

DESIGN MANUAL

SPD0031ERN-USA
PROCESS DESIGN MANUAL

VACUUM EQUIPMENT

REV. : 2

DATE: 10 Jun 2011



**SAMSUNG
ENGINEERING**

HOLDS:

1. Section 2 – Form numbers to be identified

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA
DATE: 10 Jun 2011		REV.: 2 Page i of i

CONTENTS

1. SCOPE	1
2. FORMAT	1
3. SELECTION GUIDE FOR VACUUM EQUIPMENT	1
3.1. Vacuum Equipment Selection Procedure.....	2
3.2. Comparison of Operating Costs	2
3.3. Properties of the Suction Gas	2
3.4. Type Selection	2
4. DETERMINATION OF AIR LEAKAGE	2
4.1. General	3
4.2. Recommended Method for Air Leakage Estimation	3
5. ESTIMATION OF UTILITY REQUIREMENTS.....	4
5.1. Steam Consumption.....	4
5.2. Power Consumption.....	4
6. REFERENCES	6
7. REVISION HISTORY.....	7
8. TABLES AND FIGURES	8
Table 1 – Cost Study for Evacuation Systems.....	8
Table 2 – Characteristics of Various Vacuum Pumps.....	9
Figure 1 – Selection Procedure for Vacuum Equipment.....	10
Figure 2 – Economic Comparison of Steam Ejectors and Vacuum Pumps	11
Figure 3 – Applications of Vacuum Equipment	12
Figure 4 – Air Leakage Values	13
Figure 5 – Estimation Chart of Ejector Steam.....	14
Figure 6 – Typical P&ID for Steam Ejectors	15
Figure 7 – Typical P&ID for Vacuum Pumps	16

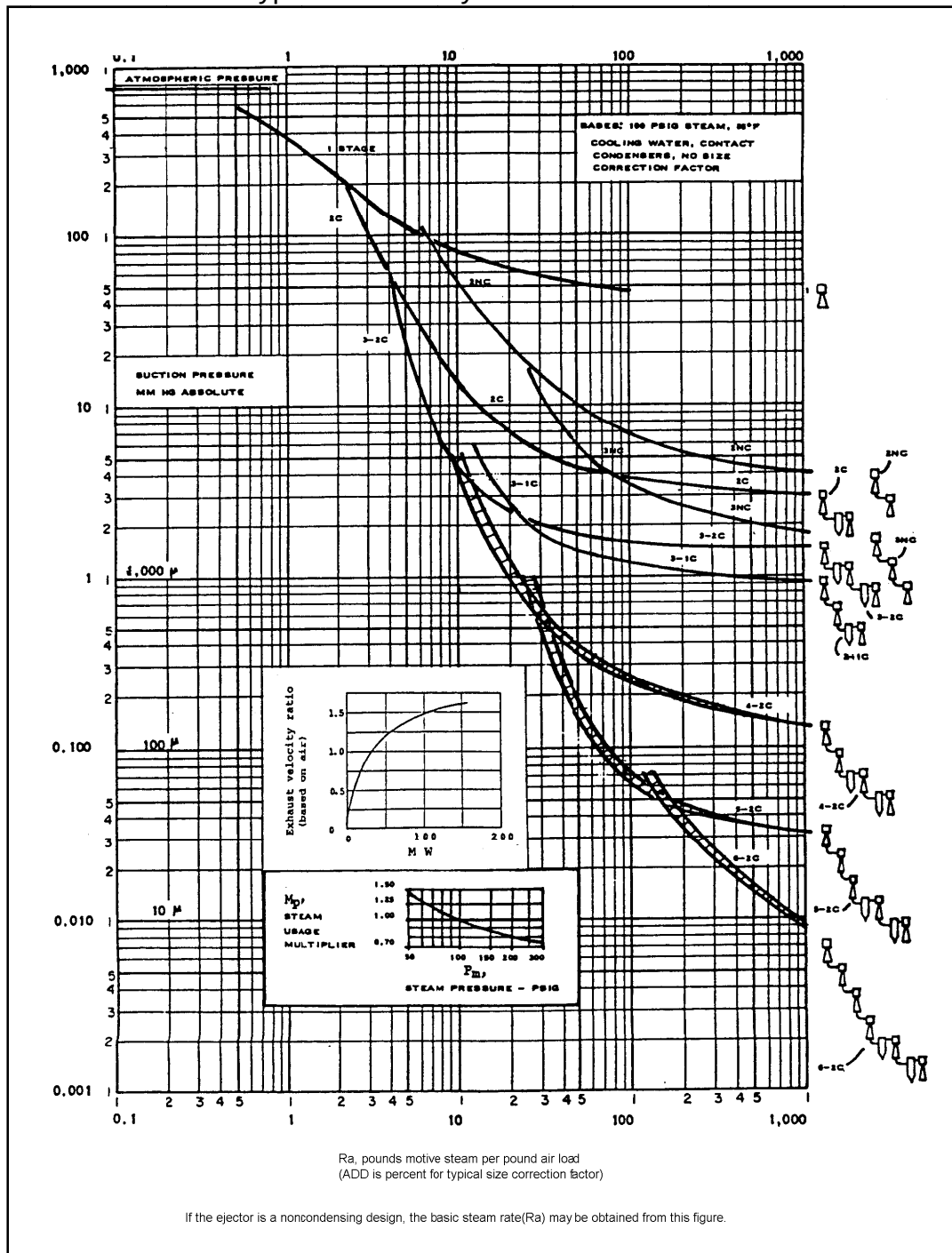
	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 7 of 16
DATE: 10 Jun 2011		

1. SCOPE

This manual gives the guidelines for the selection of vacuum equipment, the estimation estimation of air leakage, and a rough estimation of utility consumption. P&IDs for

DATE: 10 Jun 2011

typical vacuum systems are shown in



	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 7 of 16
DATE: 10 Jun 2011		

Figure 6 and

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 7 of 16
DATE: 10 Jun 2011		

Figure 7. It should be noted that completing a selection of vacuum equipment should require pertinent information from the vendors.

A general classification of vacuum systems is as follows:

Vacuum Region	Pressure
Rough	760 to 1 mmHg
Medium	1 to 10^{-3} mmHg
High	10^{-3} to 10^{-7} mmHg
Ultra-High	10^{-7} mmHg and below

This manual addresses systems for rough and medium vacuum systems.

2. FORMAT

The following forms¹ should be used, unless otherwise specified:

- Ejectors Form No.:
- Reciprocating pumps Form No.:
- Rotary pumps Form No.:
- Fans & blowers Form No.:

Hold #1: Form numbers

3. SELECTION GUIDE FOR VACUUM EQUIPMENT

Vacuum equipment can be roughly divided into two types, steam ejectors and vacuum pumps. The vacuum pumps include: reciprocating pumps, liquid-ring sealed (NASH) pumps, rotary (oil sealed) pumps, and mechanical blowers (Roots). Steam ejectors usually have a lower capital cost, no moving parts, high reliability, and high steam consumption. Vacuum pumps have a high maintenance cost (5 to 20 times higher cost than steam ejectors), and low utility consumption.

3.1. Vacuum Equipment Selection Procedure

A flow chart showing the selection procedure for vacuum equipment is

¹ Form details to be provided later.

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 7 of 16
DATE: 10 Jun 2011		

presented in Figure 1.

3.2. Comparison of Operating Costs

Criteria for selecting steam ejectors and vacuum pumps in terms of operating cost is presented in Figure 2. As a general rule, when the suction gas volume is large and the operating pressure is high, vacuum pumps have an operating cost that is lower than steam ejectors. Steam ejectors produce a large quantity of waste liquid, which is a disadvantage unless the cost of the waste liquid treatment/disposal is inexpensive.

3.3. Properties of the Suction Gas

When corrosive gases must be handled, steam ejectors, which can be manufactured from almost any material, can be advantageous. An example is the cost study for a vacuum flasher mentioned in

 SAMSUNG ENGINEERING	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA
DATE: 10 Jun 2011		REV.: 2 Page 8 of 16

TABLES AND FIGURES

Table 1.

In terms of utility consumption, vacuum pumps are typically more advantageous than steam ejectors. However, because H₂S is typically present in the suction gas, the vacuum pumps will require higher initial cost and may pose problems with reliability.

Vacuum pumps have an advantage in fouling services.

3.4. Type Selection

Once the operating pressure is known, the number of steam ejector stages required can be determined from

 SAMSUNG ENGINEERING	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA
DATE: 10 Jun 2011		REV.: 2 Page 8 of 16

Figure 3. In selecting the type of vacuum pump, the characteristics of the available types and the process conditions involved must be fully considered. Contact with vendors may be necessary. The characteristics of vacuum pumps are given in

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 1 of 16
DATE: 10 Jun 2011		

Table 2.

4. DETERMINATION OF AIR LEAKAGE

It should be noted that air inleakage is really a function of system maintenance. The objective of the designer is to determine a reasonably conservative basis for the vacuum system design. Traditionally, air inleakage has been estimated as a function of system volume, or as a function of the number of flanges and fittings. The system presented below is based on system volume. Also, the designer should note that air inleakage is estimated in units of mass (kg or lb) per hr; the leakage rate in mass units is typically lower at lower vacuum pressures, despite the higher pressure differential.

4.1. General

For an estimate of air leakage into the vacuum system as a function of system volume, it is recommended to use Figure 4, and the curve labeled “30 Torr/h” irrespective of operating pressure.

Systems which have more leak locations than normal or include agitators (whose shafts are poorly sealed) should be given an additional allowance. For instance, 5 lbs/hr of air should be added per agitator.⁽⁴⁾

4.2. Recommended Method for Air Leakage Estimation

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA
DATE: 10 Jun 2011		REV.: 2 Page 2 of 16

Figure 4 is recommended by the Heat Exchange Institute and has been conventionally used to estimate air leakage.⁽⁴⁾ When past leak test values are plotted against the recommended values, it is found that the test values are smaller than the recommended values. Concerning the leak rate, some clients have their own standards. For instance, Company A adopts 50 Torr/5 hours; Company B adopts 3 Torr/hr; and Company C, 25.4 Torr/hr. For these reasons, SECL recommends that the air leakage be taken as 30 Torr/hr, except as noted in Section 4.1 above.

A few additional notes on the sizing basis:

- a) The air estimate leakage given by the “30 torr/hr” curve on Figure 4 is significantly less than the traditional estimates from Heat Exchanger Institute (HEI) Standards. This can be seen by comparing the 30 torr/hr line to the other curves on Figure 4. It should be noted that the value obtained from those curves was sometimes multiplied by a factor of 1.5 or 2.0 to obtain a design value. As the actual air leakage may be significantly larger or smaller depending upon the conditions of sealing, maintenance factors, and application, the HEI estimate could result in a system with a capability far beyond that required for a reasonably well maintained vacuum system. This system capability could provide a quick recovery from upsets due to surges of process non-condensables, etc. As pointed-out in Note b of Section 5.2, evacuation time can become an issue for more tightly designed systems with large quantities of non-condensable gases..
- b) Vacuum System sizing is based on saturated vapor (including process non-condensables, cracked gases, etc), not simply the air inleakage. Calculation must be made to account for the flow rate and composition of the vapor and non-condensable gas entering the vacuum system, in addition to the estimated air leakage rate.
- c) A design margin is applied to the throughput, not the suction pressure. The pressure drop from the vacuum vessel to the vacuum system must be properly accounted for.

5. ESTIMATION OF UTILITY REQUIREMENTS

Utility consumption is determined by the vendors. However, steam and power consumption may be roughly estimated as follows:

5.1. Steam Consumption

Where the suction gas is rich in non-condensable gases, the steam consumption may be estimated from Figure 5 by converting the suction gas

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 3 of 16
DATE: 10 Jun 2011		

volume to its equivalent air volume. Where a large quantity of condensable vapor is present in the suction gas, steam consumption may be estimated by using estimated pressures and the suction gas volume at the individual stages of the ejector.

5.2. Power Consumption

The BHP (kW) of all types of vacuum pumps may be estimated as follows ⁽¹⁾:

- NASH pump (Size Factor valid between 0.05 and 35)

$$\text{BHP} = 10.3 \times (\text{Size Factor})^{0.924}$$

- a) Reciprocating pump (Size Factor valid between 1.00 and 25)

$$\text{BHP} = 5.33 \times (\text{Size Factor})^{0.963}$$

- b) Rotary piston pump (Size Factor valid between 0.03 and 8)

$$\text{BHP} = 5.69 \times (\text{Size Factor})^{1.088}$$

Where,

$$\text{Size Factor} = \text{Air Quantity (lb/h)} / \text{Operating Pressure (Torr)}.$$

Notes:

- a) Where the evacuation time becomes a bottle-neck in the design, the evacuation time may be made longer or start-up equipment may be installed separately to reduce utility consumption.
- b) When the system has a large quantity of non-condensable gases that can produce a possible reduction of operation a parallel installation of vacuum devices should be considered.

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 4 of 16
DATE: 10 Jun 2011		

6. REFERENCES

- i. George A Hutt, Jr., Chemical Engineering, March 15, 83 (1976)
- ii. "Vacuum Flasher Design Manual"
- iii. "Chemical Engineering Manual", 3rd Ed., Chemical Engineering Institute of Japan (1968)
- iv. "Standard for Steam Jet Ejectors", 3rd Ed., Heat Exchange Institute (1956)
- v. "Equipment Design Handbook", 2nd Ed., Gulf Publishing Company (1971)

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 5 of 16
DATE: 10 Jun 2011		

7. REVISION HISTORY

SEA issue of SPD0031ERN-USA

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2	10 Jun 2011	Revised for new Doc. Numbering System	-Team: Process Engineering -Prepared by: K. Elliott -Checked by: S. Wenger -Approved by: M. Czaikowski

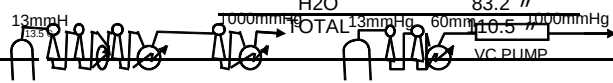
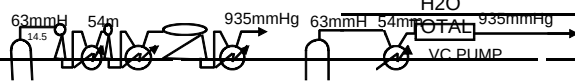
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	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2
DATE: 10 Jun 2011		Page 6 of 16

8. TABLES AND FIGURES

Table 1 – Cost Study for Evacuation Systems

DESCRIPTION	Case 1						Case 2					
CLIENT	A						B					
VACUUM FLASHER CAPACITY (BPSD)	65000 SEMI-DRY						50,000 WET					
SYSTEM OF VACUUM COLUMN												
SUCTION CONDITION (STUDY BASIS)	TEMP.		43.5°C				TEMP.		34.5°C			
	PRESS.		13mmHg-1000mmHg				PRESS.		54mmHg-935mmHg			
	FLOW		46.6 M3/S				FLOW		7.85 M3/S			
	H2S		8.2 Kg-Mol/H				H2S		6.3 Kg-Mol/H			
	C2		19.1 "				C2		14.8 "			
	H2O		83.2 "				H2O		58.5 "			
	TOTAL		10.5 "				TOTAL		79.6 "			
												
SYNPLIFIED FLOW OF EVACUATION SYST.												
EVACUATION SYST.	EJECTOR SYSTEM						VACUUM PUMP SYSTEM					
MAIN EQUIPMENTS SIZE & COST	DESCRIPTION - ×10 ⁴ YEN						DESCRIPTION - ×10 ⁴ YEN					
	EJECTORS 4Series		920				EJECTORS 2Series		500			
	1st CONDENSER 770 M ²		2000				1st CONDENSER 770 M ²		2000			
	2nd CONDENSER 150 M ²		480				NASH 2Series		30000			
	3rd CONDENSER 80 M ²		340				×3Para					
	TOTAL		- 3740				TOTAL		- 32500			
UTILITY CONSUMP. & COST	DESCRIPTION - ×10 ⁴ YEN						DESCRIPTION - ×10 ⁴ YEN					
	15.5K STEAM 11.7T/H		35200				ELEC. for NASH 500-700Kw		7000-9800			
	COOL WATER 750T/H		3300				15.5K STEAM 8.7T/H		27840			
	-		-				COOL WATER 750T/H		3300			
	TOTAL		- 38500				TOTAL		- 38140			
									-40940			
NOTE	1) UTILITY COST (S\$1.2 BASED) HP STEAM 4000 YEN/TON ELECT. 17.5 YEN/Kwh COOL WATER 5.5 YEN/TON						2) EQUIPMENT COST BASED ON THE FIRST HALF OF 1975					

	DESIGN MANUAL VACUUM EQUIPMENT	SPD0031ERN-USA REV.: 2 Page 7 of 16
DATE: 10 Jun 2011		

Table 2 – Characteristics of Various Vacuum Pumps

Type	Operating Pressure (Torr)	Suitability for Suction Gas			Notes
		Steam	Low Boiling Gas	Dust	
RECIPRO- One stage Two stage	5 - 760 10^{-1} - 760	+ +	+ r	q +	Resistant to Corrosive gases. Requires large space for installation.
NASH (Water Seal)	50 - 760	+	+	+	Suitable for chemical processes. Consumes more power. Liquid-sealed circuit is necessary.
Roots One Stage Two Stage	300 - 760 100 - 760	+ +	+ +	q q	- Large exhaust volume. - Consumes more power.
Rotary (Oil Seal)	10^{-4} - 760	-	-	-	- Low resistance to corrosive gases.
Mechanical booster	10^{-3} - 10	+	q	r	Large exhaust volume. Consumes less power. Auxiliary pumps necessary.

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

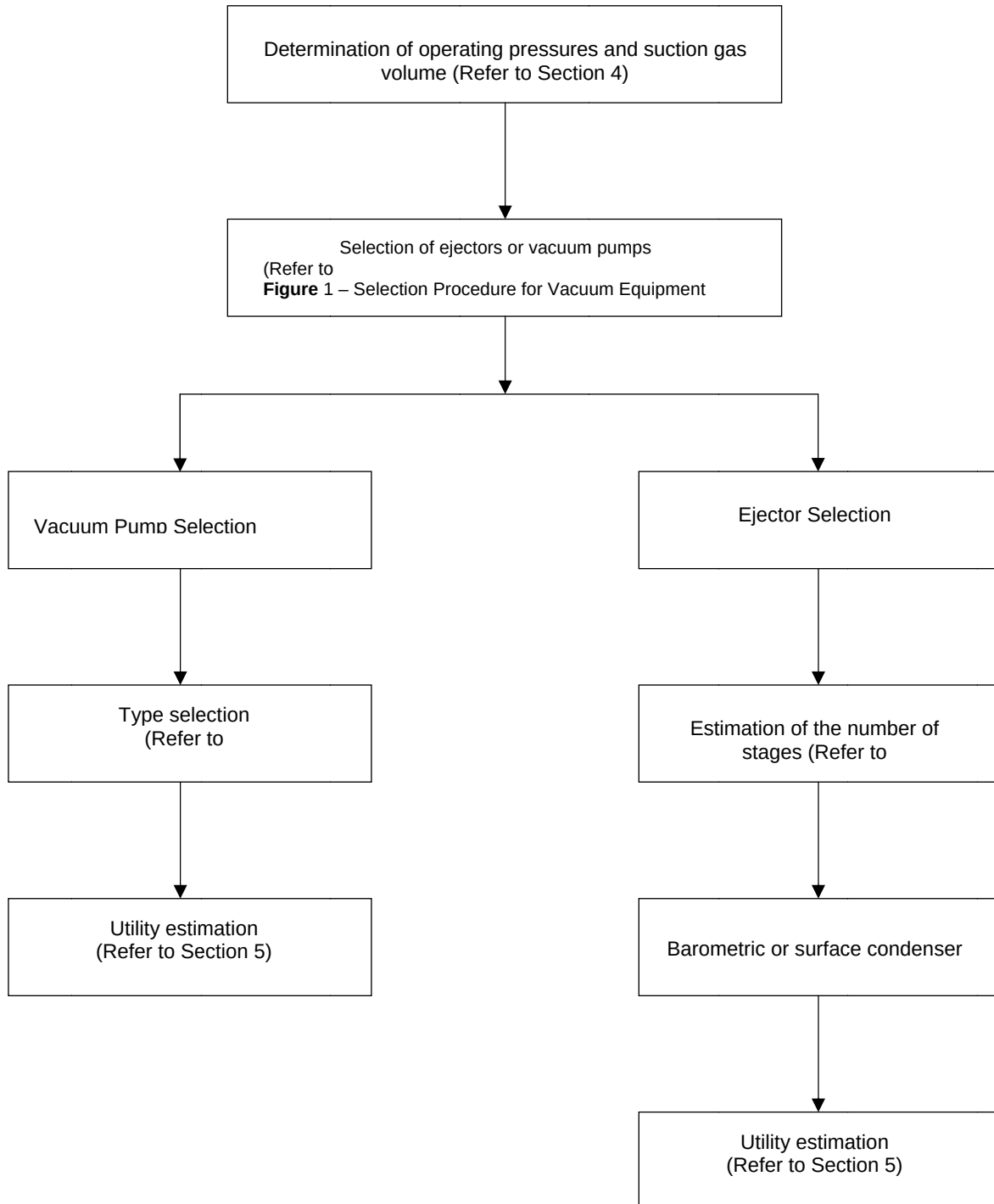
+ : Strong

q : Slightly strong

r : Slightly weak

- : Weak

Figure 1 – Selection Procedure for Vacuum Equipment



DESIGN MANUAL VACUUM EQUIPMENT

Figure 2 – Economic Comparison of Steam Ejectors and Vacuum Pumps

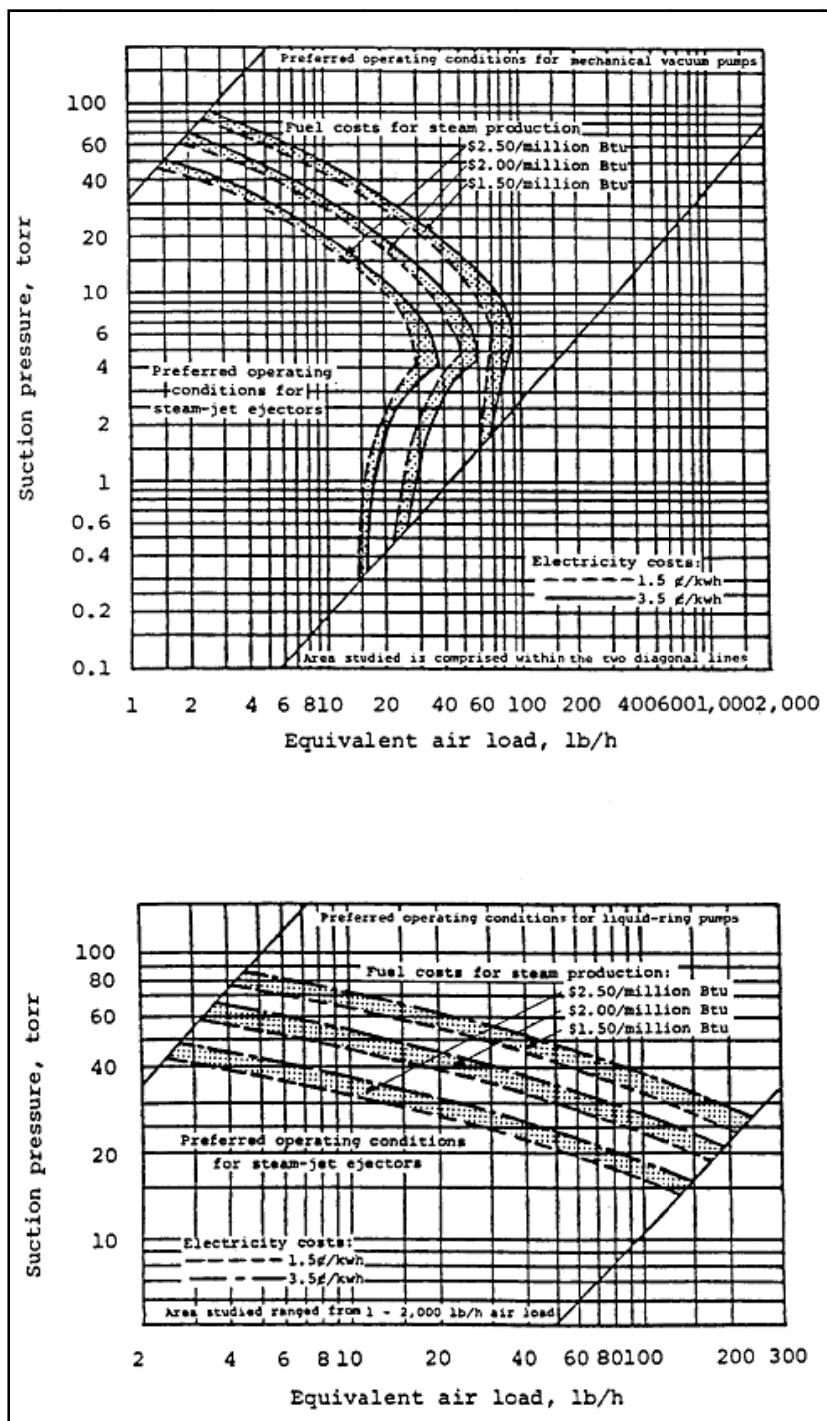


Figure 3 – Applications of Vacuum Equipment

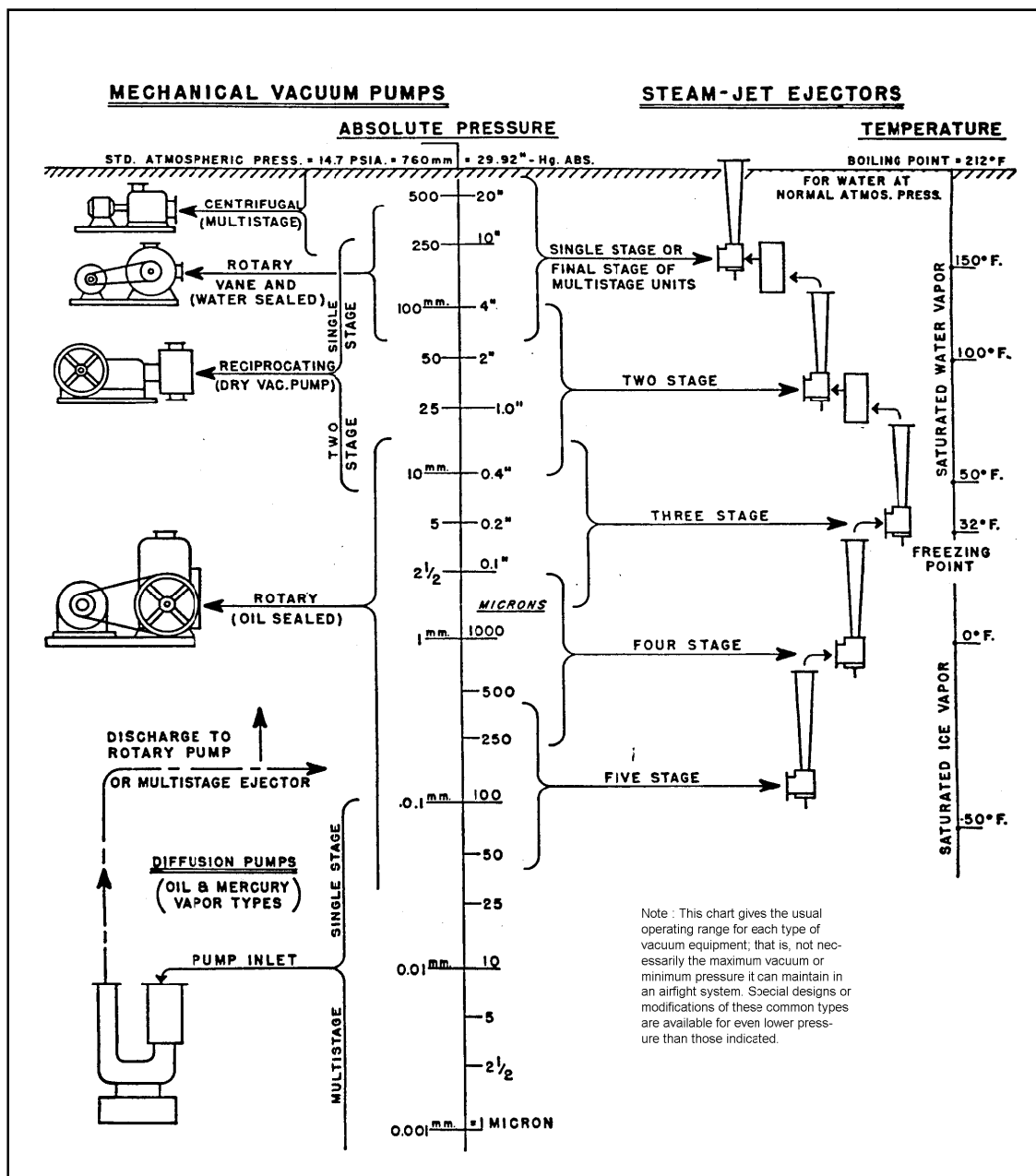
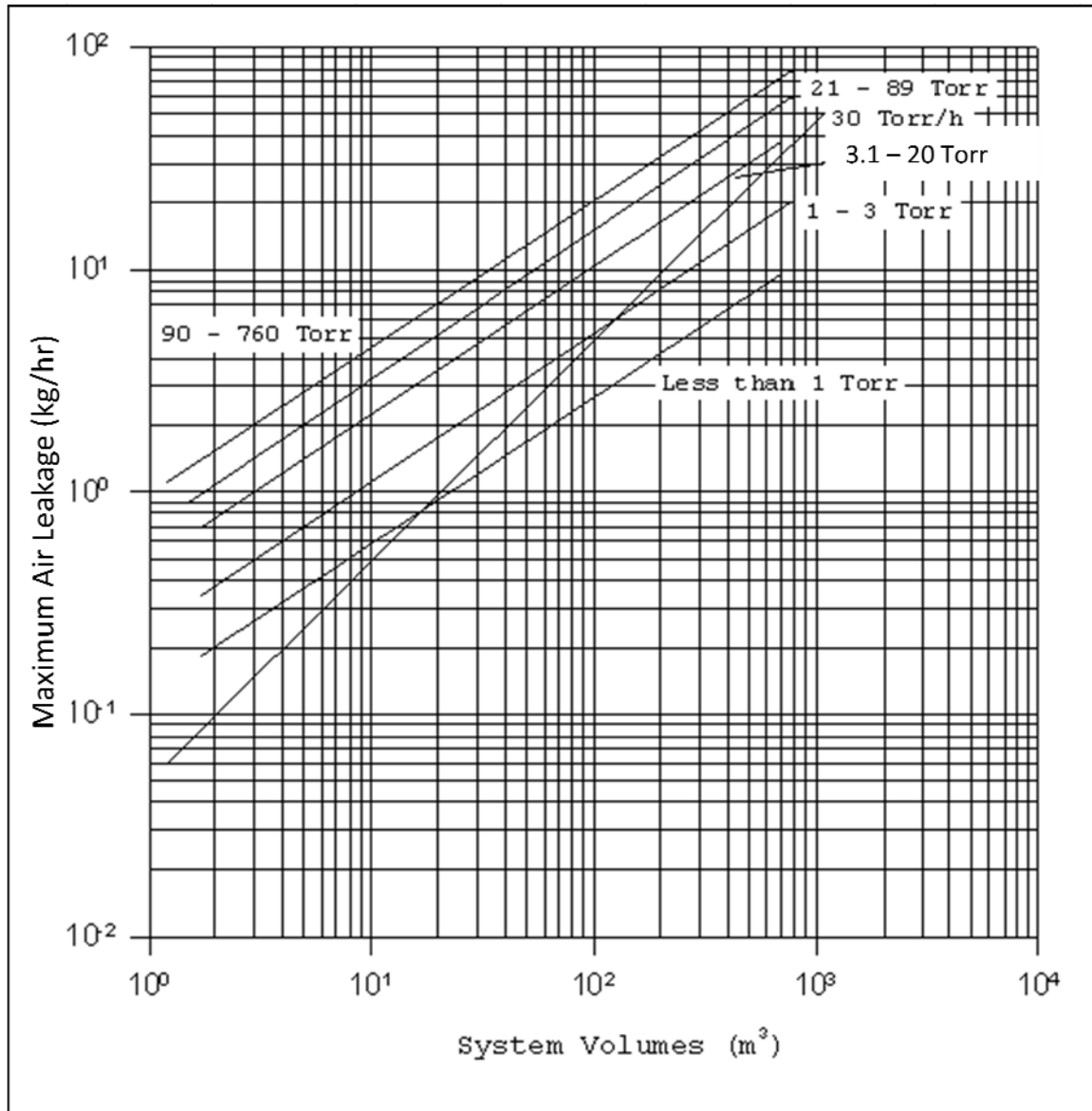


Figure 4 – Air Leakage Values



DATE: 10 Jun 2011

Figure 5 – Estimation Chart of Ejector Steam

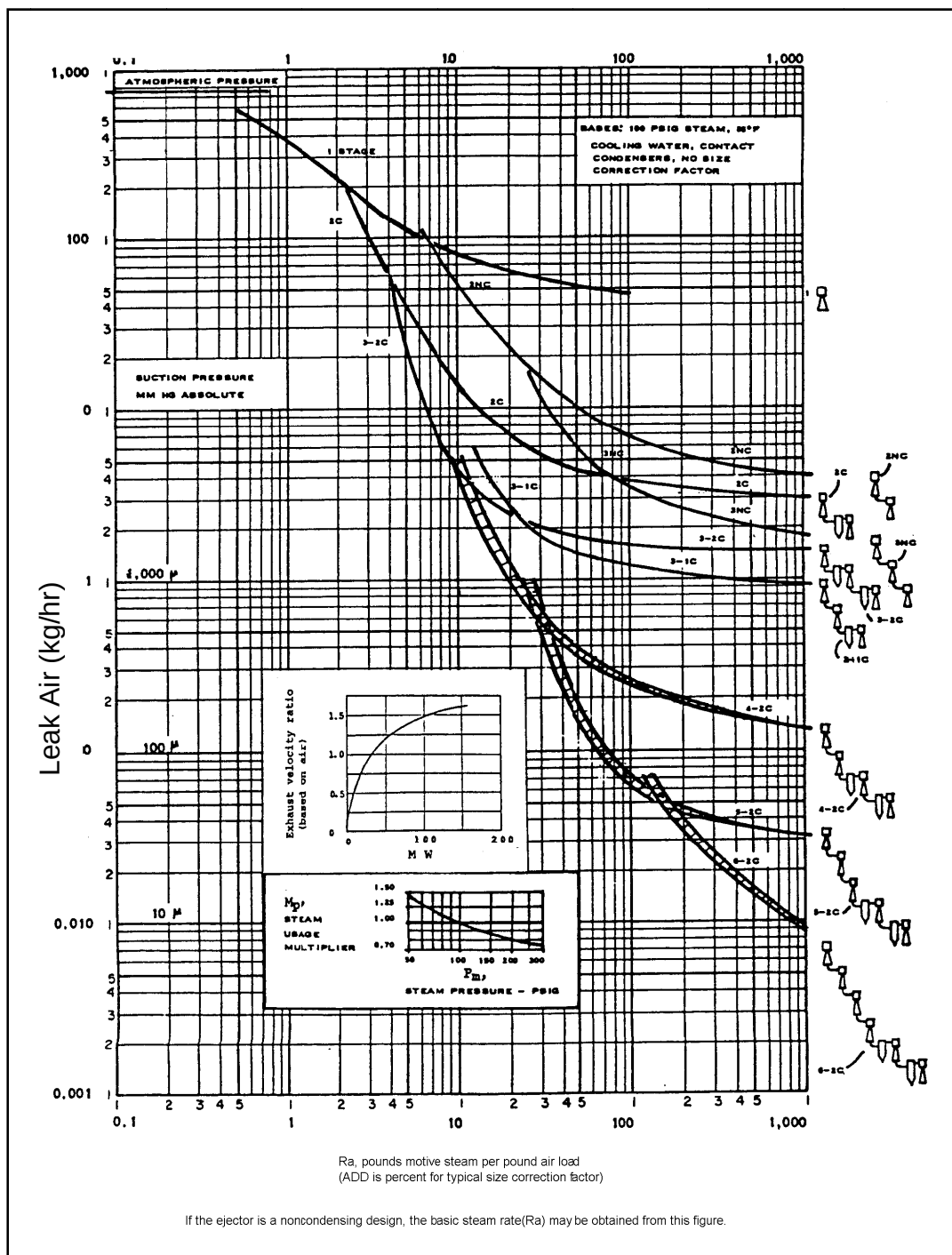
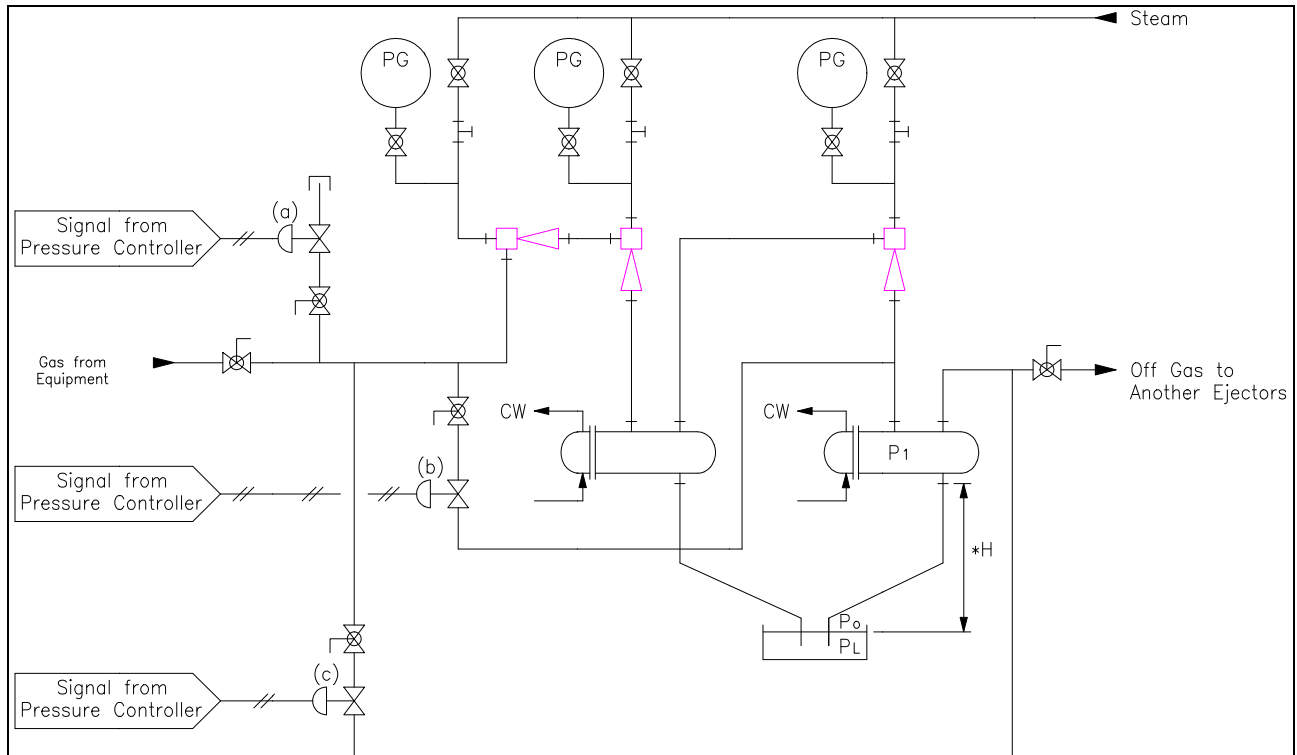


Figure 6 – Typical P&ID for Steam Ejectors



Pressure in a vacuum system using steam ejectors can be controlled:

- (a) By introducing air or inert gas from outside,
- (b) By spilling back the motive steam, or
- (c) By recycling the non-condensable gases in the system

Method (b) and (c) should be employed in such cases where non-condensable gases are definitely present in the system and the introduction of air into the system is not desirable or where the quantity of off-gas must not be increased.

In the case of Method (b), if non-condensable gases are not present in the system, the flow of steam spilled back may be reversed to the equipment.

Figure 7 – Typical P&ID for Vacuum Pumps

