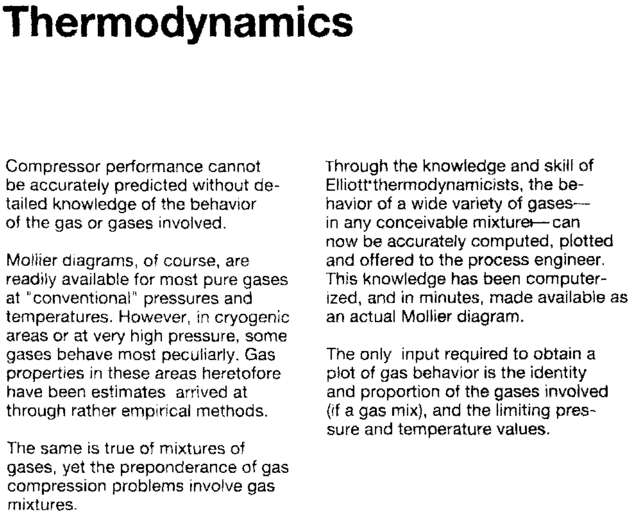
APPENDIX B

SHORTCUT CALCULATIONS AND GRAPHICAL COMPRESSOR SELECTION PROCEDURES

B.1 SELECTION GUIDE FOR ELLIOTT MULTISTAGE CENTRIFUGAL COMPRESSORS*



Thermodynamics

Compressor performance cannot be accurately predicted without detailed knowledge of the behavior of the gas or gases involved.

Mollier diagrams, of course, are readily available for most pure gases at "conventional" pressures and temperatures. However, in cryogenic areas or at very high pressure, some gases behave most peculiarly. Gas properties in these areas heretofore have been estimates arrived at through rather empirical methods.

The same is true of mixtures of gases, yet the preponderance of gas compression problems involve gas mixtures.

Through the knowledge and skill of Elliott thermodynamicists, the behavior of a wide variety of gases—in any conceivable mixture—can now be accurately computed, plotted and offered to the process engineer. This knowledge has been computerized, and in minutes, made available as an actual Mollier diagram.

The only input required to obtain a plot of gas behavior is the identity and proportion of the gases involved (if a gas mix), and the limiting pressure and temperature values.

* Reprinted from a 1994 Elliott Company sales bulletin. The reference information contained herein is provided as an assist to developing your application. However, Elliott reserves the right to modify the design or construction of the equipment described and to furnish it, as altered, without further reference to the illustrations or information contained herein.

A Practical Guide to Compressor Technology, Second Edition, By Heinz P. Bloch

Performance calculations and selection of Elliott multistage compressors

Introduction

These are basic procedures that will help you to calculate compressor performance and estimate the right unit in your installation. The data herein cover most applications; unusual or special problems can be referred to your Elliott Representative.

Our computer, too, is ready and willing to assist you. From worldwide sales offices, we can access the main computer at the factory and thus eliminate many routine and time-consuming calculations. A good example of this would be the selection of an optimum compressor/driver arrangement, which requires analysis of many alternatives and especially so when high power and multiple-casing train setups are involved.

Another time-saver worthy of mention is the high degree of standardization of Elliott compressor frames, impellers, seals, bearings and even mechanical-drive turbines. Many of these components are computerized to enable you to evaluate various alternatives in a minimum of time.

Calculation methods

The calculation procedures on the following pages apply to "straight" compression—the compression of a certain gas from a given suction pressure to a desired discharge pressure.

The methods outlined are:

1. The "N" method (so named because of the extensive use of the polytropic exponent "n"). It is used
a. when the fluid to be compressed closely approximates a "perfect" gas (air, nitrogen, oxygen, hydrogen).
b. when a chart of the properties of the gas or gas mixture is not available.

2. The "Mollier" method which involves use of a Mollier diagram and is used whenever a plot of the properties of the fluid being compressed is available.

Note that the final computerized selections use computerized data bases of actual impeller performance characteristics as well as sophisticated real-gas equations of state.

Thermodynamic equations

Fan Laws

Fan laws have been developed to estimate performance of centrifugal compressors for operating conditions other than design. These are approximate calculations and as such, can be used to estimate off-design parameters.

The fan laws are:

1. $Q \quad \alpha\, N$
2. $H \quad \alpha\, N^2$
3. $\ln r_p \quad \alpha\, N^2$
4. $\Delta T \quad \alpha\, N^2$
5. HP or kW $\alpha\, N^3$

where Q = inlet volume flow
H = head
N = speed (r/min)
r_p = absolute pressure ratio (P_2/P_1)
ΔT = change in temperature
HP or kW = power

Flow Calculations

Compressor flow conditions are often expressed in different forms, most common of which are:

1. Weight flow—lb/min, lb/h (kg/min, kg/h)
2. SCFM—60°F, 14.7 psia and dry
3. number of mols/h

None of these flows can be used directly in calculating compressor performance. All must be converted to ACFM—actual cubic feet per minute. This is also commonly referred to as ICFM—inlet cubic feet per minute.

These conversions are:

$$ACFM = w \times v$$

$$ACFM = SCFM \times \frac{P_s}{P_1} \times \frac{T_1}{T_s} \times \frac{Z_1}{Z_s}$$

$$ACFM = \text{no. of mols/ min} \times MW \times v$$

w = weight flow—lb/min (kg/min)
v = inlet specific volume—ft³/lb (m³/kg)
P_s = standard pressure—usually 14.7 psi (1.013 bar) absolute
P_1 = inlet pressure—psi (bar) absolute
T_s = standard temperature—usually 520°R
T_1 = inlet temperature—°R
Z_1 = inlet compressibility
Z_s = standard compressibility—always 1.0
MW = molecular mass

Gas Mixtures

Properties of a gas mixture necessary to select a compressor are:

1. Gas constant (dependent on molecular mass MW)
2. k (c_p and c_v)
3. P_1, T_1, v_1 and P_2
4. Compressibility, Z
5. Critical pressure, P_c
6. Critical temperature, T_c

Of the above properties of a gas mixture, MW, c_p, c_v, P_c, and T_c, are calculated by adding the products of the individual mol fractions of each constituent, times its specific property. The temperature of any constituent is obviously the temperature of the mixture. The v (specific volume) of the mixture is obtained from $Pv = ZRT$. The compressibility of a mixture is obtained from Chart 1, using the calculated values of P_c and T_c. The k of a mixture is determined from

$$k = \frac{\Sigma Mcp}{\Sigma Mcp - 1.985}$$

The ΣMcp is the summation of the mol fraction times the molal ΣMcp of each constituent. The table below can be used to calculate the properties of a gas mixture.

Gas Mixture	(1) Mol% each gas	(2) Mols/h each gas	(3) Mol Mass (Table 1)	(4) (1) × (3)	(5) Mass %	(6) T_c (Table 1)	(7) P_c (Table 1)	(8) (1) × (6)	(9) (1) × (7)	(10) Mcp (Table 1)	(11) (1) × (10)
....	....	....	....	a	a/d × 100	....	....	....	....	....	....
....	....	....	....	b	b/d × 100	....	....	....	....	....	....
....	....	....	....	c	c/d × 100	....	....	....	....	....	....
				d				....	....		....
Calculate $k_{(mixture)} = \frac{\Sigma Mcp_{(mix)}}{\Sigma Mcp - 1.985}$				Apparent Mol Mass of Mixture				$T_{c\,(mix)}$	$P_{c\,(mix)}$		ΣMcp

Determine the compressibility of the mixture Z_1 by finding the reduced temperature T_{R1} and the reduced pressure P_{R1} as follows:

$$T_{R1} = \frac{T_1}{T_{c\,(mix)}} \qquad P_{R1} = \frac{P_1}{P_{c\,(mix)}}$$

Then enter these values on Chart 1 to find Z.

Chart 1 Generalized compressibility chart

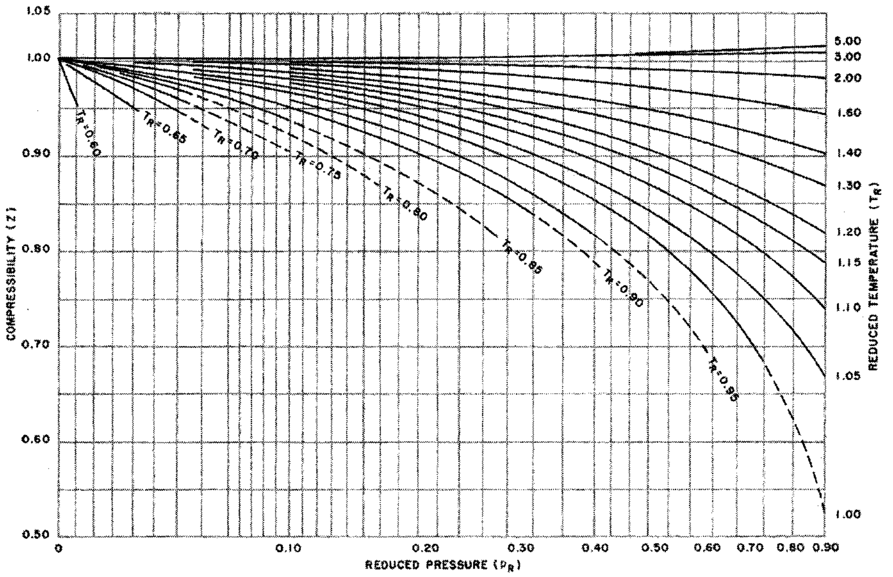
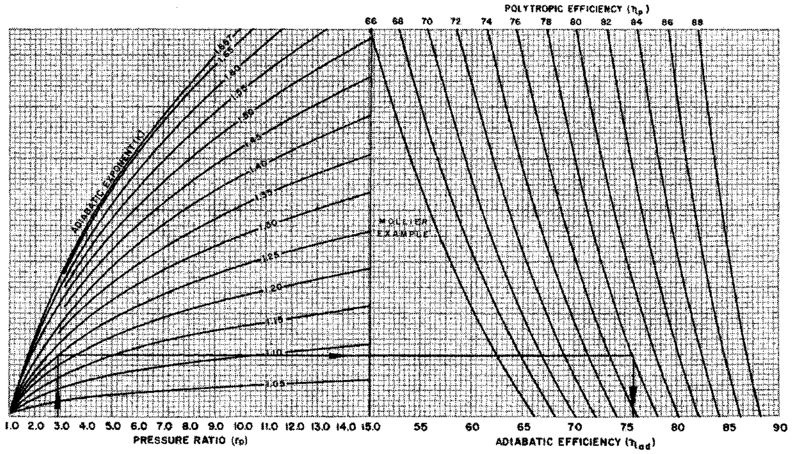


Chart 2 Polytropic to adiabatic efficiency conversion.



ENGLISH SECTION

English Units

Table 1 Gas Properties

(Most values taken from Natural Gas Processors Suppliers Association Engineering Data Book—1972, Ninth Edition)

Gas or Vapor	Hydrocarbon Reference Symbols	Chemical Formula	Molecular Mass	Specific Heat Ratio $k=c_p/c_v$ at 60°F	Critical Conditions		*Mcp	
					Absolute Pressure p_c (psia)	Absolute Temperature T_c (°R)	at 50°F	at 300°F
Acetylene	$C_2=$	C_2H_2	26.04	1.24	905	557	10.22	12.21
Air		N_2+O_2	28.97	1.40	547	239	6.95	7.04
Ammonia		NH_3	17.03	1.31	1636	731	8.36	9.45
Argon		A	39.94	1.66	705	272	4.97	4.97
Benzene		C_6H_6	78.11	1.12	714	1013	18.43	28.17
Iso-Butane	iC_4	C_4H_{10}	58.12	1.10	529	735	22.10	31.11
n-Butane	nC_4	C_4H_{10}	58.12	1.09	551	766	22.83	31.09
Iso-Butylene	iC_4—	C_4H_8	56.10	1.10	580	753	20.44	27.61
Butylene	nC_4—	C_4H_8	56.10	1.11	583	756	20.45	27.64
Carbon Dioxide		CO_2	44.01	1.30	1073	548	8.71	10.05
Carbon Monoxide		CO	28.01	1.40	510	242	6.96	7.03
Carbureted Water Gas (1)		-	19.48	1.35	454	235	7.60	8.33
Chlorine		Cl_2	70.91	1.36	1119	751	8.44	8.52
Coke Oven Gas (1)		-	10.71	1.35	407	197	7.69	8.44
n-Decane	nC_{10}	$C_{10}H_{22}$	142.28	1.03	320	1115	53.67	74.27
Ethane	C_2	C_2H_6	30.07	1.19	708	550	12.13	16.33
Ethyl Alcohol		C_2H_5OH	46.07	1.13	927	930	17	21
Ethyl Chloride		C_2H_4Cl	64.52	1.19	764	829	14.5	18
Ethylene	C_2—	C_2H_4	28.05	1.24	742	510	10.02	13.41
Flue Gas (1)			30.00	1.38	563	264	7.23	7.50
Helium		He	4.00	1.66	33	9	4.97	4.97
n-Heptane	nC_7	C_7H_{16}	100.20	1.05	397	973	39.52	53.31
n-Hexane	nC_6	C_6H_{14}	86.17	1.06	440	915	33.87	45.88
Hydrogen		H_2	2.02	1.41	188	60	6.86	6.98
Hydrogen Sulphide		H_2S	34.08	1.32	1306	673	8.09	8.54
Methane	C_1	CH_4	16.04	1.31	673	344	8.38	10.25
Methyl Alcohol		CH_3OH	32.04	1.20	1157	924	10.5	14.7
Methyl Chloride		CH_3Cl	50.49	1.20	966	750	11.0	12.4
Natural Gas (1)		-	18.82	1.27	675	379	8.40	10.02
Nitrogen		N_2	28.02	1.40	492	228	6.96	7.03
n-Nonane	nC_9	C_9H_{20}	128.25	1.04	345	1073	48.44	67.04
Iso-Pentane	iC_5	C_5H_{12}	72.15	1.08	483	830	27.59	38.70
n-Pentane	nC_5	C_5H_{12}	72.15	1.07	489	847	28.27	38.47
Pentylene	C_5—	C_5H_{10}	70.13	1.08	586	854	25.08	34.46
n-Octane	nC_8	C_8H_{18}	114.22	1.05	362	1025	43.3	59.90
Oxygen		O_2	32.00	1.40	730	278	6.99	7.24
Propane	C_3	C_3H_8	44.09	1.13	617	666	16.82	23.57
Propylene	C_3—	C_3H_6	42.08	1.15	668	658	14.75	19.91
Blast Furnace Gas (1)		-	29.6	1.39	—	—	7.18	7.40
Cat Cracker Gas (1)		-	28.83	1.20	674	515	11.3	15.00
Sulphur Dioxide		SO_2	64.06	1.24	1142	775	9.14	9.79
Water Vapor		H_2O	18.02	1.33	3208	1166	7.98	8.23

(1) Approximate values based on average composition.

*Use straight line interpolation or extrapolation to approximate Mcp (in btu/mol-°R) at actual inlet T. For greater accuracy, average T should be used.

Table 2 M-Line & MB-Line Frame Data

Frame	Nominal Flow Range (cfm)	Nominal Max No. of Casing Stages	Max Casing Pressure (psig)	Nominal Speed (r/min)	Nominal Polytropic Efficiency	Nominal H/N^2 (per stage)	Maximum Q/N
29M	750 - 9,500	10	750	11,500	0.78	7.5×10^{-5}	0.83
38M	6,000 - 22,000	9	625	7,725	0.79	1.52×10^{-4}	2.85
46M	16,000 - 34,000	9	625	6,300	0.80	2.28×10^{-4}	5.40
60M	25,000 - 58,000	8	325	4,700	0.81	3.85×10^{-4}	12.34
70M	50,000 - 84,000	8	325	4,200	0.81	5.67×10^{-4}	20.
88M	70,000 - 135,000	8	325	3,160	0.81	9.1×10^{-4}	42.7
103M	110,000 - 160,000	8	45	2,800	0.82	11.6×10^{-4}	57.1
110M	140,000 - 190,000	8	45	2,600	0.82	13.4×10^{-4}	73.1
10MB	90 - 1,600	12	10,000	18,900	0.77	2.6×10^{-5}	0.085
15MB	200 - 2,350	12	10,000	15,300	0.77	3.6×10^{-5}	0.153
20MB	325 - 3,600	12	10,000	12,400	0.77	6.2×10^{-5}	0.29
25MB	500 - 5,500	12	10,000	10,000	0.78	9.5×10^{-5}	0.55
32MB	2,000 - 8,000	10	10,000	8,300	0.78	1.39×10^{-4}	0.96
38MB	6,000 - 22,000	9	1,500	7,725	0.79	1.52×10^{-4}	2.85
46MB	16,000 - 34,000	9	1,200	6,300	0.79	2.28×10^{-4}	5.40
60MB	25,000 - 58,000	8	800	4,700	0.80	3.85×10^{-4}	12.34
70MB	50,000 - 84,000	8	800	4,200	0.80	5.67×10^{-4}	20.

(1) Number of casing stages is determined by critical speed margins. These numbers are a general guideline only.

(2) These values are typical. Flexibility in types of available staging can allow final computer selections to have significant variations in head and efficiency.

Selection Procedure

English Units

Step 1:
If MW, k, and Z are not given, determine gas mixture properties. By using the procedure and data on Pages 3 and 5, most gas compositions can be analyzed. For single gases or an analysis that has one gas consisting of up to 95% by volume, check to see if a Mollier Diagram is included, and use the Mollier method.

Step 2:
Calculate inlet volume flow (ACFM). Using the gas composition data from Step 1 and the relationships below or the Mollier charts, find the inlet volume entering the compressor. Note that for very large volumes and lower head requirements, compressors can have the flow divided in half having two inlets (double flow), one at each end of the machine. This gives the flexibility of having a smaller frame size handling larger volumes of flow. This can be important in a multi-body string such as a feed gas string in an ehtylene plant, or whenever a match in speed with other compressors or a particular driver is desired.

Step 3:
Select the compressor frame size. Using the inlet volume calculated in Step 2, enter Table 2 and select the proper frame size. Table 2 also contains other pertinent frame data to be used in the selection procedure.

Step 4:
Calculate the total head requirement. In order to determine the number of compression stages, it is necessary to know the total required head. It is important to remember that in a machine with more than one section, it is more accurate to total the heads from the various sections than to make an overall estimate.

Step 5:
Calculate the total number of casing stages. Reference the average H/N^2 values in Table 2. Multiply this by the speed squared (begin with nominal speed unless speed is fixed) to find an average amount of head developed by the impellers. Divide the total head requirement by this to determine the approximate number of casing stages.

Step 6:
Adjust the speed by using fan law relationships to agree with required discharge conditions.

Step 7:
The gas power (GHP) should be adjusted for balance piston or equalizing line leakage. For estimating purposes, we assume this to be a 2% increase. Mechanical losses can then be added to obtain shaft power (SHP).

Rough Out Example (N-method)

1) Given the following customer conditions

$w_1 = 1769$ lb/min　　$MW = 29$
$P_1 = 80$ psia　　$k = 1.4$
$T_1 = 90°$ F ($550°$ R)　　$Z = 1.0$
$P_2 = 225$ psia

2) Calculate inlet volume

$$v_1 = \frac{ZRT_1}{144\,P_1} = \frac{1.0\,(1545)\,(550)}{144\,(29)\,(80)} = 2.544\ \text{ft}^3/\text{lb}$$

$$Q = w_1 \times v_1 = 1769 \times 2.544 = 4500\ \text{ICFM}$$

3) Select compressor frame size
Based on an inlet volume of 4500 ICFM and knowing the required discharge pressure is 225 psia select a 29M frame size from Table 2.

4) Calculate the required head
Assume an efficiency of 0.78 from Table 2 and calculate the polytropic exponent.

$$\frac{n}{n-1} = \left(\frac{k}{k-1}\right)\eta_p = \left(\frac{1.4}{0.4}\right)0.78 = 2.73$$

Calculate the overall head

$$H = ZRT\,\frac{n}{n-1}\left[\frac{P_2}{P_1}^{\frac{n-1}{n}} - 1\right]$$

$$= 1.0\ \frac{(1545)}{29}\ (550)\,(2.73)\left[\frac{225}{80}^{0.3663} - 1\right]$$

$$H = 36837\ \frac{\text{ft-lb}_f}{\text{lb}_m}$$

Check the discharge temperature for a need to intercool (Cool if $T_2 > 400°$ F)

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{225}{80}\right)^{0.3663} = 1.461$$

$$T_2 = 550\,(1.461) = 803°\text{R} = 343°\text{F}$$

No iso-cooling is therefore required.

5) Determine the number of casing stages.
From Table 2 the nominal speed for a 29M is 11500 r/min. Calculate the $Q_{/N}$

$$Q_{/N} = \frac{4500}{11500} = 0.391$$

From Table 2 $H_{/N^2} = 7.5 \times 10^{-5}$

$H_{/\text{stage}}$ would then be

$$H_{/N^2} \times N^2 = (7.5 \times 10^{-5})\,(11500)^2 = 9919\ \frac{\text{ft-lb}_f}{\text{lb}_m}$$

Determine approximate number of casing stages.

$$\text{Number of stages} = \frac{36837}{9919} = 3.71 \cong 4\ \text{stages}$$

6) Adjust Speed

Adjust the nominal speed according to the casing stages.

4 stages must develop $36837\,\frac{\text{ft-lb}_f}{\text{lb}_m}$

or an average of $\frac{36837}{4} = 9209\ \frac{\text{ft-lb}_f}{\text{lb}_m}$ per stage.

Using Fan Law relationships adjust the speed.

$H \alpha N^2$

$$N = N_{NOM}\left[\frac{H_{REQ'D}}{H}\right]^{1/2} = 11500\left[\frac{9209}{9919}\right]^{1/2}$$

$N = 11{,}081$ r/min

7) Calculate the approximate power

$$GHP = \frac{w_1 \times H}{33000 \times \eta_p} = \frac{1769 \times 36837}{33000 \times 0.78} = 2532\text{HP}$$

Adjust for balance piston leakage
$2532 \times 1.02 = 2583$HP

Add losses from Chart 4
SHP $= 2583 + 78 = 2661$HP
(Assume Iso-Carbon Seal)

English Units

Rough Out Example (Mollier)

1) Given the following customer conditions

$w_1 = 1769$ lb/min
$P_1 = 80$ psia
$T_1 = 90°F$ (550°R)
$P_2 = 225$ psia

Gas: ethylene

2) Calculate inlet volume

$v_1 = 2.6$ (from Mollier chart)
$Q = w_1 \times v_1 = 1769 \times 2.6 = 4600$ ICFM

3) Select compressor frame size

Based on an inlet volume of 4600 ICFM and knowing the required discharge pressure is 225 psia select a 29M frame size from Table 2.

4) Calculate the required head

At given inlet conditions, determine inlet entropy (s) and enthalpy (h) from Mollier chart:

$P_1 = 80 \quad T_1 = 90 \quad s_1 = 1.75 \quad h_1 = 163$

At required discharge pressure and constant entropy ($s_1 = s_2$), determine h_2 from chart

$P_2 = 225 \quad T_{2_i} = N/A \quad s_2 = 1.75 \quad h_{2_i} = 205$

Head required $= 778\,(h_{2_i} - h_1)$

$$H = 778\,(205 - 163) = 32676 \ \frac{\text{ft-lb}_f}{\text{lb}_m} \quad \text{(adiabatic)}$$

Check the discharge temperature for a need to intercool. (Cool if $T_2 > 400°F$)

Step 1 Determine adiabatic efficiency

$$r_p = \frac{225}{80} = 2.81 \quad k = 1.24 \quad \eta_p = 0.78$$

$\eta_{AD} = 0.76$ from Chart 2

Step 2 determine actual (not isentropic) Δh.

$$\Delta h = \frac{h_{2_i} - h_1}{\eta_{AD}} = \frac{205-163}{0.76} = 55.3$$

Step 3 Determine h_2 and read T_2 from Mollier Chart.

$h_2 = h_1 + \Delta h = 163 + 55.3 = 218.3$
$T_2 = 232°F$ (from Mollier chart)

No iso-cooling is therefore required.

5) Determine the number of casing stages.

From Table 2 the nominal speed for a 29M is 11500 RPM. Convert adiabatic head to polytropic head by the ratio of efficiencies.

$H = 32676\,(0.78/0.76) = 33536$

From Table 2 $H/_{N^2} = 7.5 \times 10^{-5}$

$H/_{\text{stage}}$ would then be

$$H/_{N^2} \times N^2 = (7.5 \times 10^{-5})\,(11500)^2 = 9919 \ \frac{\text{ft-lb}_f}{\text{lb}_m}$$

Determine approximate number of casing stages.

$$\text{Number of stages} = \frac{33536}{9919} = 3.38 \cong 4 \text{ stages}$$

6) Adjust Speed

Adjust the nominal speed according to the casing stages.

4 stages must develop $33536 \ \frac{\text{ft-lb}_f}{\text{lb}_m}$

or an average of $\frac{33536}{4} = 8384 \ \frac{\text{ft-lb}_f}{\text{lb}_m}$ per stage.

Using Fan Law relationships adjust the speed.

$H \alpha N^2$

$$N = N_{NOM}\left[\frac{H_{REQ'D}}{H}\right]^{1/2} = 11500\left[\frac{8384}{9919}\right]^{1/2} = 10573$$

7) Calculate the approximate power

$$GHP = \frac{w_1 \times H}{33000 \times \eta_p} = \frac{1769 \times 33536}{33000 \times 0.78} = 2305HP$$

Adjust for balance piston leakage

$2305 \times 1.02 = 2351HP$

Add losses from Chart 4.

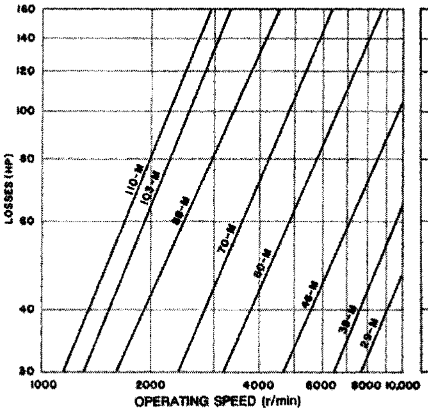
SHP = 2351 + 70 = 2421HP
(Assume Iso-Carbon Seal)

English Units

Mechanical Losses

Chart 3

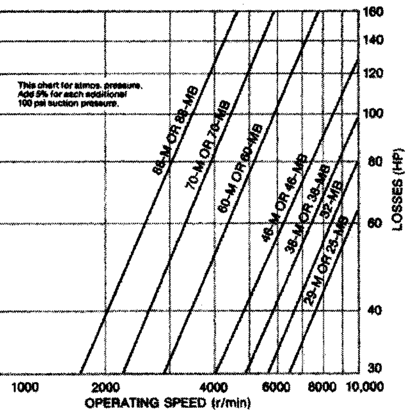
LABYRINTH, DRY CARBON RING
OR GAS FACE SEAL



For 10MB, 15MB and 20MB, use 40 HP for losses.

Chart 4

ISO-CARBON OR ISO-SLEEVE SEAL



This chart for atmos. pressure. Add 5% for each additional 100 psi suction pressure.

METRIC SECTION

Metric Units

Table 3 Gas Properties

(Most values taken from Natural Gas Processors Suppliers Association Engineering Data Book—1972, Ninth Edition)

Gas or Vapor	Hydrocarbon Reference Symbols	Chemical Formula	Molecular Mass	Specific Heat Ratio $k = c_p/c_v$ at 15.5°C	Critical Conditions		*Mcp	
					Absolute Pressure p_c (bar)	Absolute Temperature T_c (K)	at 0°C	at 100°C
Acetylene	$C_2=$	C_2H_2	26.04	1.24	62.4	309.4	42.16	48.16
Air		N_2+O_2	28.97	1.40	37.7	132.8	29.05	29.32
Ammonia		NH_3	17.03	1.31	112.8	406.1	34.65	37.93
Argon		A	39.94	1.66	48.6	151.1	20.79	20.79
Benzene		C_6H_6	78.11	1.12	49.2	562.8	74.18	103.52
Iso-Butane	iC_4	C_4H_{10}	58.12	1.10	36.5	408.3	89.75	116.89
n-Butane	nC_4	C_4H_{10}	58.12	1.09	38.0	425.6	93.03	117.92
Iso-Butylene	$iC_4—$	C_4H_8	56.10	1.10	40.0	418.3	83.36	104.96
Butylene	$nC_4—$	C_4H_8	56.10	1.11	40.2	420.0	83.40	105.06
Carbon Dioxide		CO_2	44.01	1.30	74.0	304.4	36.04	40.08
Carbon Monoxide		CO	28.01	1.40	35.2	134.4	29.10	29.31
Carbureted Water Gas (1)		-	19.48	1.35	31.3	130.6	31.58	33.78
Chlorine		Cl_2	70.91	1.36	77.2	417.2	35.29	35.53
Coke Oven Gas (1)		-	10.71	1.35	28.1	109.4	31.95	34.21
n-Decane	nC_{10}	$C_{10}H_{22}$	142.28	1.03	22.1	619.4	218.35	280.41
Ethane	C_2	C_2H_6	30.07	1.19	48.8	305.6	49.49	62.14
Ethyl Alcohol		C_2H_5OH	46.07	1.13	63.9	516.7	69.92	81.97
Ethyl Chloride		C_2H_5Cl	64.52	1.19	52.7	460.6	59.61	70.16
Ethylene	$C_2—$	C_2H_4	28.05	1.24	51.2	283.3	40.90	51.11
Flue Gas (1)		-	30.00	1.38	38.8	146.7	30.17	30.98
Helium		He	4.00	1.66	2.3	5.0	20.79	20.79
n-Heptane	nC_7	C_7H_{16}	100.20	1.05	27.4	540.6	161.20	202.74
n-Hexane	nC_6	C_6H_{14}	86.17	1.06	30.3	508.3	138.09	174.27
Hydrogen		H_2	2.02	1.41	13.0	33.3	28.67	29.03
Hydrogen Sulphide		H_2S	34.08	1.32	90.0	373.9	33.71	35.07
Methane	C_1	CH_4	16.04	1.31	46.4	191.1	34.50	40.13
Methyl Alcohol		CH_3OH	32.04	1.20	79.8	513.3	42.67	55.32
Methyl Chloride		CH_3Cl	50.49	1.20	66.7	416.7	45.60	49.82
Natural Gas (1)		-	18.82	1.27	46.5	210.6	34.66	39.54
Nitrogen		N_2	28.02	1.40	33.9	126.7	29.10	29.31
n-Nonane	nC_9	C_9H_{20}	128.25	1.04	23.8	596.1	197.07	253.10
Iso-Pentane	iC_5	C_5H_{12}	72.15	1.08	33.3	461.1	112.09	145.56
n-Pentane	nC_5	C_5H_{12}	72.15	1.07	33.7	470.6	115.21	145.94
Pentylene	$C_5—$	C_5H_{10}	70.13	1.08	40.4	474.4	102.11	130.37
n-Octane	nC_8	C_8H_{18}	114.22	1.05	25.0	569.4	176.17	226.17
Oxygen		O_2	32.00	1.40	50.3	154.4	29.17	29.92
Propane	C_3	C_3H_8	44.09	1.13	42.5	370.0	68.34	88.68
Propylene	$C_3—$	C_3H_6	42.08	1.15	46.1	365.6	60.16	75.70
Blast Furnace Gas (1)		-	29.6	1.39	—	—	29.97	30.64
Cat Cracker Gas (1)		-	28.83	1.20	46.5	286.1	46.16	57.31
Sulphur Dioxide		SO_2	64.06	1.24	78.7	430.6	38.05	40.00
Water Vapor		H_2O	18.02	1.33	221.2	647.8	33.31	34.07

(1) Approximate values based on average composition.

*Use straight line interpolation or extrapolation to approximate Mcp [in kJ/(kmol·K)] at actual inlet T. For greater accuracy, average T should be used.

Table 4 M-Line & MB-Line Frame Data

Frame	Nominal Flow Range (m³/h)	Nominal Max No. of Casing Stages	Max Casing Pressure (bar)	Nominal Speed (r/min)	Nominal Polytropic Efficiency	Nominal H/N² (per stage)	Maximum Q/N
29M	1 275 - 16 140	10	52	11 500	0.78	2.25×10^{-4}	1.403
38M	10 200 - 37 380	9	43	7725	0.79	4.56×10^{-4}	4.84
46M	27 200 - 57 750	9	43	6300	0.80	6.84×10^{-4}	9.17
60M	42 500 - 98 550	8	23	4700	0.81	11.55×10^{-4}	20.97
70M	85 000 - 142 700	8	23	4200	0.81	17.01×10^{-4}	33.98
88M	119 000 - 229 400	8	23	3160	0.81	27.3×10^{-4}	72.6
103M	186 900 - 272 000	8	3	2800	0.82	34.8×10^{-4}	97.
110M	237 900 - 323 000	8	3	2600	0.82	40.2×10^{-4}	124.
10MB	150 - 2 700	12	690	18 900	0.77	8.0×10^{-5}	0.14
15MB	340 - 4 000	12	690	15 300	0.77	10.8×10^{-5}	0.26
20MB	550 - 6 120	12	690	12 400	0.77	18.6×10^{-5}	0.49
25MB	850 - 9 345	12	690	10 000	0.78	28.5×10^{-5}	0.94
32MB	3 400 - 13 600	10	690	8300	0.78	4.2×10^{-4}	1.64
38MB	10 200 - 37 380	9	103	7725	0.79	4.56×10^{-4}	4.84
46MB	27 200 - 57 750	9	83	6300	0.79	6.84×10^{-4}	9.17
60MB	42 500 - 98 550	8	55	4700	0.80	11.55×10^{-4}	20.97
70MB	85 000 - 142 700	8	55	4200	0.80	17.01×10^{-4}	33.98

(1) Number of casing stages is determined by critical speed margins. These numbers are a general guideline only.

(2) These values are typical. Flexibility in types of available staging can allow final computer selections to have significant variations in head and efficiency

Selection Procedure

Step 1:

If MW, k, and Z are not given, determine gas mixture properties. By using the procedure and data on Pages 3 and 9, most gas compositions can be analyzed. For single gases or an analysis that has one gas consisting of up to 95% by volume, check to see if a Mollier Diagram is available, and use the Mollier method.

Step 2:

Calculate inlet volume flow (m³). Using the gas composition data from Step 1 and the relationships below or the Mollier charts, find the inlet volume entering the compressor. Note that for very large volumes and lower head requirements, compressors can have the flow divided in half having two inlets (double flow), one at each end of the machine. This gives the flexibility of having a smaller frame size handling larger volumes of flow. This can be important in a multi-body string such as a feed gas string in an ethylene plant, or whenever a match in speed with other compressors or a particular driver is desired.

Step 3:

Select the compressor frame size. Using the inlet volume calculated in Step 2, enter Table 4 and select the proper frame size. Table 4 also contains other pertinent frame data to be used in the selection procedure.

Step 4:

Calculate the total head requirement. In order to determine the number of compression stages, it is necessary to know the total required head. It is important to remember that in a machine with more than one section, it is more accurate to total the heads from the various sections than to make an overall estimate.

Step 5:

Calculate the total number of casing stages. Reference the average H/N² values in Table 4. Multiply this by the speed squared (begin with nominal speed unless speed is fixed) to find an average amount of head developed by the impellers. Divide the total head requirement by this to determine the approximate number of casing stages.

Step 6:

Adjust the speed by using fan law relationships to agree with required discharge conditions.

Step 7:

The gas power (GkW) should be adjusted for balance piston or equalizing line leakage. For estimating purposes, we assume this to be a 2% increase. Mechanical losses can then be added to obtain shaft power (SkW).

Rough Out Example (N-method)

1) Given the following customer conditions

$w_1 = 802.4$ kg/min $\quad MW = 29$
$P_1 = 5.5$ bar $\quad k = 1.4$
$T_1 = 32°C$ (305 K) $\quad Z = 1.0$
$P_2 = 15.52$ bar

2) Calculate inlet volume

$$v_1 = \frac{ZRT_1}{10^5\,P_1} = \frac{1.0\,(8314)\,(305)}{10^5\,(29)\,(5.5)} = 0.159\ \mathrm{m^3/kg}$$

$$Q = w_1 \times v_1 = 802.4 \times 0.159 = 127.6\ \mathrm{m^3/min}$$
$$127.6 \times 60 = 7656\ \mathrm{m^3/h}$$

3) Select compressor frame size

Based on an inlet volume of 7656 m³/h, and knowing the required discharge pressure is 15.52 bar, select a 29M frame size from Table 4.

4) Calculate the required head

Assume an efficiency of 0.78 from Table 4 and calculate the polytropic exponent.

$$\frac{n}{n-1} = \left(\frac{k}{k-1}\right)\eta_p = \left(\frac{1.4}{0.4}\right)0.78 = 2.73$$

Calculate the overall head

$$H = ZRT\,\frac{n}{n-1}\left[\frac{P_2}{P_1}^{\frac{n-1}{n}} - 1\right]$$

$$= 1.0\,\frac{(8314)}{29}\,(305)\,(2.73)\left[\frac{15.52}{5.5}^{0.3663} - 1\right]$$

$$H = 110\,350\ \frac{\mathrm{Nm}}{\mathrm{kg}}$$

Check the discharge temperature for a need to intercool (Cool if $T_2 > 205°C$)

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{15.52}{5.5}\right)^{0.3683} = 1.462$$

$$T_2 = 305\,(1.462) = 446K = 173°C$$

No iso-cooling is therefore required.

5) Determine the number of casing stages.

From Table 4 the nominal speed for a 29M is 11 500 RPM. Calculate the $Q_{/N}$

$$Q_{/N} = \frac{7\,656}{11\,500} = 0.666$$

From Table 4 $H_{/N^2} = 2.25 \times 10^{-4}$

$H_{/stage}$ would then be

$$H_{/N^2} \times N^2 = (2.25 \times 10^{-4})(11\,500)^2 = 29\,756\ \frac{\mathrm{Nm}}{\mathrm{kg}}$$

Determine approximate number of casing stages.

$$\text{Number of stages} = \frac{110\,350}{29\,756} = 3.71 \cong 4 \text{ stages}$$

6) Adjust Speed

Adjust the nominal speed according to the casing stages.

4 stages must develop $110\,350\ \frac{\mathrm{Nm}}{\mathrm{kg}}$

or an average of $\frac{110\,350}{4} = 27\,588\ \frac{\mathrm{Nm}}{\mathrm{kg}}$ per stage.

Using Fan Law relationships adjust the speed.

$$H\ \alpha\ N^2$$

$$N = N_{NOM}\left[\frac{H_{REQ'D}}{H}\right]^{1/2} = 11\,500\left[\frac{27588}{29\,756}\right]^{1/2}$$

$$N = 11073\ \mathrm{r/min}$$

7) Calculate the approximate power

$$GkW = \frac{w_1 \times H}{60\,000 \times \eta p} = \frac{(802.4)(110\,350)}{(60\,000)\,(0.78)} = 1892\mathrm{kW}$$

Adjust for balance piston leakage
$1892 \times 1.02 = 1930$kW

Add losses from Chart 6
SkW = 1930 + 58 = 1988kW
(Assume Iso-Carbon Seal)

Metric Units

Rough Out Example (Mollier)

1) Given the following customer conditions

$w_1 = 802.4$ kg/min
$P_1 = 5.5$ bar
$T_1 = 32°$C (305 K)
$P_2 = 15.52$ bar

Gas: ethylene

2) Calculate inlet volume

$v_1 = 0.163$ m^3/kg (from Mollier chart)
$Q = w_1 \times v_1 = 802.4 \times 0.163 = 130.79$ m^3/min
$130.79 \times 60 = 7847$ m^3/h

3) Select compressor frame size

Based on an inlet volume of 7847 m^3/h and knowing the required discharge pressure is 15.52 bar select a 29M frame size from Table 4.

4) Calculate the required head

At given inlet conditions, determine inlet entropy (s) and enthalpy (h) from Mollier chart:

$P_1 = 5.5$ bar $\quad T_1 = 32°$C $\quad s_1 = s_2 \quad h_1 = 379 \frac{\text{kJ}}{\text{kg}}$

At required discharge pressure and constant entropy ($s_1 = s_2$), determine h_2 from chart

$P_2 = 15.52 \quad T_{2_i} = $ N/A $\quad s_2 = s_1 \quad h_{2_i} = 477 \frac{\text{kJ}}{\text{kg}}$

Head required $= 1000\ (h_{2_i} - h_1)$

$H = 1000\,(477 - 379) = 98000$ (adiabatic) $\frac{\text{Nm}}{\text{kg}}$

Check the discharge temperature for a need to intercool. (Cool if $T_2 > 205°$C)

Step 1 Determine adiabatic efficiency

$r_p = \frac{15.52}{5.5} = 2.82 \quad k = 1.24 \quad \eta_p = 0.78$

$\eta_{AD} = 0.76$ from Chart 2

Step 2 Determine actual (not isentropic) Δh

$$\Delta h = \frac{h_{2_i} - h_1}{\eta_{AD}} = \frac{(477-379)}{0.76} = 128.9$$

Step 3 Determine h_2 and read T_2 from Mollier Chart.

$h_2 = h_1 + \Delta h = 379 + 128.9 = 507.9$
$T_2 = 109°$C (from Mollier chart)

No iso-cooling is therefore required.

5) Determine the number of casing stages.

From Table 4 the nominal speed for a 29M is 11 500 r/min. Convert adiabatic head to polytropic head by the ratio of efficiencies.

$H = 98000\,(0.78/0.76) = 100579 \frac{\text{Nm}}{\text{kg}}$

From Table 4 $H/_{N^2} = 2.25 \times 10^{-4}$

$H/_{\text{stage}}$ would then be

$H/_{N^2} \times N^2 = (2.25 \times 10^{-4})\,(11500)^2 = 29\,756 \frac{\text{Nm}}{\text{kg}}$

Determine approximate number of casing stages.

Number of stages $= \frac{100\,579}{29756} = 3.38 \cong 4$

6) Adjust Speed

Adjust the nominal speed according to the casing stages.

4 stages must develop $100579 \frac{\text{Nm}}{\text{kg}}$

or an average of $\frac{100579}{4}$ per stage. $= 25145$

Using Fan Law relationships adjust the speed.

$H \alpha N^2$

$$N = N_{NOM} \left[\frac{H_{REQ'D}}{H}\right]^{1/2} = 11500 \left[\frac{25145}{29756}\right]^{1/2}$$

$N = 10571$ r/min

7) Calculate the approximate power

$$GkW = \frac{w_1 \times H}{60\,000 \times \eta_p} = \frac{(802.4)\ (100579)}{(60000)\ (0.78)} = 1724 \text{ kW}$$

Adjust for balance piston leakage

$1724 \times 1.02 = 1759$ kW

Add losses from Chart 6

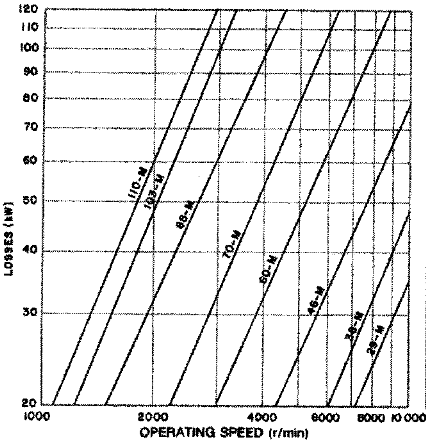
$SkW = 1759 + 54 = 1813$kW
(Assume Iso-Carbon Seal)

Metric Units

Mechanical Losses

Chart 5

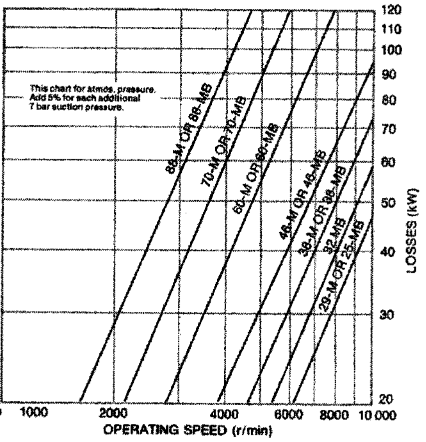
LABYRINTH, DRY CARBON RING OR GAS FACE SEAL



For 10MB, 15MB and 20MB, use 30 KW for losses

Chart 6

ISO-CARBON OR ISO-SLEEVE SEAL

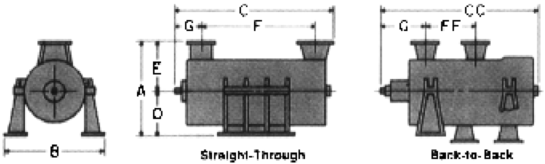


This chart for atmos. pressure. Add 5% for each additional 7 bar suction pressure.

Approximate dimensions and weights

Vertically Split

English units



Straight-Through

Back-to-Back or Iso-Cooled

Technical Data

Elliott Compressor Frame	Material	(PSIG) Pressure Rating	* Total Weight lbs.		Nozzle Size		Rotation Facing inlet
			Three Stages	Each Add'l Stage	Inlet inches	Discharge inches	
15MB	Fgd. Steel	2000	5,035	350	6, 8	4, 6	CCW
15MBH	Fgd. Steel	4200	6,930	460	6, 8	4, 6	CCW
15MBHH	Fgd. Steel	7500	11,000	550	6, 8	4, 6	CCW
20MB	Plate	1500	9,560	660	8, 10	6, 8	CCW
20MBH	Fgd. Steel	4200	13,150	870	8, 10	6, 8	CCW
25MB	Fgd. Steel	1500					CW
		2000	18,140	1,250	14, 12, 10 or 8	10, 8 or 6	CCW
25MBH	Fgd. Steel	3150					CW
		4200	25,000	1,655	12, 10 or 8	8 or 6	CCW
25MBHH	Fgd. Steel	5150	38,500	1,475	10, 8 or 6	6 or 4	CW
		10000	53,200	5,100	8 or 6	6 or 4	CCW
32MB	Fgd. Steel	1500					CW
		2000	23,800	2,490	16, 14 or 12	12 or 10	
32MBH	Fgd. Steel	3150					CW
		4200	36,500	3,650	12, 10 or 8	8 or 6	
32MBHH	Fgd. Steel	10000	56,600	7,250	10 or 8	8 or 6	CW
38MB	Fgd. Steel	700	30,045	3,440	24, 20 or 16	16 or 14	CW
		1200	36,300	4,130	20 or 16	16 or 14	
		1500	51,300	5,250	16 or 14	14 or 12	CW
46MB	Fab. Steel	750	40,700	4,000	30 or 24	20 or 16	CW
		1200	50,700	4,800	24 or 20	26 or 14	
60MB	Fab. Steel	400	73,200	8,115	36 or 30	24 or 20	CW
		800	99,200	9,637	36 or 30	20 or 16	
70MB	Fab. Steel						CW
		800	152,300	18,800	42 or 36	30 or 24	
88MB	Fab. Steel						CW
		800	198,000	40,400	54 to 48	36 or 30	

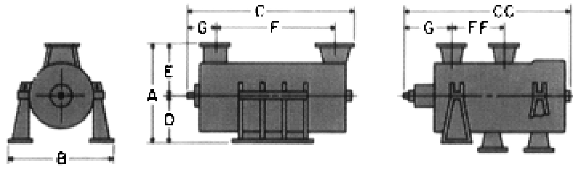
NOTE: The drive end is normally the suction end.

*For back-to-back machines, add weight of two stages.

Approximate Dimensions (inches)

Elliott Compressor Frame	A	B	C	CC	Length Each Add'l Stage	D	E	F	FF	Length Each Add'l Stage	G
			Min. 3 Stages	Six Stages				Min. 3 Stages	Six Stages		
15MB	38	36	38.5	50	2.6	17	21	16	19	2.6	11
15MBH	39	38	40	52	2.6	17.5	21.5	16	21	2.6	13.75
15MBHH	45	41	48	61	3.3	22	23	17	23.5	3.3	19
20MB	47	44	48	62	3.2	21	26	19	23.5	3.2	13.75
20MBH	49	47	51	68	3.2	22	27	19	26	3.2	17
25MB	58	55	59	77	4	26	32	24	29	4	17
25MBH	60	58	63	84	4	27	33	24	32	4	21
25MBHH	69	63	73	93	5	34	35	26	36	5	29
	83	70	76	98	6	41	42	29	48	6	31
32MB	72	71	68	83	5	33	39	29	44	5	18
32MBH	75	74	74	88	6	34	41	31	46	6	21
32MBHH	86	88	82	95	6	39	47	34	50	6	34
38MB	76	79	80	116	8	36	40	33	63	8	18
	78	82	83	119	8	37	41	33	63	8	20
	86	90	95	128	8	41	45	37	71	8	32
46MB	86	109	92	137	9	38	48	43	88	9	24
	92	118	98	142	9	41	51	44	90	9	27
60MB	113	122	105	165	12	56	57	57	117	12	26
	125	134	111	171	12	62	63	59	119	12	28
70MB	134	142	142	217	15	66	68	70	147	15	41
88MB	146	160	152	252	20	69	77	89	192	20	51

Metric units



Straight-Through

Back-to-Back or Iso-Cooled

Technical Data

Elliott Compressor Frame	Material	(BAR) Pressure Rating	* Total Weight kg		Nominal Nozzle Size				Rotation Facing Inlet
			Three Stages	Each Add'l Stage	Inlet		Discharge		
					inches	millimetres	inches	millimetres	
15MB	Fgd. Steel	138	2290	160	6, 8	152, 203	4, 6	102, 152	CCW
15MBH	Fgd. Steel	290	3150	210		152, 203		102, 152	CCW
15MBHH	Fgd. Steel	520	5000	250	6, 8	152, 203	4, 6	102, 152	CCW
20MB	Plate	103	4350	300	8, 10	203, 254	6, 8	152, 203	CCW
20MBH	Fgd. Steel	290	6000	400	8, 10	203, 254	6, 8	152, 203	CCW
25MB	Fgd. Steel	103							CW
		138	8250	570	14, 12, 10, 8	356, 305, 254, 203	10, 8, 6	254, 203, 152	CCW
25MBH	Fgd. Steel	217							CW
		290	11 315	750	12, 10, 8	305, 254, 203	8, 6	203, 152	CCW
25MBHH	Fgd. Steel	355	17 464	670	10, 8, 6	254, 203, 152	6, 4	152, 102	CW
		690	24 131	2310	8, 6	203, 152	6, 4	152, 102	CCW
32MB	Fgd. Steel	103							CW
		138	10 796	1130	16, 14, 12	406, 356, 305	12, 10	305, 254	
32MBH	Fgd. Steel	217							CW
		290	16 556	1655	12, 10, 8	305, 254, 203	8, 6	203, 152	
32MBHH	Fgd. Steel	690	25 674	3285	10, 8	254, 203	8, 6	203, 152	CW
38MB	Fgd. Steel	48	13 628	1558	24, 20, 16	610, 508, 406	16, 14	406, 356	CW
		83	16 467	1870	20, 16	610, 508, 406	16, 14	406, 356	
		103	23 270	2378	16, 14	406, 356	14, 12	356, 305	CW
46MB	Fab. Steel	52	18 458	1815	30, 24	762, 610	20, 16	508, 406	CW
		83	23 014	2175	24, 20	610, 508	26, 14	660, 356	
60MB	Fab. Steel	27	33 180	3676	36, 30	914, 762	24, 20	610, 508	CW
		55	44 998	4365	36, 30	914, 762	20, 16	508, 406	
70MB	Fab. Steel								CW
		55	69 083	8515	42, 36	1067, 914	30, 24	762, 610	
88MB	Fab. Steel								CW
		55	89 813	18 300	54, 48	1372, 1219	36, 30	914, 762	

NOTE: The drive end is normally the suction end.

*For back-to-back machines, add weight of two stages.

Approximate Dimensions (millimetres)

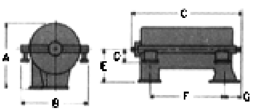
Elliott Compressor Frame	A	B	C	CC	Length Each Add'l Stage	D	E	F	FF	Length Each Add'l Stage	G
			Min. 3 Stages	Six Stages				Min. 3 Stages	Six Stages		
15MB	965	914	978	1270	66	432	533	406	483	66	279
15MBH	990	965	1016	1320	66	445	546	406	533	66	350
15MBHH	1143	1041	1219	1550	84	559	584	432	597	84	483
20MB	1194	1118	1219	1575	81	533	660	483	597	81	350
20MBH	1245	1194	1295	1725	81	559	686	483	660	81	432
25MB	1470	1400	1500	1960	100	660	810	610	740	100	430
25MBH	1520	1470	1600	2130	100	690	840	580	810	100	530
25MBHH	1750	1600	1850	2360	130	860	890	660	910	130	740
	2110	1780	1930	2490	150	1040	1070	740	1220	150	790
32MB	1830	1800	1730	2110	130	840	990	740	1120	130	460
32MBH	1900	1880	1880	2240	150	860	1040	790	1170	150	530
32MBHH	2180	2240	2080	2410	150	990	1190	860	1270	150	860
38MB	1930	2010	2030	2950	200	910	1020	840	1600	200	460
	1980	2080	2110	3020	200	940	1040	840	1600	200	510
	2180	2290	2410	3250	200	1040	1140	940	1800	200	810
46MB	2180	2770	2340	3480	230	970	1220	1090	2240	230	610
	2340	3000	2490	3610	230	1040	1300	1120	2290	230	690
60MB	2870	3100	2670	4190	300	1420	1450	1450	2970	300	660
	3180	3400	2820	4340	300	1570	1600	1500	3020	300	710
70MB	3400	3610	3610	5510	380	1680	1730	1780	3730	380	1040
88MB	3710	4060	3860	6400	510	1750	1960	2260	4880	510	1300

All dimensions and weights are approximate and to be used only for preliminary planning. See your Elliott Representative for more accurate data.

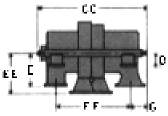
Approximate dimensions and weights

Horizontally Split

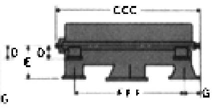
English units



Straight-through compression



Iso-Cooled with external volutes



Iso-Cooled with internal volutes

Technical Data

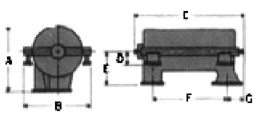
Elliott Compressor Frame	Material	Min. Casing Length (stages)	Total Weight lbs.		Weight Heaviest Part, lbs.		Nozzle Size, inches		Rotation* Facing Inlet
			Min.	Add'l Stage	Min.	Add'l Stage	Inlet	Discharge	
29M	C.I.	3	8,405	886	3,855	400	16	6, 8 or 10	CW
	C.S.	3	8,052	935	3,855	400	16	6, 8 or 10	CW
	C.S.	3	9,025	1,034	4,915	500	16	6, 8 or 10	CW
	F.S.	3	9,025	1,034	4,915	500	12,8	8	CW
38M	C.I.	3	15,124	2,462	8,624	950	20	16	CW
	F.S.	3	15,597	2,276	7,953	850	20 or 24	16	CW
	F.S.	3	18,905	2,400	9,965	1,000	20 or 24	16	CW
46M	C.I.	2	23,534	2,992	10,350	1,800	24	20	CW
	F.S.	3	25,888	3,950	12,359	2,000	30	20	CW
	F.S.	3	29,954	4,189	15,072	2,300	30	20	CW
60M	C.I.	3	46,904	6,688	22,373	2,200	36	24	CW
	F.S.	3	41,861	6,688	20,409	2,500	36	24	CW
70M	C.I.	2	54,412	10,876	27,293	3,100	42	30	CW
	F.S.	2	59,616	11,952	30,021	3,400	42 or 48	30	CW
88M	C.I.	2	98,716	21,860	48,904	8,000	54 or 48	36 or 30	CW
	F.S.	2	105,305	24,290	52,531	8,200	54 or 48	36 or 30	CW
103M	C.I.	2	88.000	26.000	40,000	13,000	66 or 60	42	CCW
	F.S.	2	95.000	28,000	44,000	13,800	66 or 60	42	CCW
110M	C.I.	2	115,715	29,872	52,545	15.000	72	48	CCW
	F.S.	2	124,364	31,740	56,746	16,000	72	48	CCW

Approximate Dimensions (inches)

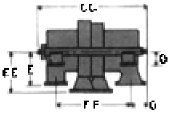
Elliott Compressor Frame	A	B	Overall Length				Nozzle Distance				G	E	EE	D
			C Min. Stages	CC Six Stages	CCC Four Stages	Each Add'l Stage	F Min. Stages	FF Six Stages	FFF Four Stages	Each Add'l Stage				
29M	61	58	52	74	—	4.5	24	38	—	4.5	17½	32	32	27
	61	58	52	74	—	4.5	24	38	—	4.5	17½	32	32	27
	61	58	52	74	—	4.5	24	38	—	4.5	18½	32	32	27
	61	58	52	74	—	4.5	24	38	—	4.5	18½	29	29	27
38M	68	83	65	86	—	7	31	52	—	7	20	35	35	27
	68	83	65	86	87	7	31	52	57	7	20	35	39	27
	68	83	65	86	87	7	31	52	57	7	21	35	39	27
46M	84	97	73	100	—	9	39	66	—	9	21	42	42	28
	71	79	87	114	119	9	39	66	69	9	22	44	52	22
	71	79	87	114	119	9	39	66	69	9	23	44	52	22
60M	124	119	105	141	—	12	51	86	—	12	22	68	68	24
	92	103	105	141	146	12	51	86	93	12	25	57	64	24
70M	146	131	103	148	—	15	50	95	—	15	30	80	84	22
	120	128	103	148	157	15	53	98	106	15	23	68	77	24
88M	125	131	115	175	—	20	65	123	—	20	24	72	75	24
	142	131	115	171	161	20	65	123	127	20	24	84	96	24
103M	141	144	131	194	—	21	71	132	—	21	23	78	84	24
	156	148	133	194	198	21	71	132	139	21	27	82	102	24
110M	158	176	128	210	—	24	83	155	—	24	25	92	98	24
	177	176	130	210	222	24	83	155	162	24	29	94	114	24

*The normal drive end is the discharge end. For units requiring opposite rotation, the drive end is the suction end.

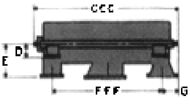
Metric units



Straight-through
compression



Iso-Cooled
with external volutes



Iso-Cooled
with internal volutes

Technical Data

Elliott Compressor Frame	Material	Min. Casing Length (stages)	Total Weight kg		Weight, Heaviest Part kg		Nominal Nozzle Size				Rotation* Facing Inlet
							Inlet		Discharge		
			Min.	Add'l Stage	Min.	Add'l Stage	inches	millimetres	inches	millimetres	
29M	C.I.	3	3813	402	1749	180	16	406	6, 8, 10	152, 203, 254	CW
	C.S.	3	3652	424	1749	180	16	406	6, 8, 10	152, 203, 254	CW
	C.S.	3	4093	469	2229	230	16	406	6, 8, 10	152, 203, 254	CW
	F.S.	3	4093	469	2229	230	12,8	305, 203	8	203,	CW
38M	C.I.	3	6860	1117	3912	430	20	508	16	406	CW
	F.S.	3	7075	1032	3607	390	20, 24	508, 610	16	406	CW
	F.S.	3	8575	1089	4520	450	20, 24	508, 610	16	406	CW
46M	C.I.	2	10 675	1357	4695	820	24	610	20	508	CW
	F.S.	3	11 743	1792	5606	910	30	762	20	508	CW
	F.S.	3	13 587	1900	6837	1040	30	762	20	508	CW
60M	C.I.	3	21 276	3034	10 148	1000	36	914	24	610	CW
	F.S.	3	18 988	3034	9258	1130	36	914	24	610	CW
70M	C.I.	2	24 681	4933	12 380	1410	42	1067	30	762	CW
	F.S.	2	27 042	5421	13 618	1540	42, 48	1067, 1219	30	762	CW
88M	C.I.	2	44 778	9916	22 183	3630	54, 48	1372, 1219	36, 30	914, 762	CW
	F.S.	2	47 766	11 018	23 828	3720	54, 48	1372, 1219	36, 30	914, 762	CW
103M	C.I.	2	39 917	11 794	18 144	5900	66, 60	1676, 1524	42	1067	CCW
	F.S.	2	43 092	12 701	19 956	6260	66, 60	1676, 1524	42	1067	CCW
110M	C.I.	2	52 488	13 550	23 834	6800	72	1829	48	1219	CCW
	F.S.	2	56 412	14 397	25 740	7250	72	1829	48	1219	CCW

Approximate Dimensions (millimetres)

Elliott Compressor Frame	A	B	Overall Length				D	E	EE	Nozzle Distance				G
			C Min. Stages	CC Six Stages	CCC Four Stages	Each Add'l Stage				F Min. Stages	FF Six Stages	FFF Four Stages	Each Add'l Stage	
29M	1550	1470	1320	1880	—	110	690	810	810	610	970	—	110	440
	1550	1470	1320	1880	—	110	690	810	810	610	970	—	110	440
	1550	1470	1320	1880	—	110	690	810	810	610	970	—	110	470
	1550	1470	1320	1880	—	110	690	810	810	610	970	—	110	470
38M	1730	2110	1650	2180	—	180	690	890	890	790	1320	—	180	510
	1730	2110	1650	2180	2210	180	690	890	990	790	1320	1450	180	510
	1730	2110	1650	2180	2210	180	690	890	990	790	1320	1450	180	530
46M	2130	2460	1850	2540	—	230	710	1070	1070	990	1680	—	230	530
	1800	2010	2210	2900	3020	230	560	1120	1320	990	1680	1750	230	580
	1800	2010	2210	2900	3020	230	560	1120	1320	990	1680	1750	230	580
60M	3150	3020	2670	3580	—	300	610	1730	1730	1300	2180	—	300	560
	2340	2620	2570	3580	3760	300	610	1450	1630	1300	2180	2360	300	640
70M	3710	3330	2620	3760	—	380	560	2030	2130	1270	2410	—	380	760
	3050	3250	2620	3760	3990	380	610	1730	1960	1350	2490	2690	380	580
88M	3175	3330	2920	4440	—	510	610	1830	1900	1650	3120	—	510	610
	3610	3330	2920	4340	4090	510	610	2130	2440	1650	3120	3230	510	610
103M	3580	3660	3330	4930	—	530	610	1980	2130	1800	3350	—	530	580
	3960	3760	3380	4930	5030	530	610	2080	2590	1800	3350	3530	530	690
110M	4010	4470	3250	5330	—	610	610	2340	2490	2110	3940	—	610	640
	4500	4470	3300	5330	5640	610	610	2390	2900	2110	3940	4110	610	740

*The normal driving end is the discharge end. For units requiring opposite rotation, the drive end is the suction end.

B.2 QUICK SELECTION METHODS FOR MULTISTAGE COMPRESSORS*

Among the many purely graphical methods of rapidly selecting multistage compressors is one developed around 1965 by Don Hallock of the Elliott Company, Jeannette, Pa. To use these charts, the following quantities must be known:

1. W—weight flow, in lb/min or scfm (standard ft^3/min).
2. P_1—inlet pressure, in psia
3. R_p—pressure ratio (discharge psia/inlet psia)
4. t_1—inlet temp., in °F
5. M—mole weight
6. K—ratio of specific heats

Determine the Inlet cfm, Q1. If W is known, use Fig. B.1, proceeding through P_1, t_1, and M to find Q_1.

If scfm is known, use Fig. B.2, proceeding through P_1, t_1, and "temperature standard" to find Q_1.

Determine the Head H. On Fig. B.3, enter R_p and proceed through K, t_1, and M as shown. If head H exceeds 80,000 to 90,000, more than one compressor body will be required.

Determine the Number of Stages Required. On Fig. B.4, enter head H and proceed through M to read the number of stages required. Round this off to the next-higher even number.

Determine the Speed and Size of the Machine. On Fig. B.5, enter Q_1 and read the maximum width in inches. Proceed to the stepped lines and read the rpm and flange sizes. Proceed through the number of stages and read the length of the machine in inches. In the example shown, the icfm is 45,000 and the gas is between propane and chlorine in mole weight. The speed is shown to be 4000 rpm and the flanges are 36 and 24 in. A slightly higher flow requires 3500 rpm and 42- and 30-in. flanges.

Determine the Horsepower Requirement. On Fig. B.6, enter W, proceed through Q_1 and H, and read HP. If W is not known, work backward from Q_1 on Fig. B.1 to find W before using Fig. B.6.

For uncooled, constant weight flow compression, such as alkylation, wet gas, recycle, or air under 50 psia, the foregoing is sufficient to determine price, size, and driver requirement. For cooled or variable weight flow compression, proceed as follows:

Cooled Compression. Assume one cooler and two compression sections, each section handling a pressure ratio equal to the square root of the overall pressure ratio.

- Determine discharge temperature t_2 from Fig. B.7, proceeding through R_p, Q_1, K, and t_1.
- Assuming that this t_2 is satisfactory, proceed through all the figures for each of the separate sections. Speed and width of the compressor will be dictated by the first sections. The total horsepower is the sum of the sections.

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* Developed and contributed by Don Hallock, Elliott Company, Jeannette, Pa. Adapted by permission of *HP* and the Elliott Company. Originally published in the October 1965 issue of *Hydrocarbon Processing*.

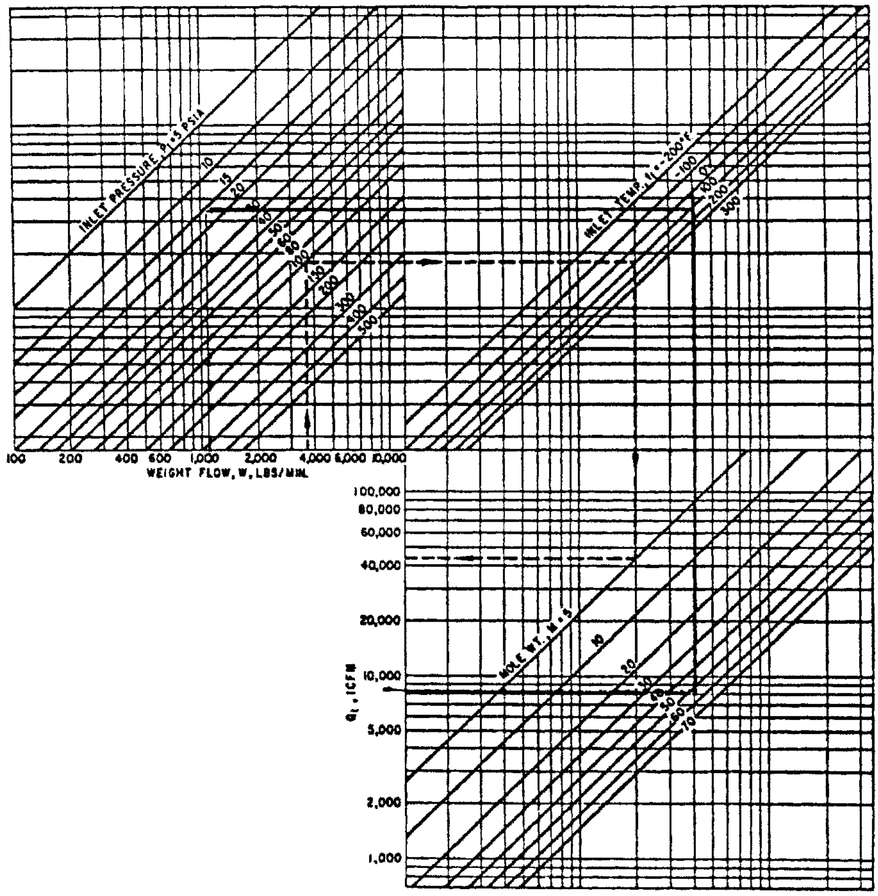

FIGURE B.1 If the weight flow of gas W is known, use this chart to find the inlet flow Q_1 (icfm).

- If one cooler does not depress t_2 sufficiently, or if still more horsepower saving is desired, try two coolers or more. R_p per section for a two-cooler three-section arrangement is the cube root of the overall R_p; for a three-cooler four-section arrangement, it is the fourth root. Bear in mind that more than one set of cooler openings is seldom available on a single compressor body. When more than one cooler is chosen, therefore, more than one compressor body is likely to be required.

Considerable judgment is required in choosing the number of coolers to use. Once the temperature limits are satisfied, the use of additional coolers becomes a matter of economics between compressor and cooler cost, and horsepower evaluation.

Variable Weight Flow. For applications having side flows either in or out, it is necessary to consider each constant flow compression section separately. Mixture temperature to the second section after the first "inward" side flow must be calculated by finding the discharge

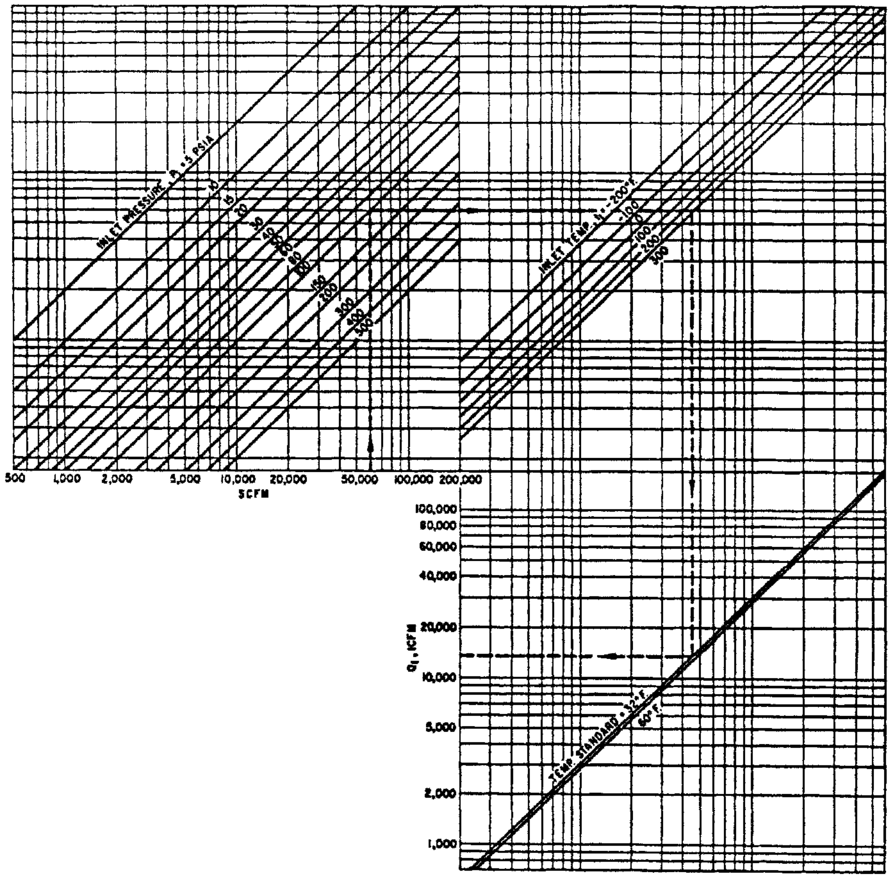

FIGURE B.2 If the scfm value is known, use this chart to find the inlet flow Q_1 (icfm).

temperature of the first section from Fig. B.7, multiplying by the first section weight flow, adding in the product of the sidestream temperature and weight flow, and dividing by the sum of the weight flows. With mixture t_1, P_1, W, M, and K known, the figures can now be used for the second section, and so on through the machine.

M and K of the sidestream will generally be the same or quite close to those of the inlet, so mixture calculations for these quantities will normally be unnecessary. For extraction side flows, the second section inlet conditions are the same as the first section discharge conditions, except for W.

Normally, the first section will "see" the largest Q_1, in which case the first section Q_1 will dictate the size and speed of the machine. An occasional refrigeration process, however, will show the second section Q_1 to be the largest. In this case, *that* Q_1 will dictate machine size and speed.

To determine the number of stages required, add the stages for each compression section and add in a blank stage for each large side load. It is impossible to give criteria for exactly what constitutes a "large" side load, but experience has shown that a typical propylene unit

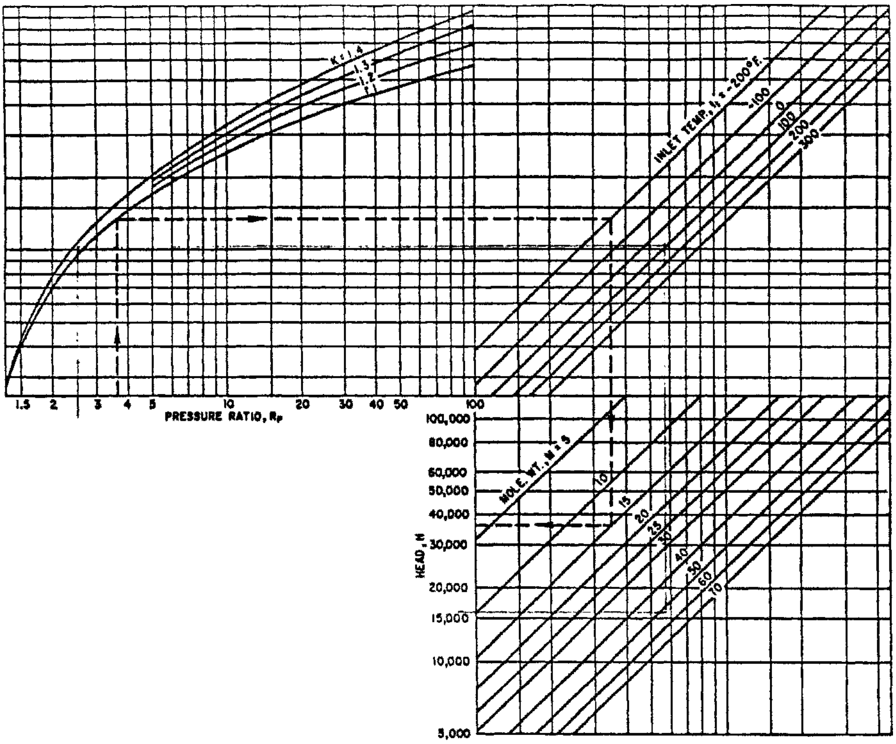

FIGURE B.3 Enter this chart at R_p, the pressure ratio (discharge/inlet, psia), to find the head H.

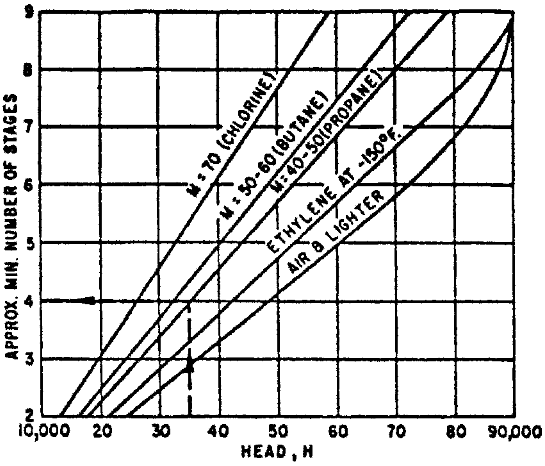

FIGURE B.4 Enter this chart with the H value on Fig. B.3 to find the number of stages required.

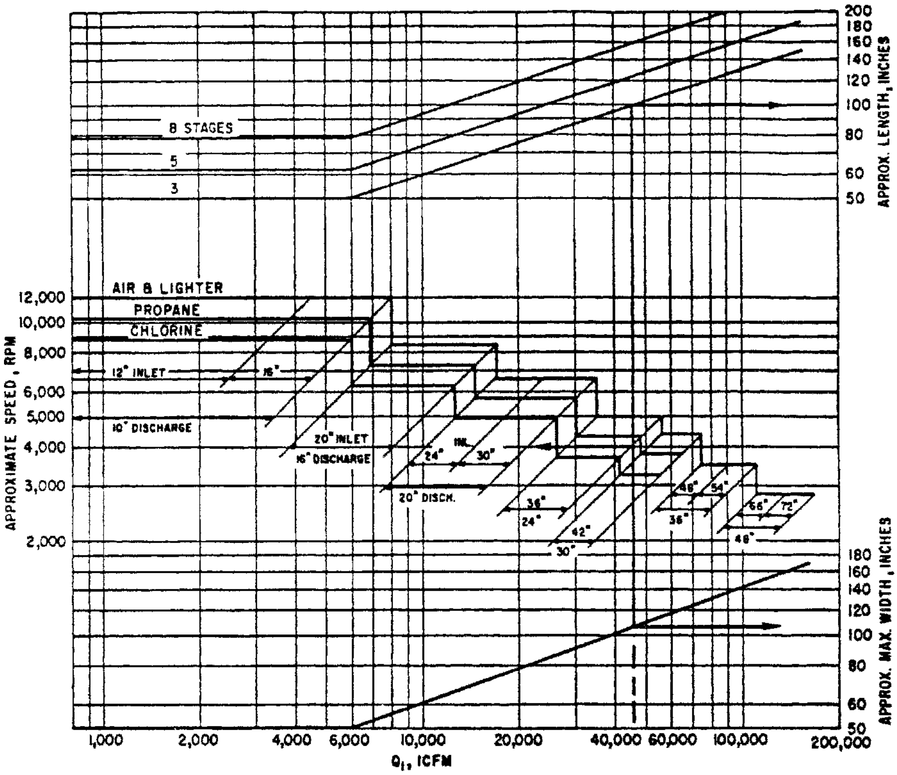

FIGURE B.5 Enter this chart at the Q_1 value from Fig. B.1 or B.2 and find the speed, width, length, and flange sizes.

will require a blank stage for the first sideload only, whereas a typical ethylene machine may require two blank stages. If the total number of stages, including blanks, exceeds nine, a second machine will probably be required.

B.3 DELAVAL ENGINEERING GUIDE TO COMPRESSOR SELECTION*

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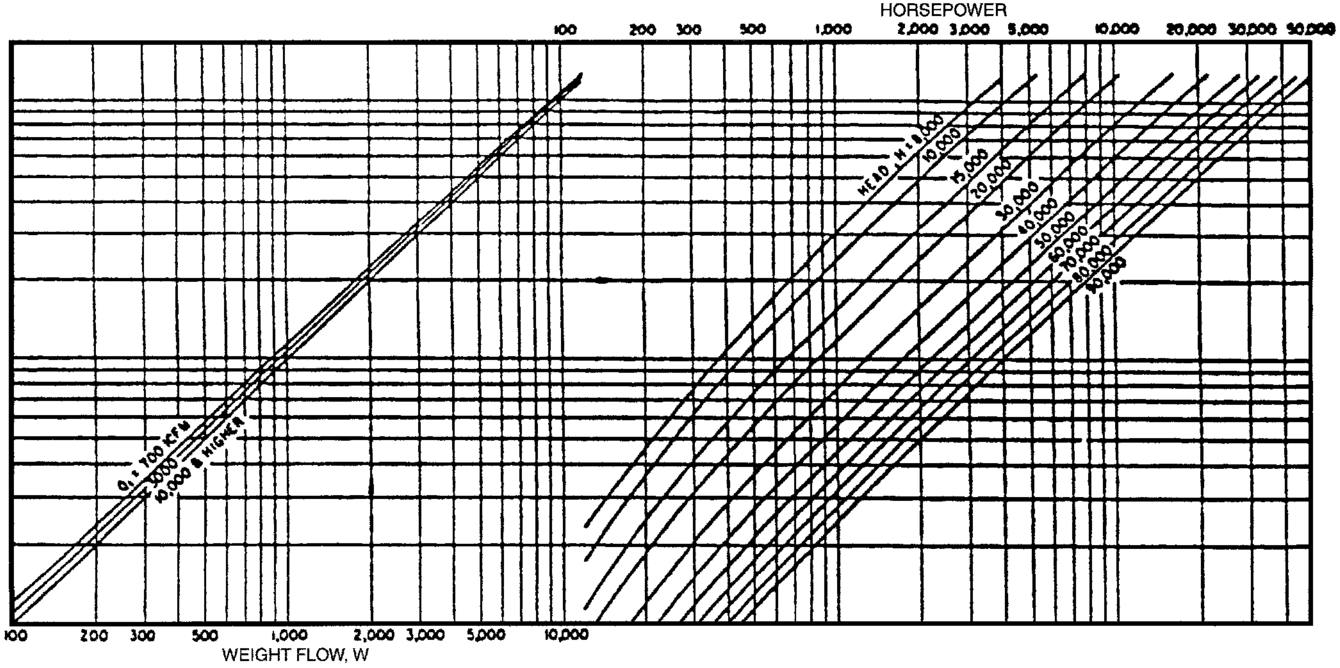


FIGURE B.6 Enter this chart at the weight flow of gas *W* and proceed to find the compressor horsepower required.

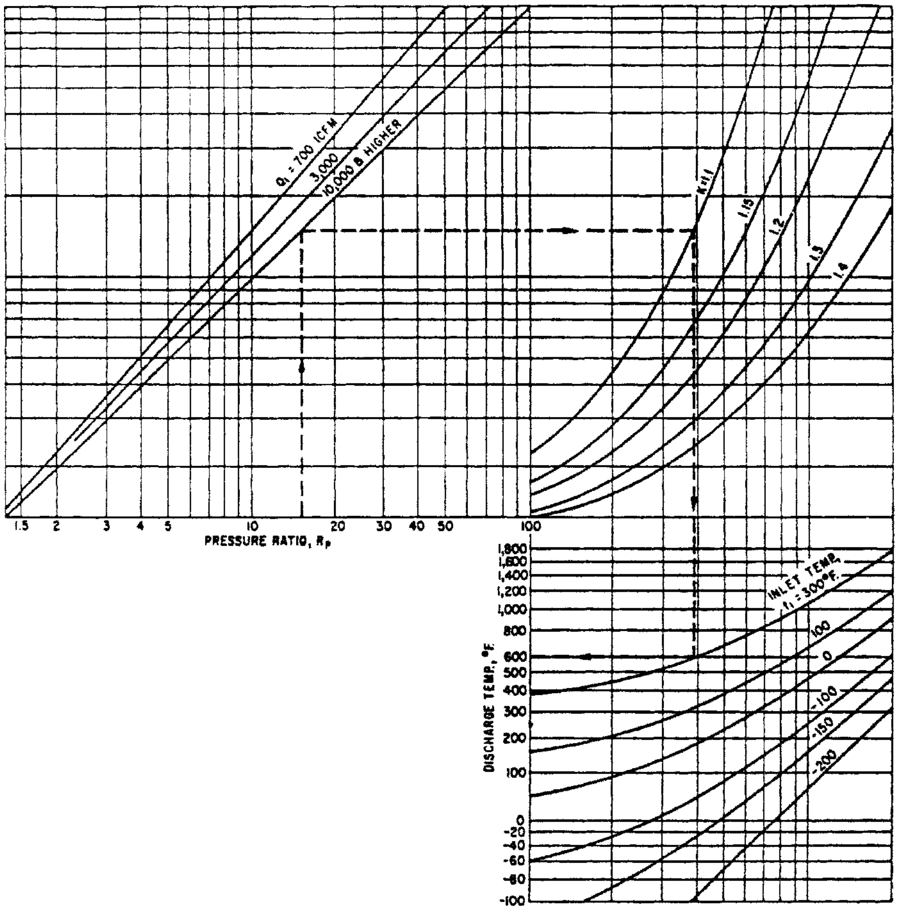


FIGURE B.7 The discharge temperature can be found on this chart.

Delaval Engineering Guide to Compressor Selection

TABLE OF CONTENTS

I. Symbols

The following are the symbols (and their definitions) and the units of measurement used throughout this section.

C	Specific heat of mixture	N	Number of compression stages	v	Specific volume (ft³/lbm)(m³/kg)
C_p	Specific heat at constant pressure	n	Polytropic exponent	W	Weight of gas (lbm)
C_v	Specific heat at constant volume	P_R	Reduced pressure	Z	Compressibility factor
D	Impeller diameter (inches) (mm)	P	Pressure (psia) (bar)	BHP	Brake horsepower (hp)
G	Weight of mixture	P_c	Critical pressure (psia) (bar)	GHP	Gas horsepower (hp)
g	Gravitational constant (32.2 ft/sec²)	P_e	Brakepower (kW)	η	Efficiency
H	Head (ft lbf/lbm) (Nm/kg)	P_i	Gaspower (kW)	Φ	Flow coefficient
k	Ratio of specific heats (C_p/C_v)	Q	Capacity (cfm) (m³/sec)	Ψ	Head coefficient
lbf	Pound force	R	Gas constant $\left(\frac{1544}{MW}\right)\left(\frac{8314}{MW}\right)$		**Subscripts**
lbm	Pound mass	r	Pressure ratio (P_2/P_1)	ad	Adiabatic process
$\dot{m}$	Mass flow (lbm/min) (kg/sec)	T	Absolute temperature (°R = °F + 460) (°K = C + 273)	p	Polytropic process
M_{cp}	Molar specific heat at constant pressure	Tc	Critical temperature (°R) (°K)	s	Standard conditions (14.7 psia, 60°F, dry Q_s) (1.0135 bar and 0 °C)
MW	Molecular weight	T_R	Reduced temperature	1	Inlet to section
MWP	Maximum working pressure (psi) (bar)	ΔT	Change in temperature (°)	2	Discharge from section
		U	Tip speed (ft/sec) (m/sec)	x	At a specific point (inlet, discharge, etc.)
		V	Total volume (ft³) (m³)		

II. The Gas Compression Theory

The relationship between the volume, absolute pressure and absolute temperature of a perfect gas, based on Charles' and Boyle's Laws, is: PV = WRT; or, on a mass basis, Pv = RT.

An important characteristic of gases is specific heat.

Specific heat is defined as the amount of heat (BTU) (kJ) required to raise the temperature of one pound (kilogram) of gas one degree Fahrenheit (Kelvin). The amount varies depending on whether the gas volume or pressure is kept constant during the heating process. This is defined by: $R \propto C_p - C_v$. The ratio (k) of specific heat of a gas at constant pressure to that at constant volume (C_p/C_v) is used in gas calculations.

If heat is neither added nor removed from the gas during compression, the process is defined as isentropic or adiabatic. The relationship of pressure and volume for a perfect gas undergoing isentropic compression is defined as PV^k, a constant.

Because many gases do not perfectly obey the theoretical laws, the deviation must be accounted for. The deviation, termed compressibility (Z), is defined as the ratio of actual gas volume at a given temperature and pressure to the volume calculated by the theoretical law (Pv = RT).

The general equation for adiabatic work is:

$$H = ZRT \frac{\left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right]}{\frac{k-1}{k}} \text{ ft lbf/lbm (Nm/kg)}$$

The actual compression path seldom follows the adiabatic process but is generally in the form PV^n, a constant. This is called a polytropic process and is defined as reversible with heat transfer.

n is the exponent of polytropic compression and is found from:

$$\frac{n-1}{n} = \frac{k-1}{k}\left[\frac{1}{\eta_p}\right]$$

where η_p is the polytropic compression efficiency. Figure 1 shows the relationship between polytropic and adiabatic efficiency.

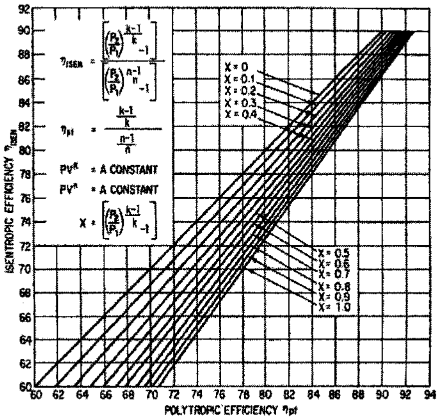


Figure 1

III. Determining Z, k, and MW

Before a compressor cycle can be calculated, it is necessary to know the specific heat ratio, k; molecular weight, MW; and compressibility, Z, of the gas. For pure gases or air, these values can be taken from Figure 2. For a mixture of gases, the values must be calculated. Mixtures are generally specified in volumetric or mole percentages.

The properties of the mixture are determined by the composite properties of the constituent gases.

The values for the compressibility (Z) of gas mixtures can be calculated if the gas analysis is known.

Z can be derived from the rule of corresponding states using reduced temperature and pressure. To calculate reduced temperature (T_R) and reduced pressure (P_R), see the following information. The critical constants T_c and P_c for various gases are given in Table 1.

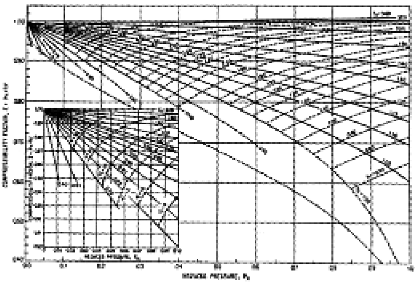


Figure 2

English & Metric

To facilitate the broadest use of the information contained in this brochure, terms have been stated in both English and Metric.

Use of parentheses, blue type or light blue shading over areas of type indicate Metric values.

Physical Constants of Gases

Compound	Formula	Mol. wt. MW	C_p and C_p/C_v at 14.7 psia and 60°F		C_p and k at 1.01325 bar and 0°C		Critical constants		Critical constants		MC_p at 60°F	MC_p at 100°F	MC_p at 200°F	MC_p at 0°C	MC_p at 25°C	MC_p at 100°C
			C_p	C_p/C_v	C_p kJ/(kg k)	k	psia P_c	°R T_c	bar P_c	K T_c						
Acetylene	C_2H_2	26.036	0.3966	1.238	1.6345	1.243	905.0	557.4	61.4	308.3	10.33	10.69	11.53	42.56	43.72	47.62
Air	$N+O_2$	28.966	0.2470	1.395	1.0048	1.400	547	238.7	37.7	132.4	6.96	6.96	6.99	29.11	29.11	29.11
Ammonia	NH_3	17.032	0.5232	1.310	2.0323	1.317	1,657	731.4	112.8	405.5	8.91	8.57	9.02	34.81	35.08	37.25
Benzene	C_6H_6	78.108	0.2404	1.116	0.9429	1.128	714	1,013.0	49.0	562.2	18.76	20.47	24.46	73.65	82.09	105.05
1,2-Butadiene	C_4H_6	54.088	0.3458	1.12	1.3934	1.124	653	799.0	45.0	443.7	18.70			75.37	80.17	93.71
1,3-Butadiene	C_4H_6	54.088	0.3412	1.12	1.3615	1.128	628	766.0	43.3	425.4	18.45			73.65	79.72	95.75
N-Butane	C_4H_{10}	58.120	0.3970	1.094	1.5625	1.101	550.7	765.6	38.0	425.2	23.07	24.51	26.16	90.84	97.83	117.83
Isobutane	C_4H_{10}	58.120	0.3872	1.097	1.5433	1.102	529.1	734.9	36.5	408.1	22.50	23.95	27.62	89.70	97.10	118.08
N-Butene	C_4H_8	56.104	0.3703	1.105	1.4160	1.117	583	755.6	40.2	419.6	20.77	22.09	25.18	79.45	85.74	103.31
Isobutene	C_4H_8	56.104	0.3701	1.106	1.4872	1.111	579.8	752.5	40.0	417.9	20.76			83.44	89.03	105.66
Butylene	C_4H_8	56.104	0.3703	1.105	1.4687	1.112	583	755.6	41.0	428.6	20.78	21.94	24.86	82.41	87.86	103.88
Carbon dioxide	CO_2	44.010	0.1991	1.300	0.8223	1.299	1,073	548.0	73.8	304.2	8.76	9.00	9.35	36.19	37.04	39.80
Carbon monoxide	CO	28.010	0.2484	1.403	1.0467	1.397	510	242.0	35.0	132.9	6.96	6.96	6.98	29.32	28.97	28.85
Chlorine	Cl_2	70.914	0.1149	1.356	0.4731	1.330	1,120	751	77.2	417.2	8.15			33.55	33.85	35.03
Ethane	C_2H_6	30.068	0.4097	1.193	1.6462	1.202	708.3	550.1	48.8	305.4	12.32	12.96	14.68	49.50	52.88	62.72
Ethyl alcohol	C_2H_5OH	46.069	0.3070	1.130	1.5240	1.135	927.0	929.6	63.8	516.3	14.14			70.21	73.49	84.10
Ethylene	C_2H_4	28.052	0.3622	1.243	1.4562	1.256	742.1	509.8	50.3	282.4	10.16	10.68	12.08	40.85	43.58	51.42
N-Hexane	C_6H_{14}	86.172	0.3964	1.062	1.5416	1.067	439.7	914.5	30.1	507.4	34.33	36.23	41.08	132.85	143.24	172.90
Helium	He	4.003	1.2480	1.6598	5.2000	1.667	480	510	2.3	5.2	5.00			20.82	20.82	20.82
Hydrogen	H_2	2.016	3.408	1.408	14.3849	1.404	188.0	60.2	13.0	33.33	6.87	6.90	6.95	28.86	28.66	28.41
Hydrogen sulfide	H_2S	34.076	0.254	1.323	0.9797	1.333	1,306	672.7	90.1	373.5	8.66	8.18	8.36	33.36	33.53	34.58
Methane	CH_4	16.042	0.5271	1.311	2.1637	1.316	673.1	343.6	46.1	190.6	8.46	8.65	9.30	34.71	35.60	39.62
Methyl alcohol	CH_3OH	32.042	0.2700	1.203	1.3398	1.241	1,157.0	924.0	80.9	512.6	8.55			42.93	45.06	51.11
Nitrogen	N_2	28.016	0.2482	1.402	1.0467	1.397	492.0	227.2	126.2	126.2	6.95	6.96	6.963	29.32	28.97	28.74
N-Octane	C_8H_{18}	114.224	0.3996	1.046	1.5349	1.050	362.1	1,025.2	24.9	568.8	45.67			175.33	189.39	228.04
Oxygen	O_2	32.00	0.2188	1.401	0.9169	1.396	730	278.2	50.8	154.8	7.00	7.03	7.120	29.34	29.21	29.61
N-Pentane	C_5H_{12}	72.146	0.3972	1.074	1.5541	1.080	489.5	845.9	33.7	469.7	28.66	30.30	34.41	112.12	120.83	145.36
Isopentane	C_5H_{12}	72.146	0.3880	1.075	1.5246	1.082	483.0	830.0	33.8	460.4	27.99	29.90	34.44	110.02	119.02	144.76
Propane	C_3H_8	44.094	0.3885	1.136	1.5516	1.139	617.4	666.2	42.5	369.8	17.13	18.21	20.90	68.42	73.85	89.58
Propylene	C_3H_6	42.078	0.3541	1.154	1.4202	1.162	667	657.4	46.1	364.8	14.90	15.77	17.88	58.76	63.96	76.15
Sulfur dioxide	SO_2	64.060	0.1470	1.246	0.6029	1.275	1,142	775.0	78.9	430.7	9.42			38.62	39.43	42.11
Toluene	C_7H_8	92.134	0.2599	1.091	1.0724	1.097	611	1,069.5	41.1	591.8	23.95			94.21	104.16	131.24
Water	H_2O	18.016	0.4446	1.335	1.8715	1.328	3,206	1,165.4	221.2	647.4	8.01	8.03	8.12	33.72	33.42	33.49
Natural gas		19.27	0.488	1.269	1.799	1.316	670	380	46.2	211.1	8.47	8.72	9.37	34.66	35.90	37.60

Table 1

For example, for a gas mixture with a composition (by volume) of 14% ethane, 85% methane and 1% nitrogen, T_C and P_C would be calculated as follows:

Gases	V (%/100)	T_C	T_C	VT_C	VT_C	P_C	P_C	VP_C	VP_C
C_2H_6	0.14	550.1	305.4	77.01	42.76	708.3	48.8	99.16	6.83
CH_4	0.85	343.5	190.6	292.00	162.01	673.1	46.1	572.19	39.14
N_2	0.01	227.2	126.2	2.27	1.26	492.0	33.9	4.92	0.34

For mixture T_C= 371.28°R (206.03°C) P_C=676.27psia (46.31 bar)

Using the above values, and assuming gas conditions of 90°F (30°C) and 124.5 psia (8.5 bar):

$$T_R = \frac{T}{T_C} = \frac{90 + 460}{371.3} \quad \frac{30 + 273.15}{206.03} = 1.48$$

$$P_R = \frac{P}{P_C} = \frac{124.5}{676.3} \quad \frac{8.5}{46.31} = 0.18$$

Using the calculated values of reduced temperature and pressure, the value of Z (.98) can be read from Figure 2, a generalized curve that can be used for any gas mixture. Figure 3 is a curve directly showing compressibility factors of natural gas at various pressures and temperatures.

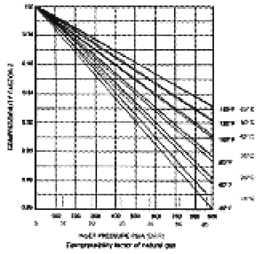


Figure 3

The molecular weight of a gas mixture is equal to the sum of the products of the proportional volume of each constituent and its molecular weight.

$$MW = m_1v_1 + m_2v_2 \ldots\ldots + m_nv_n$$

A simplified method for finding the ratio of specific heats (k) makes use of the molal specific heat M_{cp} expressed as

$$k = \frac{M_{cp}}{M_{cp} - 1.99} \qquad k = \frac{M_{cp}}{M_{cp} - 8.33}$$

Calculation of the properties of a gas mixture can best be done in tabular form. The following example determines the properties of a typical natural gas.

Gas	V (%/100)	MW	V(MW)	M_{cp} at 100°F	VM_{cp}	M_{cp} 41.26°C	VM_{cp}
C_2H_6	0.14	30.07	4.21	12.96	1.814	52.88	7.40
CH_4	0.85	16.04	13.63	8.65	7.353	35.80	30.43
N_2	0.01	28.02	0.28	6.96	0.069	28.97	0.29
Total	1.00	MW = 18.12		M_{cp} = 9.237		M_{cp} = 38.12	

$$k = \frac{9.237}{9.237 - 1.99} = 1.275$$

$$k = \frac{38.12}{38.12 - 8.33} = 1.280$$

IV. Selection Procedure

A. QUALIFYING THE SELECTION PROCEDURE

This procedure is intended to aid the user in making rapid preliminary compressor selections and estimating compressor performance. Only Delaval engineering will issue formal selections.

The method is to be used on a sectional basis. It examines a gas before it enters and after it leaves the compressor or compressor section (Figure 4). In the case of intercooled or side loaded compressors, the sections must be dealt with separately; the section with the largest inlet flow (Q) governs the frame size.

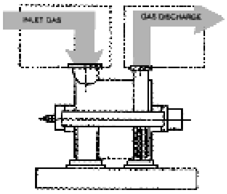


Figure 4

B. INPUT DATA REQUIRED

Selection of a compressor frame size and calculation of performance requires the following data: k, Z, MW, P_1, P_2, T_1, Q_1, (or $\dot{m}$). If the gas analysis is provided, values for k, Z, and MW can be calculated.

C. METHOD OF CALCULATION

The Delaval process compressor line was designed around the concept of component and performance similarity throughout the various frame sizes. Using the non-dimensional impeller flow coefficient (Φ) as a basis for determining aerodynamic performance of an impeller of any size, a common link between frame sizes results. In this way, theoretical and test data have been combined to define compressor characteristics for any size unit. The following procedure utilizes this approach for compressor selection.

D. FABRICATED MULTI-STAGE SELECTION PROCEDURE

Steps:

1. Calculate volmetric inlet flow (ACFM) from either of the following methods:

   a. From mass flow rate ($\dot{m}$),

   $$ACFM_X = v_X\,(\dot{m}) \text{ where } v_X = \frac{Z_X\,RT_X}{144\,P_X}$$

   b. From moles/hour,

   $$ACFM_X = \frac{(\text{Moles/hour})\,(MW)\,(v_X)}{60}$$

   c. From SCFM,

   $$ACFM_X = SCFM\;\frac{(P_S)\;(T_X)\;(Z_X)}{(P_X)\;(T_S)\;(Z_S)}$$

1. Calculate volumetric inlet capacity from either of the following methods:

   a. From mass flow rate

   $$Q_X = \dot{m}\,(v_X) \text{ where } v_X = \frac{Z_X\,(R)\,T_X}{P_X}$$

   b. From moles/hour

   $$Q_X = \frac{(\text{Moles/hour})\,(MW)\;v_X}{3600}$$

   c. From standard volumetric inlet flow,

   $$Q_X = \frac{Q_S\,(R_S)\,(T_X)\,(Z_X)}{(P_X)\,(T_S)\,(Z_S)}$$

2. Calculate adiabatic head based on inlet conditions to section,

$$H_{ad} = Z_1\,RT_1\,\frac{\left[r^{\frac{k-1}{k}} - 1\right]}{\frac{k-1}{k}}$$

3. Estimate discharge temperature (T_2) due to compression cycle[1]

$$\Delta T = T_1\,\frac{\left[r^{\frac{k-1}{k}} - 1\right]}{\eta_{ad}} \quad (\text{assume } \eta_{ad} = .75)$$

$$T_2 = T_1 + \Delta T$$

4. Determine minimum frame size from Figure 5.

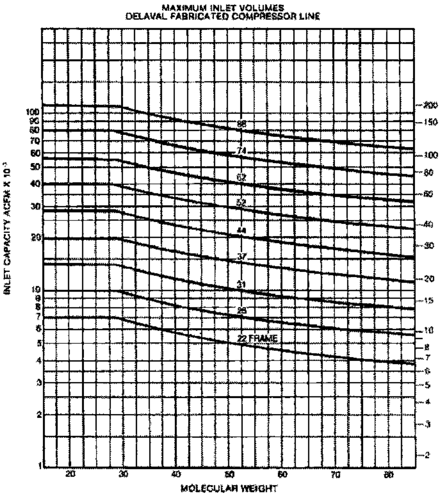


Figure 5

Footnote:
[1] Nominal temperature limitations are 450°F (250°C) for labyrith seals and 375°F (190°C) for oil face or bushing seals.

5. Find impeller wheel diameters from following table

Frame	D	Frame	D (mm)
22	13.65"	22	347
26	16.25"	26	413
31	19.25"	31	489
37	22.875"	37	581
44	27.25"	44	692
52	32.5"	52	826
62	38.5"	62	978
74	45.6"	74	1158
88	54.25"	88	1378

6. Determine maximum impeller head per stage from Figure 6. Minimum number of compression stages required from:

$$\text{No. of stages} = \frac{H_{ad}}{\text{Head per stage}}$$

Round off quantity to the next higher integer.

7. Calculate tip speed[1]

$$U = \sqrt{\frac{H_{ad}(g)}{N\Psi}} \qquad U = \sqrt{\frac{H_{ad}}{N\Psi}}$$

Select nominal Ψ

MW	Ψ
6	.45
18	.46
29	.48
44	.50
71	.51

8. Calculate inlet and discharge flow coefficients[2]

$$\Phi_X = \frac{3.056\ Q_X}{UD^2} \qquad \Phi_X = \frac{4Q_X}{\pi U D^2}$$

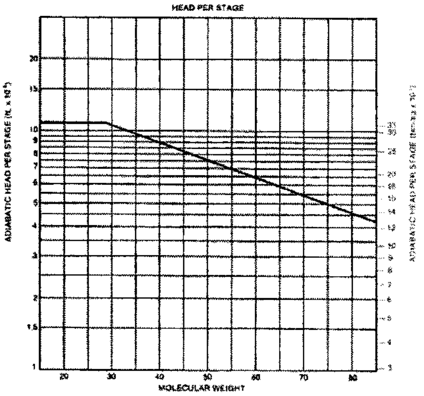


Figure 6

9. Use Figure 7 to determine first and last stage efficiency and average to get overall efficiency., If Φ falls to the right of the efficiency curve, select a larger frame size. If Φ falls to the far left, select a smaller frame size.

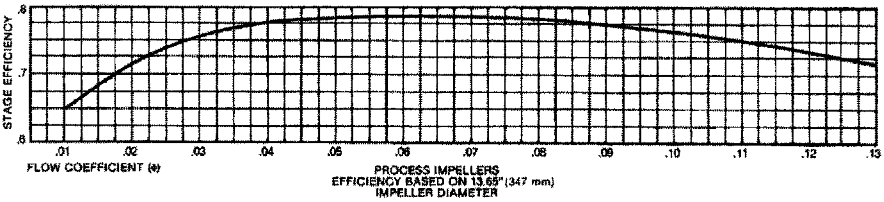


Figure 7

Footnotes:

[1] For initial sizing, limit tip speed to 900 ft/sec (275 m/sec); or 800 ft/sec (245 m/sec) if low-yield material is required.

[2] Discharge flow coefficient is calculated from discharge conditions in this procedure. It is normally determined from conditions prior to the last stage of compression.

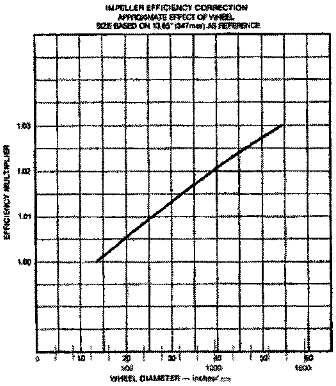


Figure 8

10. Correct efficiency for wheel size using Figure 8.

11. Calculate compressor running speed

$$\text{RPM} = \frac{229U}{D} \qquad \text{RPM} = \frac{60U}{D}$$

12. Calculate horsepower

a. $\text{GHP} = \dfrac{H_{ad}\,[\dot{m}]}{33{,}000\,[\eta_{ad}]} \qquad P_i = \dfrac{H_{ad}\,[\dot{m}]}{1000\,[\eta_{ad}]}$

b. Determine mechanical losses from Figure 9. (Divide total by 2 if labyrinth end seals are used.)

c. Calculate balance drum leakage (2% of GHP or P_i)'

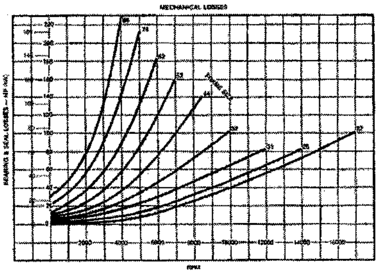


Figure 9

d. BHP = GHP + Mech. losses + balance drum leakage

P_e = P_i + Mech. losses + balance drum leakage

13. Determine casing split

The density of the gas and the maximum working pressure of the compressor will determine the casing split. The following chart is provided as a general guide:

Frame Size	22	26	31	37	44	52	62	74	88
MWP for horizontally split casing (psi)	800	600	600	600	450	300	300	300	300
(bar)	56	42	42	42	32	22	22	22	22

MWP × 1.10 (max. discharge pressure)

If the gas contains over 70% hydrogen, the casing will be vertically split between 200 to 285 psi (14 to 20 bar) MWP and above.

E. CAST CASING COMPRESSOR SELECTION

Although the calculation method presented in this section is based on the Delaval fabricated line, some performance data for cast case units can be calculated from the previous procedure. Once head and inlet flow are determined, the figures presented on pages 11 and 13 should be used to select the proper frame size and number of stages. Impeller diameter and efficiency corresponding to case size is presented below.

MULTISTAGE:

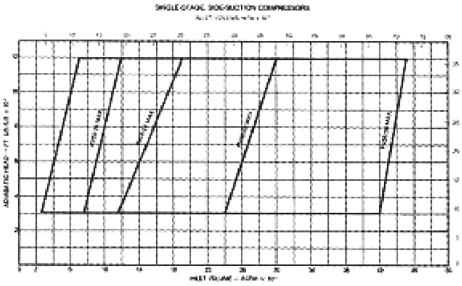
Case	12/12	16/16	18/18	20/20	24/24	30/30	36/36
Nominal Impeller Dia. (Inches)	14	14	23	23	30	38	45
(mm	355	355	584	584	762	965	1143
Avg. Adiabatic Efficiency	.78	.78	.80	.80	.81	.82	.82

SINGLESTAGE (opposed nozzles):

Case	20/20	24/24	30/30	38/38
Nominal Impeller Dia.				
(inches)	18	32	32	38
(mm)	457	813	813	965
Avg. Adiabatic Efficiency	.80	.81	.82	.84

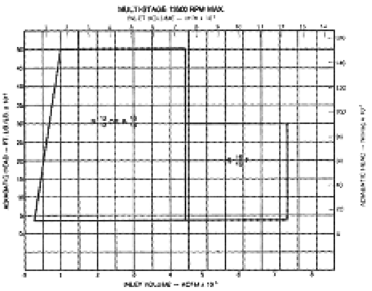
Note: All single-stage units are available in either axial inlet or opposed nozzle configurations. Refer to factory for axial inlet efficiencies.

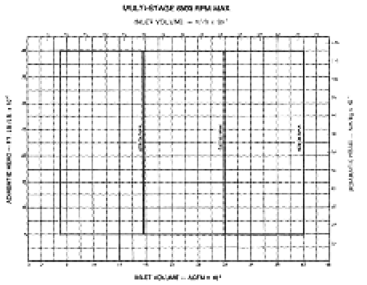
Substituting this information for steps 8 through 10 allows a quick estimation of pipeline compressor performance.

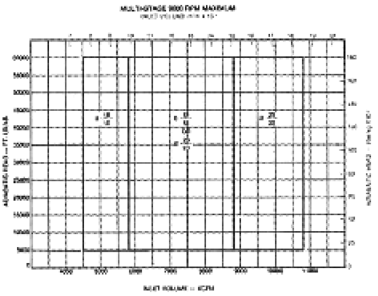


FRAME SIZE SELECTION FOR SINGLE-STAGE, OVERHUNG COMPRESSORS

Determine actual inlet flow into the compressor as well as the total head requirement to find frame size







FRAME SIZE SELECTION FOR MULTI-STAGE CAST CASING COMPRESSORS

Calculate the actual inlet flow into the compressor as well as the total head requirements using the driver speed to determine the correct sizing graph. Assume a maximum of 10,000-11,000 ft. (30,000-33,000 Nm/kg) of head per stage to pinpoint the number of compression stages required.

F. DESIGN CONSIDERATIONS

In many cases, a centrifugal compressor must be designed to match special process or driver requirements. By physical arrangement of inner components or the casing structure, specific requirements can be met while still delivering maximum performance. Variations include:

Double-flow arrangement which permits the unit to be smaller in frame size and higher in rotational speed. The inlet flow is split in half and undergoes parallel compression (see Figure 10).

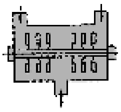


Figure 10

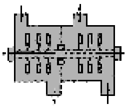


Figure 11

Back-to-back arrangement of two sections in an intercooled machine, which keeps hot discharge temperatures away from end seals and reduces or eliminates aerodynamic thrust forces (see Figure 11).

Overframing the casing and diaphragms, which is sometimes used to increase compressor efficiency. The diffuser plate diameter is increased while impeller diameter is held constant.

Uprating flow capacity of the compressor, which may only require an increase in speed for small changes in flow or an inner bundle change-out for large variations. Nozzle sizes and internal dimensions of the casing will determine the maximum flow capability of the compressor. Consult factory for specific information.

Rotational speed, which can be varied by two methods while the section still produces constant head.

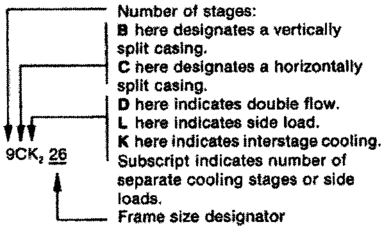
(a) Addition of one impeller permits speed reduction as shown in the equation

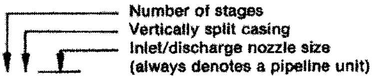
$$\text{Revised RPM} = \sqrt{\frac{N}{N+1}}\left[\text{RPM}\right]$$

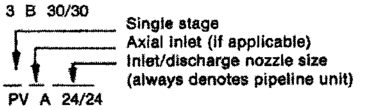
(b) Wheel triming by reducing the outside diameter of the impeller can allow for up to a 10% increase in rotational speed.

G. COMPRESSOR MODEL NUMBERS

Every Delaval centrifugal compressor is designated by a model number that describes that particular unit. Typical model numbers (and their meanings) for process and pipeline units are shown below.







V. Sample Calculations (English)

Given: $k = 1.275$, $MW = 18.12$, $Z = .98$
$P_1 = 124.5$ psia, $P_2 = 500$ psia,
$\dot{m} = 5470$ lbm/min
$T_1 = 90°F = 550°R$

Steps:

1. $$ACFM_1 = \dot{m}\,v_1;\; v_1 = \frac{.98\left[\frac{1544}{18.12}\right]550}{124.5\ (144)} = 2.56\,\frac{ft^3}{lbm}$$

   $ACFM_1 = 5470\ (2.56) = 14000\ ft^3/min$

2. $$H_{ad} = .98\left[\frac{1544}{18.12}\right](550)\left[\frac{\left(\frac{500}{124.5}\right)^{\frac{1275-1}{1275}} - 1}{\frac{1.275-1}{1.275}}\right] = 74{,}460\ ft.$$

3. $$\Delta T = 550\left[\frac{\left(\frac{500}{124.5}\right)^{\frac{1.275-1}{1.275}} - 1}{.75}\right] = \begin{array}{r} 256° \\ +90° \\ \hline 346° \end{array}$$

   $T_2 = 346°F$ (no intercooling required)

4. From Figure 5, inlet flow is close to maximum of 31 frame and well within the range of 37 frame.

5. Wheel diameters 31 ⟶ 19.25"
   37 ⟶ 22.875"

6. From Figure 6, maximum head per stage = 11,000 ft.

   Minimum number of stages = 74,460/11,000 = 6.77 or 7 stages.

7. $$U = \sqrt{\frac{74{,}450\ (32.2)}{(7)\ (.46)}} = 863\ ft/sec$$

Conversion Table

TO OBTAIN	MULTIPLY	BY
Inches	mm	0.0394
ft³	m³	35.31
ft/sec	m/sec	3.281
cfm	m³/h	0.5883
head (ft)	Nm/kg	0.335
lbm/min	kg/sec	132
psi	bar	14.22
hp	kW	1.341

8. $$\Phi_1 \text{ for 31 frame} = \frac{3.056\ (14000)}{863\ (19.25)^2} = .134$$

   According to Figure 7, a 31 frame is marginal.

   $$\Phi_1 \text{ for 37 frame} = \frac{3.056\ (14000)}{863\ (22.875)^2} = .095$$

   Φ_2 is calculated from Q_2

   $Q_2 = \dot{m}\,v_2$

   $$v_2 = \frac{Z_2RT_2}{144\ P_2};\; Z_2 = .99$$ (from example on page 27, Z_2 is found on Figure 2 from T_R and P_R)

   $$v_2 = \frac{.99\left[\frac{1544}{18.12}\right](806)}{144\ (500)} = .944\,\frac{ft^3}{lbm}$$

   $Q_2 = 5470\ (.944) = 5166\ ft^3/min$

   $\Phi_2 = .035$

9. From Figure 7:

   $\eta\,\Phi_1 = .775;\; \eta\,\Phi_2 = .775;\; \eta$ avg. $= .775$

10. Determine impeller efficiency correction from Figure 8:

    $1.0075\ (.775) = .781$

11. $$RPM = \frac{229\ (863)}{22.875} = 8640\ RPM$$

12. $$GHP = \frac{74460\ (5470.)}{33{,}000\ (.781)} = 15{,}803\ hp$$

    Mechanical losses = 81 hp.

    BHP = 1.02 (15,803) + 81 = 16,200 hp

13. A discharge pressure of 500 psia corresponds to a 550 psi MWP casing. Therefore, casing is horizontally split. Model selected is a seven-stage, 37-frame horizontally split: 7C37.

V. Sample Calculations (Metric)

Given
$k = 1.280$, $M = 18.29$, $z = 0.98$
$P_1 = 8.5$ bar, $P_2 = 34.5$ bar
$\dot{m} = 42$ kg/sec, $T_1 = 30°C = 303.15$ K

Steps.

1. $Q_1 = \dot{m}\,(v_1) = \dot{m}\,\frac{(Z_1)\,(R)\,(T_1)}{P_1}$

$$= 42\,\frac{(0.98)\,(8314.34)\,(303.15)}{(18.129)\,(8.5 \times 10^5)}$$

$= 6.732$ m³/sec $= 24235$ m³/hr

2. Had =

$$= .98\left[\frac{8314.34}{18.129}\right](303.15)\frac{\left[\frac{34.5}{8.5}^{\frac{1.280-1}{1.280}} - 1\right]}{\frac{1.280-1}{1.276}}$$

=223350 Nm/kg

3. $\Delta T = \frac{303.15}{0.75}\left[\left(\frac{34.5}{8.5}\right)^{\frac{1.280-1}{1.280}} - 1\right] = 145$ K

$T^2 = 303.15 + 145 = 448.15\,K = 175°C$
(no intercooling required)

4. $Q_1 = 24235$ m³/hr. From Figure 5, inlet flow is close to maximum of 31 frame and well within the range of 37 frame.

5. Wheel diameters
31 — frame ⟶ 489 mm
37 — frame ⟶ 581 mm

6. From Figure 6, maximum head per stage = 33000 Nm/kg.

Therefore $N = \frac{223350}{33000} = 6.77$ or 7 stages

7. $U = \sqrt{\frac{223350}{7 \;\, 0.46}} = 263$ m/sec.

Conversion Table

TO OBTAIN	MULTIPLY	BY
mm	inches	25.40
m³	ft³	0.0283
m/sec	ft/sec	0.305
m³/h	cfm	1.6992
Nm/kg	ft (head)	2.989
kg/sec	lbm/min	7.58×10^{-3}
bar	psi	0.0703
kW	hp	0.746

8. Φ_1, 31-frame $= \frac{4\,(6.732)}{263\,(\pi)\,(0.489^2)} = 0.136$

According to Figure 7, a 31-frame is marginal.

Φ_1, 37-frame $= \frac{4\,(6.732)}{262\,(\pi)\,(0.581^2)} = 0.097$

Φ_2 is calculated from Q^2.

$Q_2 = \dot{m}v_2 = \dot{m}\,\frac{(Z_2)\,(R)\,T_2}{P_2}$ Find Z_2 from reduced temperature and pressure (from example shown on page 27)

$T_R = \frac{T_2}{T_C} = \frac{448.15}{206.3} = 2.18$

$P_R = \frac{P_2}{P_C} = \frac{34.5}{46.31} = 0.74$

From Figure 2 : $Z_2 = 0.99$

Therefore Q_2 =

$$= 42\,\frac{(0.99)\,(8314.34)\,(448.15)}{(18.129)\,(34.5 \times 10^5)} = 2.477 \text{ m}^3/\text{sec}$$

$$\Phi_2 = \frac{(4)\,2.477}{(263)\,(\pi)\,(0.581^2)} = 0.036$$

9. From Figure 7: $^{\eta}\Phi_1 = 0.775$
average = 0.775
$^{\eta}\Phi_2 = 0.775$

10. Determine impeller efficiency correction from Figure 8.

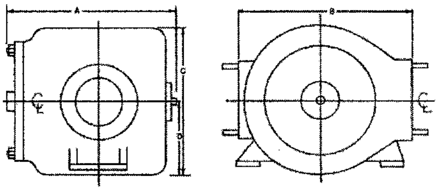
(1.0075) (0.775) = 0.781

11. $N = \frac{60\,(263)}{\pi(0.581)} = 8645$ RPM

12. $P_i = \frac{(42)\,223350}{0.781\,(1000)} = 12011$ kW

Mechanical losses = 63 kW (from Figure 9)
$P_e = (1.02)\,(12011) + 63 = 12314$ kW

13. A discharge pressure of 34.5 bar corresponds to a 42 bar MWP casing. Therefore, casing is horizontally split. Model selected is a seven-stage, 37-frame horizontally split : 7C37.

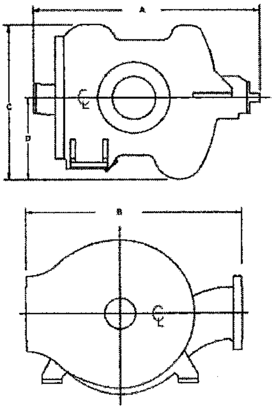


Model B 12/12
Model B 16/16

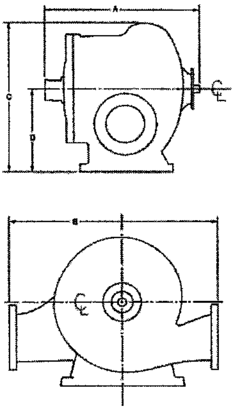
Weights and dimensions

Cast Casing Compressors

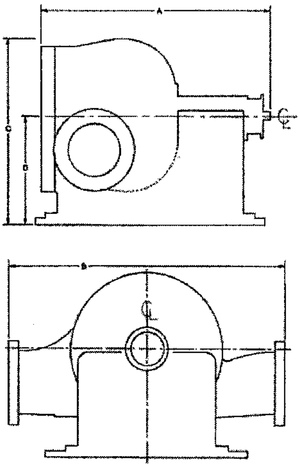
FRAME SIZE	MAX. NO. STAGES	A		B		C		D		NOZZLE SIZE SUCTION		NOZZLE SIZE DISCHARGE		TOTAL WEIGHT		MAX. MAINT. WT.	
		in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	lb.	kg	lb.	kg
B 12/12	5	53	1346	48	1219	38	965	27	686	12	305	12	305	13,000	5900	3,050	950
B 16/16	5	57	1448	48	1219	49	1295	29	737	16	406	16	406	16,200	7300	3,100	1400
B 18/18	5	103	2616	96	2348	69	1753	36	915	18	457	18	457	34,900	15800	10,300	5200
B 20/20	5	105	2667	96	2438	72	1829	30	760	20	508	20	508	45,000	20900	11,500	5300
B 24/24	3	103	2616	102	2591	84	2134	45	1143	24	610	24	610	48,000	21800	12,900	5900
B 30/30	3	125	3175	144	3658	90	2286	54	1372	30	762	30	762	85,000	38500	15,500	7000
B 36/36	3	126	3200	160	4064	117	2972	67	1702	36	914	36	914	120,000	54500	18,600	8500
PV 20/20	1	87	2210	81	2057	64	1626	33	838	20	508	20	508	30,000	13600	3,400	1550
PV 24/24	1	96	2438	120	3048	77	1956	43	1092	24	610	24	610	40,500	18300	4,980	2300
PV 30/30	1	102	2591	134	3404	81	2057	45	1143	30	762	30	762	51,000	23100	6,250	2850
PV 36/36	1	104	2642	144	3658	104	2642	53	1346	36	914	36	914	66,000	29000	8,300	3800



Model B 18/18
Model B 20/20



Model B 24/24
Model B 30/30
Model B 36/36



Model "PV" Series

Note: Axial inlet (PVA type compressor) is located in end cover at ℄ of shaft.

11

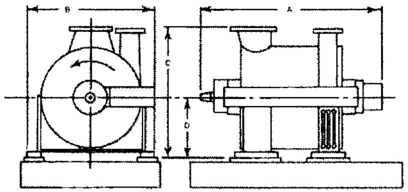
Weights and dimensions

Fabricated Centrifugal Compressors

Summary of Specifications

NOTES:

1. Speed and flow ratings are based on 275m/sec (900ft/sec) tip speed and largest standard impeller using standard materials. These ratings may be affected by gas and process conditions or special material requirements.
2. Weights given apply for listed pressure rating and nozzle sizes only.
3. Max. maint. weight is the greatest weight necessary to handle in normal maintenance.
4. All dimensions are approximate.



FRAME SIZE	RATED SPEED	RATED INLET FLOW (1)		MAX. INLET NOZZLE DIA.		MAX. DISCH. NOZZLE DIA.		NO. OF STAGES	A		B		C		D		C-LINE TOTAL WEIGHT		C-LINE MAX. MAINT. WEIGHT		B-LINE TOTAL WEIGHT		B-LINE MAX. MAINT WEIGHT		ROTOR WEIGHT	
	rpm	cfm	m³/hr	in.	mm	in.	mm		in.	mm	in.	mm	in.	mm	in.	mm	lb.	kg	lb.	kg	lb.	kg	lb.	kg	lb.	kg
22	15,100	7,000	12,000	18	406	12	305	5	64	1625	56	1420	55	1400	25	635	13000	5900	5000	2300	15500	7100	3500	1600	425	200
								6	69	1750	56	1420	55	1400	25	635	14000	6400	5500	2700	16500	7500	4000	1800	475	215
								7	73	1850	56	1420	55	1400	25	635	15000	6800	6000	2700	17500	8000	4500	2000	525	240
								8	78	1980	56	1420	55	1400	25	635	16000	7250	6500	3000	18500	8400	5000	2300	600	275
26	12,700	10,000	17,000	18	457	14	356	5	68	1725	64	1625	62	1580	28	715	18000	8200	6500	3000	22500	10200	5000	2300	675	300
								6	73	1850	64	1625	62	1580	28	715	19500	8900	7000	3200	24500	11100	6000	2700	775	350
								7	78	1980	64	1625	62	1580	28	715	21300	9700	7500	3400	26500	12000	7000	3200	875	400
								8	84	2130	64	1625	62	1580	28	715	23000	10500	8000	3700	28500	13000	8000	3700	975	450
31	10,700	14,000	24,000	20	508	16	406	5	75	1905	69	1750	69	1750	31	790	26000	11800	8500	3900	27000	12300	8000	3700	1100	500
								6	81	2060	69	1750	69	1750	31	790	28500	12900	9100	4100	29500	13400	9500	4300	1250	550
								7	88	2235	69	1750	69	1750	31	790	31000	12900	9200	4200	32000	14500	11000	5000	1400	650
								8	94	2390	69	1750	69	1750	31	790	33500	15200	10000	4600	34500	15700	12500	5700	1550	700
37	9,000	20,000	34,000	24	610	20	508	5	82	2080	77	1955	77	1960	35	890	37000	16800	13000	5900	36000	16400	13000	5900	1700	800
								6	89	2260	77	1955	77	1960	35	890	41000	18600	14000	6400	39500	18000	15250	6900	1850	900
								7	96	2440	77	1955	77	1960	35	890	45000	20400	15000	6800	43000	19500	17500	8000	2200	1000
								8	105	2670	77	1955	77	1960	35	890	49000	22250	16000	7300	48500	21000	19000	8600	2450	1100
44	7,550	28,000	48,000	30	762	24	610	5	92	2340	84	2130	84	2130	38	970	50000	22700	16000	7300	45000	20400	20000	9100	2850	1300
								6	104	2640	84	2130	84	2130	38	970	56000	25400	17000	7700	50000	22700	24000	11000	3300	1500
								7	112	2845	84	2130	84	2130	38	970	62000	28100	18000	8200	55000	25000	28000	12700	3750	1700
								8	124	3150	84	2130	84	2130	38	970	68000	30850	19000	8600	60000	27200	32000	14500	4200	1900
52	6,390	40,000	68,000	36	914	30	762	5	107	2720	98	2490	98	2490	45	1145	70000	31750	18000	8200	64000	29000	34000	15500	4200	1900
								6	117	2970	98	2490	98	2490	45	1145	78000	35400	19000	8600	72000	32700	41000	18600	4850	2200
								7	127	3225	98	2490	98	2490	45	1145	87000	39500	21000	9500	80000	36300	48000	21800	5500	2500
								8	140	3555	98	2490	98	2490	45	1145	96000	43500	24000	11000	86000	39900	55000	25000	6150	2800
62	5,350	96,000	95,000	42	1067	36	914	5	118	3000	112	2845	114	2900	53	1350	108000	49000	28000	12700	100000	45400	53000	27000	6500	3000
								6	130	3300	112	2845	114	2900	53	1350	122000	55500	30000	13600	112000	50800	64000	29000	7550	3400
								7	145	3680	112	2845	114	2900	53	1350	136000	62000	34000	15500	125000	56700	75000	34000	8600	3900
								8	157	3990	112	2845	114	2900	53	1350	150000	68000	38000	17300	137000	62100	85000	39000	9850	4400
74	4,500	79,000	135,000	48	1219	42	1067	5	134	3400	130	3300	135	3430	62	1575	161000	73000	40000	18000	153000	68000	80000	36300	10000	4500
								6	154	3910	130	3300	135	3430	62	1575	182000	82500	43000	19500	168000	77000	96000	43500	11650	5300
								7	168	4270	130	3300	135	3430	62	1575	202000	91500	50000	22700	187000	85000	112000	50800	13300	6000
								8	181	4600	130	3300	135	3430	62	1575	223000	101000	56000	25400	206000	93500	127000	57600	14900	6800
88	3,800	110,000	190,000	60	1524	48	1219	5	156	3960	150	3810	156	3965	71	1810	252000	114500	63000	28600	236000	107000	127000	57600	16100	7300
								6	179	4550	150	3810	156	3965	71	1810	285000	129500	67000	30400	266000	121000	152000	69000	18700	8500
								7	195	4950	150	3810	156	3965	71	1810	318000	144500	78000	35400	298000	134000	177000	80300	21400	9700
								8	211	5380	150	3810	156	3965	71	1810	351000	159000	89000	40400	326000	148000	202000	91500	24000	11000

T-3-87CI

B.4 SHORTCUT (GRAPHICAL) METHOD OF DETERMINING APPROXIMATE PERFORMANCE OF SULZER CENTRIFUGAL COMPRESSORS*

The calculation procedures given in the following pages permit

To determine:	Compressor size and type	
	• Nominal diameter	D (m)
	• Number of stages	z
	Power input	P (kW)
	Speed	n (r/min)
	Absolute discharge temperature	T_2 (K)
Using:	Mass flow	m (kg/s)
	Suction pressure	p_1 (bar abs)
	Absolute suction temperature	T_1 (K)
	Relative humidity	ϕ_1 (%)
	Discharge pressure	p_2 (bar abs)
	Molecular mass	M (kg/kmol)
	Isentropic exponent	k
	Compressibility factor	Z

The following factors, symbols and indices are also used:

	Actual suction volume flow	V_1 (m^3/s)
	Absolute humidity	x
	Peripheral speed	u (m/s)
	Head (polytropic)	h_p (kJ/kg)
	Temperature difference ($\Delta T = T_c - T_1$)	ΔT (K)
	Intercooling power factor	f
Indices	Suction conditions	1
	Discharge conditions	2
	Dry	t
	Wet	f
	Polytropic	p
	per casing	G
	per group of stages (between two coolings)	S
	Uncooled	*
	After cooling	c
	Total	T
	Number of casings	i
	Number of intercoolings	j

How to Use the Diagrams A guide to the selection diagrams and two examples are given in Table B.1, one with air in one casing, the other with gas in two casings.

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* These graphical methods are intended for screening studies only. Contact the manufacturer for more definitive layout and performance prediction.

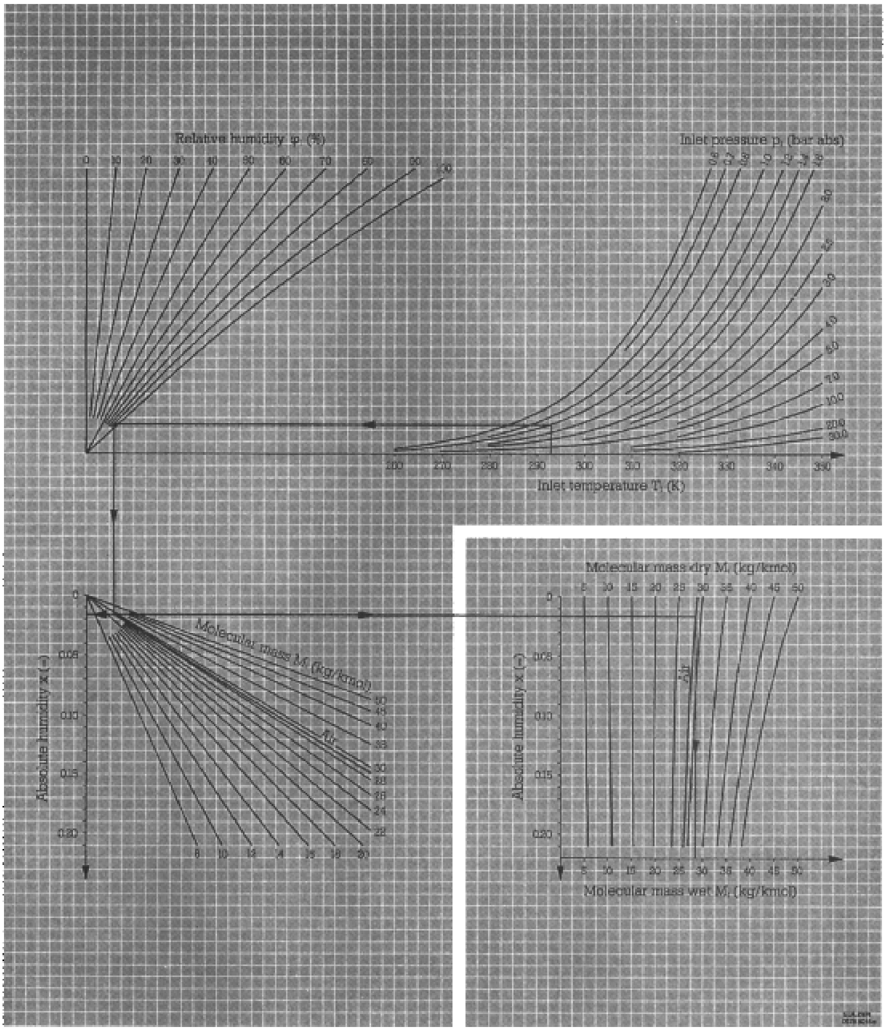


Diagram 1
Determination of the absolute humidity x
($T_i \to p_i \to \varphi_i \to M_i \to x$)

Diagram 2
Determination of the molecular mass M_f
of the wet gas ($x \to M_i \to M_f$)

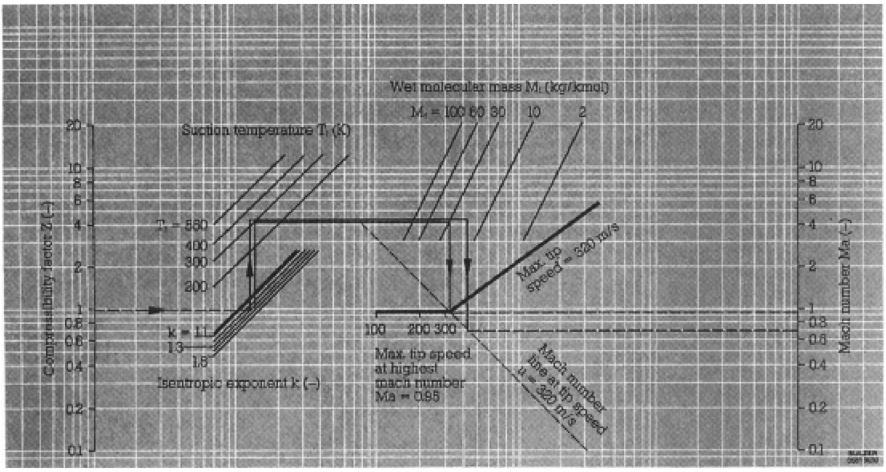


Diagram 3
Determination of the max. permissible peripheral speed u_{max} ($Z \to k \to T_1 \to M_f \to u_{max}$)

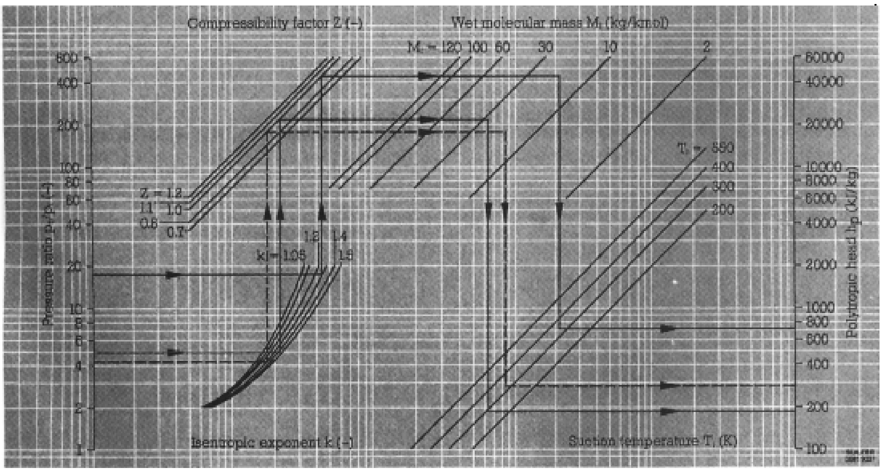


Diagram 4
Determination of the polytropic head h_p
($k \to p_2/p_1 \to Z \to M_f \to T_1 \to h_p$)

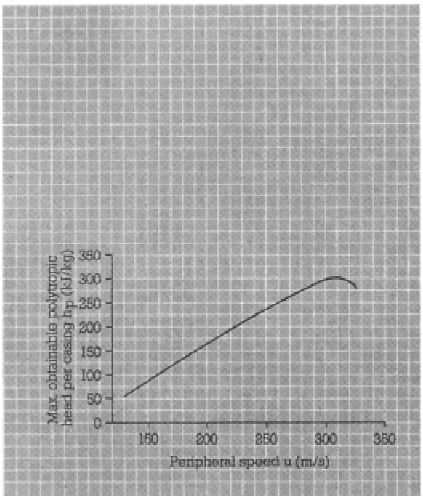
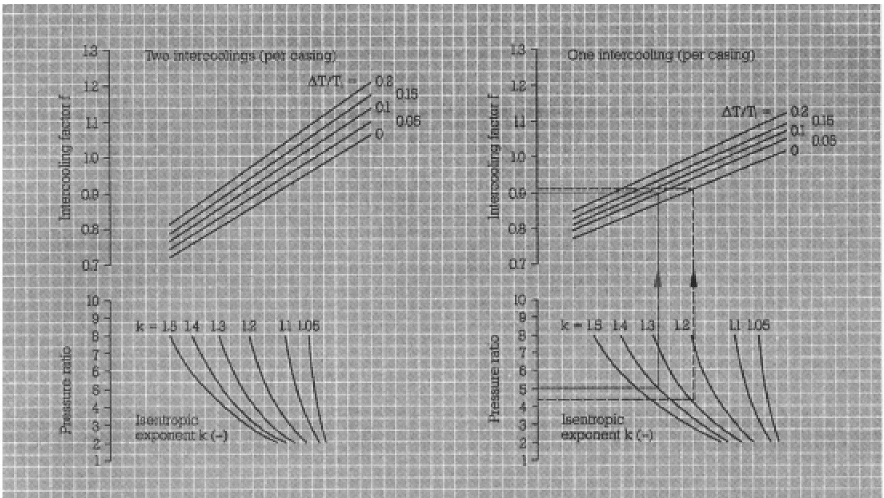


Diagram 5

Determination of the obtainable polytropic head per casing $h_{pC\,max}$ ($u_{max} \to h_{pC\,max}$)



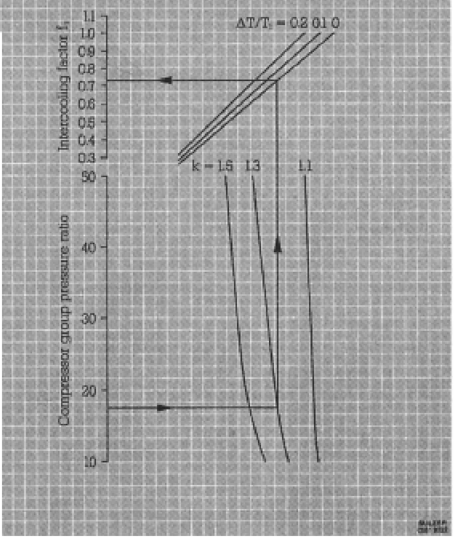


Diagram 6

Determination of the influence of intercooling on the required shaft power ($p_2/p_{1G} \to K \to \Delta T \to T_1 \to$ estimated number of intercoolings per casing $i \to f$)

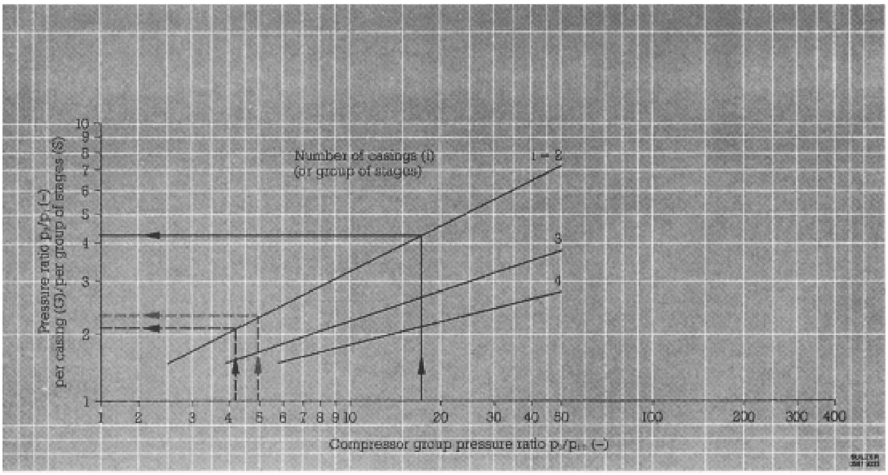


Diagram 7
Determination of the pressure ratio per casing p_2/p_{1G}

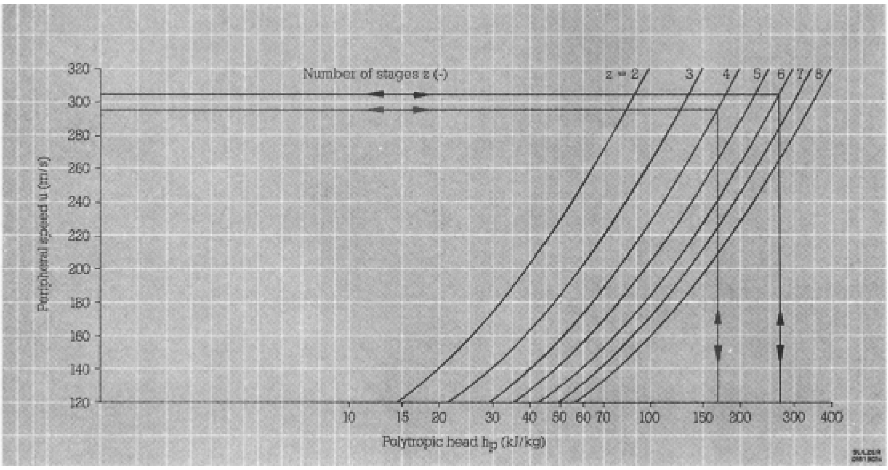


Diagram 8
Determination of the number of stages z of the compressor ($h_p \to z \to u$).
From u_{max} determined with Diagram 3, round off z to the whole number and correct peripheral speed accordingly

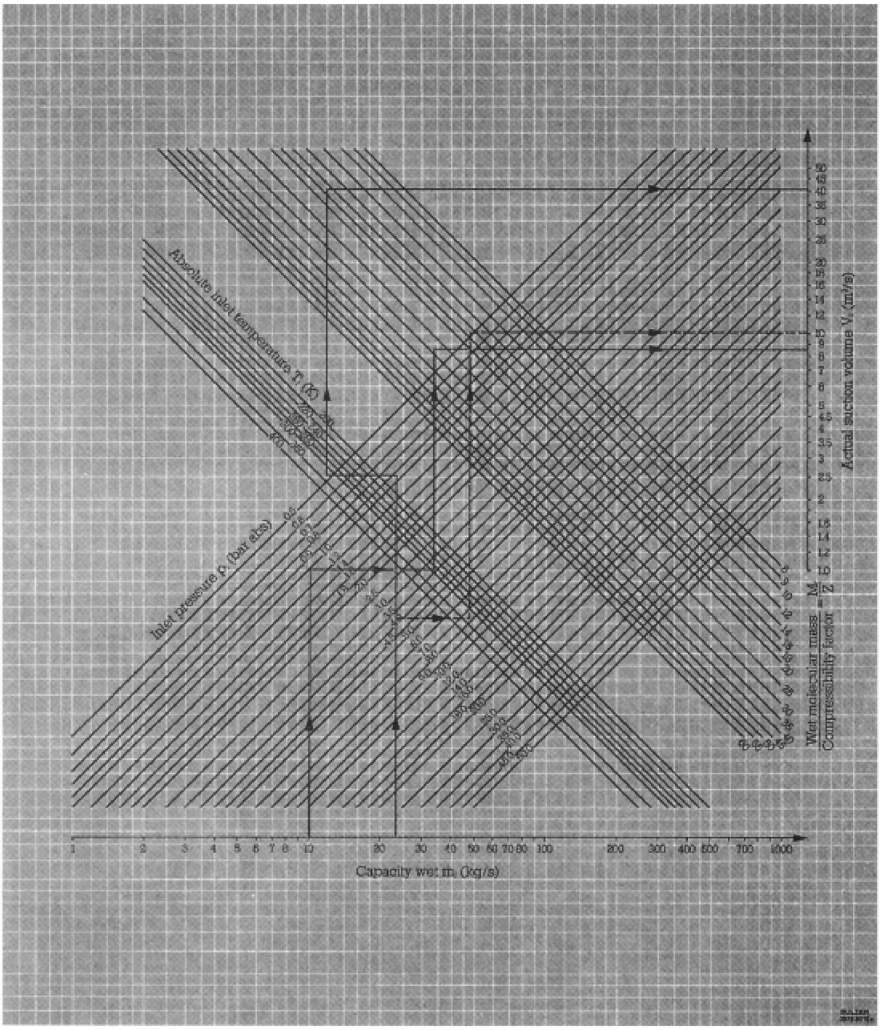


Diagram 9
Determination of the actual suction volume $\dot{V}_1$ ($\dot{m}_f \rightarrow p_1 \rightarrow T_1 \rightarrow M_f \rightarrow Z \rightarrow \dot{V}_1$)

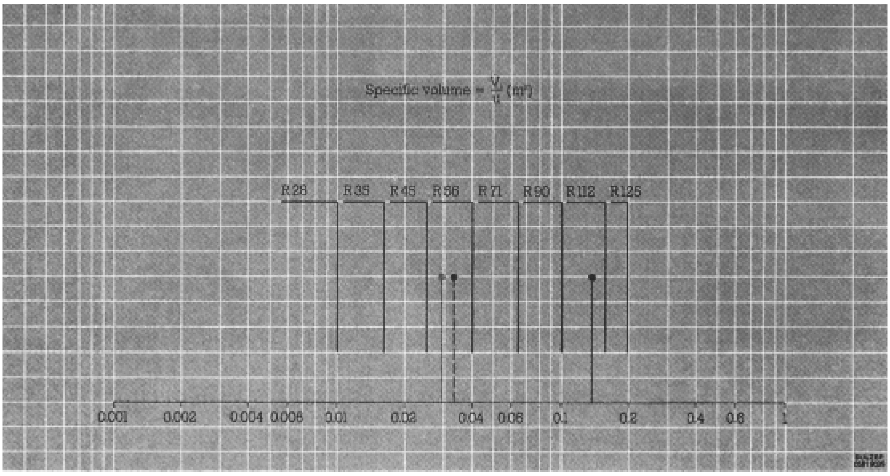


Diagram 10
Selection of the compressor size: nominal diameter D (cm) as a function of $\frac{\dot{V}_1}{u}$, where $\dot{V}_1$ = suction volume (m³/s) and u = peripheral speed (m/s)

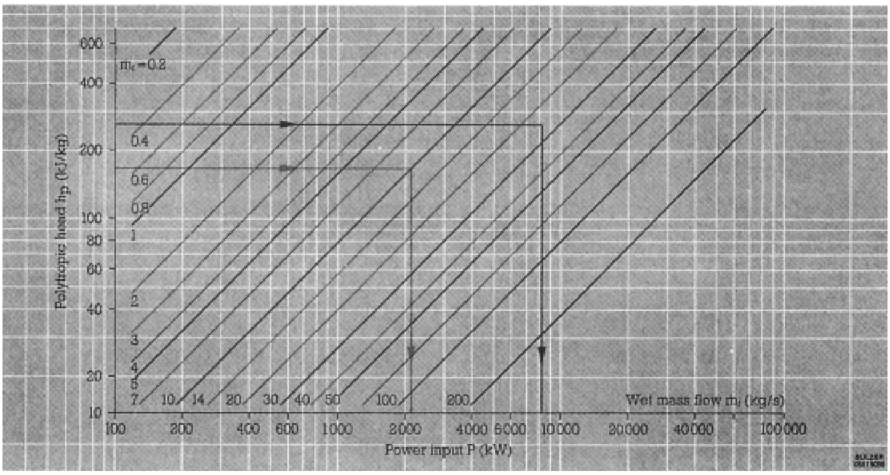


Diagram 11
Determination of the power input P
$(h_p \rightarrow \dot{m}_t \rightarrow P)$

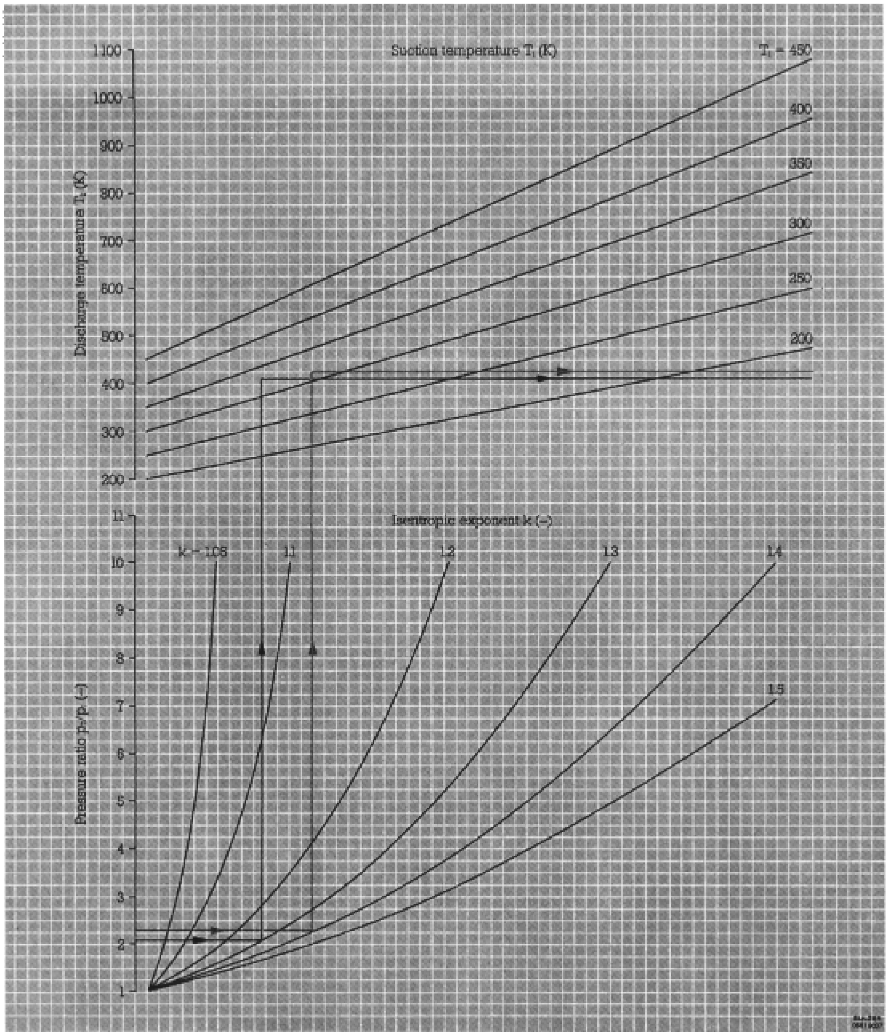


Diagram 12

Determination of the discharge temperature T_2 ($p_2/p_1 \rightarrow K \rightarrow T_1 \rightarrow T_2$)

k = isentropic exponent (–)

TABLE B.1 Selection and Performance Calculation of a Centrifugal Compressor Train

	Calculation Example 1: Air Compressor, One Casing	Calculation Example 2: Gas Compressor, Two Casings
Given:		
Capacity	$\dot{m}_t = 10\,\text{kg/s}$	$\dot{m}_t = 23.66\,\text{kg/s}$
Suction pressure	$p_1 = 1$ bar abs	$p_1 = 0.92$ bar abs
Suction temperature	$T_1 = 293\,\text{K}$	$T_1 = 333\,\text{K}$
Relative humidity	$\varphi_1 = 90\%$	$\varphi_1 = 0\%$
Discharge pressure	$p_2 = 5$ bar abs	$p_2 = 16.1$ bar abs
Dry molecular mass	$M_t = 28.95\,\text{kg/kmol}$	$M_t = 17.03\,\text{kg/kmol}$
Isentropic exponent c_p/c_v	$k = 1.4$	$k = 1.29$
Compressibility factor	$Z = 1$	$Z = 1$
Calculation instructions		
1. Determination of the absolute humidity x (from T_1, p_1, φ_1, M_t) with Diagram 1	$x = 0.016$	$x = 0$
2. Determination of the wet molecular mass M_f (from x, M_t) with Diagram 2	$M_f = 28.7\,\text{kg/kmol}$	$M_t = M_f = 17.03\,\text{kg/kmol}$
3. Calculation of the wet mass flow $\dot{m}_f = \dot{m}_t\,(1 + x)$	$\dot{m}_f = 10(1 + 0.016)_f = 10.16\,\text{kg/s}$	$\dot{m}_f = \dot{m}_t = 23.66\,\text{kg/s}$
4. Determination of the max. permissible peripheral speed u_{max} (from Z, k, T_1, M_f) with Diagram 3	Electric motor $u_{max} = 320\,\text{m/s}$ Turbine $u_{max} = 290\,\text{m/s}$	Electric motor $u_{max} = 320\,\text{m/s}$ Turbine $u_{max} = 290\,\text{m/s}$
For further calculation, motor drive has been selected.		
5. Determination of the total polytropic head h^*_{pT} (from k, p_2, p_1, Z, M_f, T_1) with Diagram 4	$h^*_{pT} = 186\,\text{kJ/kg}$	$h^*_{pT} = 722.8\,\text{kJ/kg}$
6. Determination of the max. polytropic head obtainable per casing $h_{pG\,max}$ (from u_{max}) with Diagram 5	$h_{pG\,max} = 300\,\text{kJ/kg}$	$h_{pG\,max} = 300\,\text{kJ/kg}$
7. Calculation of number of casings i $i = h_{pT}/h_{pG\,max}$, with $h_{pT} = h^*_{pT} \cdot f_T$, whereby f_T has to be estimated with Diagram 6	$i = 1$	$i = 2$ with $f_T = 0.73$
8. Determination of the pressure ratio per casing p_2/p_{1G} with Diagram 7	$p_2/p_{1T} = p_2/p_{1G} = 5$	$p_2/p_{1G} = 4.27$
9. Determination of the polytropic head per casing h^*_{pG} (from k, p_2/p_{1G}, Z, M_f, T_1) with Diagram 4	$h^*_{pG} = h^*_{pT} = 186\,\text{kJ/kg}$	$h^*_{pG} = 293\,\text{kJ/kg}$

From now on if two or more casings are necessary, the calculation has to be made for each casing separately (one after the other).

		First casing	Second casing
10. Determination of the influence of intercooling on the required shaft power (from p_2/p_{1G}, K, ΔT, T_1 and estimated number of intercoolings per casing j) with Diagram 6	$f = 0.9$ with $\Delta T = 20$ and $j = 1$	$f = 0.91$ with $\Delta T = 0$ and $j = 1$	$f = 0.91$ with $\Delta T = 0$ and $j = 1$
11. Calculation of the fictive polytropic head $h_{pG} = h^*_{pG} \cdot f$	$h_{pG} = 186 \cdot 0.9$ $= 167.4\,\text{kJ/kg}$	$h_{pG} = 293 \cdot 0.91$ $= 266.6 \cong 267\,\text{kJ/kg}$	$H_{pG} = 293 \cdot 0.91$ $= 266.6 \cong 267$
12. Determination of the number of stages z per casing and the definite peripheral speed u (from h_{pG}, $z \rightarrow u$) with Diagram 8 (round off z to whole number and correct peripheral speed correspondingly)	$z = 4$ $u = 295\,\text{m/s}$	$z = 6$ $u = 304\,\text{m/s}$	$z = 6$ $u = 304\,\text{m/s}$
13. Determination of the actual suction volume $\dot{V}_1$ (from $\dot{m}_f$, p_1, T_1, M_f, Z) with Diagram 9	$\dot{V}_1 = 8.59\,\text{m}^3/\text{s}$	$\dot{V}_1 = 41.8\,\text{m}^3/\text{s}$	$\dot{V}_1 = 10.2\,\text{m}^3/\text{s}$
14. Selection of the compressor size (nominal diameter D) as a function of $\dot{V}_1$ with Diagram 10	$D = 56\,\text{cm}$	$D = 112\,\text{cm}$	$D = 56\,\text{cm}$
15. Type designation (from steps 10, 12, 14)	RZ 56-4	RZ 112-6	RZ 56-6
16. Calculation of the speed $n = \frac{60 \cdot u}{\pi \cdot D} =$ (D in meters)	$n = \frac{60 \cdot 295}{\pi \cdot 0.56} = 10060\,\text{r/min}$	$n = \frac{60 \cdot 304}{\pi \cdot 1.12} = 5184\,\text{r/min}$	$n = \frac{60 \cdot 304}{\pi \cdot 0.56} = 10368\,\text{r/min}$
17. Determination of the power input P (from h_{pG}, $\dot{m}_f$) with Diagram 11	$P = 2173\,\text{kW}$	$P = 8100\,\text{kW}$	$P = 8100\,\text{kW}$
			Total train 16200 kW
18. Determination of the discharge temperature T_2 (from p_2/p_1 between intercooling, k, T_1) with Diagram 12 whereby T_1 is the suction temperature after preceding intercooling and pressure ratio p_2/p_1 between intercooling has to be determined with Diagram 7	$T_2 = 424\,\text{K}$ with $T_1 = 333\,\text{K}$ and $p_2/p_1 = 2.3$	$T_2 = 413\,\text{K}$ with $T_1 = 333\,\text{K}$ and $p_2/p_1 = 2.1$	$T_2 = 413\,\text{K}$ with $T_1 = 333\,\text{K}$ and $p_2/p_1 = 2.1$