

VACUUM EQUIPMENT**JGS 210-120-1-33E**

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CONTENTS

	<u>PAGE</u>
1. SCOPE	2
2. WORK PROCEDURE	2
2.1 Input to the Design	2
2.1.1 Input Data	2
2.1.3 Vendor's Technical Information	3
2.2 Output from the Design	3
2.3 Work Steps	3
2.4 Check List	3
3. DESIGN	4
3.1 Selection Guide to Vacuum Equipment	4
3.2 Determination of Suction Gas Rate	6
3.2.1 Air Leakage Q_a (m^3/h)	6
3.2.2 Condensable Gas and H_2O Rate Q_c , Q_H (m^3/h)	7
3.2.3 Total Suction Gas Rate Q (m^3/h)	7
3.2.4 Special Case (Q for VDU)	7
3.3 Evacuating Time	8
3.3.1 Time Required	8
3.3.2 Ejector Case	8
3.3.3 Vacuum Pump Case	8
3.4 Estimation of Utility Consumptions	9
3.4.1 Steam Consumption of Steam Ejectors	9
3.4.2 Power Consumption of Vacuum Pumps	10
3.5 Vacuum Control Method	10
3.6 Leak Test	11
3.7 Ejector	11
3.7.1 Features	11
3.7.2 Process Variables	11
3.7.3 Basic Components of Ejectors	12
3.7.4 Ejector Itself	13
3.7.5 Role of Condensers	15
3.7.6 Type of Condensers	15
3.7.7 Barometric Condenser	15
3.7.8 Surface Condenser	17
3.7.9 Closed Drum	17
3.8 Vacuum Pump (Liquid-ring)	18
3.8.1 Features	18
3.8.2 Basic Components of Vacuum Pump	18
3.8.3 Piping of the Seal Liquid	19
3.8.4 Combination Related to Suction Pressure	20
3.8.5 Seal Pot	21
APPENDIX: VACUUM RANGE PHENOMENA	22

1. SCOPE

- (1) This standard practice provides the guidelines for the basic design of vacuum equipment in refineries, petrochemical plants and similar plants.

The definitions of vacuum ranges are shown in Table 1.1.

Table 1.1 Vacuum Ranges

Vacuum Range		Description
10^2 Pa Over	(1 Torr Over)	Low Vacuum
$10^2 - 10^{-1}$ Pa	($1 - 10^{-3}$ Torr)	Medium Vacuum
$10^{-1} - 10^{-5}$ Pa	($10^{-3} - 10^{-7}$ Torr)	High Vacuum
10^{-5} Pa below	(10^{-7} Torr below)	Ultra-High Vacuum

[JIS Z 8126 - 1980]

Vacuum range phenomena are briefly shown in Table 3.1 [1].

Vacuum applied in refineries, petrochemical plants and similar plants is mostly in low vacuum range. Therefore vacuum equipment described hereafter is for low vacuum conditions.

- (2) Specific instructions given in the Project Specifications take precedence over requirements given in this standard practice.
- (3) The selection of vacuum pumps will require contact with JGC's Rotary Machinery Department and/or vendors as well.

2. WORK PROCEDURE

2.1 Input to the Design

2.1.1 Input Data

The following is a summary of input data to be prepared before the basic design of vacuum equipment.

- (1) Operational data

- Service name
- Fluid name
- Suction temperature T (°C)
- Suction pressure P (Torr), (mmHgA)
- Suction gas rate Q (m³/hr)

$$Q = Q_{NTP} \times \frac{760}{P} \times \frac{273 + T}{273}$$

$$= 22.4 \times \frac{G}{M_w} \times \frac{760}{P} \times \frac{273 + T}{273}$$

where:

- Q_{NTP} = Normal suction gas rate (Nm³/hr)
- G = Suction gas weight flow rate (Kg/hr)
- M_w = Molecular weight

- Physical properties

Composition, M_w , Viscosity

- (2) Construction data

- Construction material if specified

- (3) Design requirements

- Outlet pressure
- Condensate outlet temperature as waste water
- Evacuating time

- (4) Utilities conditions at Vendor's battery limits
 - Steam: Pressure (minimum pressure should be noted), Temperature
 - Cooling water: Temperature (maximum temperature should be noted)
- (5) Vendor's scope
 - Scope of Vendor's supply equipment, if specified or clarified.

2.1.3 Vendor's Technical Information

Vacuum equipment types and performance curves such as Vendor's technical documents or catalogs, if possible.

2.2 Output from the Design

The basic design of vacuum equipment should ensure the system requirements with the following output data.

- (1) Suction vapor flow rate and composition.
 - After determination of the leak air rate, the design suction vapor flow rate and composition should be specified by adding the leak air.
- (2) Suction and discharge pressures
- (3) Amount of vacuum equipment
 - For start-up and turndown operations, amount of vacuum equipment should be considered.
- (4) Preparation of data sheet and P&ID
 - Finally the data sheet and P&ID should be prepared.

2.3 Work Steps

The basic design of vacuum equipment will be conducted with the following work steps, as a guideline.

- (1) Select vacuum equipment type as shown in Section 3.1.
- (2) Estimate system volume
- (3) Estimate leak air rate as shown in Section 3.2.
- (4) Totalize suction gas rate
- (5) Determine suction and discharge pressures
 - By calculating line pressure drop and referring to equipment and instrument allowable pressure drop in data sheet, the suction pressure should be determined.
 - Conventional hydraulic calculation may be applied for low vacuum service.
 - Conductance concept should be applied only for high vacuum service.
 - Discharge pressure of the vacuum equipment should be determined based on its allowable back pressure.
 - Generally it is 0.1 kg/cm²G maximum.
- (6) Specify evacuating time as referred in Section 3.3.
- (7) Estimate utility consumption
- (8) Prepare the data sheet including Vendor's scope.
- (9) Evaluate leak test result and check the performance

2.4 Check List

The following should be checked based on the results of the basic design of vacuum equipment.

- (1) Vacuum equipment type
- (2) Operating/design pressure and temperature
- (3) Specifications of process/utility conditions
- (4) Vendor's scope of work
- (5) Construction materials
- (6) Vacuum control system

3. DESIGN

This section describes selection guidance and design procedure.

3.1 Selection Guide to Vacuum Equipment

- (1) Characteristics of various vacuum equipment are shown in Table 3.1 [1].
 (2) Typical selection steps of vacuum equipment are shown in Fig. 3.1 for ordinarily applied types.
 (3) Since there are various types of vacuum equipment, Vendor's catalogs and/or technical documents should be referred to for more detail.

Table 3.1 Characteristics of Vacuum Equipment [1]

○ : Possible
 Δ : With proper maintenance
 X : Impossible

Type			Operating Pressure		Suitability for Suction Gas				Note
			[Pa]	[Torr]	Steam	Organic	Dust	Corrosive	
Vacuum Pump	Liquid Ring, NASH		$5 \times 10^3 - 10^5$	50 - 760	○	○	○	○	
	Roots	1 stage	$5 \times 10^4 - 10^5$	300 - 760	○	○	Δ	X	For large exhaust
		2 stages	$10^4 - 10^5$	100 - 760	○	○	Δ	X	
	Oil Sealed Rotary	1 stage	$1 - 10^5$	$10^{-2} - 760$	Δ	X	X	X	Classic type of vacuum pump
		2 stages	$5 \times 10^{-2} - 10^5$	$5 \times 10^{-4} - 760$	Δ	X	X	X	
		Gas-ballast	$10 - 10^5$	$10^{-1} - 760$	○	Δ	X	Δ	
		Anti-corrosive	ditto	ditto	X	X	X	○	
		Oil-regeneration	ditto	ditto	○	○	Δ	Δ	
	Mechanical Booster	1 stage	$10^{-1} - 10^4$	$10^{-3} - 100$	○	Δ	X	X	To combine with liquid ring or oil sealed rotary
		ATM-ope.	$10^{-1} - 10^5$	$10^{-3} - 760$	○	Δ	X	X	
		Chemical	ditto	ditto	○	Δ	X	○	
Ejector	Water Ejector		$5 \times 10^3 - 10^5$	50 - 760	○	○	○	○	
	Steam Ejector	1 stage	$10^4 - 10^5$	100 - 760	○	○	○	○	
		2 stage	$1 - 10^5$	$10^{-2} - 760$	○	○	○	○	
	Air Ejector		$10^4 - 10^5$	100 - 760	○	○	○	○	

[illegible]

- 1 : Ejectors have no moving parts.
- 2 : A large amount of pressurized air needed. Cost and space saving, but large relieving noise.
- 3 : Atmospheric air used.
- 4 : Rotary pump works in wide pressure range.
- 5 : Atmospheric leg (10m) and waste water treatment needed.
- 6 : Motive water is used. Water consumption rate is high.
- 7 : Not good for the case when a lot of inert gas exists.

3.2 Determination of Suction Gas Rate

Suction gas rate consists of the following.

- (1) Air leakage Q_a (m^3/h)
- (2) Non condensible gas Q_{nc} (m^3/h)
- (3) Condensable gas Q_c (m^3/h) and H_2O Q_H (m^3/h) if any
- (4) Generated gas (ex from reaction) Q_g (m^3/h)
- (5) Desorpted gas from solid Q_d (m^3/h)

In general Q_d is nil. Q_{nc} and Q_g are determined from conditions particular to the process.

3.2.1 Air Leakage Q_a (m^3/h)

- (1) System volume V (m^3)

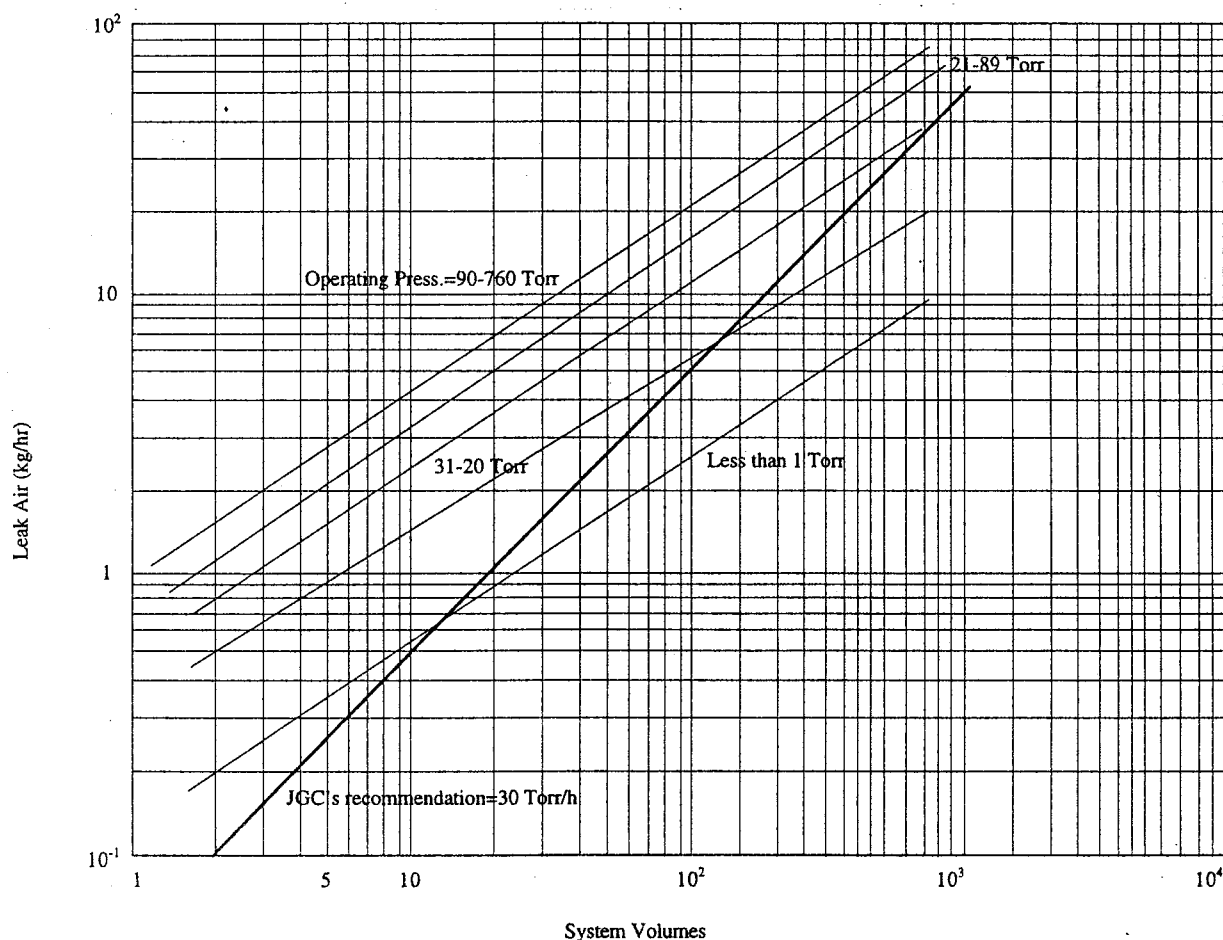
V should be estimated based on total vapor space of the equipment (tower, reactor, drum, heat exchanger, piping) connecting into the vacuum source.

- (2) The recommended value (Fig. 3.2.1)

It is recommended to assume an air leakage of 30 Torr/h irrespective of operating pressure as JGC's Method. However,

- (a) It should be noted that any system in which there are more leak locations than usual or any system including agitators whose shafts are poorly sealed should be given an allowance in addition to the above-mentioned value (for example, 2.5 kg of air/h should be added per agitator).
- (b) Heat Exchange Institute (HEI) method (rather conservative) is in wide use.

Fig. 3.2.1 Air Leakage Values



Note The original chart is from R. Frumerman, Chem. Eng., P196, June (1956) (Same as HEI method)

(3) Leak air equation

$$\Delta m = M \frac{V}{RT} \Delta P = 29 \cdot \frac{30}{62.3 \cdot (273 + 20)} \cdot V = 0.048 V \text{ (JGC method)}$$

= Fig. 3.2.1 (HEI method)

$$Q_a = \frac{\Delta m}{M} \times 22.4 \times \frac{760}{P} \times (T + 273) / 273$$

Where :

Δm = Leak air	(kg/h)
M = Air M.W = 29	(kg/kmol)
V = System volume	(m ³)
ΔP = Leak pressure	(Torr/h)
T = Suction temperature	(K)
P = Suction Pressure	(Torr)

Here, as JGC's Method $\Delta P = 30$ Torr/h at $T = 293$ K (20°C) is applied,

$$Q_a = 0.1V \cdot (T + 273) / P$$

3.2.2 Condensible Gas and H₂O Rate Q_c, Q_H (m³/h)

$$Q_c = (Q_a + Q_{nc}) \cdot P_{vc} / (P - P_{vc} - P_{H_2O})$$

$$Q_H = (Q_a + Q_{nc}) \cdot P_H / (P - P_{vc} - P_{H_2O})$$

where:

 P_{vc} = Vapor pressure of condensible gas at T°C (Torr) P_H = Vapor pressure of H₂O at T°C (Torr) P = Suction pressure (Torr)**3.2.3 Total Suction Gas Rate Q (m³/h)**

$$Q = Q_a + Q_{nc} + Q_c + Q_H + Q_g + Q_d$$

3.2.4 Special Case (Q for VDU)

Air leakage rate is not considered for the Vacuum Flasher or Vacuum Distillation Column used in the refinery, in JGC's experience. Therefore, suction gas rate for the design of ejector of the Vacuum Flasher or Vacuum Distillation Column is to be estimated by the following method.

Table 3.2.4 Estimation of Q for VDU

NON-COND * COMP.	M.W	Sp.Gr 60/60F	API	lb/h BPSD	ESTIMATION METHOD OF FLOW RATE
H ₂ S (-77F)	34.1	0.91	24.0	13.262	Calculated assuming that 1 % sulfur in feed stock becomes H ₂ S.
C ₂ (-128°F)	30.1	0.378	244	5.509	Calculated by (Total flow rate - H ₂ S flow rate)
TOTAL	-	-	-	-	(0.25wt% in feed stock becomes a total non - condensable gas.)