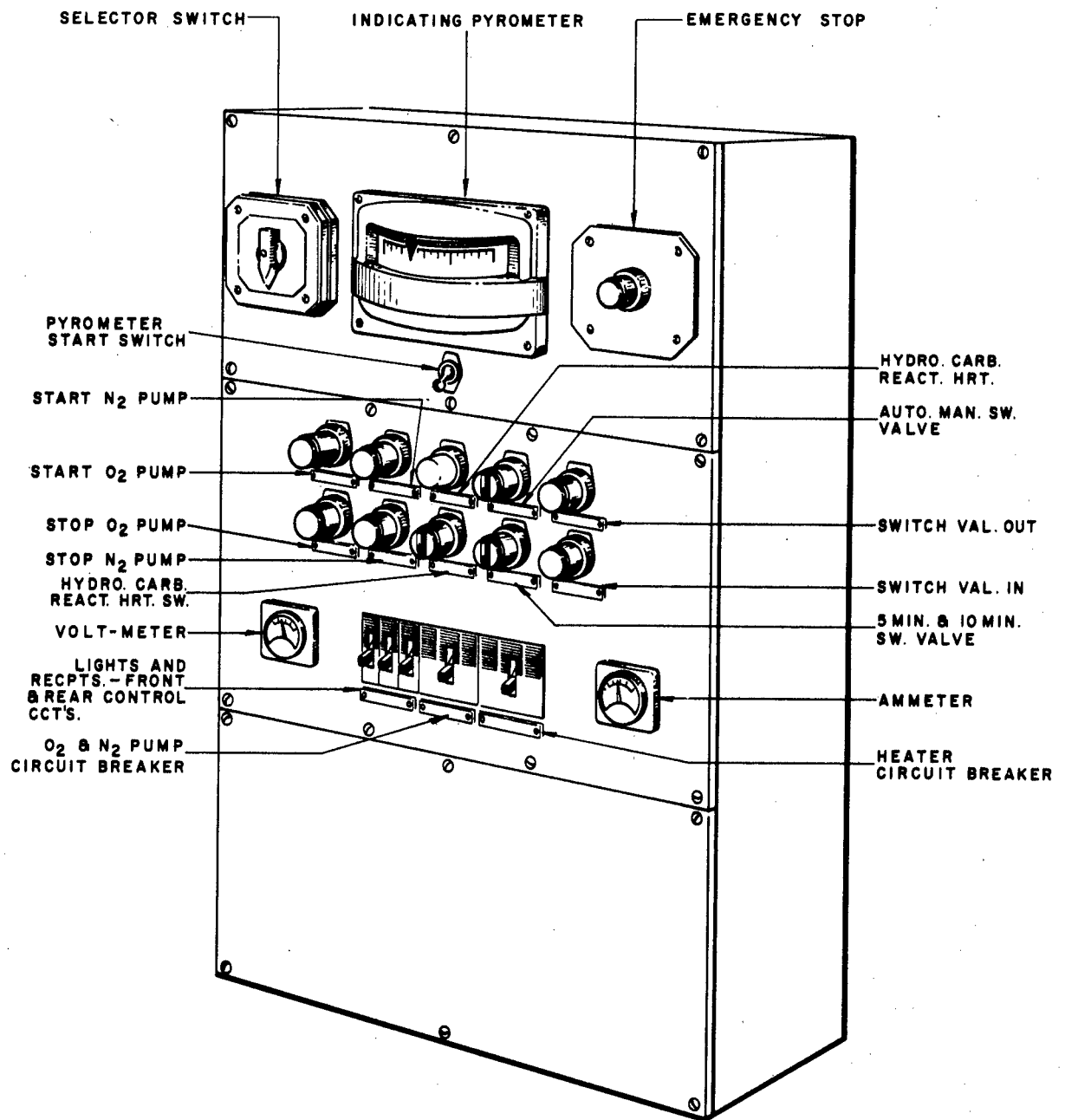


Figure 3
A.C. Control Panel

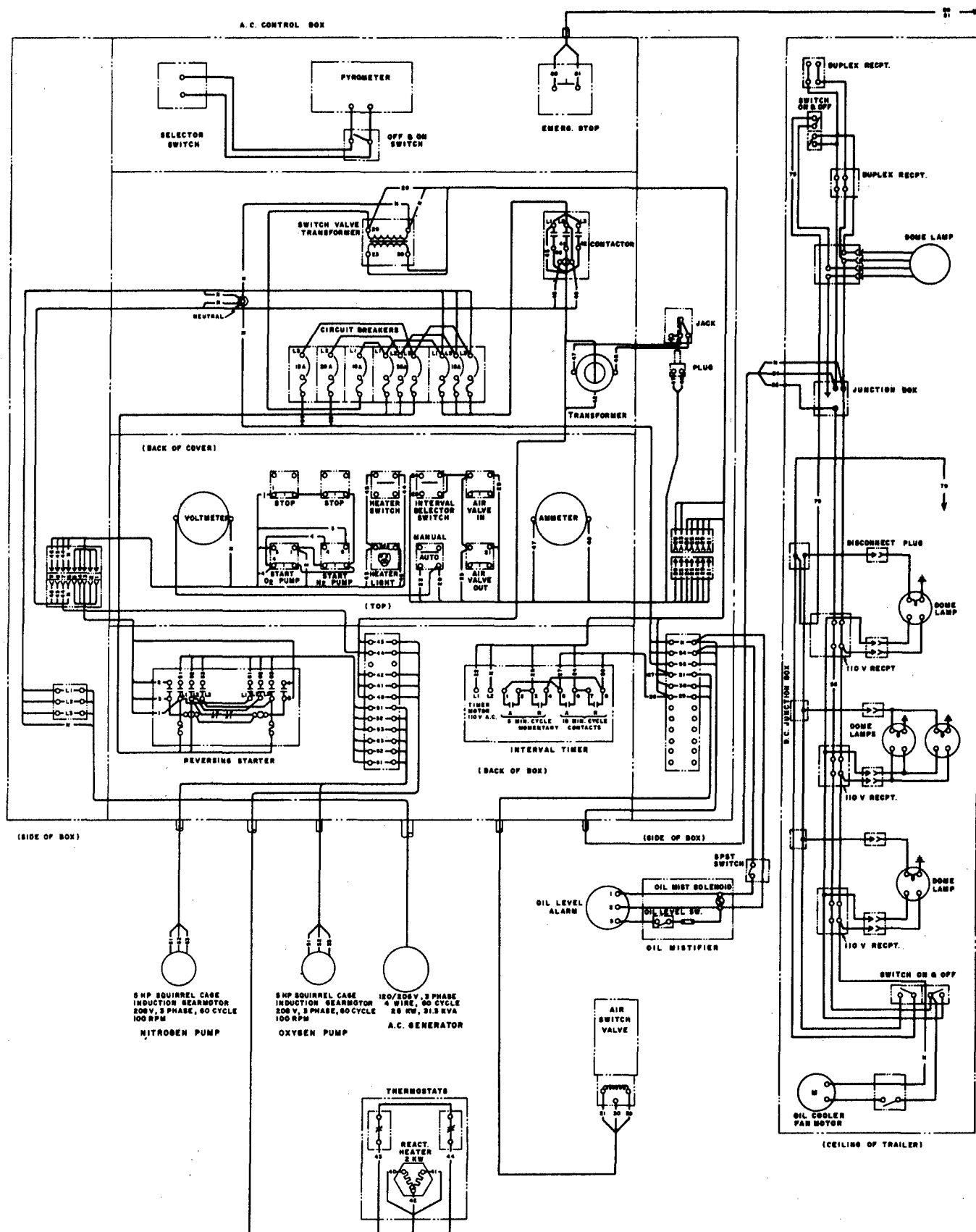


Figure 4
A.C. Wiring Diagram (Sheet 1 of 2)

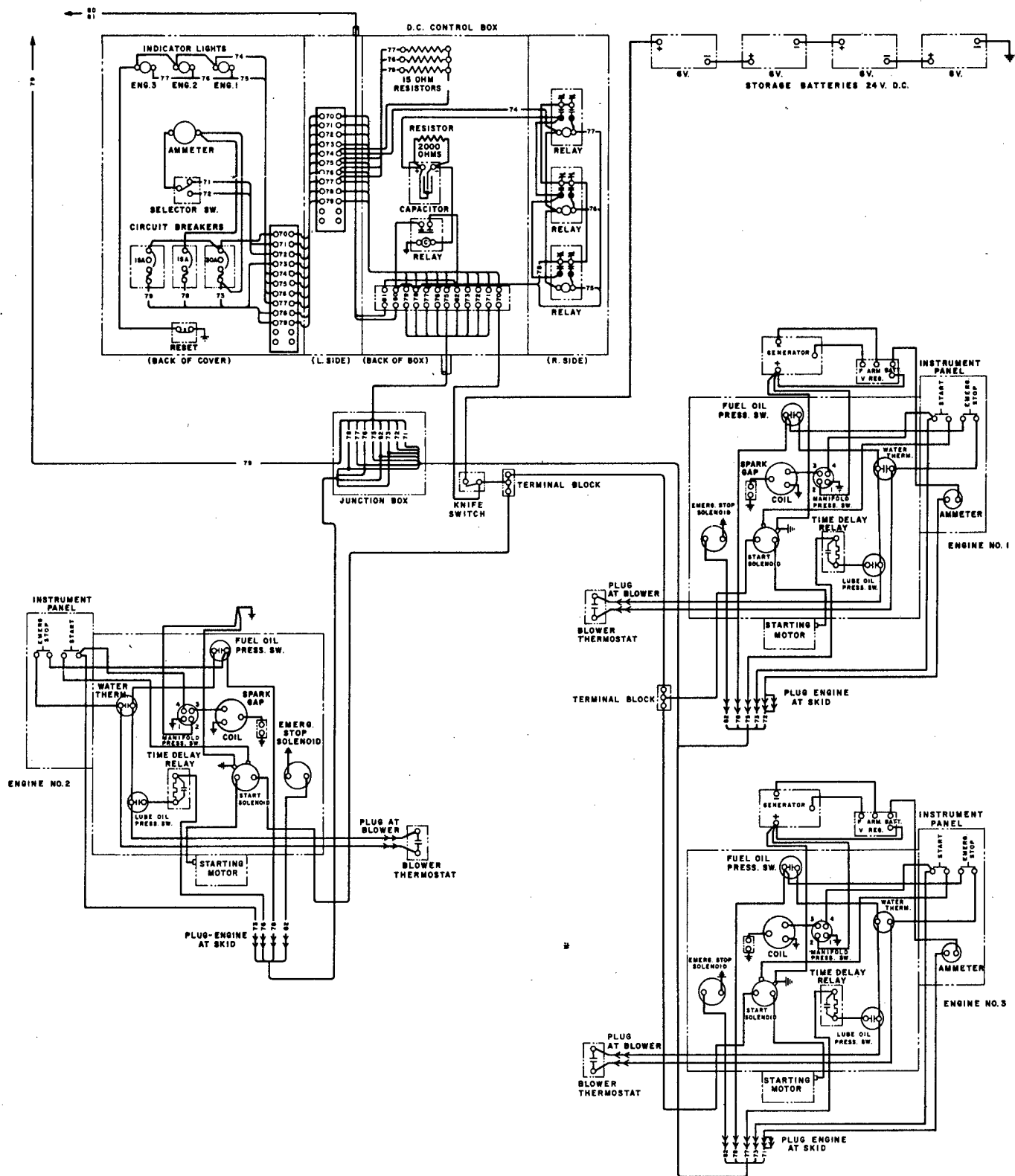


Figure 4
A.C. Wiring Diagram (Sheet 2 of 2)

DESCRIPTION OF ELECTRICAL LOADS

The Alternating Current System

The alternating current electrical system supplies power to hydrocarbon adsorber reactivation heater, oil mist lubricator, oil level indicator, oxygen and nitrogen product pumps, the 120 volt convenience outlets, the automatic components of the electrical control center, and to the air switch valve solenoid valve through a transformer in the electrical control section (Ref. to Figure 4, Wiring Diagram).

Hydrocarbon Adsorber Reactivation Heater

The hydrocarbon adsorber reactivation heater is a three thousand watt, 220 volt, 3 phase, 2 element, open delta-connected unit. The heater is in the control box located on the right side of the cold compartment (when viewed facing the rear of the trailer). It is connected to the 3 phase lines, but not to the neutral. The heater is operated from the electrical control center by means of a three-pole magnetic contactor. The temperature of the nitrogen-rich air flowing through the heater case is controlled by a thermostat element in the heater case. When the switch is turned to reactivation, current flows through the switch contacts, through the normally closed contacts of the two thermostats to the magnet coil of the contactor, which it energizes. When the magnetic coil is energized, the power carrying contacts close, and the heater is connected to the three phase alternating current power. The thermostats will maintain the gas flowing to the hydrocarbon adsorber at an even temperature. When the temperature indicator in the gas stream out of the hydrocarbon adsorber shows that the adsorber is reactivated, the operator turns the switch "Off", the magnetic contactor is de-energized and the heater is disconnected from the power supply.

Lighting

The 120 volt lights in the operator's compartment are controlled from the switch by the door. The lights for the engine compartment are controlled from the switch by the rear entrance.

The electric receptacles in the engine compartment are grouped in pairs. One pair is controlled by the lighting switch and is intended for the operation of the miniature flood lamps mounted on the ceiling. The other pair of the four are continuously energized and are intended as power outlets for small power tools. Since each flood lamp is equipped with its own switch, they may be plugged into the continuously energized receptacles and each operated as a separate unit. The receptacles are thus arranged to give the maximum of flexibility.

The Direct Current System

The direct current system is composed of two direct current 600 watt automotive type generators and vibrating contact voltage regulators mounted on the first and third stage diesel engines; a 24 volt battery bank; the 24 volt electric loads; and an engine electrical panel (Ref. to Figure 5, D.C. Control Panel).

The 24 volt direct current generators are two-pole, two-brush, shunt wound, self-excited, 25 ampere capacity. Only one generator may be used at a time to charge the storage battery bank. The generator to be used is selected by means of the "Generator Selector Switch" on the diesel control panel. It is intended,

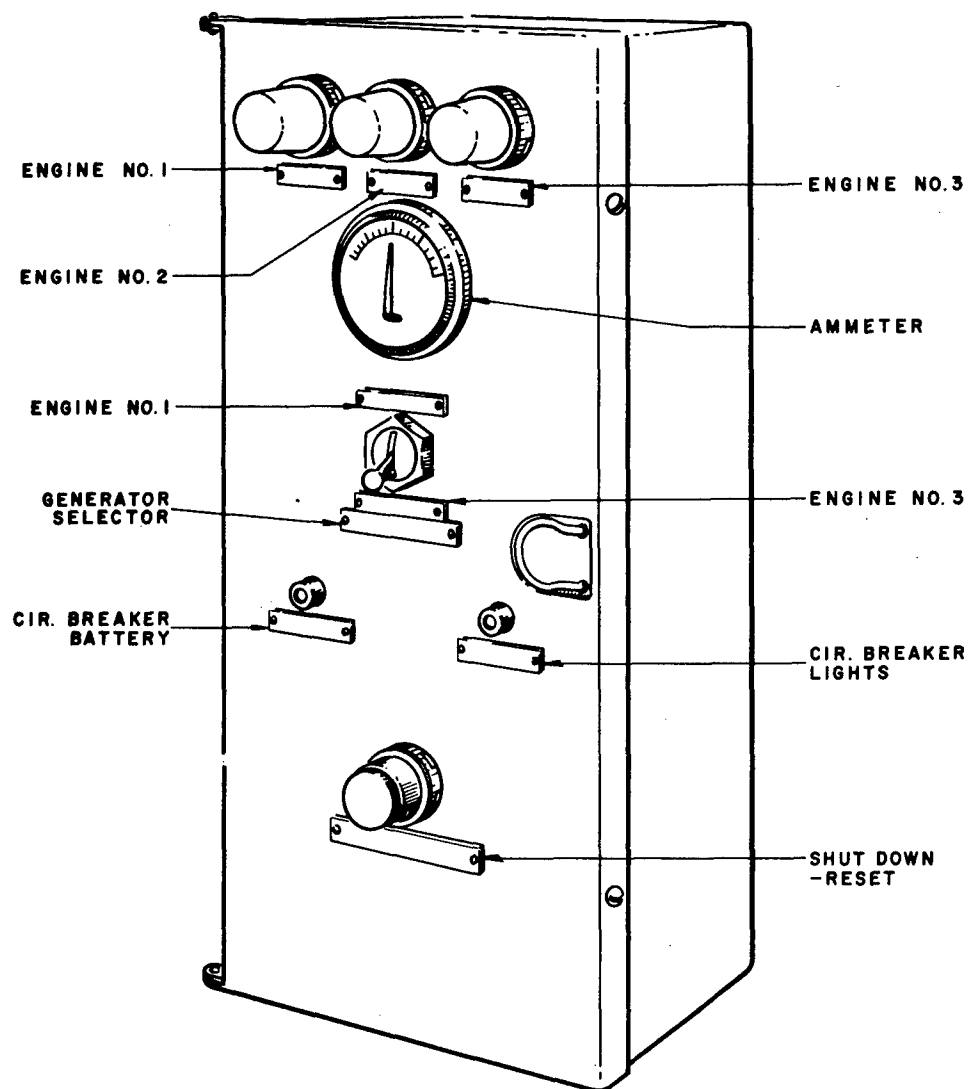


Figure 5
D.C. Control Box Assembly

for example, that when the first stage engine is started, the selector switch will be turned to the first stage generator so that the battery bank will be charged while the next engine is readied. Two generators are provided so that the battery bank can be charged in the event that one generator-equipped engine is difficult to start.

The diesel engine electrical control panel is provided with the following:

- a. A battery charging ammeter
- b. A selector switch for connecting either generator to the load
- c. An emergency engine stop button to be used only in true emergencies.

The battery bank consists of four six-volt batteries connected in series. The negative terminal is connected to the trailer chassis, which provides the return conductor for the single wire system. The water level in the cells of each battery should be checked every 24 hours of operation. The water should be kept level with the bottom ring inside the neck of the cell opening. Avoid sparks or flames when inspecting the batteries. Just above the battery bank on the post between the doors is a 4-3/4" square box with a cover held on by two screws. Inside of this box are three circuit breakers for the 24 volt direct current system. These circuit breakers reset automatically after a short circuit and should require no servicing. The 30 ampere circuit breaker protects the generators and the 15 ampere circuit breakers protect the lights.

The 24 volt direct current lights are controlled from switches beside the alternating current light switches.

SECTION V

EQUIPMENT SPECIFICATIONS

General

The equipment specifications in this section are considered to meet the requirements of the liquid oxygen-nitrogen generator from the standpoint of performance, size, and weight. These specifications are those which were used in the design and construction of this mobile liquid oxygen-nitrogen generator. The layout of the major equipment components within the semitrailer is illustrated in Figure 6. The semitrailer is a Kentucky Manufacturing Company semitrailer and is constructed so that it is adaptable for towing by a standard Army truck-tractor. It will stand the strains of service encountered when towed across the country with full equipment. The dimensions of the semitrailer are as follows:

Height - 12 ft. 0 in.
Width - 9 ft. 6 in.
Length - 32 ft. 0 in.

The total weight of the semitrailer and equipment is 50,000 pounds, of which approximately 17,000 pounds represent the weight of the semitrailer. The semitrailer permits a clear sweep of 74 inches behind the king pin for full turning. A standard SAE king pin is provided and is located 22 inches back of the trailer front edge to permit the swinging of the trailer corner through a clear space of 62 inches. The trailer fifth wheel plate is of sufficient size to fit a 36 inch diameter fifth wheel on the truck tractor and is 53 inches from a level ground surface when the trailer floor is level. (See Figure 7, Oxygen-Nitrogen Generating and Charging Plant.)

Running Gear

Wheels - The wheels, studs, and cap nuts conform to applicable Government specifications.

Wheel Hubs - The wheel hubs are fitted with tapered roller bearings of adequate size for the required speeds and loads. Bearings conform to SAE standards.

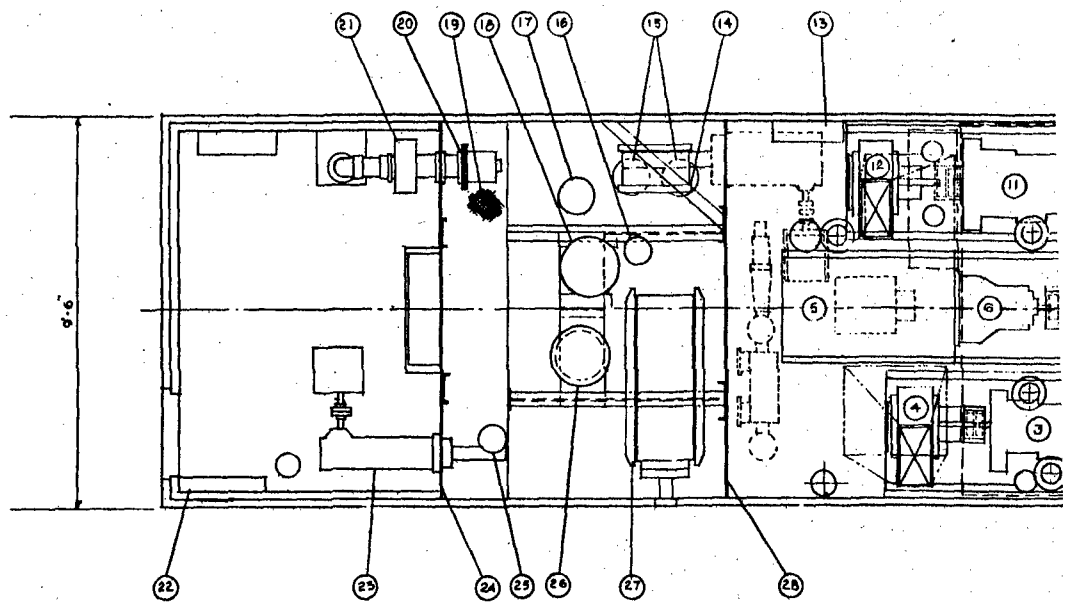
Tires - Tires are of the heavy duty, truck-and-bus, balloon type, with non-directional mud-and-snow type tread.

Tubes - Tubes are of the heavy duty type.

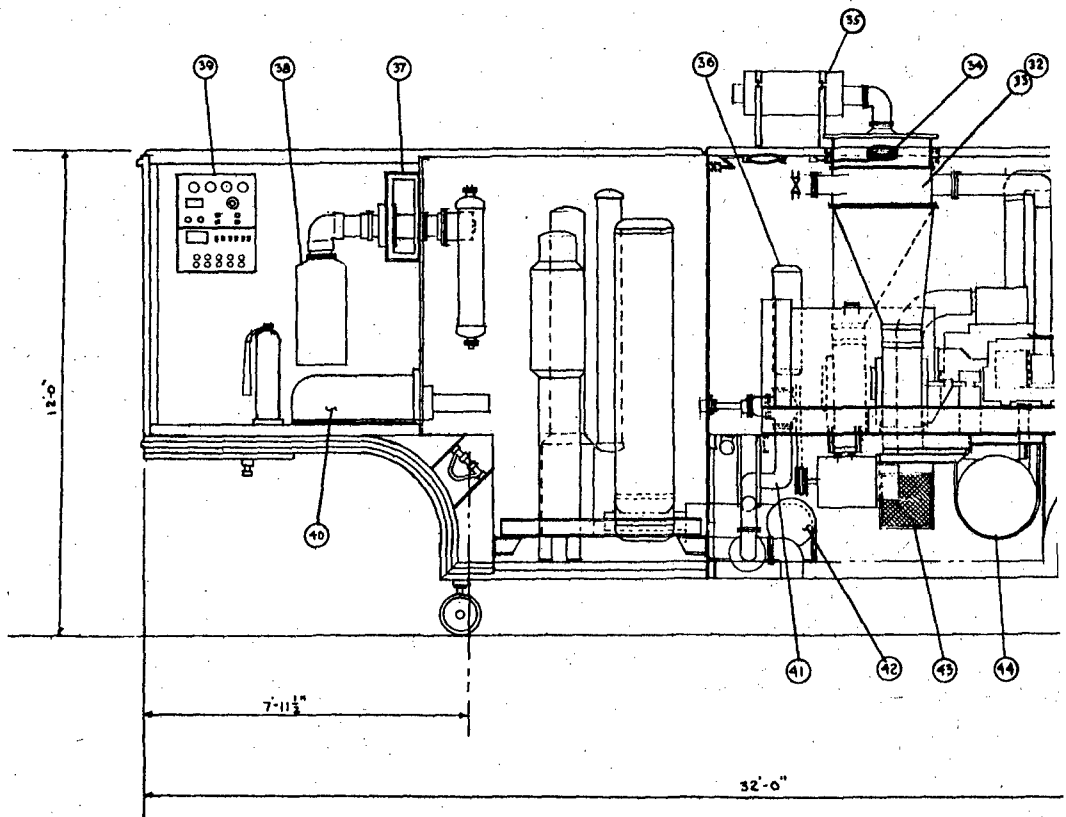
Brakes

Service Brakes - Service brakes, controllable from the driver's seat of the towing vehicle, are provided. The drums have flanges or ribbing to prevent objectionable distortion when the brakes are applied. The brakes are of the internal expanding, two shoe, heavy duty type, having constant lift cams and rigid brake-shoe anchors, and are operated through fully enclosed worm-gear type slack adjusters. Brakes, anchors, and cams have suitable lubrication fittings.

Service Brake Controls (Air) - All detail parts and assemblies of the brake control system are equal to and interchangeable with the equipment manufactured



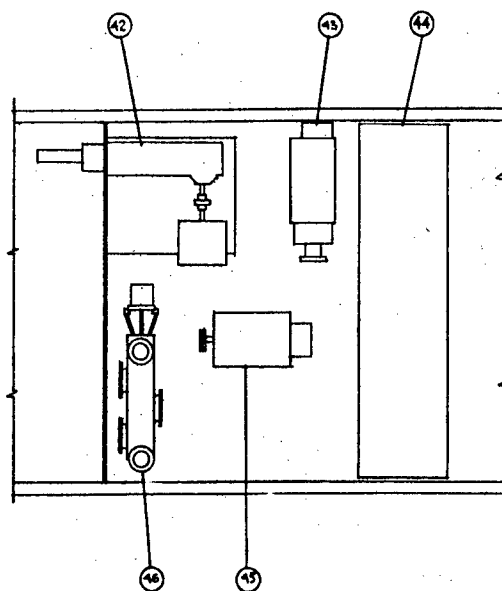
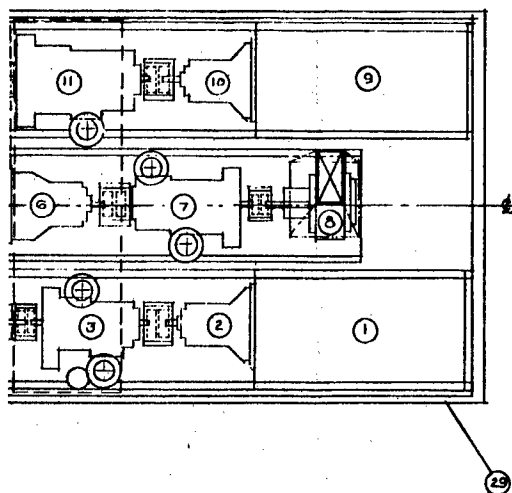
PLAN



SIDE ELEVATION

WADC TR 54-19 PT II





PLAN VIEW OF TRAILER SUB-FLOOR

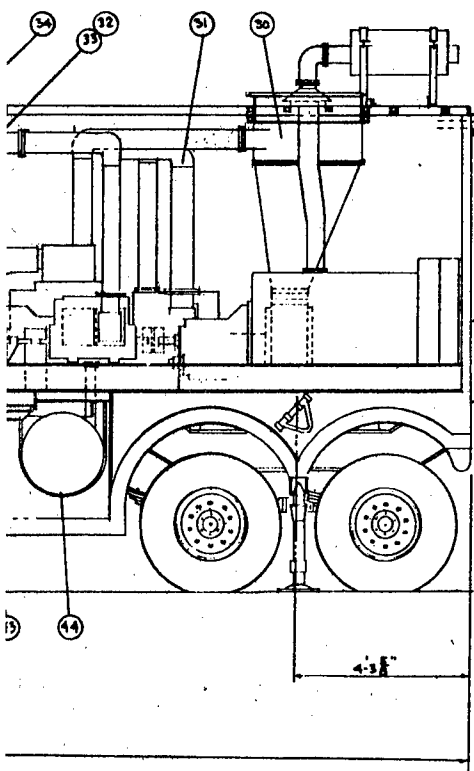


FIGURE 6

GENERATOR LAYOUT - LEGEND

- | | |
|---------------------------------|---|
| 1. Third Stage Diesel Engine | 23. Liquid Nitrogen Product Pump |
| 2. Third Stage Transmission | 24. Forward Bulkhead |
| 3. Third Stage Blower | 25. Nitrogen Column |
| 4. Third Stage Aftercooler Fan | 26. Heat Exchanger |
| 5. Second Stage Diesel Engine | 27. Rear Bulkhead |
| 6. Second Stage Transmission | 28. Trailer |
| 7. Second Stage Blower | 29. Second Stage Intercooler |
| 8. Second Stage Intercooler Fan | 30. Compressor Piping |
| 9. First Stage Diesel Engine | 31. First Stage Intercooler |
| 10. First Stage Transmission | 32. Third Stage Aftercooler |
| 11. First Stage Blower | 33. Vaporizer |
| 12. First Stage Intercooler Fan | 34. Muffler |
| 13. Batteries | 35. Condensate Trap |
| 14. Liquefier | 36. Instrument Panel |
| 15. Check Valves | 37. Expander Air Loader Intake |
| 16. Liquid Oxygen Subcooler | 38. Electrical Control Panel |
| 17. Phase Separator | 39. N ₂ Liquid Product Pump Base |
| 18. Oxygen Column | 40. Switch Valve Piping |
| 19. Insulation | 41. O ₂ Liquid Product Pump |
| 20. Expander | 42. Compressor Intake Filter |
| 21. Expander Air Loader | 43. Diesel Fuel Storage |
| 22. Oxygen-Nitrogen Test Set | 44. A.C. Generator |
| | 45. Switch Valve |

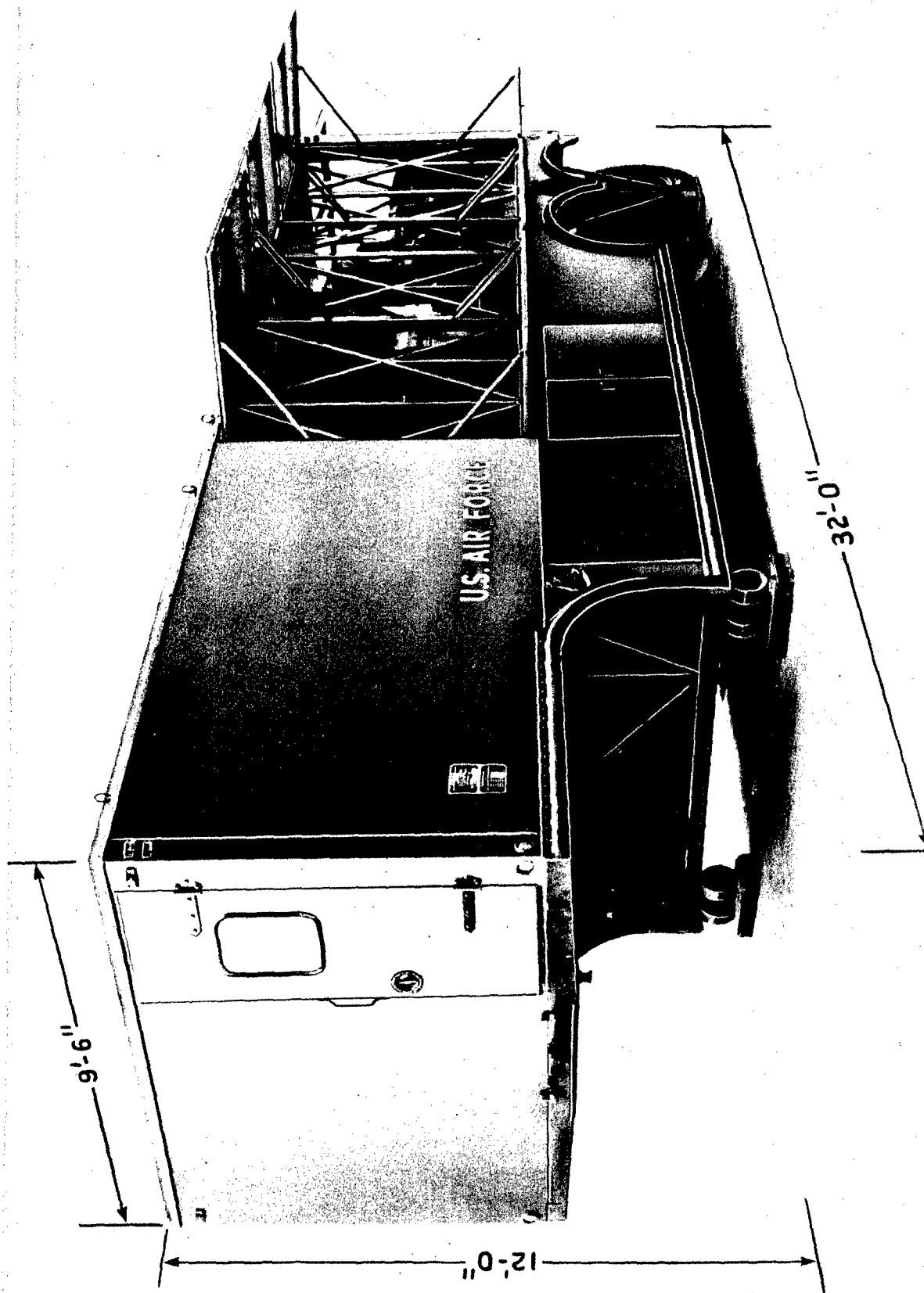


FIGURE 7
OXYGEN OR NITROGEN GENERATING AND CHARGING PLANT
SEMITRAILER MOUNTED, TYPE MA-1

by the Bendix Westinghouse Automotive Air Brake Company, Elyria, Ohio, and are installed in accordance with the manufacturer's latest recommendations. The controls are provided with standard emergency break-away features. The break-away arrangement conforms to requirements of the Interstate Commerce Commission. The controls are sealed in a manner that insures satisfactory operation in all kinds of weather. All chambers are provided with drains on the non-pressure side. Air hose connections and fittings are of the replaceable type with spring protectors. Air line filters are provided in both emergency and service lines. A relay emergency exhaust check valve and heavy-duty clamping studs are furnished. The standard air-brake couplings are provided for connecting the brake lines to the towing vehicle. A dummy coupling is attached with a chain to each of the air hose couplings.

Parking Brakes - In addition to the air-brake mechanism, a handwheel operated worm gear type mechanism is provided for operating and setting the brakes by hand. This brake is capable of skidding the wheels under full load on a dry level concrete pavement. The parking brake is operated by a handwheel at the rear of the trailer. No part of the brake mechanism is a factor limiting the road clearance.

Landing Gear

The landing gear is of rugged construction, is manually operated, and is so designed that the wheels may be independently operated to serve as leveling jacks. The landing gear is provided with a locking mechanism to lock the landing gear in any position. Two built-in, screw-type leveling jacks are provided at the rear of the trailer. The jacks are dirt-proof and self-aligning. Suitable jack planks are furnished and conveniently mounted under the trailer.

Body

The body is of the van-type with door and/or window openings designed to afford the most efficient operating conditions. The roof is crowned for drainage purposes, and is made in removable sections and provided with removable hatches to permit removal and replacement of equipment components within the van. The roofing material has sufficient strength to support a 200 pound man walking thereon. Heavy-duty drip moulding is provided around the entire roof.

Floor

The semitrailer floor is designed for the equipment loads and operating conditions. The all-metal floors are coated with non-skid floor coating. The wood floors are approved hardwood in accordance with the National Maple Flooring Manufacturer's Association or National Oak Flooring Manufacturer's Association Grading Rules. The wood flooring is not less than 1-1/4" thick and is surfaced two sides and tongue-and-grooved and is chemically treated to repel insects. Flooring is run lengthwise of the trailer and is securely fastened to each cross member by means of galvanized wood screws with heads countersunk to be flush with the floor. The floor is sealed at all joints with an approved caulking or sealing compound.

Doors and Windows

Doors and hatches are provided on the semitrailer as required for convenience of operation, accessibility of plant components, and to facilitate removal of equipment for repair and maintenance. Windows are installed in the van-type body

of the semitrailer as required and are glazed with shatterproof glass. (See Figure 7 for location of doors and windows.)

Steps

Demountable-type steps are provided for use at the doors. Steps are provided with non-slip tread plates, and are easily attached and detached at the sill. Provision is made for stowing steps inside the semitrailer when not in use.

Wiring

The vehicle is wired for an electrical supply of 24 volts direct current. Cable used for wiring is encased in flexible non-metallic tubing. Terminal lugs are soldered to the wire ends. Junction blocks have bases made of thermosetting, laminated, phenol formaldehyde plastic, or other equally suitable material, and is equipped with suitable studs, washers, and nuts for the attachment of terminal lugs. The circuits are color or number traced. Suitable grommets, or clamps, to prevent chafing of cable, are installed where wire passes through structural members. A receptacle with hinged cover, to allow the running lights of the semitrailer to be controlled from the driver's seat of the towing vehicle, is recessed in the frame.

Lamps and Reflector Assemblies

All lamps are readily accessible for the changing of bulbs and lenses, and for making repairs. The stop and tail lamps are recessed approximately 1/2" from the surface of the frame member. The following lamps and reflectors are provided on the vehicle, located to conform to Interstate Commerce Commission Motor Carrier Safety Regulations:

- Reflect Reflector (Red and Amber)
- Receptacle and Hinged Cover Assembly
- R. H. Tail Lamp Assembly, 24 Volt
- L. H. Tail Lamp Assembly, 24 Volt
- Clearance Lamp Assembly, 24 Volt

Semitrailer Insulation

The semitrailer operating space is insulated with fiberglass bonded together with a thermosetting plastic resin to form a resilient, semi-rigid, dimensionally stable insulation and sealed in place against moisture infiltration.

Electrical Equipment

A suitable number of dome lights with necessary wiring and switches, and with bulbs of sufficient candlepower are installed to provide adequate light for operating the equipment at night. A sufficient number of convenience outlets are provided for emergency droplight cords. An emergency auxiliary lighting system supplied by power from the 24 volt diesel engine starting battery bank is provided.

Lubrication

All moving parts are provided with suitable means of lubrication.

Lubricants

All moving parts are designed to operate efficiently and satisfactorily when lubricated with standard Armed Forces lubricants.

Grease Fittings

Grease fittings are located in accessible, protected positions. A bright red circle is painted around each lubricating point.

Caution Plates

Where use of high pressure lubricating equipment (1,000 PSI or higher) will damage grease seals or other parts, a suitable warning is affixed to the equipment in a conspicuous location.

Fungus Control

The semitrailer is treated to resist the growth of fungus.

Lifting Attachments

The semitrailer is provided with suitable lifting attachments to enable the trailer, with all equipment installed in it, to be lifted in its normal position. The lifting attachment has a minimum safety factor of five based on the ultimate strength of the material. The eye of each lifting attachment has a diameter of not less than three inches.

Manufacturer's Identification

The semitrailer bears the manufacturer's name and trademark on a name plate securely affixed in a conspicuous place.

Instruction Plates

The semitrailer, when applicable, is equipped with instruction plates, suitably located, describing any special or important procedures to be followed in operating and servicing the equipment.

Treatment, Painting, and Stenciling

All parts of the semitrailer body and running gear is treated and painted to resist the effects of sand, dust, humidity and moist salt air.

The gross weight of the semitrailer with all equipment installed in it is stenciled on each side of the semitrailer in such a manner as to be readily discernible to military personnel. The prescribed tire pressure is stenciled on the body of the unit in a position near the wheels, using block letters one inch high.

AIR FILTER

Description

The air filter element is a Dollinger Corporation staynew Model WKE-4, dry panel type air filter, complete with cell frame and insert. The filtering medium

is bonded glass. Two elements are required and are mounted in a lightweight steel duct.

Specifications

Nominal Filter Element	
Height	16"
Width	25"
Thickness	4"
Normal Capacity	
Air Volume, CFM	600
Air Velocity, FPM	30
Maximum Capacity	
Air Volume, CFM	800
Air Velocity, FPM	40
Active Filtering Area	20 Sq. Ft.
Pressure Drop	
At 600 CFM Air Volume, Inches of Water	0.02
At 800 CFM Air Volume, Inches of Water	0.04
Duct Size	
Height	20"
Width	14"
Length	42"
Approximate Total Weight, Inc.	125

AIR COMPRESSOR

Description

The air compressor consists of three Read Standard Corporation "Standardaire" blowers. Each blower shall be a three-lobe, rotary, positive displacement, axial flow, horizontal, heavy-duty blower having helical rotors. By compounding one Model 8B14, one Model 7B10, and one Model 5B10 blowers, 1000 standard cubic feet per minute of air is compressed from intake conditions of 14.7 PSIA and 70°F and discharged as oil-free air at 114.7 PSIA. Each blower is equipped with a shaft extension to provide a drive for an intercooler or aftercooler fan. This extensor is capable of transmitting a load of 10 HP to the cooling fan by direct drive. (See Figure 8 for sectional view of Air Compressor.)

Each stage is tested individually in accordance with the American Society of Mechanical Engineers Power Test Code (PTC-9-39). Each stage is guaranteed to be within the permissible limit of 3% of the specifications listed below.

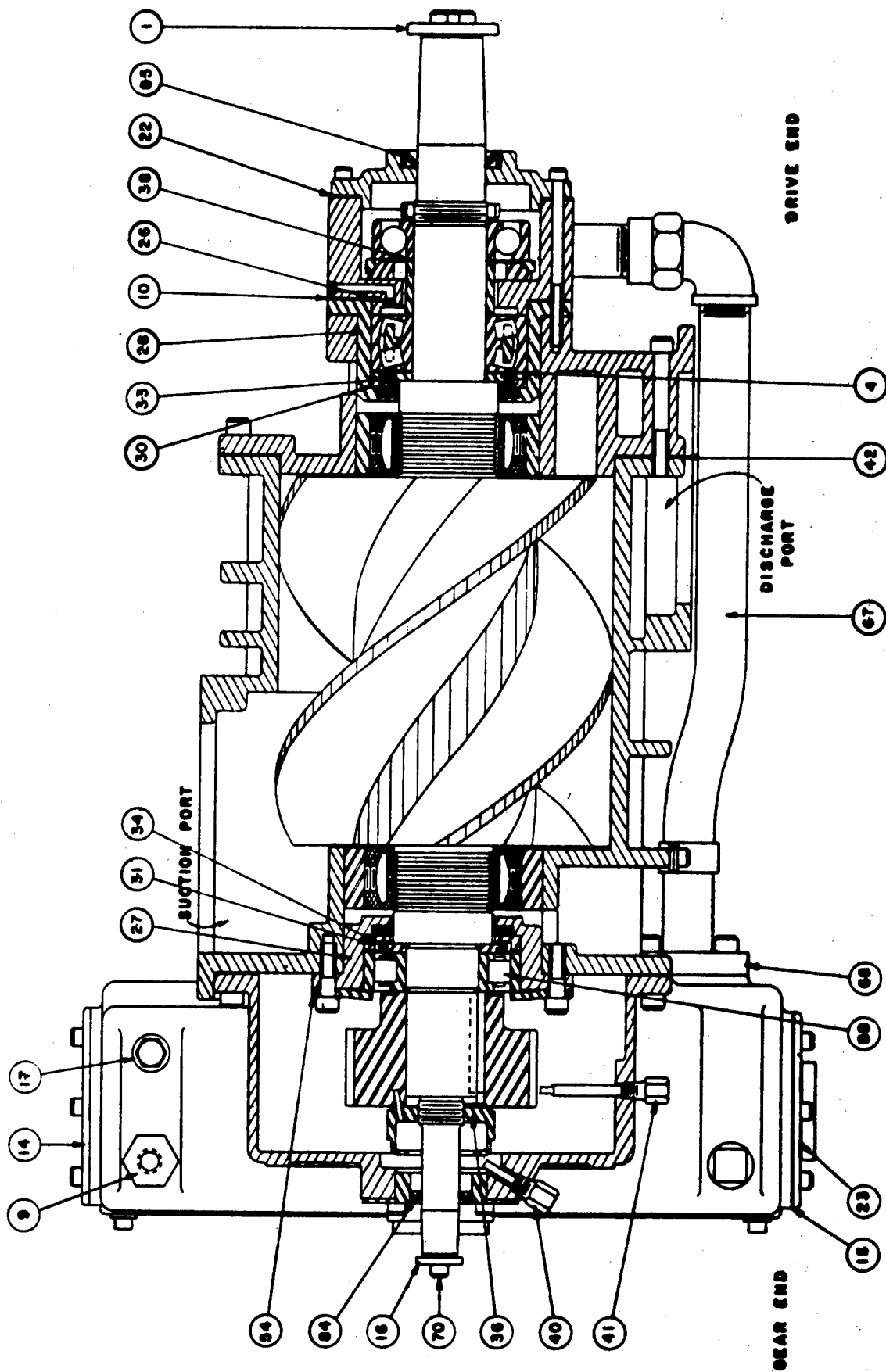


FIGURE 8
 AIR COMPRESSOR (SECTIONAL VIEW)
 - Sheet 1 of 2 -

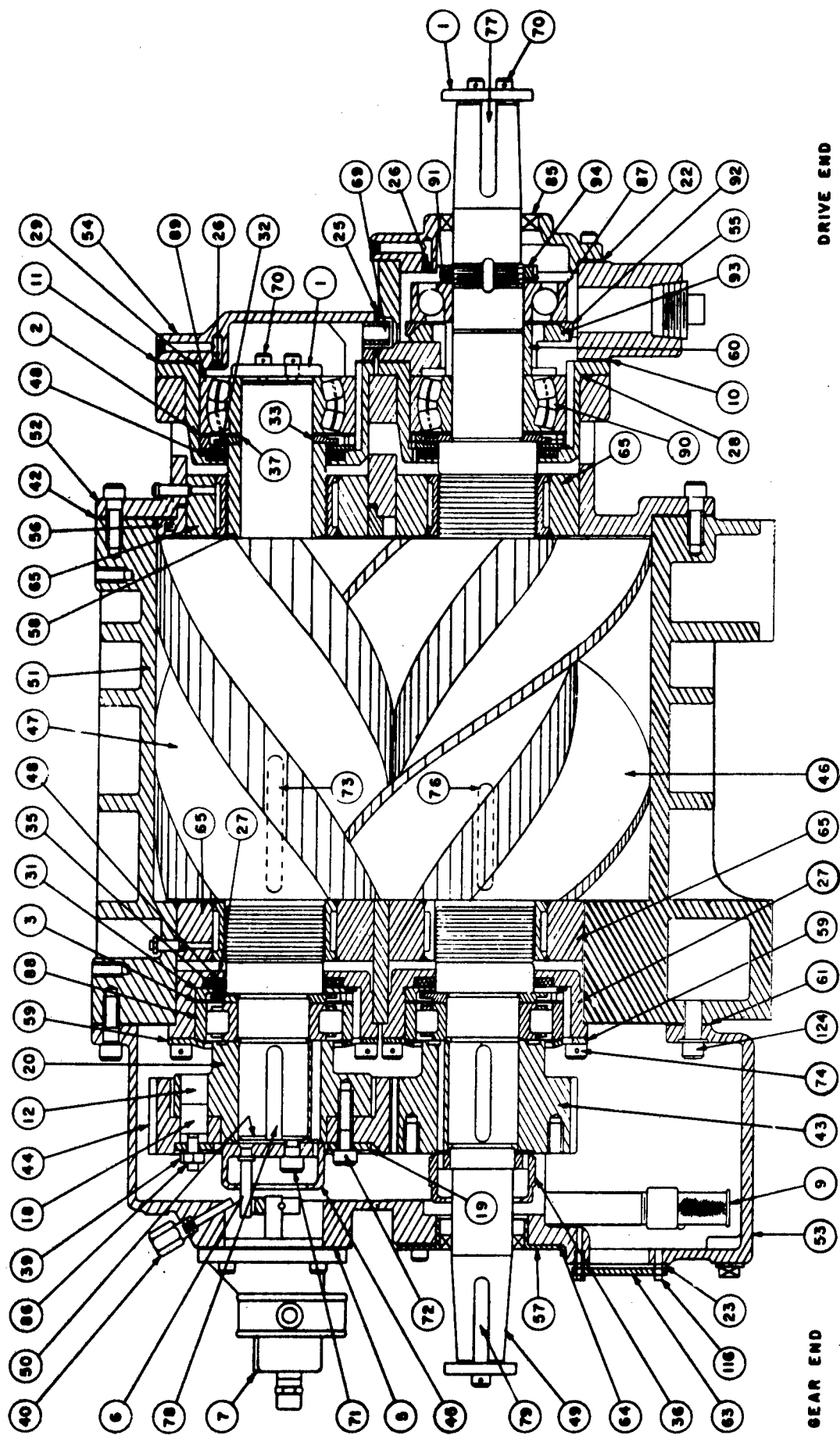


FIGURE 8
AIR COMPRESSOR (SECTIONAL VIEW)
- Sheet 2 of 2 -

AIR COMPRESSOR (SECTIONAL VIEW) LEGEND

- | | |
|--|--|
| 1. Clamp Plate | 43. Main Rotor Timing Gear |
| 2. Oil Shield Plate | 44. Gate Rotor Timing Gear |
| 3. Oil Shield Plate | 45. Clamp Plate |
| 4. Oil Shield Plate | 46. Main Rotor |
| 5. Oil Pump Gasket | 47. Gate Rotor |
| 6. Oil Pump Drive Pin | 48. Felt Seal Ring |
| 7. Oil Pump | 49. Main Rotor Shaft |
| 8. Oil Manifold | 50. Gate Rotor Shaft |
| 9. Strainer Arrangement | 51. Housing |
| 10. Bearing Retaining Housing Adjusting Shim | 52. Bearing Carrier, Drive End |
| 11. Cover Shim | 53. Gear End Cover |
| 12. Gear Timing Pin | 54. Gate Rotor Drive End Cover |
| 13. Packing Gland | 55. Bearing Retainer Housing |
| 14. Cover Plate | 56. Bearing Carrier Guide Plate |
| 15. Cover Plate Gasket | 57. Seal Retainer |
| 16. Clamp Plate | 58. Bearing Spacer, Gate Rotor Drive End |
| 17. Breather Unit | 59. Bearing Retaining Disc |
| 18. Gear Timing Wedge | 60. Thrust Bearing Spacer |
| 19. Locking Plate | 61. Gear End Cover Gasket |
| 20. Gate Rotor Timing Gear Hub | 62. Oil Gage Adapter Plate |
| 21. Main Rotor Bearing Cover | 63. Oil Gage Hole Cover Plate |
| 22. Main Rotor Bearing Cover Gasket | 64. Seal Retainer Gasket |
| 23. Oil Level Gage Gasket | 65. Expandable Seal |
| 24. Dead Soft Wire #18 Gage | 66. Pipe Nipple |
| 25. Drive End Cover Oil Drain Gasket | 67. 1-1/4" Black Iron Pipe |
| 26. Oil Spitter | 69. Oil Drain Extension |
| 27. Bearing Cartridge, Main & Gate Rotor G.E. | 70. Hex Socket Head Capscrew |
| 28. Bearing Cartridge, Main Rotor Drive End | 71. Hex Socket Head Capscrew |
| 29. Bearing Cartridge, Gate Rotor Drive End | 72. Hex Socket Head Capscrew |
| 30. Outer Bearing Spacer, Main Rotor Drive End | 73. Key R.B.E. |
| 31. Outer Bearing Spacer, Main & Gate Rotor G.E. | 74. Hex Socket Head Capscrew |
| 32. Outer Bearing Spacer, Gate Rotor Drive End | 75. Key R.B.E. |
| 33. Oil Slinger, Gate Rotor Drive End | 76. Key R.B.E. |
| 34. Oil Slinger, Main Rotor Drive End | 77. Key R.O.E. |
| 35. Oil Slinger, Main & Gate Rotor Gear End | 78. Key R.O.E. |
| 36. Timing Gear Locknut | 79. Key R.O.E. |
| 37. Gate Rotor Adjusting Shim | 80. Rope Type Packing 1/4" Diameter |
| 38. Main Rotor Adjusting Shim | 81. Taper Pin No. 7 x 1-1/2" Long |
| 39. Nut Locking Plate | 82. Oil Pressure Gage |
| 40. Oil Spitter, Main and Gate Rotor Gear End | 83. Oil Level Sight Gage, Style CW |
| 41. Oil Spitter, Gear | 84. Oil Seal |
| 42. Housing Adjusting Shim | 85. Oil Seal |
| | 86. 3/8" - 24 SAE Hex Nut |
| | 87. Angular Contact Ball Bearing |
| | 88. Cylindrical Roller Bearing |
| | 89. Spherical Roller Bearing |
| | 90. Spherical Roller Bearing |
| | 91. Bearing Lockwasher |
| | 92. Thrust Bearing Aligning Washer |
| | 93. Spherical Seat Ring |
| | 94. Bearing Locknut |

AIR COMPRESSOR (SECTIONAL VIEW) LEGEND (Cont.)

- | | |
|--|---|
| 95. Rotor Locknut | 116. Fillister Head Machine Screw #10-32
x 1" Long |
| 96. SAE Washer | 117. Round Head Machine Screw 1/4-20 x
1/2" Long |
| 97. 90° Elbow | 118. Flat Head Machine Screw #6-32 x 1"
Long |
| 98. 1/4" Street Elbow | 120. Hex Socket Head Capscrew |
| 99. 1-1/4" Street Elbow | 121. Hex Socket Head Capscrew |
| 100. 1/4" Close Nipple | 122. Hex Socket Head Capscrew |
| 101. 3/8" Close Nipple | 123. Hex Socket Head Capscrew |
| 102. 3/8" Standard Black Iron Pipe | 124. Hex Socket Head Capscrew |
| 103. 1/4" Square Head Pipe Plug | 125. Hex Socket Head Capscrew |
| 104. 3/8" Square Head Pipe Plug | 126. Hex Socket Head Capscrew |
| 105. 1/2" Square Head Pipe Plug | 127. Hex Socket Head Capscrew |
| 106. 1-1/4" Square Head Pipe Plug | 128. Bleed-off Pipe |
| 107. 1/4" Tee | 129. Pipe Clip Parker #3121-3-10 |
| 108. 3/8" Tee | 130. Oil Filter |
| 109. Male Connector 1/2 P.T. 1/2" Tubing | 131. Filter Cartridge (Separate) |
| 110. Male Connector 1/4 P.T. 3/8" Tubing | 132. 3/8" Annealed Steel Tubing |
| 111. 90° Male Elbow 1/4 P.T. 3/8" Tubing | 133. 1/2" Annealed Steel Tubing |
| 112. Male Elbow 3/8 P.T. 1/2" Tubing | 134. 1/8" Dowel Pin |
| 113. Male Branch Tee 1/4 P.T. 3/8" Tubing | |
| 114. Tee Union 3/8" Tubing | |
| 115. Round Head Machine Screw #6-32
x 1/2" Long | |

Specifications

	<u>1st Stage</u>	<u>2nd Stage</u>	<u>3rd Stage</u>
Blower Model	8B14	7B10	5B10
Speed, RFM	2330	2390	3220
Intake Pressure, PSIA	14.56	30.4	59.9
Discharge Pressure, PSIA	31.4	60.9	115.7
Absolute Pressure Ratio	2.16:1	2.0:1	1.93:1
Intake Volume, CFM	1100	556	277
Intake Temperature, °Rankine	530	560	560
Discharge Temperature, °F	285	302	314
Adiabatic Horsepower	60	56.5	52.3
Brake Horsepower	102	103	116
Overall Adiabatic Efficiency, %	59	55	45
Direction of Rotation, Viewing Driveshaft End	Clock-wise	Clock-wise	Clock-wise
Approximate Size			
Length, Inches	45-3/8	41	41
Width, Inches	26-5/8	24-5/8	20-1/2
Height, Inches	24-3/4	22-1/2	17-1/4
Approximate Weight, Pounds	1227	950	710

INTERCOOLERS AND AFTERCOOLERS

Description

The intercoolers and aftercoolers are Trane Company coolers. They are of all aluminum construction. The cooling air face measures 20-5/8 inches by 32 inches, and the cooling air flow length is 10 inches.

Specifications

	<u>1st Stage Cooler</u>	<u>2nd Stage Cooler</u>	<u>3rd Stage Cooler</u>
Duty, BTU/hr	285,000	312,500	340,000
Hot Air Side			
Flow, lbs/hr	4,950	4,950	4,950
Inlet Temperature, °F	285	314	356
Outlet Temperature, °F	90	90	90
Inlet Pressure, PSIG	16.7	46.7	101.0
Pressure Drop, PSI	0.5	0.26	0.5
H ₁ , BTU/hr, Sq. Ft., °F	29.7	29.7	29.7
Number of Passages	24	24	24
Flow Length, Inches	23-1/2	23-1/2	23-1/2
Fin Type	1/8" Serrated	1/8" Serrated	1/8" Serrated
Fin Height x Thickness, Inches	0.375 x 0.006	0.375 x 0.006	0.375 x 0.006
1/ Sensible heat transfer coefficient corrected for fin efficiency.			
Fin Spacing, Per Inch	18	18	18
Total Surface Sq. Ft.	472	472	472

	<u>1st Stage</u> <u>Cooler</u>	<u>2nd Stage</u> <u>Cooler</u>	<u>3rd Stage</u> <u>Cooler</u>
Air Inlet Connection Size, Inches	6	5	4
Air Outlet Connection Size, Inches	6	5	4
Air Blow down Connection Size, Inches	2	1-1/2	1-1/4
Cooling Air Side			
Flow, lbs/hr	20,000	20,000	20,000
Inlet Temperature, °F	80	80	80
Outlet Temperature, °F	139.2	144.9	150.5
Pressure Drop, Inches of Water	4.3	4.4	4.4
H, BTU/hr, Sq. Ft., F	21.4	21.4	21.4
Number of Passages	48	48	48
Flow Length, Inches	8	8	8
Fin Type	Herringbone	Herringbone	Herringbone
Fin Height x Thickness, Inches	0.375 x 0.006	0.375 x 0.006	0.375 x 0.006
Fin Spacing, Per Inches	18	18	18
Total Surface, Sq. Ft.	944	944	944
Approximate Total Weight, lbs.	170	168	164

INTER-AND-AFTERCOOLER FANS

Description

The inter-and-aftercooler fans are Trane Company centrifugal fans with the blades inclined backward to the direction of rotation. They are of single width and have single inlets. They are of lockseam-type construction, with convertible discharge orientation and standard steel shafts.

Specifications

	<u>1st Stage</u>	<u>2nd Stage</u>	<u>3rd Stage</u>
Fan Model	16 BI SWSI	16 BI SWSI	13 BI SWSI
Fan Size	16	16	13
Fan Arrangement	2	2	2
Fan Class	II	II	II
Wheel Width, %	85	80	95
Fan Speed, RPM	2330	2390	3100
Direction of Rotation Viewing Driveshaft End	Clockwise	Clockwise	Clockwise
Delivery, CFM	4450	4450	4450
Static Pressure, Inches of Water	4.4	4.4	4.4
Brake Horsepower	4.48	4.67	6.88
Orientation of Discharge	Up Blast	Up Blast	Up Blast
Approximate Size			
Length, Inches	28-3/4	28-3/4	26-1/8
Width, Inches	31-3/4	31-3/4	26
Height, Inches	33-3/8	33-3/8	27-5/8
Approximate Weight, lbs.	250	250	170

DIESEL ENGINE

Diesel Engine Horsepower Requirements

In this generator, the blowers and inter-and-aftercooler fans of each stage are direct-driven in tandem by separate diesel engines through suitable transmissions. In addition, a 33.3 KVA, 120-208 Volt, 3 phase, 60 cycle electrical generator is belt driven by the third stage diesel engine. The following table is a compilation of the brake horsepower loads on the individual diesel engines required to drive these components:

BRAKE HORSEPOWER					
<u>State</u>	<u>Blower</u>	<u>Transmission Loss - 2 to 4%</u>	<u>Intercooler Fan</u>	<u>Electric Generator</u>	<u>Total</u>
1st Stage	102	3.57	3.28		108.85
2nd Stage	103	3.60	3.42	11.0	121.02
3rd Stage	116	3.46	3.69		127.15

Description

The three diesel engines are General Motors Corporation two cycle, six cylinder, radiator-cooled, short base, open diesel engines, Series 6-71, Model 6030C. (See Figures 9 and 10 for illustration of Air Source Section.)

Specifications

Engine Model Number	6030C
Engine	GM 6-71 RC55 2-Cycle Diesel
Number of Cylinders	6
Bore, Inches	4-1/4
Stroke, Inches	5
Total Displacement, Cubic Inches	425.6
Rated BHP, Basic Engine at 200 RPM	200
Rated BHP, with Standard Equipment at 1800 RPM	153
Continuous BHP, with Standard Equipment at 1800 RPM	138
Continuous BHP, with Standard Equipment at 1600 RPM	130
BMEP, Continuous Rating at 1800 RPM, PSI	71
BMEP, Continuous Rating at 1600 RPM, PSI	75
Maximum Torque, 1000 RPM (60 Cu. MM Injector), lb. Ft.	526
Piston Speed at 1800 RPM, FPM	1500
Piston Speed at 1600 RPM, FPM	1333
Compression Ratio	16:1
Lubrication	Forced Feed
Flywheel Housing Size	No. 1 SAE
Maximum Fuel Pump Lift to Fuel Pump Level, Inches	48
Heat Absorbed by Cooling Water (Per HP at Ambient Temp. of 110°F) BTU/HP/Min.	35
Air Required for Scavenging and Combustion at 1800 RPM, CFM	600
Exhaust Back Pressure (Max. at Manifold Flange at 1800 RPM), In. Hg.	4
Lubricating Oil Refill Capacity, Including Filter(s), Qt.	29
Cooling Water System Capacity, Gal.	8-3/4
Approximate Size	
Length, Inches	62-13/16

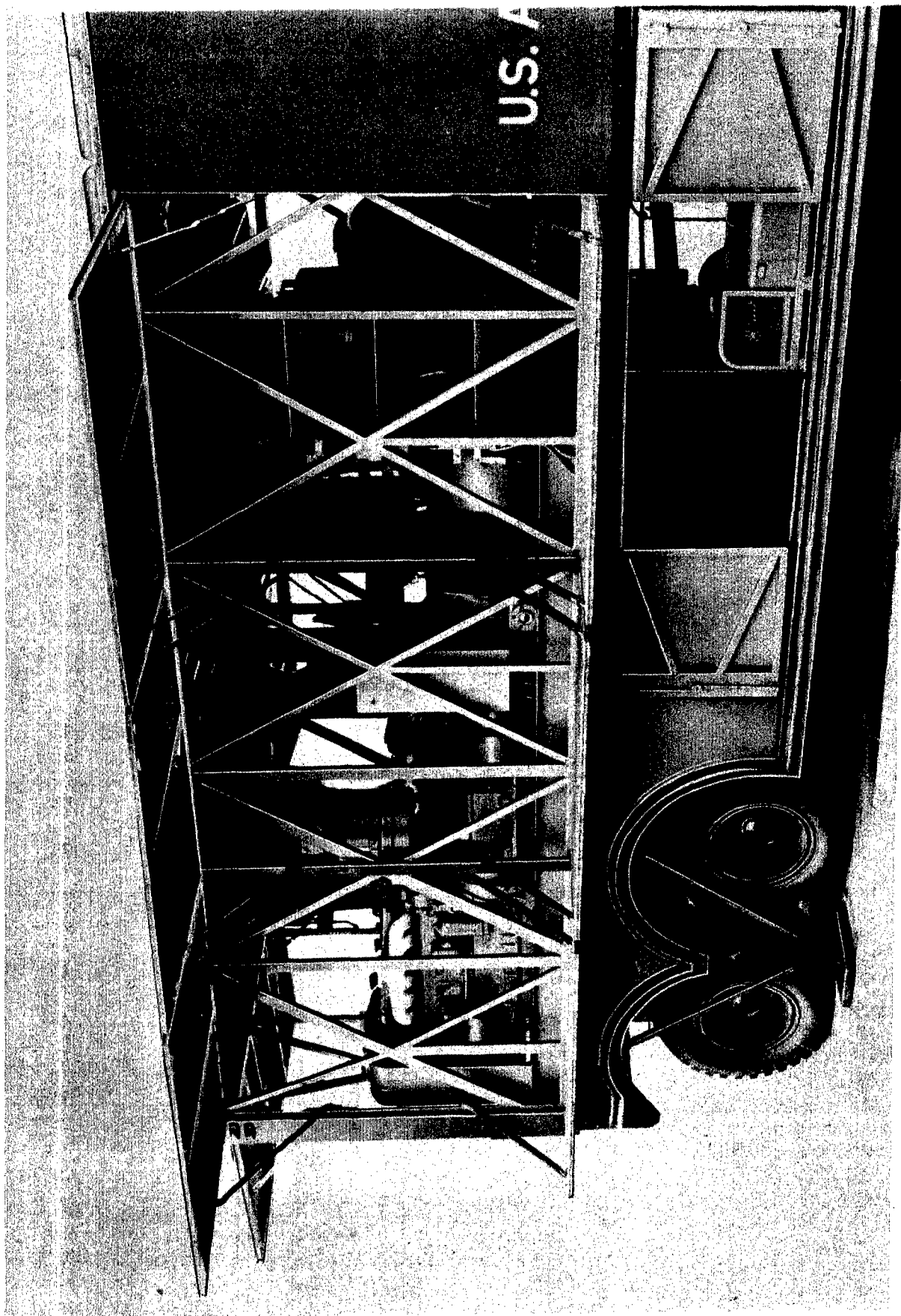


FIGURE 9
CURB SIDE VIEW
TYPE MA-1 OXYGEN OR NITROGEN GENERATING AND CHARGING PLANT

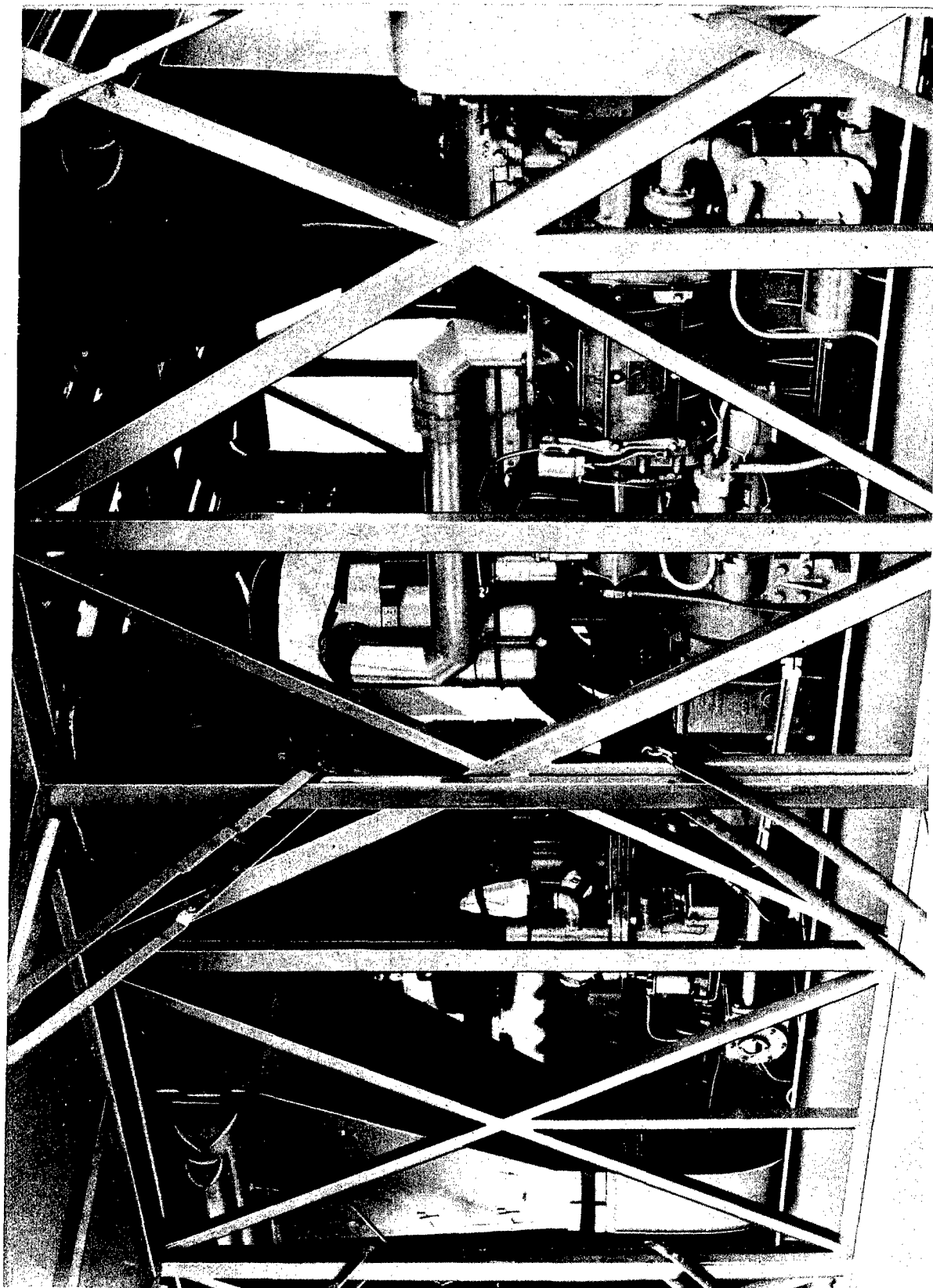


FIGURE 10
AIR COMPRESSION SECTION
TYPE MA-1 OXYGEN OR NITROGEN GENERATING AND CHARGING PLANT

Width, Inches
Height, Inches
Approximate Weight, Dry, lbs.

32
49-1/8
2800

Standard Equipment

Rotation -- Counterclockwise, viewing flywheel end.

Cooling System - Heavy-duty radiator, lubricating oil cooler, water outlet manifold, thermostat for temperature control, engine water circulating pump, suction type fan.

Fuel System - Primary and secondary fuel filters, 60 cu. mm. injectors, fuel circulating pump.

Lubricating System - Lubricating oil pressure pump, oil filter assembly.

Instruments - Instrument Panel Assembly includes: Starter switch, ammeter, lube oil pressure gage, water temperature gage, throttle control knob, remote control lever and space for accessory air heater controls and tachometer with hourmeter.

Miscellaneous - Fabricated steel base, hydraulic type governor with control on instrument panel, exhaust manifold and companion flange.

Optional Equipment

Electrical - Battery charging generator and voltage regulator assembly (24 volt, 600 watt insulated) starting motor (24 volt, insulated).

Miscellaneous -- Air inlet housing for remotely mounted extra capacity air cleaner Donaldson extra heavy duty oil bath type air cleaner.

Accessories

Automatic Bell Alarm for high water temperature and low oil pressure, air heater and pump for cold weather starting, 18 inch flexible exhaust connection with pipe thread ends, unmounted muffler for moderate silencing.

DIESEL ENGINE TRANSMISSION

Description

The diesel engine transmission is a Cotta Transmission Company Model FAUU-R Transmission equipped with a SAE No. 1 bell housing and Rockford single plate, 14 inch, over-center clutch. It is complete with pilot bearings and oil circulating pump. The transmission is so designed and constructed, that it is capable of attachment and connection to a General Motors Model 6030C Series 6-71 RC55 Diesel Engine without modification. The transmission bell housing is fabricated with a clutch operating shaft extending through and to the outside on both right and left hand sides of the bell housing to provide for optional location of a clutch operating lever. (See Figure 11 for sectional view of Transmission.)

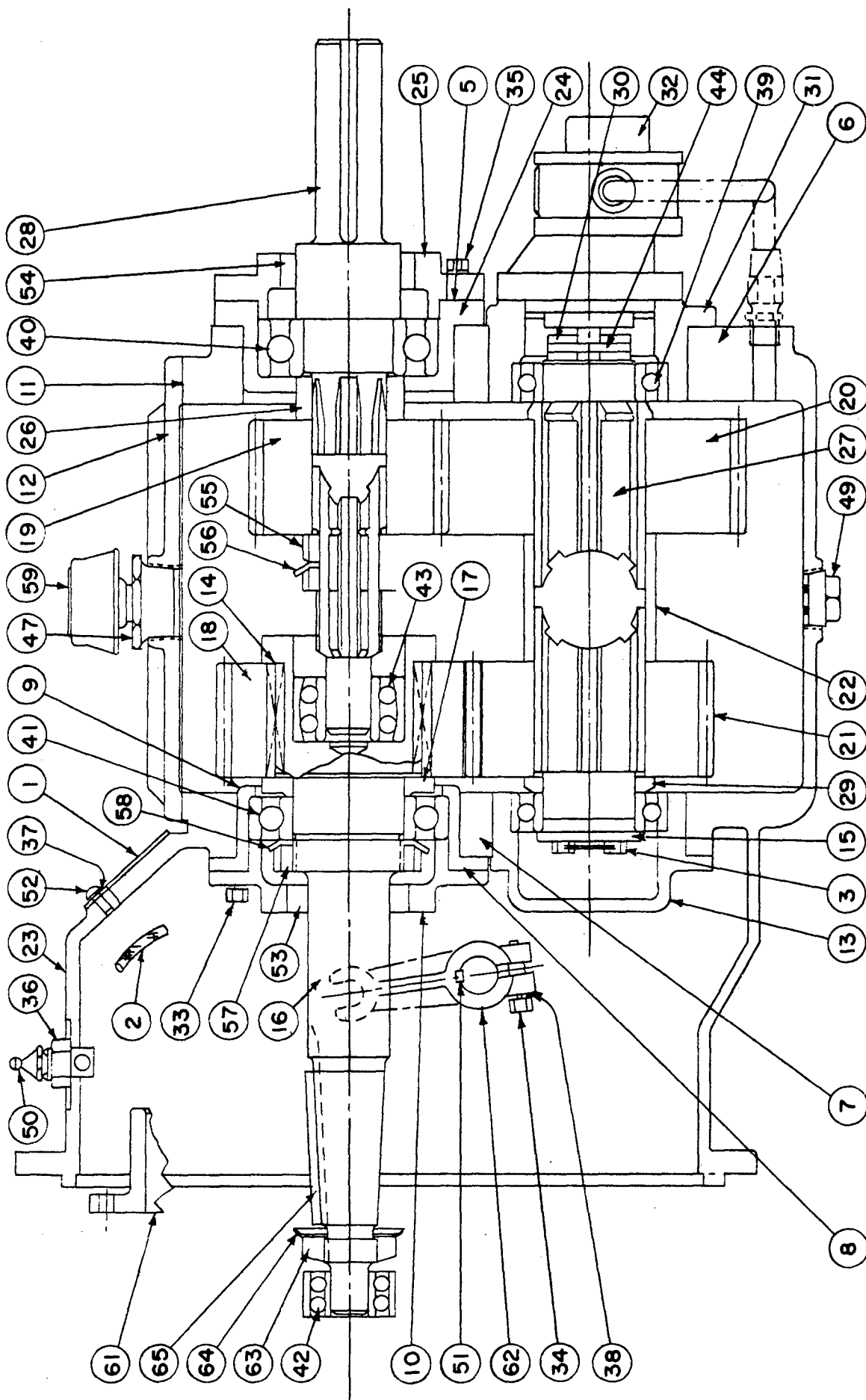


FIGURE 11
TRANSMISSION ASSEMBLY (SECTIONAL VIEW) - Sheet 1 of 2 -

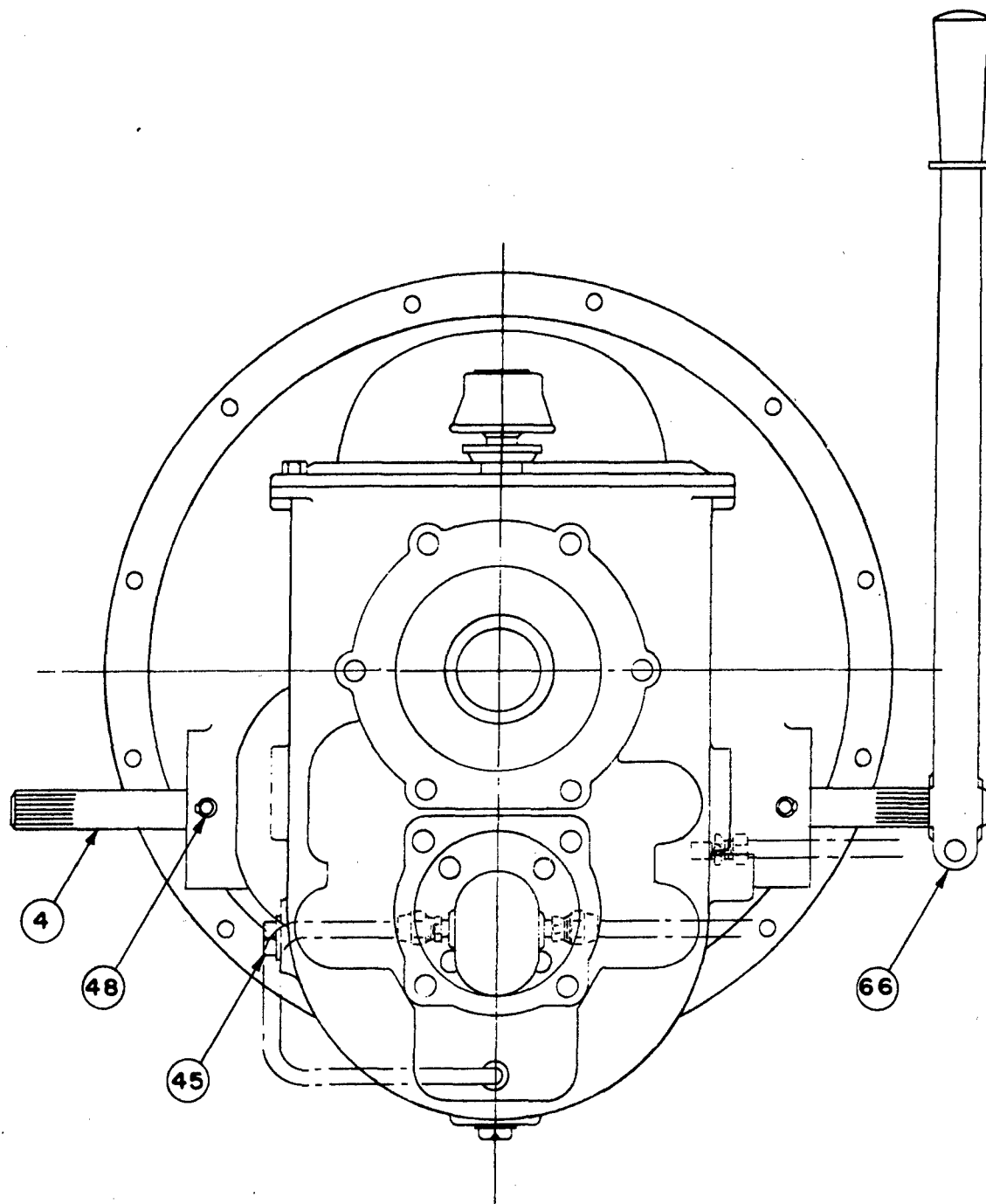


FIGURE 11
TRANSMISSION ASSEMBLY (END VIEW) - Sheet 2 of 2 -

TRANSMISSION ASSEMBLY (SECTIONAL VIEW) LEGEND

- | | |
|---|--|
| 1. Cover-Clutch Case | 33. Screw - Cap 3/8"-16 x 1-1/2" |
| 2. Tube-Grease Assembly | 34. Screw - Cap 3/8"-16 x 1-1/4" |
| 3. Screw Drilled Head Cap 5/16"-18 x 3/4" | 35. Screw - Cap 3/8"-16 x 2" |
| 4. Shaft-Clutch Release | 36. Nut - Half 5/8"-18 |
| 5. Gasket - M.S. Inside and Outside Housing | 37. Lockwasher 1/4" |
| 6. Gasket - C.S. Housing | 38. Lockwasher 3/8" |
| 7. Gasket - D.S. Front Inside Housing | 39. Bearing - C.S. |
| 8. Gasket - D.S. Front Outside Housing | 40. Bearing - M.S. |
| 9. Housing - D.S. Front Inside | 41. Bearing - D.S. |
| 10. Housing - D.S. Front Outside | 42. Bearing - Pilot |
| 11. Gasket - Top Cover | 43. Bearing - Pocket |
| 12. Cover - Case Top | 44. Pin - Roll (Pump Drive) |
| 13. Housing - C.S. Front | 45. Plug - Pipe 1" |
| 14. Key - D.S. Gear | 46. Plug - Pipe 3/8" |
| 15. Plate - C.S. Front Bearing Clamp | 47. Bushing - Reducer 1-1/4" to 3/4" |
| 16. Shaft - Drive | 48. Fitting - Zerk 1/8" x 45' |
| 17. Spacer - D.S. Bearing | 49. Plug - Pipe (Magnetic) 1" |
| 18. Gear - D.S. | 50. Fitting - Zerk 1/8" Straight |
| 19. Gear - M.S. O'Speed | 51. Key - Woodruff #15 |
| 20. Gear - C.S. O'Speed | 52. Screw - Button Head 1/4"-20 x 5/8" |
| 21. Gear - C.S. Driving | 53. Seal - Oil (D.S.) |
| 22. Spacer - C.S. Gear | 54. Seal - Oil (M.S.) |
| 23. Case - Transmission #1 Bell | 55. Nut - Lock |
| 24. Housing - M.S. Rear Inside | 56. Lockwasher |
| 25. Housing - M.S. Rear Outside | 57. Nut- Lock |
| 26. Spacer - M.S. Rear Bearing | 58. Lockwasher |
| 27. Shaft - Counter | 59. Breather |
| 28. Shaft - Main | 61. Ring - Driving |
| 29. Spacer - C.S. Front | 62. Fork |
| 30. Coupling - Pump Drive | 63. Nut |
| 31. Housing - C.S. Rear | 64. Washer |
| 32. Pump | 65. Key |
| | 66. Lever - Hand |

Specifications

	<u>Unit No. 1</u> <u>1st Stage</u>	<u>Unit No. 2</u> <u>2nd Stage</u>	<u>Unit No. 3</u> <u>3rd Stage</u>
Horsepower to be transmitted, Minimum	138	138	138
Input Speed, RPM (approximate)	1580	1620	1600
Output Speed, RPM (approximate)	2330	2390	3220
Overspeed Ratio	1:1.378	1:378	1:1.778
Transmission Efficiency, Per Cent	96 to 98	96 to 98	96 to 98
Type of Duty	Continuous	Cont.	Cont.
Direction of Rotation, Viewing Output Shaft	Counter-clockwise	Counter-clockwise	Counter-clockwise
Approximate Size			
Length, Inches	34	34	34
Width, Inches	22	22	22
Height, Inches	24	24	24
Approximate Weight, lbs.	630	630	630

DIESEL ENGINE STARTING BATTERY

Description

The diesel engine starting battery is a Delco Products Division of General Motors Corporation Heavy Duty, Model 25A1, 6 volt, Storage Battery. The battery has three lead and acid type cells enclosed in a composition rubber case. Four of these batteries are connected in series to generate the 24 volts necessary to start the diesel engines.

Specifications

Capacity

200 Ampere hours at 20 hour rating
150 Ampere hours at 4 hour rating

Delivery Rates

50 Amperes for 175 Minutes at 80°F
300 Amperes for 11 Minutes at 0°F
820 Amperes for 1.5 Minutes at 0°F
1060 Amperes for 1.5 Minutes at 32°F

At the above rates, the battery will be depleted to an average of one volt per cell.

Approximate Size

Length, Inches	16-1/2
Width, Inches	7-1/2
Height, Inches	10

Approximate Weight, lbs.

80

DIESEL ENGINE FUEL OIL SUPPLY TANK

Calculation of Size

In accordance with the contract, the fuel supply tank has a minimum capacity for 12 hours of continuous operation for the generator operating at full load.

Specific Fuel Consumptions

First Stage Engine at 108.85 BHP, 1600 RPM	7.14 GPH
Second Stage Engine at 110.02 BHP, 1600 RPM	7.23 GPH
Third Stage Engine at 117.15 BHP, 1600 RPM	7.68 GPH
Total	22.05 GPH

Capacity Required

$$V_{\text{req'd}} = 22.05 \frac{(\text{Gal})}{(\text{Hr.})} \times 12 (\text{Hrs.})$$
$$= 265 \text{ Gals.}$$

$$\text{Use } V_{\text{tank}} = 275 \text{ Gals.}$$

For the trailer which is 9 feet 6 inches wide, a steel cylindrical fuel tank 8 feet 10" long is strapped beneath the floor of the air source section.

$$V_{\text{cyl}} = \frac{\pi D_1^2}{4} (\text{Cross Sectional Area}) \times L (\text{Length})$$

Also

$$V_{\text{cyl}} = 275 (\text{Gals}) \times 231 \frac{(\text{Cu In})}{(\text{Gal})}$$

$$D_1^2 = \frac{275 \times 231 \times 4}{\pi \times 106}$$

$$D_1 = 27.68 \text{ Inches. Use } 27.75 \text{ Inches}$$

Specifications

Inside Diameter, Inches	27.75
Length, Inches	106.0
Thickness, Inches	1/8
Capacity, Gals.	275
Weight, Dry, lbs.	360
Weight, Wet, lbs.	2310

AIR COMPRESSOR CONDENSATE TRAP

Description

The air compressor condensate trap is fabricated by Air Products, Incorporated. It has a tangential side inlet and a bottom outlet. It has a condensate drain connection at the lowest point in the bottom head.

Specifications

Material	Steel
Shell Length, Inches	30
Shell Diameter, Inches	10
Shell Thickness, Inches	1/8
Head Diameter, Inches	10
Head Thickness, Inches	1/8
Head Height, Inches	4
Inlet Connection Size, Inches	4
Outlet Connection Size, Inches	4
Condensate Drain Connection Size, Inches	1
Maximum Working Pressure, PSIG	100
Approximate Weight, lbs.	50

SWITCH VALVE

Description

The switch valve is manufactured by Air Products, Incorporated. It is a double poppet-type valve having a carbon steel body and stainless steel stem. It has two 4-inch high pressure air inlet connections; one 5-inch waste air outlet connection; and two 5-inch connections common to both the high pressure air outlet and the waste air inlet. The switch valve is actuated by a Logansport Machine Company, Incorporated non-rotating, double-acting air cylinder, Model No. 21060. The air cylinder has a 6-inch bore, 4-inch stroke, and 1/2-inch iron pipe size air connections. The air cylinder, in turn, is controlled by a Bellows Company four-way solenoid air valve, Model No. EV-15B Electroaire Valve, having a 115/8 volt transformer and 1/2-inch iron pipe size air inlet connection. The solenoid valve is air powered and is actuated in both directions by low-voltage, momentary-energized solenoid coils. It has an operating pressure of 50 PSIG and has adjustments provided to limit the speed of the control cylinder in both directions. (See Figure 12 for Switch Valve Assembly.)

WARM HEAT EXCHANGER

Description

The warm heat exchanger is a Trane Company brazed aluminum core type heat exchanger.

Specifications

Core Size

- 17" Passage Width over Channels
- 20-7/8" No Flow (passage stack height)
- 88-1/2" Core Length over Face Channels

Core Passages

- 50 Passages per Core are Headered into 2 Streams of 25 Passages Each
- 16-1/2" Width Inside Channels
- 0.375" Nominal Passage Height

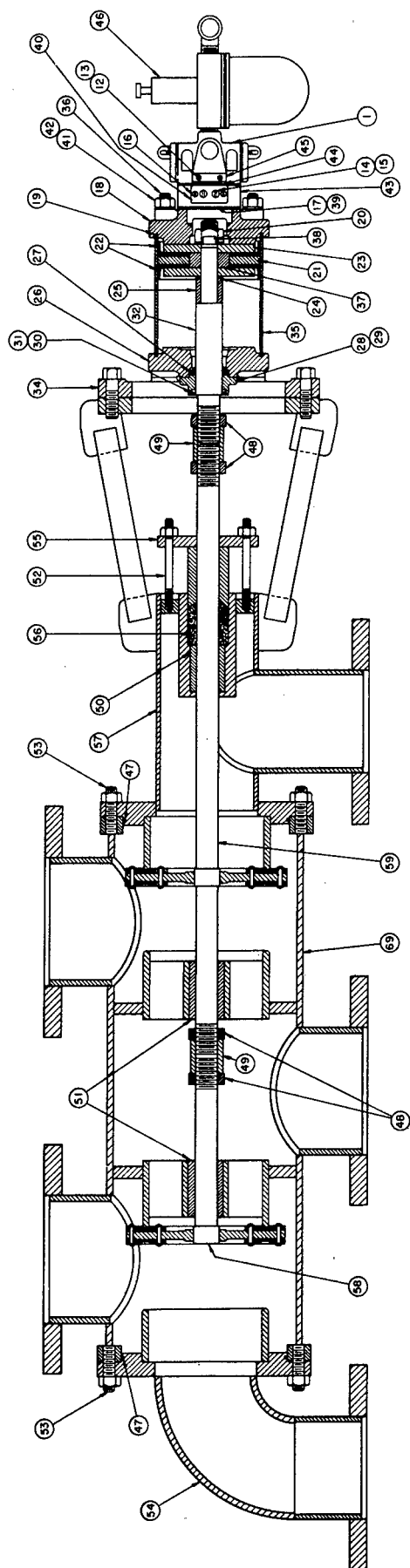


FIGURE 12
SWITCH VALVE ASSEMBLY

SWITCH VALVE ASSEMBLY LEGEND

- | | |
|----------------------|---|
| 1. Air Motor | 32. Piston Rod |
| 2. Screw | 33. Nut |
| 3. Ex Block | 34. Front Flange |
| 4. Piston Assembly | 35. Cylinder |
| 5. Screw | 36. Tie Rod |
| 6. Cover | 37. Spacer |
| 7. Screw | 38. Lockwasher |
| 8. Terminal Retainer | 39. Gasket |
| 9. Terminal Nut | 40. Screw Plate |
| 10. Valve Chest | 41. Washer |
| 11. Terminal | 42. Nut |
| 12. Lockwasher | 43. Exhaust Block |
| 13. Screw | 44. Gasket |
| 14. "O" Ring | 45. Conduit Bracket |
| 15. Adjustment Screw | 46. Air Line Lubricator, 1/2" IPS |
| 16. Screw | 47. "O" Ring Gasket, 1/8" w. x 7" I.D.
x 7-1/4" O.D. |
| 17. Gasket | 48. Locknut |
| 18. Rear Head | 49. Coupling |
| 19. Gasket | 50. Bearing, Oilite 1-1/2" O.D. x 2-1/2"
Long |
| 20. Nut | 51. Bearing, Oilite 1-1/2" O.D. x 2" Long |
| 21. Piston | 52. Stud |
| 22. Cup | 53. Stud |
| 23. Piston Plate | 54. Assembly of Elbow |
| 24. "O" Ring | 55. Packing Gland |
| 25. Spacer | 56. Packing, Style 115-AA |
| 26. Front Head | 57. Cylinder and Bearing Support |
| 27. Seal | 58. Upper Valve Plate |
| 28. Guide | 59. Lower Valve Plate |
| 29. Screw | 60. Shell Assembly |
| 30. Seal | |
| 31. Seal | |

Fins

Trane 1/8" Serrated
0.375" Nominal Height
15 Fins per Inch
0.008" Thickness
78" Effective Heat Transfer Length

Distribution

Provision is made for gas distribution at each end of a passage.

Headers

The headers are fabricated from standard 5 inch 3SF aluminum pipe.

Shell

External parting sheets and 1/4 inch protective pads are provided on each core, one on each side of 20-7/8 inch no flow (passage stack height).

Supports

Support boxes and angles are provided at each end of the core.

Material Thickness

Outside Core Sheets, Inches	.102
Parting Sheets, Inches	.032
Side Channels, Inches	.040
Top Header Channels, Inches	.064
Side Protection Fin, Inches	.024
Packing Fin, Inches	.008
Distributor Fin, Inches	.024 Perforated

Tests

The core is subjected to hydrostatic and air pressure tests to check for inter-passage and external leakage. The core is guaranteed to be satisfactory at a maximum working pressure of 100 PSIG.

COLD HEAT EXCHANGER

Description

The cold heat exchanger is a Trane Company brazed aluminum core type heat exchanger.

Specifications

Core Size

17" Passage Width over Channels
20-7/8" No Flow (passage stack height)
80-1/2" Core Length over Face Channels

Core Passages

50 Passages per Core are Headered into 3 Streams of 20, 20, and 10 passages respectively.

16-1/2" Width Inside Channels
0.375" Nominal Passage Height

Fins

Trane 1/8" Serrated
0.375" Nominal Height
15 Fins per Inch
0.008" Thickness
78" Effective Heat Transfer Length

Distribution

Provision is made for gas distribution at each end of a passage.

Headers

The headers are fabricated from standard 5" 3SF aluminum pipe.

Shell

External parting sheets and 1/4" protective pads are provided on each core, one on each side of 20-7/8" no flow (passage stack height).

Supports

Support boxes and angles are provided at each end of the core.

Material Thickness

Outside Core Sheets, Inches	.102
Parting Sheets, Inches	.032
Side Channels, Inches	.040
Top Header Channels, Inches	.064
Side Protection Fin, Inches	.024
Packing Fin, Inches	.008
Distributor Fin, Inches	.024 Per-
	forated

Tests

The core is subjected to hydrostatic and air pressure tests to check for interpassage and external leakage. The core is guaranteed to be satisfactory at a maximum working pressure of 100 PSIG.

AIR LIQUEFIER

Description

The air liquefier is a Trane Company brazed aluminum core type heat exchanger.

Specifications

Core Size

17" Passage Width over Channels
12-3/4" No Flow (passage stack height)
51-1/4" Core Length Over Face Channels

Core Passages

30 Passages per Core to be Headered into 2 Streams of 20 and 10 Passages.
16-1/2" Width Inside Channels
0.375" Nominal Passage Height

Fins

Trane 1/8" Serrated
0.375" Nominal Passage Height
15 Fins per Inch
0.008" Thickness
40-3/4" Effective Heat Transfer Length

Distribution

Provision is made for gas distribution at each end of a passage.

Headers

The headers are fabricated from standard 3 and 5 inch 3SF aluminum pipe.

Shells

External parting sheets and 1/4" protective pads are provided on each core, one on each side of 12-3/4" no flow (passage stack height).

Supports

Support boxes and angles are provided at each end of the core.

Material Thickness

Outside Core Sheets, Inches	.102
Parting Sheets, Inches	.032
Side Channels, Inches	.040
Top Header Channels, Inches	.064
Side Protection Fin, Inches	.024
Packing Fin, Inches	.008
Distributor Fin, Inches	.024 Per- forated

Tests

The core is subjected to hydrostatic and air pressure tests to check for inter-passage and external leakage. The core is guaranteed satisfactory at a maximum working pressure of 100 PSIG.

CHECK VALVE

Description

The check valve is manufactured by Air Products, Incorporated. It is a double poppet-type valve of stainless steel construction. In one end it has one 4" high pressure air outlet connection; in the opposite end, it has one 5" waste air inlet connection; and in the side, it has one 5" connection common to both the incoming high pressure air and the effluent waste air. The check valve measures approximately 14" in length and weighs approximately 125 pounds.

PHASE SEPARATOR

Description

The phase separator is manufactured by Air Products, Incorporated. It is provided with a tangential side air inlet connection, a top vapor outlet connection, and a bottom liquid outlet connection. In addition, the phase separator is provided with connections to accommodate a liquid level gage.

Specifications

Model	44166C
Material	Copper
Shell Length, Inches	24
Shell Diameter, Inches	8-1/8 O.D.
Shell Thickness, Inches	0.170
Head Diameter, Inches	8-1/8 I.D.
Head Thickness, Inches	1/4
Air Inlet Connection Size, Inches	3-1/8 O.D.
Vapor Outlet Connection Size, Inches	3-1/8 O.D.
Liquid Outlet Connection Size, Inches	5/8 O.D.
Upper Liquid Level Gage Connection Size, Inches	5/8 O.D.
Maximum Working Pressure, PSIG	100
Approximate Overall Length, Inches	32
Approximate Weight, lbs.	53

HYDROCARBON ADSORBER

Description

The hydrocarbon adsorber is an Air Products, Incorporated, silica gel type adsorber, Model No. 41510D. It consists of a pressure vessel, having top inlet and bottom outlet connections. The pressure vessel is charged with silica gel. It is provided with filters to keep foreign particles from entering and silica gel from leaving the adsorber.

Specifications

Pressure Vessel	
Material	Copper
Shell Length, Inches	36
Shell Diameter, Inches	8-1/8 O.D.
Shell Thickness, Inches	0.170
Head Diameter, Inches	8-1/8 I.D.
Head Thickness, Inches	1/4
Inlet Connection Size, Inches	5/8 O.D.
Outlet Connection Size, Inches	5/8 O.D.
Maximum Working Pressure, PSIG	15
Approximate Overall Length, Inches	46
Approximate Weight, Charged, lbs.	123
Adsorbent	
Material	Silica Gel
Size, Mesh	3-8

Density, lbs/Cu. Ft.
Quantity, Required, lbs.

38-40
42

Inlet Filter

Material	Porex Grade 1
Diameter, Inches	1-1/8 O.D.
Wall Thickness, Inches	1/8
Length, Inches	5-1/4

Primary Outlet Filter

Material	Alumina Tabular Balls
Ball Diameter, Inches	1/4
Quantity Required, Cu. Ft.	1/2

Secondary Outlet Filter

Material	Porex Grade 1
Diameter, Inches	1-1/8
Wall Thickness, Inches	1/8
Length, Inches	5-1/4

OXYGEN DISTILLATION COLUMN

Description

The distillation column is an Air Products, Incorporated column. It consists of a tube-type condenser and a low pressure column having a number of bubble-cap pans of conventional design. The high pressure side of the condenser is designed and fabricated for a maximum working pressure of 100 PSIG. The low pressure column, which is also the low pressure side of the condenser, has a maximum working pressure of 15 PSIG. The column is provided with connections, properly sized and located, to accommodate all of the required column feeds and offtakes. Sufficient pans are included in the low pressure column to ensure that the product liquid oxygen, when withdrawn from the column at a rate of two tons per day, shall be 99.5% pure when the air available to the oxygen generator is approximately 1000 standard cubic feet per minute, and when the material balances are as calculated in Section III of this report. The column is approximately 13-1/8 inches in diameter and 8 feet 6 inches high and weighs approximately 600 pounds, dry.

NITROGEN DISTILLATION COLUMN

Description

The distillation column is an Air Products, Incorporated column. It consists of a tube-type condenser and a high pressure column having a number of bubble-cap pans of conventional design. The high pressure column and high pressure side of the condenser are designed and fabricated for a maximum working pressure of 100 PSIG. The low pressure column and low pressure side of the condenser are designed and fabricated for a maximum working pressure of 15 PSIG. The column is provided with the necessary connections, properly sized and located to accommodate all of the required column feeds and offtakes. Sufficient pans are included in the high pressure column to insure that the product liquid nitrogen when withdrawn from the column at a rate of two tons per day shall be 99.0 percent pure, when the air available to the generator is approximately 1000 standard cubic feet per minute and when the material balances are as calculated in Section III of this report. The column

is approximately 13-1/8 inches in diameter, and 5 feet 6 inches high and weighs approximately 450 pounds, dry.

SUBCOOLER

Description

The subcooler is an Air Products, Incorporated extended-surface type heat exchanger, Model No. 41506C. In the subcooler, pure liquid flows through the tubes of the core while waste air gas flows around the tubes through the shell.

Specifications

Core

Material	Finned Copper Tube
Tube Size, IPS	3/4
Tube Length, Inches	60
Fin Height, Inches	1/2
Fin Orientation	Axial
No. of Fins per Circumference	18
No. of Tubes	7
Liquid Inlet Connection Size, Inches	7/8 O.D.
Liquid Outlet Connection Size, Inches	7/8 O.D.
Maximum Working Pressure, PSIG	15

Shell

Material	Copper
Length, Inches	75
Diameter, Inches	6-1/8 O.D.
Thickness, Inches	0.140
Head Diameter, Inches	6-1/8 I.D.
Head Thickness, Inches	0.187
Waste Air Inlet Connection Size, Inches	3-1/8 O.D.
Waste Air Outlet Connection Size, Inches	3-1/8 O.D.
Maximum Working Pressure, PSIG	15

Approximate Overall Length, Inches	91
Approximate Weight, lbs.	154

TURBO EXPANDER

Description

The turbo expander is an Air Products, Incorporated high-speed, centrifugal, expander equipped with an air loaded energy absorber complete with lubrication system. (See Figure 13 for sectional view of Expansion Turbine.)

Specifications

The turbo expander is designed, built, and guaranteed to operate satisfactorily under the following conditions:

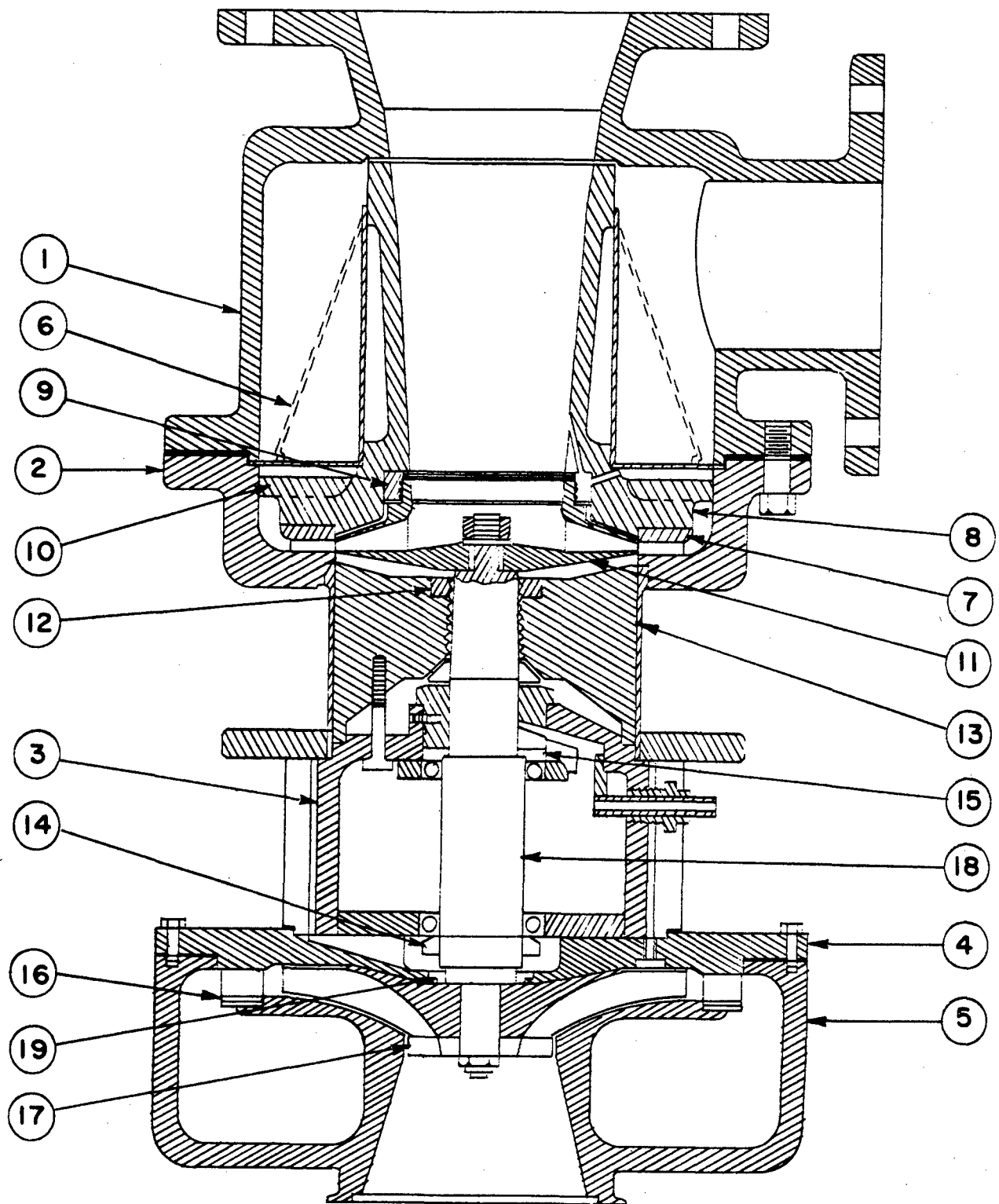


FIGURE 13
EXPANSION TURBINE (SECTIONAL VIEW)

EXPANSION TURBINE (SECTIONAL VIEW) LEGEND

- | | |
|--------------------------|-------------------------------|
| 1. Manifold Housing | 10. Outer Seal Keeper |
| 2. Turbine Housing | 11. Turbine Wheel Assembly |
| 3. Bearing Housing | 12. Inner Labyrinth Ring |
| 4. Manifold Flange | 13. Labyrinth Seal Assembly |
| 5. Manifold Air Loader | 14. Locknut Assembly |
| 6. Inlet Screen Assembly | 15. Oil Retainer |
| 7. Turbine Nozzle Ring | 16. Diffuser |
| 8. Nozzle Ring Support | 17. Compressor Wheel Assembly |
| 9. Outer Labyrinth Seal | 18. Shaft |
| | 19. Seal |

Fluid	Air
Flow Rate, lb/Min.	54.6
Inlet Pressure, PSIA	112
Exhaust Pressure, PSIA	21
Inlet Temperature, °F	-240
Exhaust Temperature, °F	-306
Approximate Weight, lbs.	160

EXPANDER LOADER

Description

The expander loading device consists of a centrifugal impeller keyed to the expander shaft. The impeller rotates at the same speed as the expander wheel and imparts the shaft energy to the fluid being pumped. The amount of power which is absorbed is proportional to the quantity and density of the pumped fluid. This can be controlled by a butterfly valve on the discharge line of the air loader.

LIQUID PRODUCT PUMPS AND DRIVE MOTORS

Description

The liquid product pumps are Air Products, Incorporated horizontal, reciprocating-plunger type. The pumps are driven through a crank-and-connecting rod mechanism by electric motors through a gear reduction. The pumps are provided with thermal breaks which will allow the pump drive mechanisms to operate at atmospheric temperature while the pump cylinders are at the temperature of the liquid product being pumped. The pump capacities are controlled by variation of the pump stroke. (See Figure 14 for sectional view of Pump Motor.)

Specifications

Pump

Delivery, CFH gas Equivalent	2000
Plunger Diameter, Inches	5/8
Stroke, Inches	Variable up to 3
Speed, RPM	100
Intake Pressure, PSIG	7
Discharge Pressure, PSIG	4000

Motors

5 horsepower, 220/440 volts, 3 phase, 60 cycle, squirrel-cage induction, ball bearing, horizontal, open, 40° rise, continuous duty, normal torque, low starting current, with 100 RPM American Gear Manufacturers' Association Class III, helical gears hand matched for minimum back lash and quiet operation.

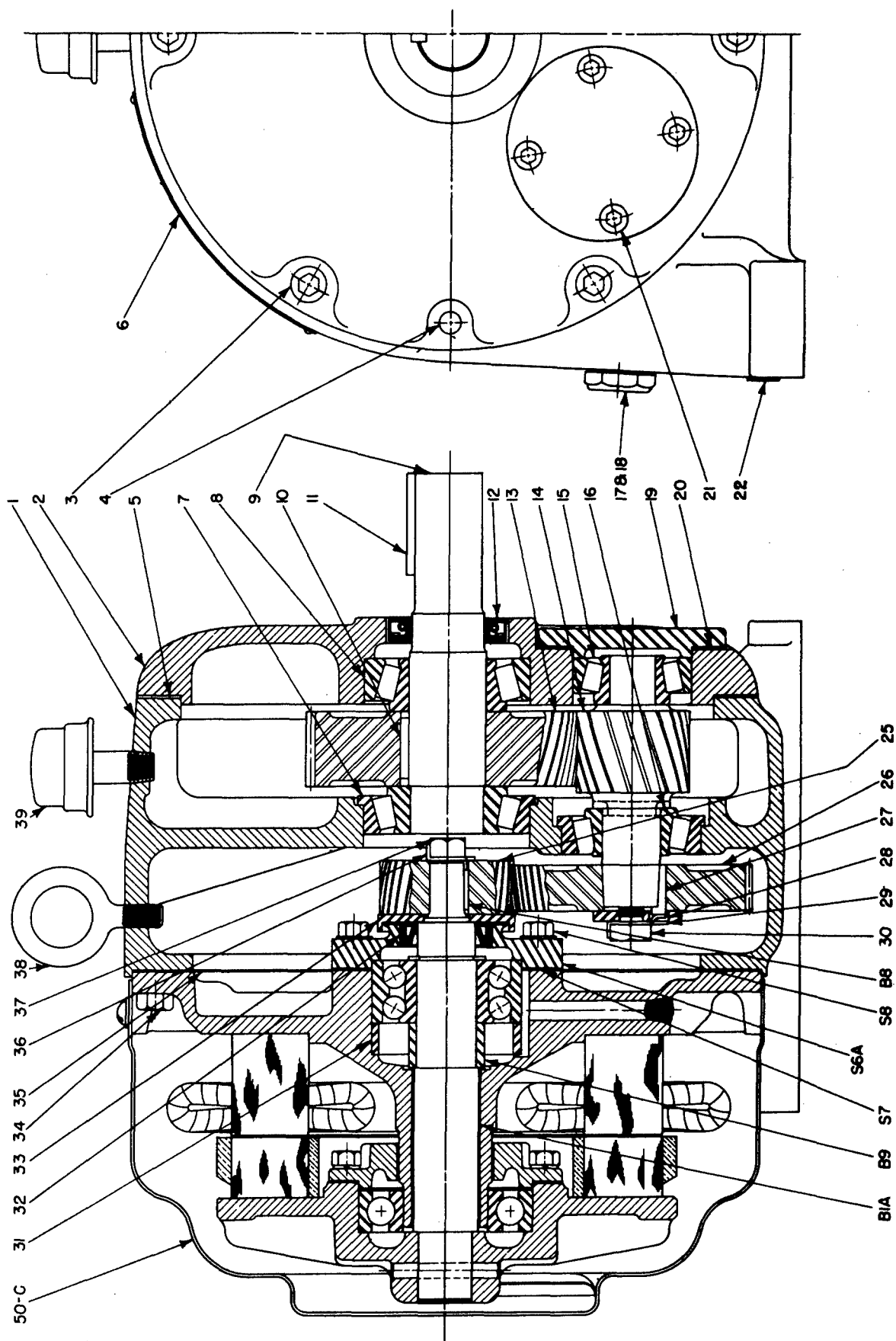


FIGURE 14
PRODUCT PUMP MOTOR (SECTIONAL VIEW)

PRODUCT PUMP MOTOR (SECTIONAL VIEW) LEGEND

- | | |
|---|---|
| 1. Housing | 21. Intermediate Shaft Closure Screws, 3/8"-16 x 1" |
| 2. Housing Cover | 22. Drain Plugs, 3/8" Pipe Plug |
| 3. Housing Cover Screws, 1/2"-13 x 1-1/4" | 25. High Speed Pinion |
| 4. Taper Dowel Pins, #6 x 3/4" | 26. High Speed Gear |
| 5. Cover Shims | 27. High Speed Gear Key |
| 6. Motor Gear Nameplate | 28. High Speed Gear Retaining Washer |
| 7. Low Speed Shaft Inner Bearing Complete | 29. High Speed Gear Locking Washer |
| 8. Low Speed Shaft Outer Bearing Complete | 30. High Speed Gear Locking Screw, 5/8"-18 x 7/8" |
| 9. Low Speed Shaft | 31. Stator Bearing Spacer |
| 10. Low Speed Gear Key | 32. Motor Shaft Oil Seal, Model 63 |
| 11. Low Speed Shaft Key | 33. Motor Shaft Oil Slinger |
| 12. Low Speed Shaft Dust Seal | 34. Motor Frame Screws, 3/8"-16 x 1" |
| 13. Low Speed Gear | 35. Motor Gasket |
| 14. Low Speed Pinion & Intermediate Shaft | 36. High Speed Pinion Locking Washer |
| 15. Intermediate Shaft Outer Bearing Complete | 37. High Speed Pinion Locking Screw or Nut |
| 16. Intermediate Shaft Inner Bearing Complete | 38. Eyebolt |
| 17. Oil Window | 39. Breather |
| 18. Oil Level Plug, 3/4"-14 Pipe Plug | B1A Motor Shaft |
| 19. Intermediate Shaft Closure | B8 High Speed Pinion Key |
| 20. Intermediate Shaft Closure Shims | B9 Shaft Collar |
| | S6A Motor Stator Bearing Closure |
| | S7 Stator Bearing Closure Gasket |
| | S8 Stator Bearing Closure Screw |

OXYGEN-NITROGEN VAPORIZER

Description

The oxygen-nitrogen vaporizer is manufactured by Air Products, Incorporated. It is a tube type heat exchanger consisting of copper coils mounted on the warm air side of the first stage intercooler and third stage aftercooler cooling fan discharge. The pure high pressure product flows through the copper coils while the warm air flows around the tubes.

Specifications

Coils

Material	Copper
Overall Coil Length, Feet	450
Tube Diameter, Inches	3/8 O.D.
Wall Thickness, Inches	0.10
Maximum Working Pressure, PSIG	4000
Approximate Overall Length, Inches	56

ALTERNATING-CURRENT GENERATOR

Specifications

The alternating-current generator has the following characteristics: 33.3 KVA, 120/208 volts, 3 phase, 4 wire, 60 cycle, .8 power factor, 1800 RPM, synchronous, horizontal, ball bearing, drip-proof, self-excited by direct connected exciter, windings of generator and exciter are moisture and fungus proof.

The alternating-current generator has a shaft extension suitable for a V-belt drive and is complete with a solid adjustable base or slide rails.

HYDROCARBON ADSORBER REACTIVATION HEATER

Description

The hydrocarbon adsorber reactivation heater is an Air Products, Incorporated resistance heater, Model No. 3144C. It consists of two heating elements, the resistance heating coils of which are imbedded in compacted magnesium oxide which is contained within a grounded, chrome-steel sheath. Each element is rated at 1 kilowatt at 230 volts alternating current single phase. The two elements are connected in open-delta for the three phase circuit. The maximum allowable sheath temperature is 1400 to 1500°F.

INTERCONNECTING PIPING

Description

The interconnecting piping is of as lightweight material as practical. It is adequately strong for the service intended and is sized to keep pressure losses within tolerable limits. Operating conditions such as temperature, pressure, loca-

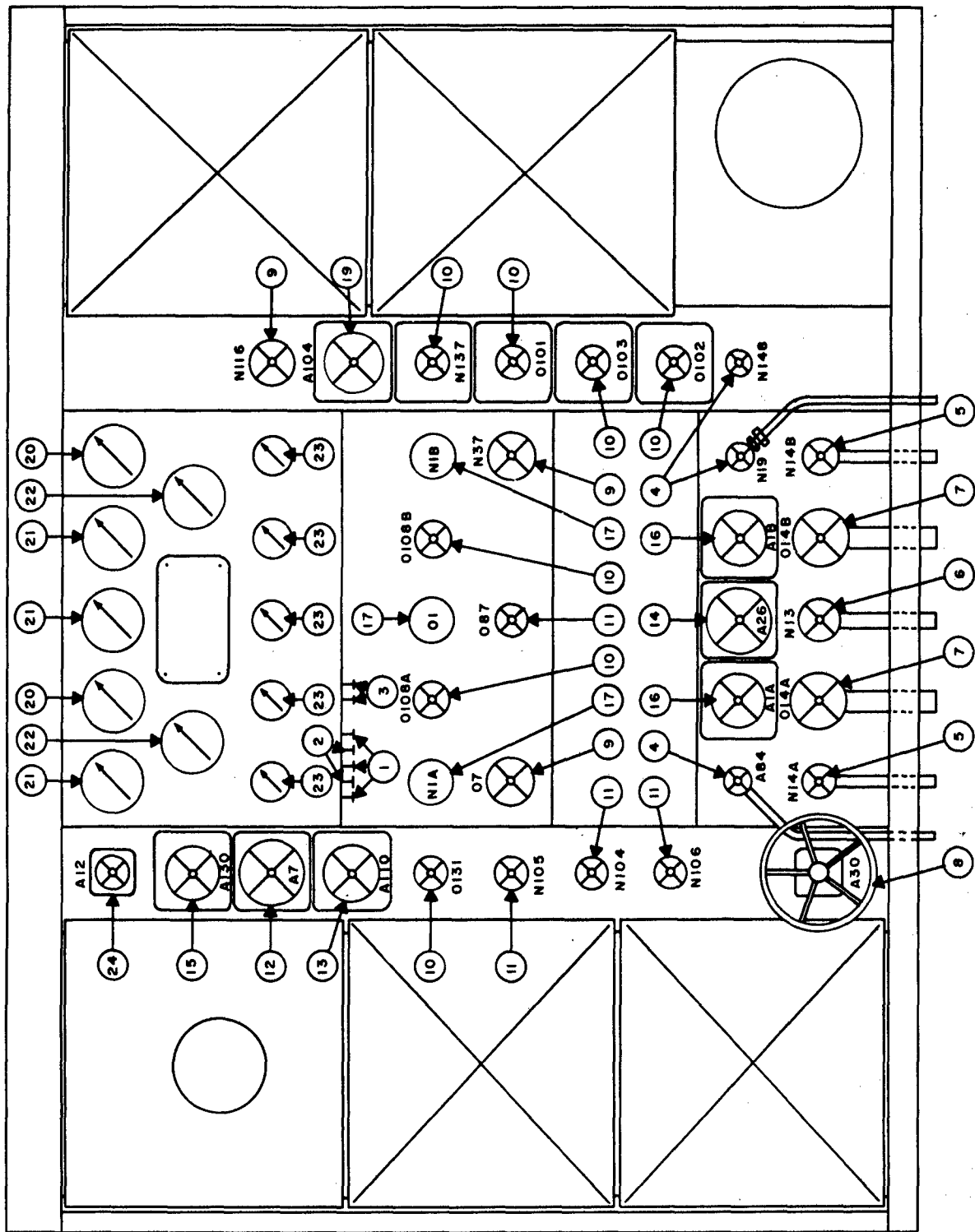


FIGURE 15
CONTROLS, FRONT OF COLD COMPARTMENT

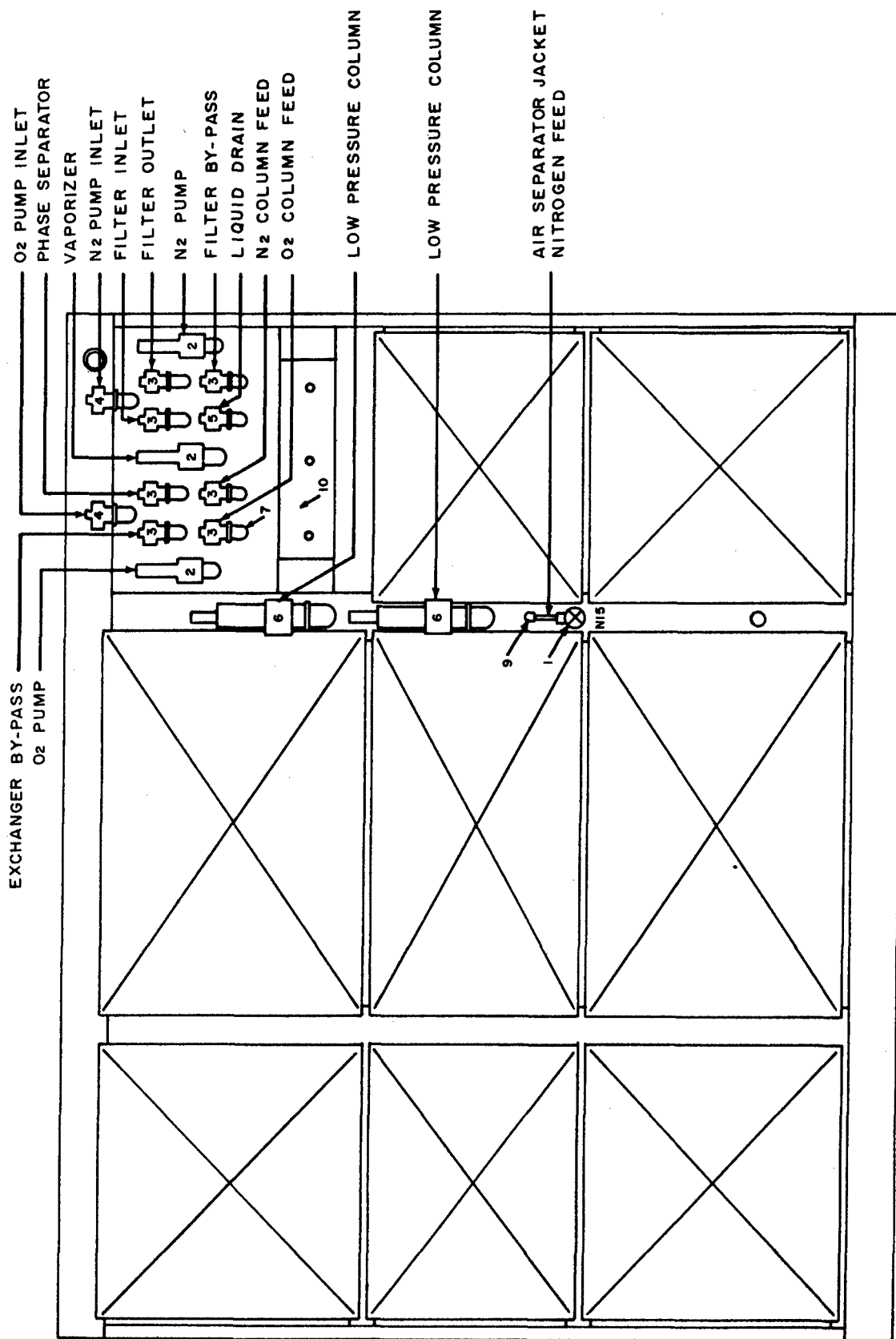


FIGURE 16
CONTROLS, REAR OF COLD COMPARTMENT

CONTROLS, FRONT OF COLD COMPARTMENT - LEGEND

- | | |
|---|--|
| 1. Valve, Brass, Globe, 1/8" FNPT | 11. Valve Assembly - O87, N104, N105, N106 |
| 2. Valve, Brass, Angle, 1/8" FNPT | 12. Valve Assembly - A7 |
| 3. Valve, St. Steel, 3/8" FNPT, 4000# | 13. Valve Assembly - A110 |
| 4. Valve, Bronze, Angle, 1/2" FNPT | 14. Valve Assembly - A26 |
| 5. Valve, Bronze, Angle, 3/4" FNPT | 15. Valve Assembly - A130 |
| 6. Valve, Bronze, Angle, 1" FNPT | 16. Expansion Valve - A1A, A1B |
| 7. Valve, Bronze, Angle, 1-1/2" FNPT | 17. Expansion Valve - N1A, N1B, O1 |
| 8. Handwheel, Indicating, 25/64" Dia. Hole, 1-1/2" Deep, Two Set Screws 90 Degrees Apart, 12 Turn Dial to Read Counterclockwise | 18. Bulkhead - Front |
| 9. Expansion Valve - O7, N37, N116 | 19. Valve Assembly - A104 |
| 10. Valve Assembly - O131, N137, O101, O102, O103, O108A, O108B | 20. Pressure Gage - 0 to 30 pounds |
| | 21. Pressure Gage - 0 to 160 pounds |
| | 22. Pressure Gage - 0 to 5000 pounds |
| | 23. Liquid Level Gage - 0 to 50" water |
| | 24. Extension Stem Assembly - A12 |

CONTROLS, REAR OF COLD COMPARTMENT - LEGEND

- | | |
|--|---|
| 1. Valve, Angle, Brass, 1/4" FNPT 200# | 5. Pop Safety Valve, Oxygen, 1/2" IPS Male Inlet, Set 15 PSIG |
| 2. Safety Relief Valve, 1/2" Oxygen Gas, Brass Body, Spring Chamber and Cap, Type 316 Internal Parts Set 4350 PSIG | 6. Pop Safety Valve, Oxygen, 2-1/2" IPS Male Inlet, Set 15 PSIG |
| 3. Pop Safety Valve, Oxygen, 1/2" IPS Male Inlet, Set 125 PSIG | 7. Cover Sheets |
| 4. Pop Safety Valve, Oxygen, 1/2" IPS Male Inlet, Set 100 PSIG | 8. Rear Bulkhead Structure |
| | 9. Nipple Details |
| | 10. Thermal Break Assembly |

tion and application dictated the choice of the material used. Every piping circuit of the liquid product generator is protected against excess pressure by means of pop safety valves.

AIR SEPARATOR INSTRUMENT PANEL

Description

The air separator instrument panel is fabricated by Air Products, Incorporated. It supports pressure gages, liquid level gages, and temperature indicators which serve as operating aids for the liquid oxygen generator. The instrument panel and its supports are fabricated of steel. Its measurements are approximately 30 inches long by 37 inches wide. The following instruments are flush mounted and readily accessible and demountable for service, if necessary. (See Figures 15 and 16.)

High Pressure Column Pressure Gages
Low Pressure Column Pressure Gages
High Pressure Product Pressure Gages

Phase Separator Liquid Level Gage
High Pressure Column Liquid Level Gages
Low Pressure Column Liquid Level Gages

ELECTRICAL CONTROL PANEL

Description

The electrical controls are contained within a National Electrical Manufacturers' Association Type 1 enclosure, and all visual indicators and manual controls are flush mounted on the face of the enclosure cover. The electrical controls consist of the following: power distribution circuit breakers, an indoor switchgear unit complete with an alternating current voltmeter, ammeter, current transformer, and all controls necessary for alternating-current generator operation. The indicating pyrometer and selector switch for the air separator temperature is mounted on this panel (see Figure 3).

INSULATION

Description

The fiberglass insulation for the air separator is Owens-Corning Fiberglass Corporation Basic Fiber No. 28, Type E. The entire air separator section (cold box) is packed with this fiberglass. All cold piping is mounted on low conductivity material to minimize heat leaks into the cold box.

SECTION VI

FABRICATION

The fabrication of this unit presented no special problems because of the experience gained in the fabrication of approximately 500 liquid oxygen or liquid nitrogen generators. The pumping requirements were more severe than normal, but did not present any problems in either design fabrication or installation of the pumps or pumping system. All construction design methods and materials for all parts of the unit were selected for the lightest possible end item without sacrificing dependability and strength.

All purchased components were built to Air Products, Incorporated specifications as listed in the Equipment Specifications, Section V of this handbook, and were carefully checked and tested for compliance to these specifications.

No special fixtures were used in the fabrication of this unit other than those normally used in the fabrication of a liquid and gas, oxygen-nitrogen generator.

Extreme care was taken in the selection and fabrication of the piping and fittings, especially the high pressure product pumping system. All piping circuits were pressure tested and inspected for leaks. The procedure for this leak and pressure test is to pressurize the piping circuit being tested with dry nitrogen at 1-1/2 times the working pressure and soaping the outside surface to check for leaks. Each individual component such as the heat exchangers, columns, pumps, phase separator, hydrocarbon adsorber, etc. is pressure tested prior to assembly at 1-1/2 times the working pressure.

The high pressure pumping circuit was hydrostatically tested at 4500 PSIG, since an air test at this pressure would be dangerous to personnel. After successfully passing the hydrostatic test the lines were blown free of moisture with dry nitrogen.