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SCOPE

This Project Standards and Specifications is intended to cover guidelines for selection of proper type vacuum system, process calculation stages for vacuum systems including capacity, estimation of air leakage and rough estimation of utility consumption and a typical P & I diagram for a vacuum system.

REFERENCES

Throughout this Standard the following dated and undated standards/codes are referred to. These referenced documents shall, to the extent specified herein, form a part of this standard. For dated references, the edition cited applies. The applicability of changes in dated references that occur after the cited date shall be mutually agreed upon by the Company and the Vendor. For undated references, the latest edition of the referenced documents (including any supplements and amendments) applies.

1. Heat Exchange Institute Inc.

   "Standard for Steam Jet Ejectors", 3rd. Ed. 1980

   "General Construction Standard for Ejector Componenets other than Ejector Condensers", 1st. Ed.

2. ISO (International Organization for Standardization)

   3529/2 "Vacuum Technology-Vocabulary" Part 2: "Vacuum Pumps and Related Terms"

   1st. Ed. 1981

SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION	DESCRIPTION
A	Quotational Price
B	Steam Cost Per Ton
C	Cooling Water Cost Per 1000 m^3
F	Capital Charge Percentage
g	Acceleration of Gravity = 9.806 m/s^2
G_s	Steam Consumption, Tons Per Year in (t/a)
G_w	Cooling Water Consumption, in (1000 m^3/a)
H	Height, in (meters)

L	Air Leakage, in (kg/h)
M_n	Molecular Mass of Noncondensable Gas, in (kg/kmol)
M_v	Molecular Mass of Condensable Vapor, in (kg/kmol)
P_1	Initial Pressure in System, in [mm Hg (abs.)]
P_2	Final Pressure in System, in [mm Hg (abs.)]
P_c	Condensate Pressure in Condenser, in (kPa)
P_n	Partial Pressure of Non-Condensable Gas, in [mm Hg (abs.)]
P_o	Barometric Pressure at Liquid Level, in (kPa)
P_v	Partial Pressure of Condensable Vapor, in [mm Hg (abs.)]
Q	Throughput of a Vacuum Pump, in (Pa. m^3/s)
S	Volume Flow Rate of a Vacuum Pump, in (m^3/s)
T	Absolute Temperature, in (K)
V	Volume, in (m^3)
W	Capacity of Ejector, in (kg/h)
t	Time, in (h)
W_n	Mass Flow Rate of Non-Condensable Gas, in (kg/h)
W_v	Mass Flow Rate of Condensable Vapor, in (kg/h)
uP	Pressure Difference due to Friction Losses, in (kPa)
ρ_L	Mass Density of Liquid, in (kg/m^3)

UNITS

This Standard is based on International System of Units (SI) except where otherwise specified.

GENERAL

Vacuum equipment, as called by ISO (International Organization for Standardization),"Vacuum Pumps", are defined as devices for creating, improving and/or maintaining a vacuum.

In Oil and Gas Processing industries the name "Vacuum Pump" is conventionally used for rotating machine vacuum devices and vacuum equipment are divided into two main groups, Vacuum Pumps and Steam Ejectors.

Definition of Vacuum Pumps and Related Terms

Definitions of vacuum pumps and related terms of ISO-3529/2, are generally accepted in this Standard. The following selected definitions are recommended emphatically.

1. Vacuum pump

   A device for creating, improving and/or maintaining a vacuum. Two basically distinct categories may be considered: gas transfer pumps and entrapment or capture pumps

2. Positive displacement (vacuum) pump

   A vacuum pump in which a volume filled with gas is cyclically isolated from the inlet, the gas being then transferred to an outlet. In most types of positive displacement pumps the gas is compressed before the discharge at the outlet. Two categories can be considered: reciprocating positive displacement pumps and rotary positive displacement pumps.

3. Oil - sealed (liquid - sealed) vacuum pump

   A rotary positive displacement pump in which oil is used to seal the gap between parts which move with respect to one another and to reduce the residual free volume in the pump chamber at the end of the compression part of the cycle.

4. Dry - sealed vacuum pump

   A positive displacement pump which is not oil-sealed (liquid-sealed).

5. Piston vacuum pump

   A positive displacement pump in which the gas is compressed and expelled due to the movement of a reciprocating piston moving in a cylinder.

6. Liquid ring vacuum pump

   A rotary positive displacement pump in which an eccentric rotor with fixed blades throws a liquid against the stator wall. The liquid takes the form of a ring concentric to the stator and combines with the rotor blades to define a varying volume.

7. Sliding vane rotary vacuum pump

   A rotary positive displacement pump in which an eccentrically placed rotor is turning tangentially to the fixed surface of the stator. Two or more vanes sliding in slots of the rotor (usually radial) and rubbing on the internal wall of the stator, divide the stator chamber into several parts of varying volume.

8. Roots vacuum pump

   A positive displacement pump in which two lobed rotors, interlocked and synchronized, rotate in opposite directions moving past each other and the housing wall with a small clearance and without touching.

9. Kinetic vacuum pump

   A vacuum pump in which a momentum is imparted to the gas or the molecules in such a way that the gas is transferred continuously from the inlet to the outlet. Two categories can be considered: fluid entrainment pumps and drag vacuum pumps.

10. Ejector vacuum pump

    A kinetic pump which use the pressure decrease due to a Venturi effect and in which the gas is entrained in a high-speed stream towards the outlet. An ejector pump operates when viscous and intermediate flow conditions obtain.

11. Liquid jet vacuum pump

    An ejector pump in which the entrainment fluid is a liquid (usually water).

12. Gas jet vacuum pump

    An ejector pump in which the entrainment fluid is a noncondensable gas.

13. Vapor jet vacuum pump

    An ejector pump in which the entrainment fluid is a vapor (water, mercury or other vapor).

14. Diffusion pump

    A kinetic pump in which a low pressure, high-speed vapor stream provides the entrainment fluid. The gas molecules diffuse into this stream and are driven to the outlet. The number density of gas molecules is always low in the stream. A diffusion pump operates when molecular flow conditions obtain.

15. Entrapment [capture] vacuum pump

    A vacuum pump in which the molecules are retained by sorption or condensation on internal surfaces.

16. Inlet

    The port by which gas to be pumped enters a pump, also called "Suction Chamber", (see Fig. 6).

17. Outlet

    The outlet or discharge port of a pump.

18. Pump fluid

    The operating fluid of an ejector or diffusion pump.

19. Steam chest

    The compartment between the motive steam inlet port and the nozzle inlet (or nozzle plate) of an ejector, (see Fig. 6).

20. Nozzle plate

    The plate on which nozzles (or nozzle extensions) of an ejector are mounted, (see Fig. 6).

21. Nozzle

    The part of an ejector or diffusion pump used to direct the flow of the pump fluid in order to produce the pumping action.

22. Nozzle throat

    Smallest cross-section of the nozzle.

23. Nozzle extension

    The part (a small piece of pipe) between steam chest (or nozzle plate) and the nozzle, (see Fig. 6).

24. Nozzle clearance area

    The smallest cross-sectional area between the outer rim of a nozzle and the wall of the pump casing.

25. Nozzle clearance

    The width of the annulus determining the nozzle clearance area.

26. Jet

    The stream of pump fluid issuing from a nozzle, in an ejector or diffusion pump.

27. Diffuser

    The converging section of the wall of an ejector pump.

28. Diffuser throat

    The part of a diffuser having the smallest cross-sectional area.

29. Volume flow rate of a vacuum pump [symbol: S; unit: $m^3.s^{-1}$]

    It is the volume flow rate of the gas removed by the pump from the gas phase within the evacuated chamber. This kind of definition is only applicable to pumps which are distinct devices, separated from the vacuum chamber. For practical purposes, however, the volume flow rate of a given pump for a given gas is, by convention , taken to be the throughput of the gas flowing from a standardized test dome connected to the pump, divided by the equilibrium pressure measured at a specified position in the test dome, and under specified conditions of operation.

30. Throughput of a vacuum pump [symbol: Q; unit: $Pa.m^3.s^{-1}$]

    The throughput flowing through the inlet of the pump.

31. Starting pressure

    Pressure at which a pump can be started without damage and a pumping effect can be obtained.

32. Backing pressure

    The pressure at the outlet of a pump which discharges gas to a pressure below atmospheric.

33. Critical backing pressure

    The backing pressure above which a vapor jet or diffusion pump fails to operate correctly. It is the highest value of the backing pressure at which a small increment in the backing pressure does not yet produce a significant increase of the inlet pressure. The critical backing pressure of a given pump depends mainly on the throughput.

    <u>Note:</u>

    For some pumps the failure does not occur abruptly and the critical backing pressure cannot then be precisely stated.

34. Maximum backing pressure

    The backing pressure above which a pump can be damaged.

35. Maximum working pressure

    The inlet pressure corresponding to the maximum gas flow rate that the pump is able to withstand under continuous operation without any deterioration or damage.

36. Ultimate pressure of a pump

    The value towards which the pressure in standardized test dome tends asymptotically, without introduction of gas and with the pump operating normally. A distinction may be made between the ultimate pressure due only to noncondensable gases and the total ultimate pressure due to gases and the total ultimate pressure due to gases and vapors.

37. Operating pressure

    The absolute pressure, expressed in mm Hg or kPa(abs.), that a vacuum pump or ejector unit can maintain in a system operating at design capacity and normal operating conditions.

38. Compression ratio

    The ratio of the outlet pressure to the inlet pressure, for a given gas.

Vacuum Pumps Classification

ISO classification of vacuum equipment (vacuum pumps) is shown in Fig. 1.

Type Selection Considerations

Vacuum equipment can be roughly divided into "Steam Ejectors" and "Vacuum Pumps", as mentioned in previous sections. Three major factors should be considered in the type selection stage for vacuum devices. These factors are operating requirements (i.e., suction pressure), suction gas properties and cost. As a general procedure for type selection, the flow chart shown in Fig. 2 can be used.

1. Operating conditions

   Application range of different type of vacuum equipment can be found in Fig. 3.
   In selecting the type of vacuum pump, the characteristics of the individual types and the process conditions involved must be fully considered. Contact with the vendors is also necessary. The characteristics of vacuum pumps are given in Table. 1.
   For ejector, once the operating pressure is determined, the number of stages can be determined from Fig. 3.

2. Comparison of costs

   Generally speaking, steam ejectors require less initial cost and have no moving parts, and hence they have high reliability. On the other hand, their

disadvantage is that their utility cost is high. Meanwhile, in the case of vacuum pumps, although they cost 5 to 20 times as much as steam ejectors and require high maintenance cost, their utility cost is lower.
Regarding the operating costs, a general measure will be that, where the suction gas volume is large and the operating pressure is high, vacuum pumps will require less operating cost than steam ejectors.

3. Properties of suction gas

   a. In the case of steam ejectors which produce a large quantity of waste liquid, their use will be disadvantageous unless the cost of the waste liquid treatment is cheap.

   b. Where corrosive gases must be handled, steam ejectors, which can be manufactured of almost any material, will be advantageous.

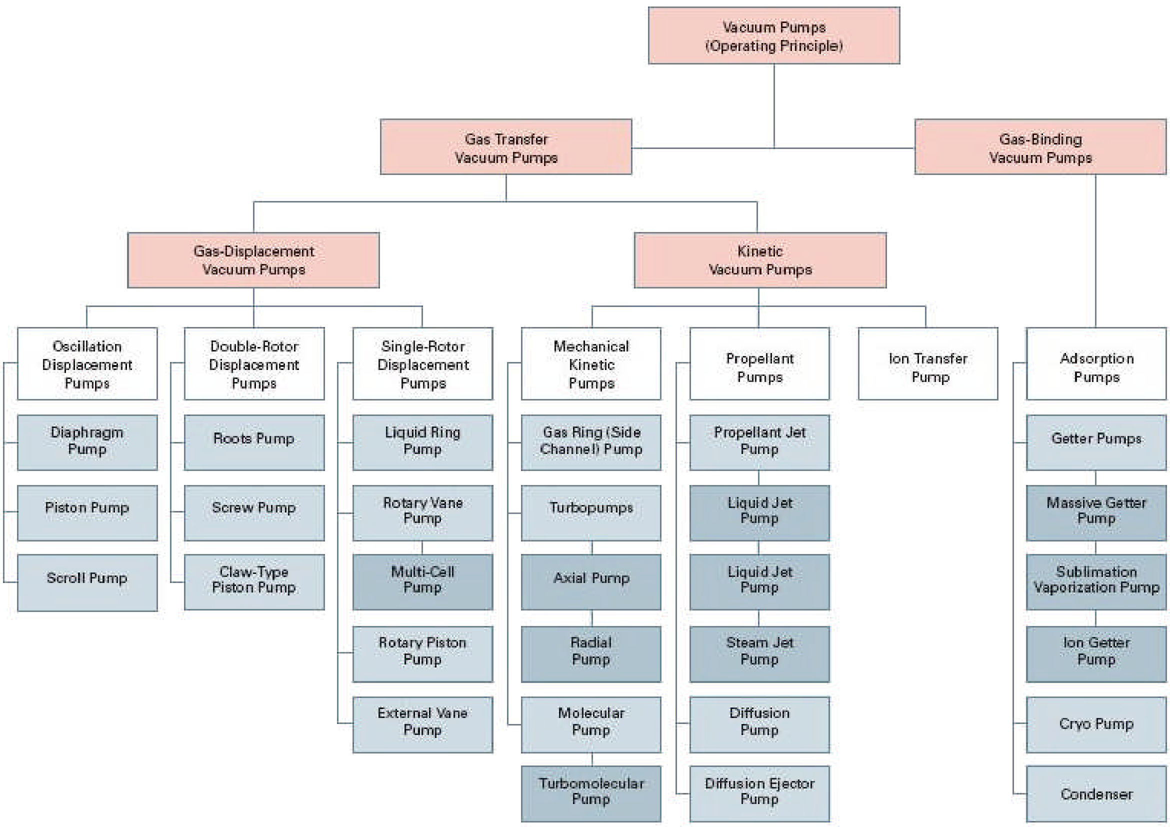


Fig. 1 Classification Table of Vacuum Pumps

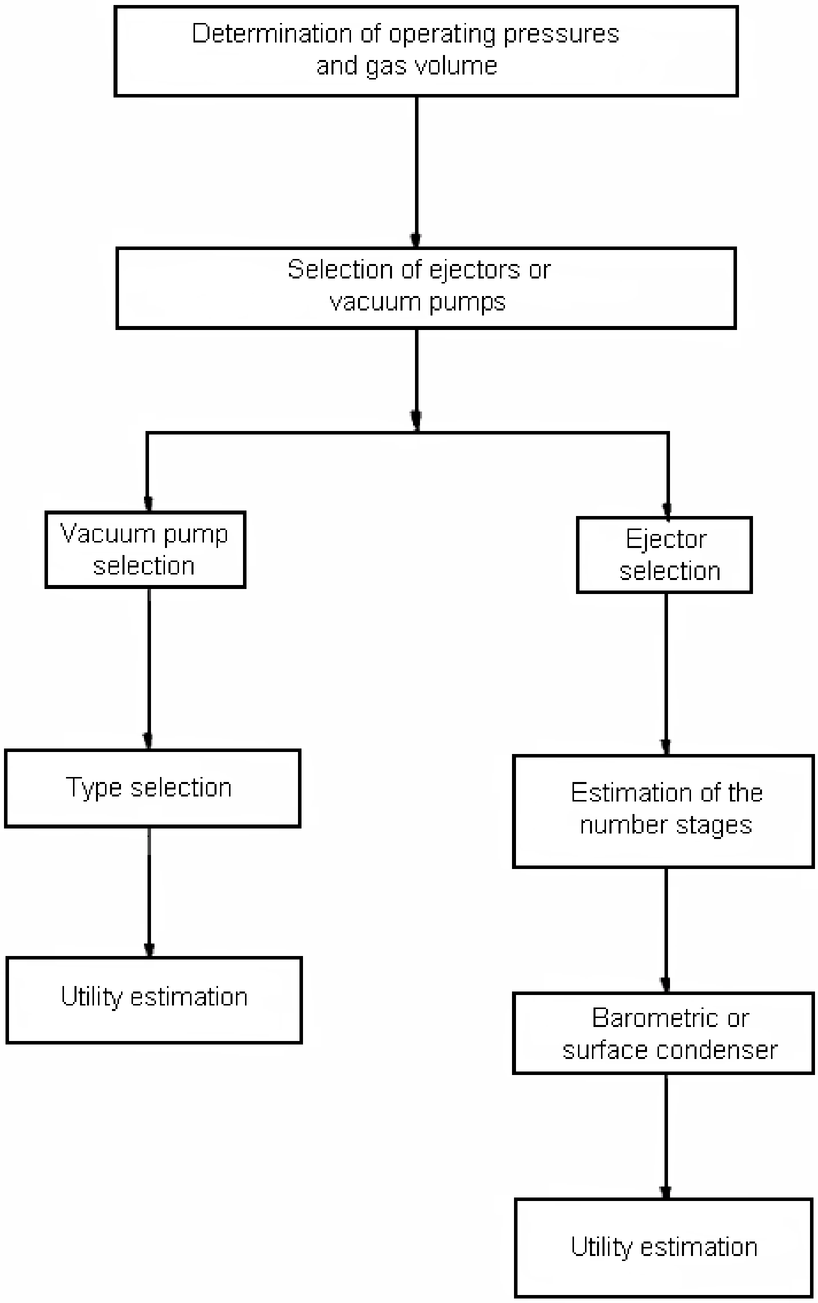
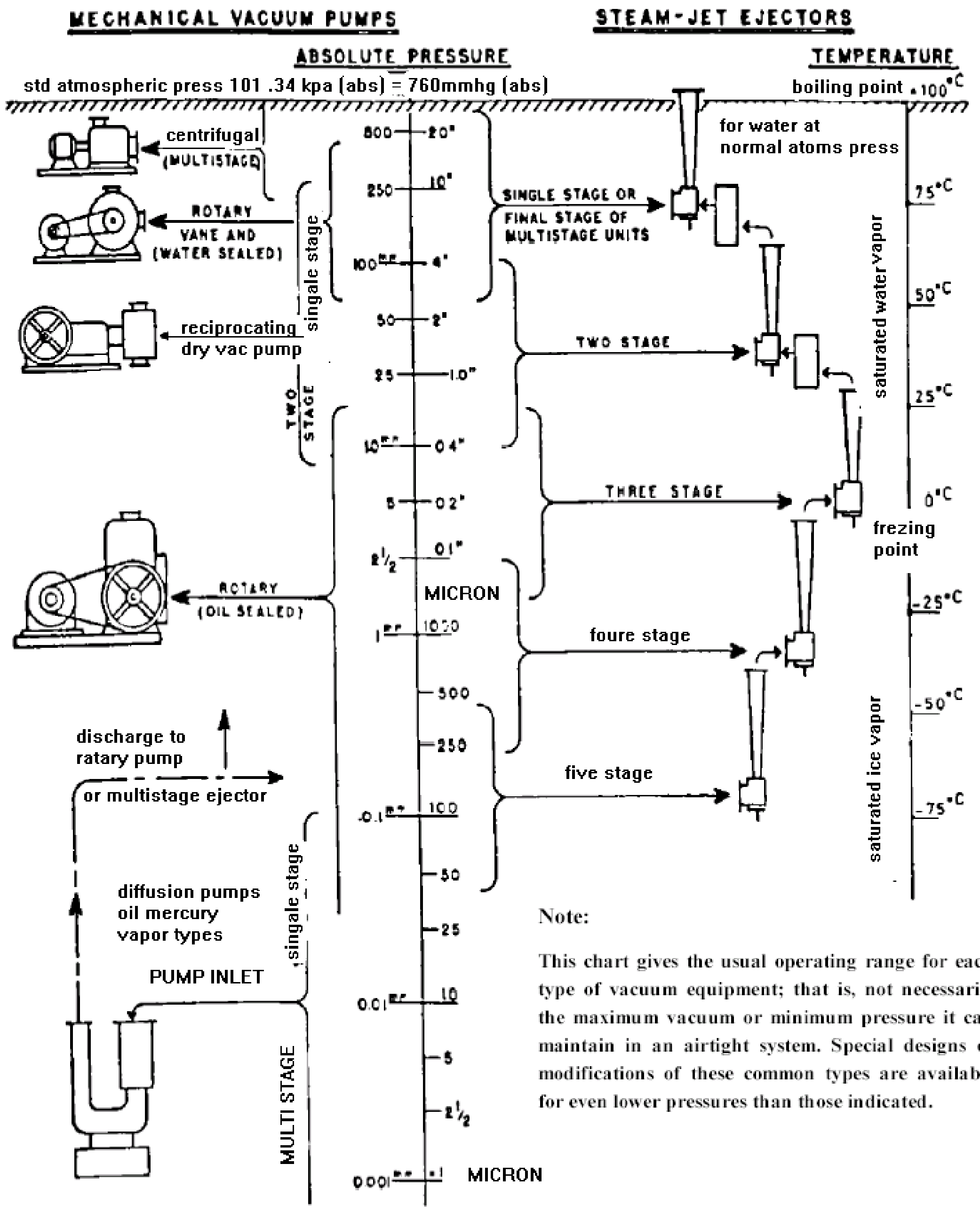


Fig. 2 Selection Procedure for Vacuum Equipment



Note:

This chart gives the usual operating range for each type of vacuum equipment; that is, not necessarily the maximum vacuum or minimum pressure it can maintain in an airtight system. Special designs or modifications of these common types are available for even lower pressures than those indicated.

Fig. 3 Application Range of Vacuum Equipment

Table 1 Characteristic of Various Vacuum Pumps

Type	Operating Pressure* (mm Hg)	Suitability for Suction Gas			Note
		St'm	Low-Boil'g Gas	Dust	
RECIPROCATING One Stage Two Stage	 5 - 760 10^{-1} - 760	 + +	 + ⊕	 ⊕	Corrosive gases can be handled. Required large Space for installation.
NASH (Water seal)	50 - 760	+	+		Suitable for chemical Processes. Consumes much power. Liquid sealed circuit necessary.
Roots One stage Two stage	 300 - 760 100 - 760	 + +	 + +	 ⊕ ⊕	Large exchaust volume Consumes much power.
Rotary (Oil seal)	10^{-4} - 760	---	---		Low resistance against corrosive gases.
Mechanical booster	10^{-3} - 10	+	⊕	⊕	Large exchaust volum. Consumes less power. Auxiliary pumps necessary.

Note:

* It is possible to lower operating pressure by adopting heavy liquid sealing.

\+ Strong.

⊕ Slightly strong.

⊕ Slightly weak.

\- Weak.

DESIGN CRITERIA

The basic design stage of vacuum pumps and ejectors, can be divided into two distinct parts, first is the calculation of parameters or factors which are common for all vacuum devices, such as those concerning the suction conditions. On the other hand, there are some calculations which regards specifically on; and differs for; each equipment type. In the following sections, each part is individually discussed, except that since vacuum pumps are considered principally as compressors, no special basic calculation method for this type is presented here.
Typical P&I diagrams for vacuum pump and ejector vacuum systems are shown in Appendix B.

Common Basic Calculation

The following procedure should be followed for calculating the suction parameters required to fix a vacuum system and to design the equipment basically.

a. Determine vacuum required at the critical process point in the system.

b. Calculate pressure drop from this point to the process location of the suction flange of the first stage vacuum equipment.

c. At the vacuum device suction condition determine:

   i) Kilogram per hour of condensable vapor.

   ii) Kilogram per hour of non-condensable gases which are:

   - dissolved
   - injected or carried in the process
   - formed by reaction
   - air leakage

1. Suction pressure

   The suction pressure of a vacuum device is expressed in absolute units. If it is given as millimeters of vacuum it must be converted to absolute units by using the local or reference barometer.
   In actual operation suction pressure follows the ejector capacity curve, varying with the non-condensable and vapor load to the unit.

2. Discharge pressure

   As indicated, performance of a vacuum unit is a function of backpressure. In order to insure proper performance, the atmospheric discharge units shall be designed for a back pressure of 6 kPa (ga.) unless otherwise specified. The pressure drop through any discharge piping and aftercooler must be taken into consideration. Discharge piping should not have pockets for condensation.

3. Capacity of the unit

   The capacity of a vacuum unit is expressed as kilograms per hour total of non-condensable plus condensables to the inlet flange of the unit. For multistage ejector units, the total capacity must be separated into kilograms per hour of condensables and noncondensables. The final stages are only required to handle the non condensable portion of the load plus the saturation moisture leaving the intercondensers.