FUNDAMENTALS OF SIZING SEPARABLE FIELD GAS COMPRESSORS

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INTRODUCTION

Recent increases in the demand and price for natural gas have stimulated requirements for gas compressors of all sizes. This paper develops the basic fundamentals of gas compressor sizing.

The scope of this discussion is limited to slow speed (300-1000 RPM), horizontal, double acting, reciprocating compressors. Since exact specifications vary between different manufacturers, it is advisable to consult the manufacturer concerning his product's performance. The data and tables shown are intended to be as universally applicable as possible.

A field gas compressor normally consists of the gas compressor itself, a prime mover, and other components all coordinated to meet a specific condition or range of conditions. The emphasis here will be given to sizing the compressor, and its flexibility and coordination with other components of the package.

OPERATING CONDITIONS AND REQUIREMENTS

Before any steps in compressor design can be taken, a thorough analysis must be made to determine the expected operating conditions. Since each of the following factors plays an important role in the selection of the right compressor, it is essential that the preliminary data used for sizing be as close as possible to the actual operating conditions which will exist.

Suction Pressure

The suction pressure is that gas pressure which is measured at the inlet to the compressor. This pressure is a vital factor used in determining compression ratio, horsepower, capacity and rod load. Hence, an accurate value for the proposed suction pressure is essential. If possible, the well or system should be tested to determine the optimum suction pressure. For future discussion, in this paper suction pressure will be expressed in psia, i.e.:

Suction Pressure = (gauge pressure + atmospheric pressure), psia

Suction Temperature

The suction temperature is the temperature of the gas stream before it enters the compressor. It also plays an important role in designing a compression system. For convenience, the temperature reading in °F is converted to the Rankin scale and compared to standard temperature conditions:

Suction Temperature, °R = °F + 460°F

Discharge Pressure

The discharge pressure is the pressure which the compressor must overcome to move the gas from the cylinder into the sales line. In determining the discharge pressure the compressor must handle, the effect of the increased volume of gas being forced into the sales line must be calculated. Also, a pressure drop due to friction in the pipe leading to the sales line must be compensated for by an increase in discharge pressure. Thus it may be incorrect to assume that the discharge pressure will simply be equal to that of the sales line pressure. Discharge pressure will be expressed in psia.

Discharge Pressure = (gauge pressure + atmospheric pressure), psia.

Capacity Required

The actual volume of gas to be compressed, or the capacity, is an equally important factor which must be determined. Here again, the necessary tests must be performed to determine the volume of gas which the compressor will be sized to handle. For sizing calculations it is better to be optimistic since most compressors are sized at a maximum volume which can be lowered but often not raised.

This paper will use MCFD as the unit of volumetric measurement.

Elevation and Atmospheric Pressure

The elevation at the compressor site will determine the atmospheric pressure for that location. Since both the suction and discharge pressures used are expressed in psia, it is important that we know the correct atmospheric pressure at the location. This value can be determined from Table 1.

TABLE 1

ATMOSPHERIC PRESSURE & BAROMETER READINGS AT DIFFERENT ALTITUDES					
ALTITUDE	PSIA	INCHES HG	ALTITUDE	PSIA	INCHES HG
0	14.69	29.92	8000	10.91	22.22
500	14.42	29.38	8500	10.70	21.80
1000	14.16	28.86	9000	10.50	21.38
1500	13.91	28.33	9500	10.30	20.98
2000	13.66	27.82	10000	10.10	20.58
2500	13.41	27.31	10500	9.90	20.18
3000	13.16	26.81	11000	9.71	19.75
3500	12.92	26.32	11500	9.52	19.40
4000	12.68	25.84	12000	9.34	19.03
4500	12.45	25.36	12500	9.15	18.65
5000	12.22	24.89	13000	8.97	18.29
5500	11.99	24.43	13500	8.80	17.93
6000	11.77	23.98	14000	8.62	17.57
6500	11.55	23.53	14500	8.45	17.22
7000	11.33	23.09	15000	8.28	16.88
7500	11.12	22.65			

Gas Characteristics

To accurately size a compressor, it is important to know the nature of the gas to be compressed, since certain characteristics will affect the calculations. The gas analysis should include: the specific gravity of the gas; the N or K value, (which is the ratio of the specific heat at a constant pressure to the specific heat at a constant volume); and the content of hydrogen sulfide, if present. The determination of the N or K value is important, since it affects horsepower calculations. The presence of hydrogen sulfide in a gas necessitates the use of special compressor trim to combat the corrosive nature of the sour gas.

The most common type of natural gas has a specific gravity of 0.65 and an N or K value of 1.26. Figure 1 provides the information for determining the N or K value from a specific gravity.

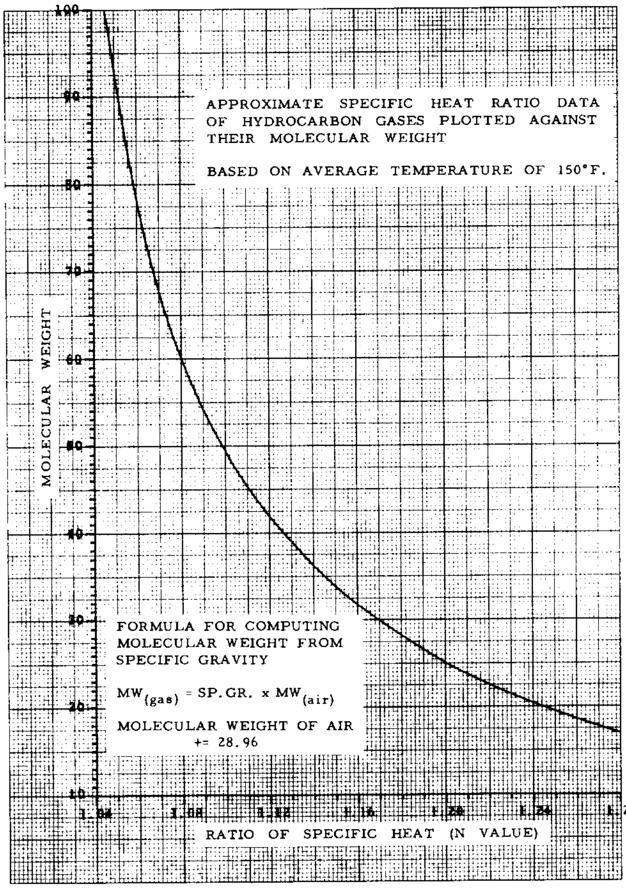

FIG. 1—MOLECULAR WEIGHT OF GAS VS RATIO OF SPECIFIC HEAT (N)

THE COMPRESSION RATIO

The compression ratio is the key in the designing of any compression system. To calculate the compression ratio simply divide the absolute discharge pressure by the absolute suction pressure:

$$CR = \frac{\text{Discharge Pressure (psia)}}{\text{Suction Pressure (psia)}}$$

It is normal practice to limit the compression ratio for a single stage of compression to 5:1. High compression ratios create high gas temperatures which shorten valve life. Also, volumetric efficiencies and overall efficiency are adversely affected.

When a compression ratio above five is needed, the gas should be compressed in two or more stages. Multistage compressors compress the gas through progressively smaller cylinders until it reaches the desired discharge pressure. If the total number of compressions is between five and twenty-five a two-stage compressor may be used. To find the compression ratio of each stage, take the square root of the total number of compressions. This is called an "ideal compression ratio" (ICR) because it assumes perfect cylinder sizing to equally balance the work done by each stage. If the CR is greater than 25 the cube root should be used to calculate the ICR for a three-stage compressor.

Since properly sized multistage compressors do approach perfect balance between cylinders, the ICR can be used to calculate interstage pressures and the work done by each stage.

HOW TO CALCULATE HORSEPOWER REQUIREMENTS

Most compressor manufacturers classify the power frames of their compressor by horsepower. Therefore it is necessary to determine the horsepower requirement for each application before an appropriate compressor can be selected.

To calculate the required horsepower, refer to Table 2 and determine the horsepower required per million cubic feet per day. This is done by locating the requirements for the particular CR (or use ICR for multistage units) under the appropriate column for the N or K value.

Once the horsepower has been determined from Table 2, substitute that value into the following equation:

$$\text{Horsepower} = \text{HP (by Table 2)} \times \text{Capacity Required} \times \text{Atmospheric Pressure, psia} \times \text{Suction Temperature, °R} \qquad (1)$$

for example:

$$\text{Horsepower} = \text{HP (by Table 2)} \times 1 \times 1000\ \text{MCFD} \times 14.4\ \text{psia} \times 520°\text{R}$$

The horsepower calculated above is the work required for one stage of compression. To calculate the total horsepower required for a multistage unit enter horsepower from Table 2 using the ICR. Substitute that value into the above equation. The subsequent figure derived for horsepower can then be multiplied by the number of stages to find the total horsepower required.

Total horsepower = Hp (Eq. 1) x Number of Stages

DETERMINATION OF COMPRESSOR CAPACITY

The displacement of a cylinder is the swept volume of that cylinder as the piston moves in a reciprocating motion. This value allows for the volume required for the piston rod and varies with RPM, cylinder size, and length of stroke. Table 3 provides cylinders displacement values in MCFD for a double-acting compressor operating at 100 RPM.

TABLE 2—HORSEPOWER DETERMINATION CHART FOR 14.4 PSI ATMOSPHERIC PRESSURE 70°F. HP SHOWN FOR MILLION CUBIC FEET PER DAY

C.R.	1.14	1.18	1.22	1.26	1.30	1.34	1.38	1.40
1.1	14	14	14	14	14	14	14	14
1.2	21	21	21	21	21	21	21	21
1.3	25	25	25	25	26	26	26	26
1.4	29	29	29	29	30	30	30	30
1.5	32	32	32	32	33	33	33	33
1.6	35	35	35	36	36	36	37	37
1.7	38	38	38	39	40	40	40	41
1.8	43	43	43	44	44	44	44	45
1.9	46	46	46	47	47	47	48	48
2.0	48	48	49	50	50	51	51	51
2.1	51	51	52	53	53	53	54	54
2.2	54	54	54	55	56	56	57	57
2.3	56	56	57	58	58	59	59	60
2.4	58	59	59	60	61	61	62	62
2.5	60	61	62	62	63	64	64	65
2.6	62	63	64	65	65	66	67	67
2.7	64	65	66	67	68	68	69	70
2.8	66	67	68	69	70	71	71	72
2.9	68	69	70	71	72	73	74	74
3.0	70	71	72	73	74	75	76	76
3.1	71	73	74	75	76	77	78	79
3.2	73	74	75	77	78	79	80	81
3.3	75	76	77	78	80	81	82	83
3.4	76	77	79	80	82	83	84	85
3.5	78	79	81	82	83	85	86	87
3.6	79	81	82	84	85	86	88	88
3.7	81	82	84	85	87	88	89	90
3.8	82	84	85	87	88	90	91	92
3.9	84	85	87	89	90	92	93	94
4.0	85	87	88	90	92	93	95	96
4.1	86	88	90	92	93	95	97	97
4.2	88	90	92	93	95	97	98	99
4.3	89	91	93	95	97	98	100	101
4.4	90	92	94	96	98	100	102	102
4.5	92	94	96	98	100	101	103	104
4.6	93	95	97	99	101	103	105	106
4.7	94	96	98	101	103	105	107	108
4.8	95	98	100	102	104	106	108	109
4.9	97	99	101	104	106	108	110	111
5.0	98	100	103	105	107	109	112	113
5.1	99	102	104	107	109	111	113	114
5.2	100	103	106	108	110	113	115	116
5.3	102	105	107	110	112	114	117	118
5.4	103	106	108	111	114	116	118	119
5.5	104	108	110	113	115	118	120	121
5.6	106	109	112	114	117	120	122	123
5.7	107	110	113	116	118	121	123	125
5.8	109	112	115	118	120	123	125	127
5.9	110	113	116	119	122	125	127	129
6.0	112	115	118	121	124	126	129	130

Suction Pressure Correction

Once the correct displacement for the compressor at operating speed has been determined, it is necessary to calculate the effect of a positive suction pressure. This is accomplished by multiplying the displacement by the suction pressure in psia and then dividing that product by the atmospheric pressure.

The equation for calculating suction pressure correction is:

$$\text{Corrected Displacement} = \frac{\text{Displacement (Table 3)} \times \text{Suction Pressure, psia}}{\text{Atmospheric Pressure, psia}}$$

Temperature Correction

The corrected displacement may be subject to a temperature correction. If this is the case, the correction factor equals the temperature at which the gas is to be measured in °R divided by the suction temperature in °R:

$$\text{Temperature correction} = \frac{\text{Corrected Displacement x Temp. of Measurement °R}}{\text{Suction Temperature °R}}$$

Volumetric Efficiency

In reciprocating compressors, loss of volumetric efficiency is due to the "inherent clearances" which are present in the cylinder. Inherent clearance is the sum of all the unswept spaces in a given cylinder and is usually expressed as a percent of the volume of that cylinder. The higher the inherent clearance at a given CR, the lower the VE. Each manufacturer and each cylinder has a different set of inherent clearances which will affect the volumetric efficiency of the machine. Once the displacement has been corrected for suction pressure and temperature, it is multiplied times the volumetric efficiency to determine the actual through-put of gas for the machine.

It would be difficult to list the inherent clearance of each and every cylinder or to show the specific effect the compression ratio has on the volumetric efficiency. Table 4 shows some approximate volumetric efficiencies for varying compression ratios. These values are used in calculating compressor capacity using the following equation:

Corrected Displacement =
Compressor Capacity x Volumetric Efficiency

PRIME MOVERS

Proper sizing of the compressor in both power frame and cylinder is only a part of the job of selecting the right compressor package. Most compressor packages use some type of natural gas engine to provide the power. It is standard practice to derate natural gas engines to 65% of their rated maximum power outputs.

This derated horsepower normally will be matched with the maximum horsepower rating of the compressor frame. An engine of this sufficient size will allow for full flexibility of the compressor.

Recent years have brought about an increasing use of electric motors for compressor power plants. When using an electric motor, it is permissible to use the rated hp of the motor. However, there are other power requirements which must be added to the compressor requirements. Coolers may require up to 20 hp in addition to a 3% loss occurring in a belt drive.

SCRUBBERS, COOLERS AND ACCESSORIES

A frequent difficulty which occurs when adapting gas compressors to new conditions is that often the accessary equipment is not designed to withstand pressure, volumes or other demands that may be placed upon the system. The scrubbers which remove the liquids from the inlet gas stream should be designed to handle the maximum flow of gas through the broadest range of pressure. In addition the scrubber should have a maximum working pressure which approaches the maximum cylinder pressure.

The dump trap mounted with the scrubber performs a vital function of removing any liquid before it can get to the compressor. The dump trap should be checked at regular intervals to ensure proper operation.

Coolers are generally sized to remove the heat of gas compression created by the horsepower energy transformation. It is important in compressor design that the interstage and aftercooling coils have the pressure capability necessary for the operation. Here again, the pressure ratings for coolers should approach the maximum cylinder working pressure.

Normal cooler design calls for aftercooling of the gas to 120°F with the intercooling coils rated at 130°F. Since most of the coolers in use are air-cooled heat exchangers, this means a 20°F approach to normal ambient of 100°F.

Table 5 shows the approximate heat buildup for a corresponding compression ratio. This table is based on a gas with specific gravity of 0.65 and an N value of 1.26.

COMPRESSOR SAFETY LIMITATIONS

To protect gas compression equipment, safety relief valves and shutdowns are included on today's compressor packages. They should be periodically checked. It is important to remember that before a packaged unit is moved from the job for which it was designed to a new one, it should be thoroughly examined to ensure that all vessels, piping, valves, etc., meet the new pressure requirements.

Rod load is another factor which must be considered to safeguard the compressor design. The easiest way to ensure that a compressor is not overloaded on rod load is by calculating the maximum differential pressure the compressor can handle. This maximum differential pressure must always be greater than the actual discharge pressure minus the suction pressure or the compressor is over rod load.

The maximum differential pressure equals the rod load divided by the area of the bore of the cylinder:

$$\text{Maximum Differential} = \frac{\text{Rod Load}}{\text{Area of Cylinder}}$$

Rod load can be calculated by subtracting the suction pressure from the discharge pressure and then multiplying this value times the area of a circle which would correspond to the bore of the cylinder.

$$\text{Rod load} = (\text{Discharge - Suction Pressure}) \times \text{Area of Cylinder}$$

Table 6 provides information concerning the various areas of a circle which can be used in the above formula.

MODIFICATION

Compressors can be altered to change their capacity by slowing the unit down, by adding clearances either with variable pockets or the addition of fixed clearance bottles, by use of unloading valves, by using a bypass, by removal of a portion of the valves, or by changing suction pressure. The most frequent method used to control capacity is adding clearance. If a unit still moves too much gas for the operation after adding maximum clearance, one or more of the other methods can be used.

SUMMARY

Gas compressors perform a vital role for the petroleum industry in the production of natural gas. When a gas compressor is needed, a thorough examination of the job conditions must be made. This study must determine the expected suction pressure, suction temperature, discharge pressure, capacity required, elevation, and the characteristics of the gas to be compressed. Once the expected operating conditions have been compiled, the methods described in this paper can be used to calculate compression ratio. From the CR and capacity, the horsepower requirement and subsequent cylinder size can be determined.

When the compressor has been properly sized, the rest of the components of the package should be designed to provide the maximum flexibility for the different job requirements of the compressor. The field compressor consists of a group of interdependent components all of which must be matched in capability and kept in top operating form if there is to be an adequate and safe return on the significant investment it represents.

TABLE 3

Bore	Stroke 5	7	9	11	13
2-1/2	3.5 mcfd	4.8	---	---	---
3	5.4 m	7.3	---	---	---
3-1/4	6.3 m	8.8	---	---	---
3-1/2	7.5 m	10.3	---	---	---
3-3/4	8.6 m	11.9	14.7	---	---
4	9.9 m	13.7	17.0	20.1	---
4-1/4	11.3 m	15.6	19.4	23.1	---
4-1/2	12.7 m	17.6	22.0	26.3	---
4-3/4	14.2 m	19.7	---	29.6	33.1
5	15.8 m	21.9	27.6	33.1	37.1
5-1/2	---	---	33.8	40.6	45.9
6	23.0 m	32.1	40.6	38.9	55.2
6-1/2	---	---	---	57.9	65.7
7	31.5 m	43.8	55.9	67.6	76.9
7-1/2	---	---	---	78.1	89.0
8	41.3 m	57.5	73.5	89.3	101.9
9	52.4 m	73.2	93.6	---	----
9-1/2	58.3 m	81.5	103.9	120.6	137.2
10	64.8 m	90.5	115.7	141.1	161.3
11	---	---	140.6	171.4	195.9
12	93.5 m	130.7	167.5	204.5	234.0
14	---	----	228.9	279.7	319.9
15	---	----	263.1	321.5	----
16	---	----	----	366.1	419.1
17	---	----	338.2	413.6	473.9
19	---	----	422.9	517.3	592.9
20	---	----	----	573.5	657.4

To determine compressor displacement locate the capacity value for the correct cylinder bore and stroke. The above values are displacement at 100 RPM, 14.7 PSI, and 70°F. To correct for compressor speed multiply by the $\frac{\text{speed}}{100}$.

TABLE 4

Volumetric Efficiency Values

Compression Ratio	Volumetric Efficiency
1.5	85%
2.0	80%
2.5	78%
3.0	74%
3.5	71%
4.0	68%
4.5	65%
5.0	60%
5.5	55%
6.0	50%

TABLE 5

Compressor Discharge Temperature

	Compression Ratio									
Suction Temperature	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
40°	90°	118°	148°	170°	192°	205°	220°	235°	250°	265°
50°	95°	130°	158°	182°	205°	220°	235°	255°	270°	280°
60°	104°	140°	170°	196°	218°	235°	255°	270°	288°	295°
70°	116°	152°	182°	210°	232°	250°	270°	285°	300°	310°
80°	128°	164°	194°	220°	245°	265°	285°	300°	315°	328°
90°	138°	176°	208°	235°	258°	280°	295°	315°	330°	345°
100°	150°	188°	220°	248°	270°	292°	310°	330°	345°	357°
110°	160°	200°	232°	260°	282°	305°	325°	342°	360°	373°
120°	170°	215°	245°	272°	292°	318°	338°	355°	375°	387°
130°	180°	225°	255°	285°	310°	330°	352°	370°	388°	400°

Table based on Gas with a 1.26 N value

TABLE 6

AREAS OF CIRCLES							
DIA.	AREA	DIA.	AREA	DIA.	AREA	DIA.	AREA
1	.78540	4-1/2	15.9043	10	78.5398	17	226.980
1-1/8	.99402	4-5/8	16.8002	10-1/4	82.5159	17-1/4	233.705
1-1/4	1.2272	4-3/4	17.7206	10-1/2	86.5902	17-1/2	240.528
1-3/8	1.4849	4-7/8	18.6655	10-3/4	90.7626	17-3/4	247.450
1-1/2	1.7671	5	19.6350	11	95.0332	18	254.469
1-5/8	2.0739	5-1/8	20.6290	11-1/4	99.4020	18-1/4	261.587
1-3/4	2.4053	5-1/4	21.6476	11-1/2	103.869	18-1/2	268.803
1-7/8	2.7612	5-3/8	22.6906	11-3/4	108.434	18-3/4	276.117
2	3.1416	5-1/2	23.7583	12	113.097	19	283.529
2-1/8	3.5466	5-5/8	24.8505	12-1/4	117.859	19-1/4	291.039
2-1/4	3.9761	5-3/4	25.9672	12-1/2	122.718	19-1/2	298.648
2-3/8	4.4301	5-7/8	27.1085	12-3/4	127.676	19-3/4	306.354
2-1/2	4.9087	6	28.2743	13	132.732	20	314.159
2-5/8	5.4119	6-1/4	30.6796	13-1/4	137.886	20-1/4	322.062
2-3/4	5.9396	6-1/2	33.1831	13-1/2	143.139	20-1/2	330.064
2-7/8	6.4918	6-3/4	35.7847	13-3/4	148.489	20-3/4	338.163
3	7.0686	7	38.4845	14	153.938	21	346.361
3-1/8	7.6699	7-1/4	41.2825	14-1/4	159.485	21-1/4	354.656
3-1/4	8.2958	7-1/2	44.1787	14-1/2	165.130	21-1/2	363.050
3-3/8	8.9462	7-3/4	47.1730	14-3/4	170.873	21-3/4	371.542
3-1/2	9.6211	8	50.2655	15	176.715	22	380.133
3-5/8	10.3206	8-1/4	53.4562	15-1/4	182.654	22-1/4	388.821
3-3/4	11.0447	8-1/2	56.7450	15-1/2	188.692	22-1/2	397.608
3-7/8	11.7932	8-3/4	60.1321	15-3/4	194.828	22-3/4	406.493
4	12.5664	9	63.6173	16	201.062	23	415.476
4-1/8	13.3640	9-1/4	67.2007	16-1/4	207.394	23-1/4	424.557
4-1/4	14.1863	9-1/2	70.8822	16-1/2	213.825	23-1/2	433.736
4-3/8	15.0330	9-3/4	74.6619	16-3/4	220.353	23-3/4	443.014