ENGINEERING STANDARD

FOR

PROCESS DESIGN OF COMPRESSED AIR SYSTEMS

CONTENTS :

APPENDICES:

0. INTRODUCTION

"Process Design of Utility Systems for OGP Processes" are broad and contain subjects of paramount importance. Therefore a group of IPS Standards are prepared to cover the subject.

The Process Engineering Standards of this group includes the following Standards:

Standard Codes	Standard Titles
IPS-E-IN-200	"Instrument Air Systems"
IPS-E-PR-310	"Process Design of Water Systems"
IPS-E-PR-320	"Process Design of Steam and Condensate Systems"
IPS-E-PR-330	"Process Design of Production and Distribution of Compressed Air Systems"
IPS-E-PR-340	"Process Design of Fuel Systems"
IPS-E-EL-100	"Electrical System Design (Industrial & Nonindustrial)"
IPS-E-PR-460	"Process Design of Flare and Blowdown Systems"
IPS-E-PR-350	"Process Design of Inert Gas Systems"
IPS-E-SF-120, 140, 160, 180, 200, 220, 240 & 380	"Fire Fighting Systems"

This Standard covers: "Process Design of Production and Distribution of Compressed Air Systems".

This Engineering Standard titled as "Process Design of Production and Distribution of Compressed Air Systems" is intended to cover the process requirement and design guide for plant and instrument air systems as applicable to OGP industries.

1. SCOPE

This Process Engineering Standard specifies the minimum requirements for the process design of compressed air system for OGP industries.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard . The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor:

API (AMERICAN PETROLEUM INSTITUTE)

API 672 "Packaged, Internally Geared Centrifugal Air Compressors for General Refinery Services", 2nd. Ed., April 1988.

API 680 "Packaged Reciprocating Plant and Instrument Air Compressors for General Refinery Services", 1st. Ed., October 1987.

IPS (IRANIAN PETROLEUM STANDARDS)

IPS-E-IN-200 "Instrument Air Systems"
IPS-E-GN-100 "Units"
IPS-E-PR-400 "Process Design of Cooling Water Circuits"
IPS-E-PR-440 "Process Design of Piping Systems (Process Piping & Pipelines), Parts 1-4.
IPS-E-PR-740 "Process Design of Pumps"
IPS-E-PR-745 "Process Design of Vacuum Equipment (Vacuum Pumps and Steam Jet Ejectors)"
IPS-E-PR-750 "Process Design of Compressors"
IPS-E-PR-755 "Process Design of Fans and Blowers"
IPS-E-PR-760 "Process Design of Steam Turbines"
IPS-E-PR-765 "Process Design of Expanders"
IPS-E-PR-880 "Process Design of Gas (Vapor)-Solid Separators"
IPS-E-PM-100 "General Design Requirements of Machineries"
IPS-M-PM-170 "Centrifugal Compressors for Process Services"
IPS-M-PM-190 "Axial Flow Centrifugal Compressors"
IPS-M-PM-200 "Reciprocating Compressors for Process Services"
IPS-M-PM-210 "Reciprocating Compressors for Utility and Instrument Air Services"
IPS-M-PM-220 "Positive Displacement Compressors, Rotary"

3. DEFINITIONS AND TERMINOLOGY

The definition of terms herein used, are in accordance with API Std. 672, Section 1.3; API "Glossary of Terms used in Petroleum Refining", ANSI / ASME B 19.1 C and "Safety Standard for Air Compressor Systems" Section 1.4; and CAGI "Compressed Air and Gas Handbook", item dew point, however selective items are defined hereunder:

3.1 Dry-Bulb Thermometer

AN ordinary thermometer, especially that one of the two similar thermometers of a psychrometer whose bulb is unmoistened.

3.2 Dry Gas

A gas which does not contain fractions that may easily condense under normal atmospheric condition.

3.3 Dew Point (Air)

Dew point is the temperature at which condensate will begin to form if the air is cooled at constant pressure. At this point, the relative humidity is 100 percent.

3.4 Standard Cubic Meter Per Hour (Sm^3/h)

Refers to the flow rate at any location corrected to a pressure of 101.325 kPa and a temperature of 15°C with a compressibility factor of 1.0 and in a dry condition.

3.5 Normal Cubic Meters per Hour (Nm^3/h)

Refers to capacity at normal conditions (101.325 kPa & 0°C) and relative humidity of 0 percent.

3.6 Normal Operating Point

Is the point at which usual operation is expected and optimum efficiency is desired. This point is usually the point at which the vendor certifies that performance is within the tolerances stated in this standard.

3.7 Relative Humidity

The ratio of actual pressure of existing water vapor to maximum possible pressure of water vapor in the atmosphere at the same temperature, expressed as a percentage.

3.8 Standard Air

Air at 20°C dry bulb temperature, 50 percent relative humidity, and 101.325 kPa, which has a density of 1.201 kg per cubic meter.

3.9 Wet-Bulb Temperature

The temperature taken on the wet-bulb thermometer, the one whose bulb is kept moist while making determinations of humidity. Because of cooling that results from evaporation, the wet bulb thermometer registers a lower temperature than the dry bulb thermometer.

3.10 Aftercooling

Involves cooling of air in a heat exchanger following the completion of compression to:

a) reduce the temperature; and,
b) liquefy condensate vapors.

3.11 Intercooling

The cooling of air between stages of compression:

a) to reduce the temperature;
b) to reduce volume to be compressed in the succeeding stage;
c) to liquefy condensable vapors; and,
d) to save energy.

3.12 Inlet Pressure

The lowest air pressure in the inlet piping to the compressor, may be expressed as either gage pressure or absolute pressure.

3.13 Inlet Temperature

The air temperature at the inlet flange of the compressor.

4. UNITS

International System of Units (SI) in accordance with IPS-E-GN-100 shall be used.

5. COMPRESSED AIR SYSTEMS

5.1 General

5.1.1 A compressed air system may consist essentially of one or more compressors with a power source,control system, intake air filter, aftercooler and separator, air receiver, air dryer, and inter connecting piping, plus a distribution system to carry the air to points of application.

5.1.2 The object of installing a compressed air system shall be to provide air to the various points of application in sufficient quantity and quality and with adequate pressure for efficient operation of air tools or other pneumatic devices.

5.1.3 Before attempting to determine the amount of compressed air required, an investigation shall be made of all likely as well as known air applications.

5.1.4 It is important that this study shall include in addition to immediate applications, anticipated future uses as well, since the availability of compressed air always leads to new applications.

5.2 Design

5.2.1 Establishing the required compressed air capacity

5.2.1.1 The total air requirement is the sum of the plant air and instrument air inclusive of contingency for each category.

5.2.1.2 The plant air requirements should not be designed for coincident operation. Optimum schedule for overhaul, regeneration, decoking, etc. shall be considered when arriving at the total capacity of the complex.

5.2.1.3 A rough estimate of probable air requirements can be made based on Table C.1 in Appendix C, represents a typical air requirement of one refinery.

5.2.1.4 Air for steam-air decoking requirement should be considered based on furnace tube size and as an estimation it can be 10 percent of steam flow or 2.93 kg/s.m^2 of furnace tube.

5.2.1.5 The total air requirement for pneumatic devices should not be the total of the individual maximum requirement but the sum of the average air consumption of each.

5.2.1.6 Sufficient air storage to meet short-term high demands should also be available.

5.2.1.7 Determination of the average air consumption is faciliated by the use of the concept of the load factor.

5.2.1.8 The ratio of actual air consumption to the maximum continuous full-load air consumption, each measured in cubic meter of air per hour, is known as the load factor.

5.2.1.9 Pneumatic devices are generally operated only intermittently and are often operated at less than full load capacity.

5.2.1.10 It is essential that the best possible determination or estimate of load factor be used in arriving at the plant capacity needed.

5.2.1.11 Two items are involved in the load factor, the first is the time factor, which is the percentages of the total work time during which a device is actually in use. The second is the work factor, which is the percentage of air for maximum possible output of work per hour that is required for the work actually being performed by the device. The load factor is the product of time factor and work factor.

5.2.1.12 A brief compilation of maximum air requirements of various tools is shown as a guide in Table C.2 of Appendix C. It shall be used for preliminary estimates, but tool and compressor manufacturers shall be consulted in the final design.

5.2.1.13 If air requirements of a manufacturing process are evaluated on a basis of unit production in cubic meters of free air (standard air) per piece produced, they shall then be combined on the basis of total production to arrive at the average rate of air required.

5.2.1.14 For determination of m^3/h* required for various tools, the procedure shall be as below:

a) number of tools (A),
b) load factor (product of time factor and work factor) (B),
c) m^3/h per tool when operating (C).

Total m^3/h required if all tools operated simultaneously = $\sum_{1}^{n} (A) \times (C)$

*** m^3/h is cubic meters of free air (standard air) per hour.**

Total m^3/h actually used = $\sum_{1}^{n} \frac{(A) \times (B) \times (C)}{100}$

Note:

Total m^3/h actually used should be considered for required compressor sizing.

5.2.1.15 The capacity of dry air system should be established by requirement of the instrument system.

5.2.1.16 The instrument air requirement customarily, should be considered about 1.6 Sm^3/h of dry air for each instrument pilot in process units.

5.2.1.17 The total requirement of instrument air would be varied with types of process facilities and instruments installed.

5.2.1.18 Table C.3 of Appendix C represents a typical air requirements for various instruments.

5.2.1.19 Typical refinery process units air requirement is shown in Table C.4 of Appendix C.

5.2.2 Selecting the size and number of compressors

5.2.2.1 In sizing and number of compressors, the following features shall be considered:

1) total actual air requirement;
2) estimated leakage of the air system;
3) spare & operational philosophy;

4) criticality of air supply;
5) energy management;
6) optimum size based on market availability.

5.2.2.2 Air compressors of the rotary design usually require less downtime and should be considered when making selection.

5.2.2.3 Air leakage of the compressed air system, customarily should be considered about 10 percent to the estimated amount of consumption.

5.2.3 Locating the compressors

5.2.3.1 The efficiency of larger compressors is generally higher than that of smaller machines. However smaller air-cooled machines may be more economical and especially advantageous for variable demand situations.

5.2.3.2 The cost of standby equipment should be weighed against the value of production losses, where compressed air is used in regular operation of the plant and any shutdown may be very costly.

5.2.3.3 The centralized system, has several inherent advantages. A good location may be selected where clean, cool air can be taken in. A separate compressor room should be justified in which the equipment can be protected from dirt and where control of maintenance should be relatively simple.

5.2.3.4 Water and electricity are needed only at the central compressor room rather than multiples throughout the plant.

5.2.3.5 In centralized system Noise may be better isolated or reduced.

5.2.3.6 In centralized system, auxiliary equipment and controls may be provided, which could not be justified economically in smaller, multiple unit installations.

5.2.4 Non lubricated air compressors

5.2.4.1 Reciprocating, nonlubricated air compressors substitute low friction or self lubricating materials such as carbon or teflon for piston and packing rings, where the piston is usually supported on wear rings of similar materials.

5.2.4.2 Oil free rotary screw and lobe-type compressors are available, having a design that does not require lubrication in the compression chamber for sealing and lubrication.

5.2.4.3 Centrifugal air compressors are inherently nonlubricated due to their configuration.

5.2.4.4 Generally, nonlubricated compressors have a higher initial cost due to the special design and materials.

5.2.4.5 Nonlubricated reciprocating air compressors also tend to have higher operating costs due to higher maintenance cost associated with shorter valve and ring life.

5.2.5 Regulation of compressed air

Regulation of compressed air system shall be as per Standard IPS-E-PR-750, "Process Design of Compressors".

5.2.6 Compressor selection

Compressor selection shall be as per Standard IPS-E-PR-750, "Process Design of Compressors".

In addition the following Process Machineries Standards shall be considered as complementary:

IPS-E-PM-100	"Design General Requirements of Machineries"
IPS-M-PM-170	"Centrifugal Compressors for process Services"
IPS-M-PM-190	"Axial Flow Centrifugal Compressors"

IPS-M-PM-200 "Reciprocating Compressors for Utility and Instrument Air Services"
IPS-M-PM-220 "Positive Displacement Compressors, Rotary".

5.2.7 Automatic warning and shutdown systems

5.2.7.1 An automatic warning and shutdown system should be considered for installation with most air compressors for a complete reliable air system.

5.2.7.2 Compressor shutdown should be scheduled to occur at a preset point after a warning condition is reached.

5.2.7.3 Some conditions, such as low oil pressure or excessive vibration, shall demand immediate shutdown.

5.2.7.4 Protective control systems employing shutdown without indication, which merely drops out the holding coil of the motor starter, shall be usually warranted only on very small compressors.

5.2.8 Compressed-air distribution system

Any drop in pressure between the compressor and the point of use is an unrecoverable loss. The distribution system is therefore one of the most important elements of the compressed air plant. In planning it, the following general rules should be observed:

5.2.8.1 Pipe sizes should be large enough that the pressure drop between the plot limits of air compression and consumer units does not exceed 10 percent.

5.2.8.2 Where it is possible, a loop system around the plant within each shop and building is recommended. This gives a two-way distribution to the point where air demand is greatest. The loop pipe should be made large enough that the pressure drop will not be excessive at any outlet regardless of the direction of flow around the loop.

5.2.8.3 Long distribution lines, including those in a loop system, should have receivers liberal size located near the far ends or at points of occasional heavy use. Many peak demands for air are of short duration, and storage capacity near such points avoids excessive pressure drop and may permit the use of smaller compressor. Certain applications such as starting diesel engines or gas turbines are examples of this type of demand where the required rate may exceed the total compressor capacity.

5.2.8.4 Each header or main should be provided with outlets as close as possible to the point of application. This permits the use of the shorter hose lengths and avoids large pressure drops through the hose. Outlets should always be taken from the top of the pipe line to prevent carry-over of condensed moisture to tools.

5.2.8.5 All piping should be sloped so that it drains toward a drop leg or moisture trap in order that condensation may be removed to prevent its reaching air-operated devices in which it would be harmful. The slope of lines should always be away from the compressor to prevent flow back into the compressor cylinder. A slope of about (2.0 mm/m) may be used, with drains provided at all low points. These may consist of a short pipe with a trap or drain at the bottom. All branches taken from the compressor discharge line shall be from the top of the header.

5.2.8.6 For systems using only oil-free compressor, it is strongly recommended that corrosion-resistant pipe be used. Unlike a system using lubricated compressors in which an oil film will form to protect the pipe from the corrosive effect of the moisture in the warm air, a non lubricated system will experience corrosion.

This corrosion can lead to contamination of products and control systems.

5.2.9 Air storage (air receiver)

5.2.9.1 A liberal "ASME" Air Receiver should be provided for the system.

5.2.9.2 The receiver serves several important functions. It damps pulsations from the discharge line, resulting in essentially steady pressure in the system. It serves as a reservoir to take care of sudden or unusually heavy demands in excess of compressor capacity. It prevents too frequent loading and unloading of the compressor. In addition, it serves to precipitate some of the moisture that may be present in the air, as it comes from the compressor or that may be carried over from the aftercooler. The horizontal receiver should be so sloped that the collected water in the receiver moves toward the pot under the receiver for better drainage. The slope should be 2 mm/m.

5.2.9.3 The time interval which receiver can supply air without excessive drop in pressure shall be found from the equation:

$$T = V\frac{P_1 \quad P_2}{C.Po} \qquad \text{(Eq. 1)}$$

Where:

T is time, hours;
P_1 is initial receiver pressure, kPa (ga);
P_2 is final pressure, kPa (ga);
P_0 is atmospheric pressure, kPa (abs);
C is air requirement, standard cubic meters of air per hour;
V is receiver capacity, m^3.

This equation assumes that the temperature of the receiver is constant at standard atmospheric temperature and that P_0 is standard atmospheric pressure. It also assumes that no air is supplied to the receiver during the time interval. If air is being supplied steadily to the receiver at a rate of S cubic meters of free air per hour, then C in the equation should be replaced by C minus S.

5.2.10 Inlet and discharge piping

5.2.10.1 Air inlet

5.2.10.1.1 A clean, cool, dry air should be supplied for plant & instrument air compressor.

5.2.10.1.2 The compressor inlet should be taken from outside air.

5.2.10.1.3 The filter should take air from at least 2m or more from the ground or roof and should be located a few meters away from any wall to minimize the pulsating effects on the structure.

5.2.10.1.4 The air inlet shall always be located far enough from steam, gas, or oil engine exhaust pipes to ensure that the air will be free from dust, dirt, moisture and contamination by exhaust gases.

5.2.10.1.5 Silencer shall be provided according to noise limitation.

5.2.10.1.6 Heating facilities shall be provided where icing is expected.

5.2.10.2 Inlet piping

5.2.10.2.1 The inlet piping should be as short and direct as possible, with long-radius elbows where bends are necessary.

5.2.10.2.2 The inlet piping should be the full diameter of the intake opening of the compressor.

5.2.10.2.3 If the inlet pipe is extremely long a larger size shall be used.

5.2.10.2.4 For large reciprocating compressors, the air inlet can be located on the bottom of the cylinder with the inlet piping located below the floor level.

5.2.10.2.5 It is essential that underground piping be watertight, as the lower pressure within the pipe tends to draw leakage into the system.

5.2.10.2.6 For centrifugal compressors, the air piping shall be arranged for best performance to achieve uniform air velocity over the entire area of the compressor inlet. To attain this condition, there should be a run of straight pipe prior to the compressor inlet, with a length equivalent to about four diameters.

5.2.10.2.7 It is frequently necessary to reduce the inlet-pipe diameter to match a centrifugal compressor inlet flange of lesser diameter. Where such conversion is necessary,the transition shall be gradual.

5.2.10.3 Air filters

Air compressors handle large volumes of air over a period of time. Air-borne contamination that would otherwise seem insignificant can accumulate to a significant amount, the proper location of the inlet air source or inlet pipe can, to a great extent, minimize the amount of debris in the inlet air. However, it should be the job of the air filter to keep the quantity of abrasive materials that the air compressor would normally take in within acceptable limits.

5.2.10.3.1 For the best air filter selection a compromise among a number of variables such as filter design, compressor requirements, and atmospheric conditions shall be made. Dry type filters shall be selected.

5.2.10.3.2 Filters shall provide a high degree of efficiency,to remove approximately 99 percent of particles larger than 10 μm (micron) and 98 percent or better of particles larger than 3 μm (micron).

5.2.10.3.3 Dry type filters shall have some means of monitoring the air pressure drop through the element as an indicator of element contamination.

5.2.10.3.4 Depending on housing configuration, size and element material, a clean element pressure drop of 75 to 200 mm of water (735 to 1960 Pa) is typical.

5.2.10.4 Discharge piping

5.2.10.4.1 The discharge piping is considered to be the piping between the compressor and the aftercooler, the aftercooler separator, and the air receiver.

5.2.10.4.2 The discharge pipe shall be the full size of the compressor outlet or larger, and it shall run directly to the aftercooler if one is used.

5.2.10.4.3 If an aftercooler is not used, the discharge pipe shall run directly to the receiver, the latter shall be set outdoors, and as close to the compressor as is practical.

5.2.10.4.4 The discharge pipe shall be as short and direct as possible, with long-radius elbows where bends are necessary, and shall have as few fittings, as possible.

5.2.10.4.5 Unnecessary pockets shall be avoided.

5.2.10.4.6 If the design can not avoid pockets between the compressor and the aftercooler or receiver, it shall be provided with a drain valve or automatic trap to avoid accumulation of oil and water mixture in the pipe itself.

5.2.10.4.7 If the discharge line is more than 30m long, pipe of the next larger diameter than that calculated shall be used throughout.

5.2.10.4.8 Piping after the air receiver will have accessories dictated by the application (dryers for oil-free air) pre-separators, afterseparators for the dryers, and so on.

5.2.10.4.9 The installation of a safety valve between the aftercooler and the compressor discharge piping shall be considered.

5.2.10.4.10 If designer desires to install a shut off valve between the separator and the receiver, installation of a suitable safety valve between the compressor and the valve shut off point is mandatory.

5.2.10.4.11 A method of bleeding the air pressure from the system between the shutoff valves and the compressor discharge shall be required. This may consist of a simple plug valve located in the piping between these two points.

5.2.10.4.12 To detect possible clogging of aftercooler tubes, a means of monitoring the discharge pressure between the aftercooler and compressor discharge shall be provided.

5.2.10.4.13 For centrifugal compressor, if it is necessary to increase the pipe diameter just beyond the compressor discharge flange, this transition shall be gradual.

5.2.10.4.14 The main header size for plant air shall not be less than DN 80 (3 inch). (See Table B.1 in Appendix B).

5.3 Refinery Air System

5.3.1 Design

5.3.1.1 General

5.3.1.1.1 In the design of refinery air system the required quantities and pressures for plant, instrument and other air systems must be determined, and standby and crossover provision should be provided.

Specifications and capacities should be established for compressors, inter-and aftercoolers, receiver vessels, and air dryers when required. Air-distribution system between compressor locations and offsite users must be provided. These air facilities are frequently included within refinery utility plant limits to simplify airdistribution systems.

5.3.1.1.2 Air outlets should be provided in all areas requiring air such as for air driven tools, exchangers, both ends of heaters, compressor area,top platform of reactors and on columns, so that each manway can be serviced with 15 meters hose.

5.3.1.1.3 Discharge check valves on air compressor shall be installed as near to the compressor as possible.

5.3.1.1.4 Moisture content of air should be considered in plant & instrument air design (see attached Appendix A).

5.3.1.1.5 A typical schematic flow diagram of compressed air system of refinery is presented in Fig. D.1 in App. D.

5.3.1.2 Plant air

5.3.1.2.1 Air compressor(s) should be provided in addition to the available main air compressor(s) as emergency spare, to supply separately, air for user in the process. Additionally a separate compressor shall be supplied for regeneration of hydrocracker and similar units.

This compressor will be also used as spare for the main air compressors.

5.3.1.2.2 Units using air in the process, shall have their own supply of air. Tie into the refinery air header may be also considered for small users.

5.3.1.2.3 For further information about plant air see Section 5.2.1.

5.3.1.3 Instrument air

5.3.1.3.1 Instrumentation shall be provided so that the spare unit will start automatically in the event of failure of running unit, and/or excessive demand.

5.3.1.3.2 Instrumentation shall be provided, so that the supply of instrument air has always the first priority and the spare unit(s) will start automatically in the event of failure of running unit(s) and/or excessive demand.

5.3.1.3.3 Instrument air pressure typically should be kept at 700 kPa (ga).

5.4 Air Dryers

5.4.1 Design

5.4.1.1 Performance

5.4.1.1.1 This equipment will dry compressed air having 100% relative humidity to the stipulated dew point, and shall be durable for continuous operation under the specified pressure, humidity and flow rate.

5.4.1.1.2 The design dew point for instrument air shall be more than 10°C below the lowest recorded outside temperature under the line pressure. The design dew point for plant air shall be of lowest ambient recorded outside temperature under the line pressure.

5.4.1.2 Desiccant type dryer

5.4.1.2.1 The continuous operating time of one desiccant drum shall not be less than 8 hours under the specified conditions. However, based on ultimate life and other parameters, the operating time shall be optimized.

5.4.1.2.2 The dryer has two desiccant drums, regeneration equipment, instrumentation, piping and other accessories. While one desiccant drum is being operated, the other drum will be automatically regenerated.

5.4.1.2.3 When using an electric heater for regeneration integrated into the desiccant drum, this heater shall be capable of being maintained without affecting dryer operation.

5.4.1.3 Instrumentation

5.4.1.3.1 Operation control of the dryer shall be fully automatic control. Switching valves should not block the air flow in their failure unless an automatic back-up bypass valve across the dryer is installed.

5.4.1.3.2 Control panels shall be provided as follows:

a) a local control panel for the air dryer shall be employed;
b) the control panel shall be equipped with necessary instrument for monitoring operation of the air dryer.

5.4.1.4 Air filter

5.4.1.4.1 An air prefilter with a drain trap shall be installed at the entrance of the desiccant drum.

5.4.1.4.2 An air after-filter with a drain valve shall be installed at the exit of the dryer system. For the desiccant type dryer, the filter mesh shall be less than 3 micrometers (microns).

5.4.1.4.3 Measures shall be provided so that the flow of air will not stop even in the case of replacement or cleaning of the filter elements.

5.4.1.5 Performance characteristics

The following characteristics shall be guaranteed:

5.4.1.5.1 Inlet/outlet air flow rate.

5.4.1.5.2 Dew point of outlet air.

5.4.1.5.3 Drying and regeneration cycle time.

5.4.1.5.4 Pressure drop through the dryer including air filters.

6. PACKAGED UNITS

Whenever use of packaged units are to be made, API Standards 672 and 680, shall be considered for centrifugal and reciprocating compressors.

APPENDICES

APPENDIX A

1. MOISTURE CONTENT OF THE AIR

1.1 General

1.1.1 All air contains moisture, the amount being influenced by pressure,temperature and proximity to oceans, lakes and rivers.

1.1.2 Condensed water vapor can have corrosive effects on metals and wash out protective lubricants from tools and other pneumatic devices. To protect against such undesirable effects in a compressed air system, the use of various types of air drying systems has become increasingly popular.

1.1.3 Relative Humidity and dew point are two methods of indicating the amount, of moisture in the air.

1.2 Effect of Pressure & Temperature on Relative Humidity

1.2.1 Table A.1 lists the water content of air in milliliters per one cubic meter at various temperatures and relative humidities.

1.2.2 Pressure has a major effect on the vapor content in air. The capacity of air at a given temperature to hold moisture in vapor form decreases as the pressure increases. Table A.2 lists the water content of saturated air (relative humidity 100 per cent) at given temperatures and pressures.

TABLE A . 1
WATER CONTENT OF AIR IN MILLILITERS PER ONE CUBIC METER AT ATMOSPHERIC PRESSURE

RH %	TEMPERATURE °C									
	2	5	10	15	20	25	30	35	40	45
5	.26	.33	.47	.65	0.89	1.21	1.62	2.16	2.84	3.67
10	.53	.66	.92	1.30	1.79	2.43	3.25	4.32	5.68	7.37
15	.79	0.99	1.39	1.95	2.68	3.65	4.90	6.52	8.56	11.11
20	1.07	1.33	1.86	2.60	3.57	4.87	6.55	8.71	11.46	14.90
25	1.34	1.67	2.33	3.26	4.48	6.10	8.21	10.92	14.38	18.71
30	1.60	2.00	2.80	3.91	5.38	7.34	9.86	13.14	17.32	22.57
35	1.87	2.33	3.26	4.56	6.28	8.57	11.54	15.37	20.29	26.47
40	2.11	2.67	3.73	5.22	7.19	9.81	13.21	17.62	23.27	30.41
45	2.41	3.00	4.20	5.89	8.11	11.06	14.90	19.88	26.29	34.39
50	2.67	3.34	4.67	6.54	9.01	12.31	16.59	22.16	29.32	38.40
55	2.94	3.67	5.13	7.20	9.93	13.56	18.30	24.44	32.38	42.46
60	3.21	4.01	5.60	7.86	10.84	14.82	20.00	26.75	35.47	46.55
65	3.48	4.35	6.07	8.52	11.75	16.08	21.71	29.06	38.58	50.69
70	3.75	4.69	6.55	9.19	12.67	17.35	23.43	31.39	41.71	54.88
75	4.02	5.02	7.02	9.85	13.60	18.62	25.16	33.74	44.87	59.11
80	4.28	5.36	7.48	10.52	14.52	19.89	26.90	36.10	48.05	63.38
85	4.56	5.70	7.97	11.19	15.45	21.17	28.64	38.46	51.26	67.71
90	4.83	6.04	8.47	11.86	16.38	22.46	30.41	40.86	54.50	72.07
95	4.93	6.37	8.90	12.52	17.31	23.74	32.16	43.25	58.03	76.49
100	5.37	6.71	9.38	13.20	18.24	25.03	33.93	45.67	61.04	80.94

TABLE A . 2
WATER CONTENT OF SATURATED AIR IN MILLILITERS PER ONE STANDARD CUBIC METER

kPa(ga)	TEMPERATURE °C									
	2	5	10	15	20	25	30	35	40	45
0	5.37	6.71	9.38	13.20	18.24	25.03	33.93	45.67	61.04	80.94
68.9	3.18	3.97	5.56	7.79	10.74	14.69	19.83	26.52	35.16	46.15
137.9	2.25	2.81	3.94	5.53	7.61	10.40	14.00	18.68	24.69	32.27
206.8	1.75	2.18	3.06	4.29	5.90	8.05	10.83	14.43	19.02	24.81
275.8	1.43	1.79	2.50	3.49	4.82	6.56	8.82	11.75	15.47	20.15
344.7	1.22	1.51	2.11	2.95	4.06	5.53	7.44	9.90	13.04	16.97
413.7	1.05	1.30	1.83	2.56	3.52	4.79	6.43	8.56	11.26	14.65
482.6	0.93	1.14	1.61	2.25	3.09	4.22	5.67	7.54	9.92	12.90
551.6	0.82	1.04	1.44	2.01	2.77	3.77	5.06	6.73	8.86	11.51
620.5	0.75	0.93	1.31	1.82	2.50	3.42	4.58	6.09	9.00	10.39
689.5	0.68	0.85	1.19	1.66	2.29	3.11	4.18	5.55	7.29	9.47
758.4	0.62	0.78	1.09	1.52	2.10	2.87	3.85	5.10	6.70	8.71
827.4	0.58	0.72	1.02	1.41	1.95	2.64	3.55	4.72	6.21	8.05
896.3	0.54	0.67	0.95	1.32	1.81	2.46	4.22	4.39	5.77	7.48
965.3	0.50	0.63	0.88	1.23	1.69	2.30	3.09	4.11	5.40	7.00
1034.2	0.48	0.59	0.83	1.16	1.58	2.16	2.90	3.86	5.07	6.57
1103.2	0.45	0.55	0.77	1.09	1.50	2.04	2.74	3.63	4.77	6.19
1172.1	0.42	0.53	0.73	1.04	1.42	1.93	2.59	3.43	4.51	5.85
1241.	0.40	0.50	0.69	0.97	1.34	1.83	2.45	3.26	4.28	5.55
1310	0.38	0.47	0.67	0.93	1.28	1.73	2.33	3.10	4.07	5.28
1379	0.37	0.45	0.64	0.87	1.21	1.66	2.22	2.95	3.87	5.03

1.2.3 Temperature itself has a significant effect on the ability of air at a given pressure to hold moisture. The higher the air temperature is, the greater its capacity to hold water vapor. Conversely, as the air temperature is lowered, its capacity to hold water vapor is decreased, measured in terms of relative humidity .

1.2.4 Figure A.1 illustrates the ability of air to hold water vapor at various temperatures while maintaining a constant pressure. It will be noted that as the temperature decreases the quantity of water vapor that can be held decreases, but the relative humidity remains constant. However,when the volume is reheated,its ability to hold moisture is increased; but since the excess moisture has been drained off, no additional moisture is available. The relative humidity therefore, decreases.

1.2.5 An illustration of pressure effect on vapor content and relative humidity is shown in Fig. A.2

1.3 Effect of Temperature & Pressure on Dew Point

A more useful term than relative humidity for indicating of the condition of water vapor in a compressed air system is dew point.

The dew point is the temperature at which condensate will begin to form if the air is cooled at constant pressure. At this point,the relative humidity is 100 per cent.

1.3.1 It should be noted that as air leaves a compressor it is under both an elevated pressure and elevated temperature. A delicate balance exists under this condition since air under pressure has less capacity for water vapor, whereas air at elevated temperatures has a greater capacity for water vapor.

1.3.2 The air leaving the compressor is generally saturated and any reduction in air temperature will cause water to begin to condense inside the downstream piping .

ILLUSTRATIVE EXAMPLE 1

The 7.29 ml moisture content for saturated air (see Fig. A.1) can be determined from Table A.2 at the intersection of the 40 deg. C column and 689.5 kPa(ga) row. The moisture content for 25 deg. C and 5 deg. C air at 689.5 kPa(ga) can also be determined in the same manner.

As the air temperature is increased from 5 deg. C to 40 deg. C, it again has the ability to hold 7.29 mL. However, since the excess moisture has been drained away, only 0.85 mL of moisture remain. The relative humidity is therefore reduced to (0.85/7.29) × 100 or 11.66 percent.

ILLUSTRATIVE EXAMPLE 2

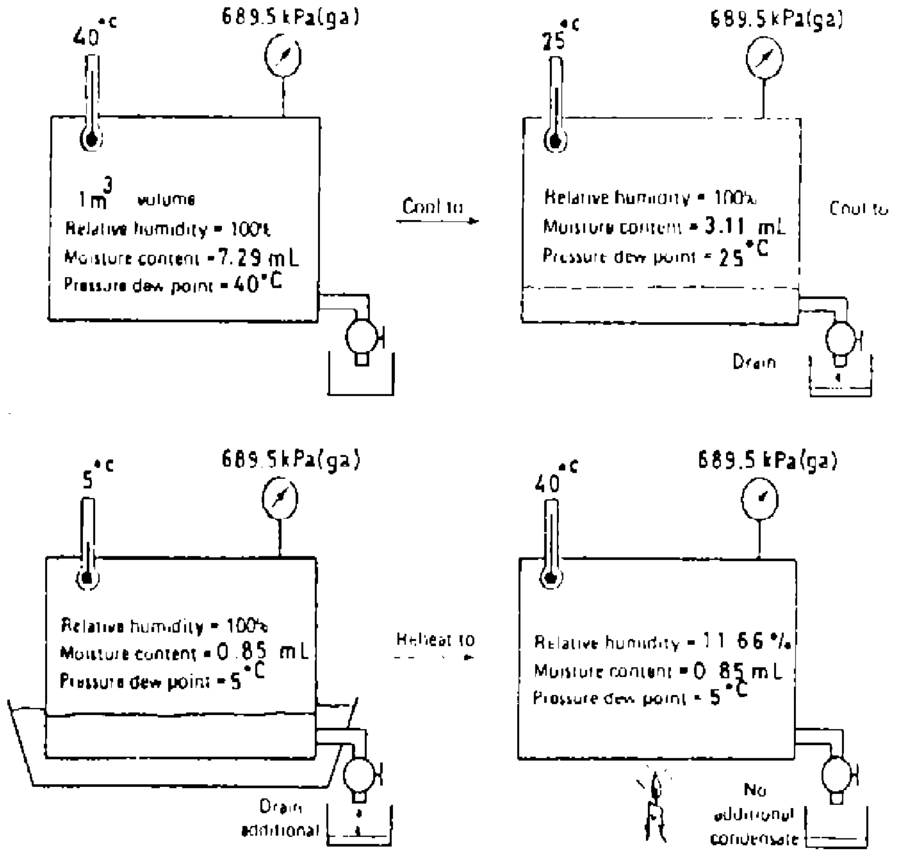
The amount of water vapor in 0.1 m^3 of air at 80 per cent relative humidity and 25 deg. C was determined from Table A.1:

(19.89) ¢ $\frac{0.1}{1}$ = 1.989 mL (see Fig. A.2a).

Now, if air is compressed from 0.1m^3 to 0.01m^3 (Fig. A.2b),the pressure is increased to 912 kPa(ga) (from relation $P_1.V_1 = P_2.V_2$). That $P_1.V_1$ equals original pressure and volume, and P_1,P_2 must be stated as absolute pressures for calculation purposes. At 912 kPa(ga) and 25 deg. C, the 0.01m^3 volume of air can hold only 0.0242 mL (refer to Table A.2: $\frac{0.01}{1}$ ¢ 2.42).

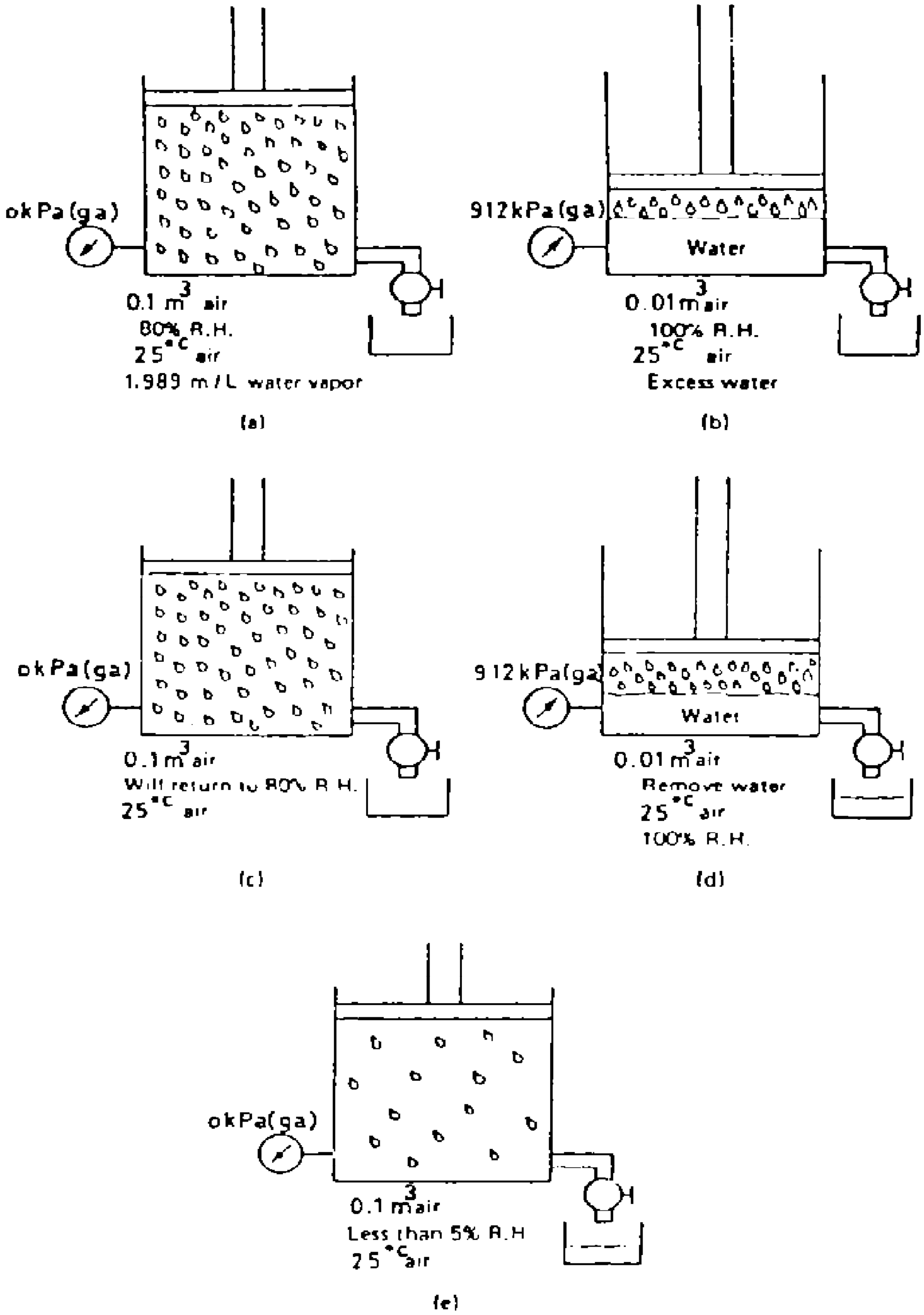
Since there were 1.989 mL in the air but it can now hold only 0.0242 mL, the excess moisture will condense. If the condensed water is not removed (see Fig. A. 2c) and pressure is reduced to atmospheric, the excess water will gradually evaporate back into the air until an equilibrium is established. This will happen because the air under this condition can again hold 1.989 mL of water vapor. If the condensed water is removed as shown in Fig. (A. 2d) and the pressure again reduced as shown in Fig. (A. 2e), the excess water will not be available for evaporation back into the air. The water vapor content of 0.1 m^3 of air will then be 0.0242 mL, which was the maximum vapor content that 0.01 m^3 of air hold at 25 deg. C and 912 kPa (ga).

The 0.0242 mL per 0.1 m^3 thus determined is 0.242 mL per 1 m^3 . Referring to Table A.1, it will be seen that the 0.242 mL per 1 m^3 is less than any quantity listed for 25 deg. C. Therefore, the relative humidity is less than 5 percent.



HOW TEMPERATURE INFLUENCES THE CAPACITY OF AIR TO HOLD WATER VAPOR, THE PRESSURE REMAINING CONSTANT

Fig. A.1



HOW CHANGE IN PRESSURE AFFECTS MOISTURE CONTENT OF AIR AT CONSTANT TEMPERATURE

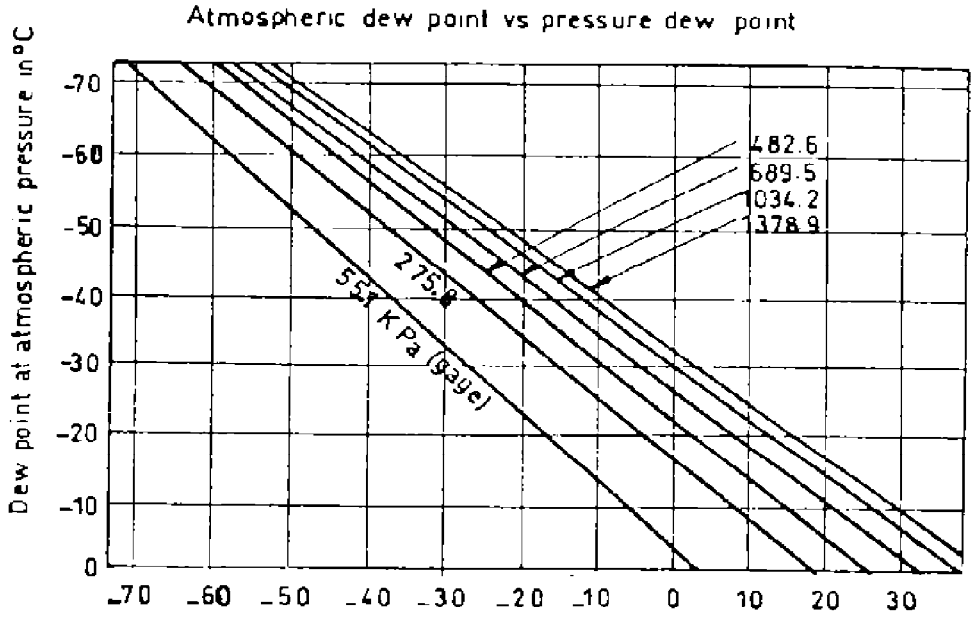
Fig. A.2

1.3.2 Pressure Dew Point

1.3.2.1 Refrigerant dryers are rated at pressure dew points, whereas desiccant dryers have been traditionally rated at atmospheric dew points. However, there is a trend toward rating desiccant dryers at the pressure dew point as well.

1.3.2.2 A pressure dew point temperature is more meaningful, since it indicates the temperature at which water vapor will begin to condense inside a pipeline at a given pressure.

1.3.2.3 For reference purposes, pressure dew points can be converted to atmospheric dew points by use of the graph shown in Fig. A. 3.



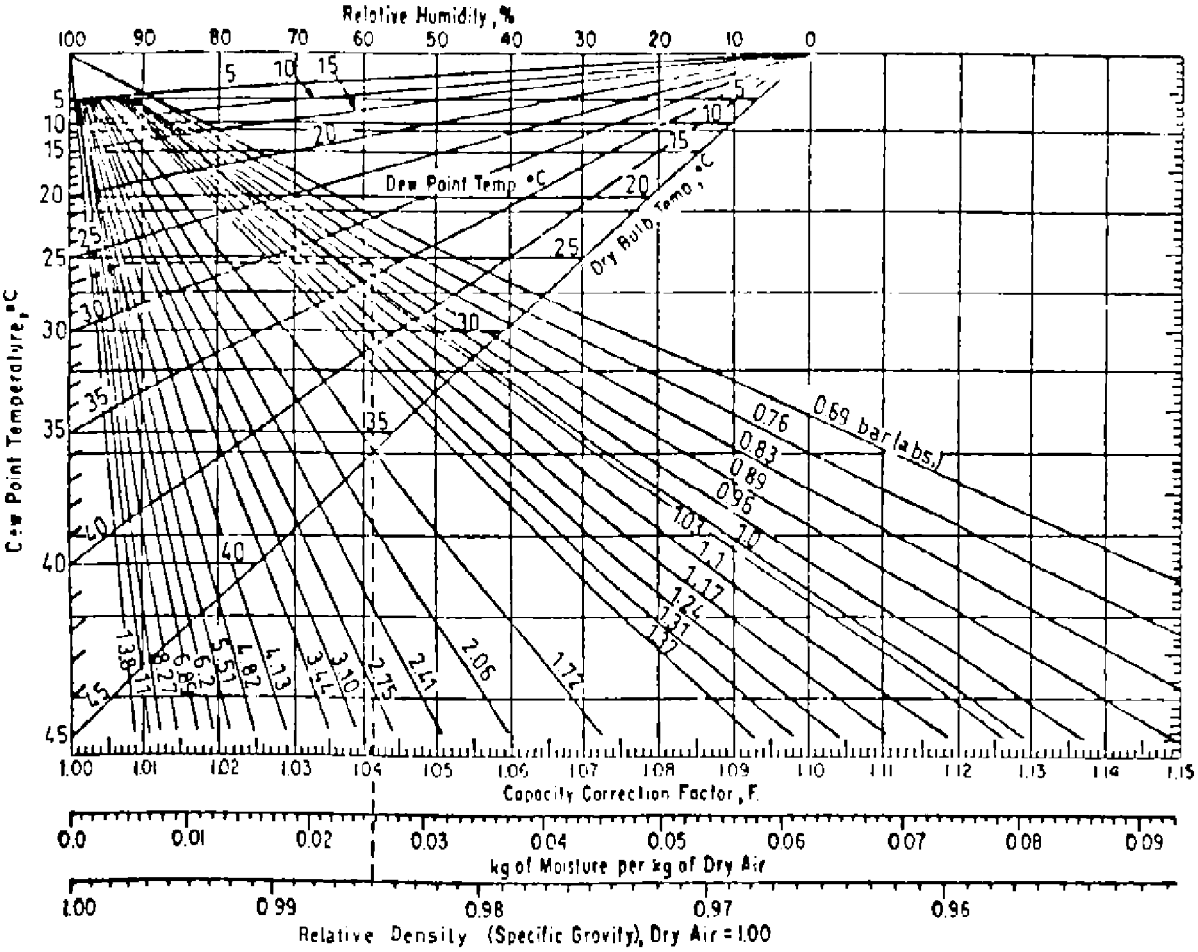
DEW POINT AT ELEVATED PRESSURE IN °C
Fig. A.3

1.4 Effect of Moisture on Air Compressor Intake Capacity

1.4.1 When establishing intake capacity for air compressors, the moisture content of the air shall be taken into account.

1.4.2 It is not always necessary or desirable to assume that the air is saturated, however, this is the maximum condition with respect to water content.

1.4.3 Intake air temperature shall be selected with some recognition of maximum-minimum-normal for summer conditions. Figure A.4 is convenient for reading air condition. Example 3 represents the sample calculation of using Fig. A. 4.



AIR PROPERTIES COMPRESSION CHART
Fig. A.4

EXAMPLE 3 A plant air system requires 17000 Sm^3/h of dry air. The air is required at 6.89 bar abs. Intake conditions are: Atmospheric pressure at location =0.89 bar (abs.) (89 kPa abs)

Temp.= 27°C

Relative humidity =92%

Aftercooler : Water used can cool air to 23.9°C

Pressure at this point =6.89 bar abs. (689 kPa abs).

SOLUTION: Referring to Fig. A.4, follow dashed line starting at left hand scale at dry bulb temperature 27°C. Follow up and to the right to intersection with vertical relative humidity of 92%, follow across to intersection with inlet pressure of 0.89 bar (abs)and read vertically down:

Moisture capacity correction	F= 1.0412
kg. water vapor/kg. dry air	= 0.026
Relative density (specific gravity) of air-water vapor mixture	= 0.985

At aftercooler conditions, the dry bulb equals the wet bulb temperature (air is saturated):

Wet bulb = dry bulb temperature = 23.9°C

Pressure = 6.89 bar (abs), (690 kPa abs)

kg. water /kg. dry air = 0.003

Dry air capacity at inlet $= 17000 \frac{(1.013)}{0.89} ¢ \frac{(300)}{288.5}$ =20120 m^3/h

Atmospheric air required = (1.0412)(20120) =20949 m^3/h

Specific volume of moist air, Vm $= \frac{R}{MW} ¢ \frac{P}{T(S_p . G_r)}$

Where:

R = 8.314 kJ/kmol.K

P = kPa (abs)

T = K

MW = 28.69 kg/kmol/

Or:

V_m = 0.286 (T_1)/(Sp. Gr)(P_1)

= 0.286(300)/(0.985)(89)

= 0.978 m^3 moist air /kg

Mass of moist air = 20949/0.978 = 21420.2 kg/h

Mass of dry air $= \frac{21420.2}{(1.0412)(0.985)} =$ 20885.9 kg/h

Mass of water vapor entering compressor = 21420.2-20885.9 = 534.3 kg/h

Leaving :

Mass of water leaving in air from aftercooler = 20885.9 (0.003) = 62.7 kg/ h

Mass of water condensed = 534. 3 - 62 .7 = 471.6 kg/h

APPENDIX B
PIPE COMPONENTS-DEFINITION OF NOMINAL SIZE

1. DEFINITION

Nominal size (DN): A numerical designation of size which is common to all components in a piping system other than components designed by outside diameters or by thread size. It is a convenient round number for reference purposes and is only loosely related to manufacturing dimensions.

Notes:

1) It is designated by DN followed by a number.

2) It should be noted that not all piping components are designated by nominal size, for example steel tubes are designated and ordered by outside diameter and thickness.

3) The nominal size DN cannot be subject to measurement and shall not be used for purposes of calculation.

The purpose of this Appendix is to present an equivalent identity for the piping components nominal size in SI System and Imperial Unit System.

TABLE B.1
PIPE COMPONENT-NOMINAL SIZE

Nominal Size		Nominal Size		Nominal Size		Nominal Size	
DN (1)	NPS (2)	DN	NPS	DN	NPS	DN	NPS
6	¼	100	4	600	24	1100	44
15	½	125	5	650	26	1150	46
20	¾	150	6	700	28	1200	48
25	1	200	8	750	30	1300	52
32	1¼	250	10	800	32	1400	56
40	1½	300	12	850	34	1500	60
50	2	350	14	900	36	1800	72
65	2½	400	16	950	38		
80	3	450	18	1000	40		
90	3½	500	20	1050	42		

1) Diameter nominal, mm.

2) Nominal pipe size, inch.

APPENDIX C

TABLE C.1 - TYPICAL REFINERY AIR REQUIREMENT DATA (COMPLEXITY FACTOR = 7)

@ 1325 Sm^3/h (200,000 bbl/sd) CRUDE CHARGE		
A. NORMAL PROCESS CONSUMPTION		
ITEM		S m^3/h
INSTRUMENTS, ALL PLANTS		2875
ASPHALT PLANT		*
PLANT AIR, ALL PLANTS		2550

		5425
B. REGERENRATION & DECOKING AIR REQUIREMENTS		
	UNIT DESIGN CAPACITY Sm^3/h	
CRUDE HEATER	663	480
VACUUM HEATER	324	186
PLATFORMER CATALYST	111	120
UNIFINER CATALYSTS	111	420
VISBREAKER HEATER	126	247
ISOMAX CATALYST	119	6800
NITROGEN PLANT	1700 (N_2 PRODUCT)	850
LUBE UNIT HEATER, i. e.,		231
PROPANE DEASPHALTING	25	
FURFURAL	48	

*** Air requirement for asphalt plant oxidizer air would be produced by separate system, (about 51-85 m^3 air per ton asphalt feed at 207 kPa (ga) like air blower, compressor, etc.**

Note:

Installed three compressors each of 6796 Sm^3/h.

(to be continued)

APPENDIX C (continued)
TABLE C.2 - TYPICAL AIR REQUIREMENTS OF VARIOUS TOOLS

TOOL	FREE AIR m^3/h AT 620 kPa (ga.) 100% LOAD FACTOR
GRINDER 152.4 mm and 203.2 mm WHEELS	85
GRINDER 50.8 mm and 63.5 mm WHEELS	24-34
FILE AND BURR MACHINES	31
ROTARY SANDERS, 228.6 mm PADS	90
ROTARY, SANDER, 177.8 mm PADS	51
SAND RAMMERS AND TAMPERS	
25.4 mm × 101.6 mm CYLINDER	42
31.75 mm × 127 mm CYLINDER	48
38.1 mm × 152.4 mm CYLINDER	66
CHIPPING HAMMERS, WEIGHING 4.53-5.89 kg	48-51
HEAVY	66
WEIGHING 0.9-1.81 kg	20
NUT SETTERS TO 7.93 mm WEIGHING 3.62 kg	34
NUT SETTERS 12.7 mm to 19.05 mm WEIGHING 8.16 Kg	51
SUMP PUMPS 32.93 m^3/h (a 15.24 m HEAD)	119
PAINT SPRAY, AVERAGE	12
VARIES FROM	3-34
BUSHING TOOLS (MONUMENT)	25-42
CARVING TOOLS (MONUMENT)	17-25
PLUG DRILLS	68-85
RIVETERS 2.38 mm-25.4 mm RIVETS	20
LARGER WEIGHING 8.16-9.97 kg	59
RIVET BUSTERS	59-66
WOOD BORERS TO 25.4 mm DIAMETER WEIGHING 1.81 kg	68
50.8 mm DIAMETER WEIGHING 11.79 kg.	136
STEEL DRILLS, ROTARY MOTORS	
CAPACITY UPTO 6.35 mm WEIGHING 0.56-1.81 kg	31-34
CAPACITY 6.35 mm TO 9.52 mm WEIGHING 2.72-3.62 kg	34-68
CAPACITY 12.7 mm TO 19.05 mm WEIGHING 4.08-6.35 kg	119
CAPACITY 22.22 mm TO 25.4 mm WEIGHING 11.33 kg	136
CAPACITY 31.75 mm WEIGHING 13.6 kg	161
STEEL DRILLS, PISTON TYPE	
CAPACITY 12.7 mm TO 19.05 mm WEIGHING 5.89-6.80 kg	76
CAPACITY 22.22 mm TO 31.75 mm WEIGHING 11.33-13.60 kg	127-136
CAPACITY 31.75 mm TO 50.8 mm WEIGHING 18.14-22.67 kg	136-153
CAPACITY 50.8 mm TO 76.2 mm WEIGHING 24.94-84.80 kg	170-187

(to be continued)

APPENDIX C

TABLE C.2 (continued)
CUBIC METERS OF AIR PER HOUR REQUIRED BY SANDBLAST

NOZZLE DIAMETER (mm)	COMPRESSED AIR GAGE PRESSURE (kPa)			
	414	483	552	689
1.58	6.8	8.5	9.3	11.0
2.38	15.3	18.7	20.4	25.5
3.17	28.9	32.3	35.7	44.2
4.76	64.6	73.0	79.8	98.5
6.35	113.8	129.1	144.4	175.0
7.93	178.4	202.2	226.0	273.5
9.52	256.5	290.5	324.5	394.1
12.7	455.3	516.5	577.7	700.0

TABLE C.3 - AIR REQUIREMENT OF VARIOUS INSTRUMENTS AT STEADY STATE CONDITIONS

a) Normal pneumatic actuated control valve with diaphragm actuator operating on 20-100 kPa (0.2-1.0 bar) signal.

If fitted with pneumatic positioner: 0.4 Sm^3/h.
If fitted with electro-pneumatic positioner: 0.49 Sm^3/h.

b) Normal pneumatic actuated control valve with diaphragm actuator operating on 40-200 kPa (0.4-2.0 bar) signal.

If fitted with pneumatic positioner: 0.57 Sm^3/h.
If fitted with electro-pneumatic positioner: 0.68 Sm^3/h.

c) Under steady state conditions an on/off valve would not use any air, when the valve is operated the volume of air used will be equal to (diaphragm area × valve stroke).

d) I/P converter: 0.22 Sm^3/h.

(to be continued)

APPENDIX C

TABLE C.4 - TYPICAL AIR REQUIREMENT OF EACH REFINERY PROCESS UNITS 994 Sm^3/h (150.000 bb1/sd) CRUDE CHARGE

	AIR (Sm^3/h)	
ITEM	**INSTRUMENT 6.9 (bar ga)**	**PLANT 6.9 (bar ga)**
CRUDE AND VACUUM	422	(1142)*
HEAVY NAPHTHA HYDROTREATER AND CCR PLATFORMER	836	(1165)
VISBREAKER	133	(441)
LPG RECOVERY	46	(91)
HYDROCRACKER	244	(2854)
HYDROGEN	211	—
AMINE TREATING AND SOUR WATER STRIPPER	85	(91)
SULFUR RECOVERY AND SOLIDIFICATION	106	(6737)
ASPHALT BLOWING	116	(5300)
NITROGEN	(54)	(91)
OFF-SITE	73	11
UTILITY	528	666
FLARE	14	(91)
WASTE WATER TREATMENT	21	43 (254)
LPG TANKAGE AND LOADING	4	91
TOTAL	2893	(6737)

*** Parentheses indicates intermittent services.**

APPENDIX D

TYPICAL SCHEMATIC FLOW DIAGRAM OF COMPRESSED AIR SYSTEM OF REFINERY

Fig. D.1