BECKER

TECHNICAL GUIDE

&

Rules of Thumb

HANDBOOK II

for Vacuum & Low Pressure Compressed Air

THE BECKER TECHNICAL GUIDE and RULES OF THUMB HANDBOOK for VACUUM and LOW PRESSURE COMPRESSED AIR

This handbook has been compiled for the use of our distributors and customers as an aid in the designing of applications involving vacuum and low pressure compressed air. While every consideration has been made to ensure accurate information, errors may occur, and differences in interpretation may result in incorrect solutions; therefore, Becker Pumps Corporation assumes no responsibility for any application of these data.

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(Items in blue are graphs)

460 - 370 B.C.
Demokritos started it all, when he concieved of the smallest particle that could not be divided: the atom (a, “not”, tomos, “cut”), around which there should be only empty space, or nothing—a vacuum.

"Nature abhors a vacuum"
Aristotle, 384 - 322 B.C.

SIMILARITY OF UNITS

Electricity, pressure, and vacuum have analogous units:
force, current, resistance, conductance.

Electricity	Pressure & Vacuum
Volts (Force)	**In. Hg; Torr, etc.** (Force—Pressure)
Amps (Current) The current in a direct-current circuit is directly proportional to the voltage	**CFM** (Current—Flow) The flow of a positive displacement pump is directly proportional to the pressure
Ohms (Resistance)	**Pressure Drop / Rise** (Resistance—ΔP)
Mho (Conductance)	**CFM** (Conductance)

CFM -vs- SCFM -vs- ACFM

CFM

Cubic Feet per Minute

(displacement)

Total physical displacement of the pump chambers (swept volume) at 100% volumetric efficiency.

SCFM

Standard Cubic Feet per Minute

(mass flow)

Air at Standard Conditions of
68°F, 29.92 in. Hg, 36% R.H., 0.075#/$ft.^3$

ACFM

Actual Cubic Feet per Minute

(volumetric flow)

Air that has been expanded
in a vacuum (less dense)

Sometimes called CFM

1618
Dutch scientist Isaac Beekman suggests that air has physical properties. Galileo and Descartes disagree.

Q
(THROUGHPUT)

Q = TorrCFM = Torr x ACFM = Throughput

Q = ACFM @ pressure x pressure (Torr)

Q / New absolute pressure = New ACFM

Q / 760 = SCFM

Q / 169 = Lbs./hr. air equivalent

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1 SCFM = 4.5 lbs./hr. (air equivalent)
= 0.472 Nl/s
= 2.04 kg/hr.

$$ACFM = SCFM \times \frac{760}{P_O} \times \frac{T_O + 460}{530}$$

-or-

$$ACFM = W \times \frac{359}{M_W} \times \frac{760}{P_O} \times \frac{460 + T_O}{492} \times \frac{1}{60}$$

Where:
- W = Load (lbs./hr.)
- M_W = Mol. Wt. of gas
- P_O = Operating Pressure (Torr)
- T_O = Operating Temperature (°F)

SCFM* to ACFM
Conversion Ratios

Vacuum Level (in. Hg Vac)	Ratio (SCFM : ACFM)
0	1:1
15	1:2
18	1:2.5
19	1:2.75
20	1:3
21	1:3.33
22	1:3.75
23	1:4.28
24	1:5
25	1:6
26	1:7.5
27.5	1:12
28	1:15
28.5	1:20
29	1:30
29.1	1:33.3
29.2	1:37.5
29.3	1:42.86
29.4	1:50
29.5	1:60
29.6	1:75
29.7	1:100
29.8	1:150
29.9	1:300

Vacuum Level (Torr)	Ratio (SCFM : ACFM)
760	1:1
500	1:1.5
380	1:2
300	1:2.5
250	1:3
200	1:3.8
150	1:5
125	1:6
100	1:7.6
75	1:10.0
50	1:15.2
35	1:22
25	1:30.4
20	1:38
15	1:50.7
10	1:76
5	1:152
2	1:380
1	1:760
0.5	1:1520
0.1	1:7600
0.01	1:76000
0.001	1:760000

At Constant Temperature

* Using the 30 in. Hg Barometric Pressure standard

1640
Gaspar Berti demonstrates how a vacuum can be created, using a lead tube and a bucket of water.

PRESSURE EQUIVALENTS

ABSOLUTE				RELATIVE (GAUGE)		
Torr	In. Hg, Abs.	mbar	PSIA	In. Hg, Vac	PSIG	% Vacuum
760	29.92	1013	14.696	0	0	0
500	19.68	666.4	9.668	10.24	-5.027	34.21
450	17.72	599.8	8.701	12.20	-5.994	40.79
400	15.75	533.2	7.735	14.17	-6.961	47.37
375	14.76	499.8	7.251	15.15	-7.445	50.66
350	13.78	466.5	6.768	16.14	-7.928	53.95
325	12.79	433.2	6.284	17.12	-8.411	57.24
300	11.81	399.9	5.801	18.11	-8.895	60.53
275	10.83	366.6	5.318	19.09	-9.378	63.82
250	9.84	333.2	4.834	20.08	-9.862	67.11
225	8.86	299.9	4.351	21.06	-10.345	70.39
200	7.87	266.6	3.867	22.05	-10.829	73.68
175	6.89	233.3	3.384	23.03	-11.312	76.97
150	5.91	199.9	2.901	24.01	-11.795	80.26
125	4.92	166.6	2.417	25.00	-12.279	83.55
100	3.94	133.3	1.934	25.98	-12.762	86.84
95	3.74	126.6	1.837	26.18	-12.859	87.50
90	3.54	120.0	1.740	26.38	-12.956	88.16
85	3.35	113.3	1.644	26.57	-13.052	88.82
80	3.15	106.6	1.547	26.77	-13.149	89.47
75	2.95	99.97	1.450	26.97	-13.246	90.13
70	2.76	93.30	1.354	27.16	-13.342	90.79
65	2.56	86.64	1.257	27.36	-13.439	91.45
60	2.36	79.97	1.160	27.56	-13.536	92.11
55	2.17	73.31	1.064	27.75	-13.632	92.76
50	1.97	66.64	0.967	27.95	-13.729	93.42
45	1.77	59.98	0.870	28.15	-13.825	94.08
40	1.57	53.32	0.773	28.35	-13.923	94.74
35	1.38	46.65	0.677	28.54	-14.019	95.39
30	1.18	39.99	0.580	28.74	-14.006	96.05

25	0.98	33.32	0.483	28.94	-14.213	96.71
20	0.79	26.66	0.387	29.13	-14.309	97.37
18	0.71	23.99	0.348	29.21	-14.348	97.63
16	0.63	21.32	0.309	29.29	-14.387	97.89
15	0.59	19.99	0.290	29.33	-14.406	98.03
14	0.55	18.66	0.271	29.37	-14.425	98.16
13	0.51	17.33	0.251	29.41	-14.445	98.29
12	0.47	15.99	0.232	29.45	-14.464	98.42
11	0.43	14.66	0.213	29.49	-14.483	98.55
10	0.39	13.33	0.193	29.53	-14.503	98.68
9	0.35	12.00	0.174	29.57	-14.522	98.82
8	0.31	10.66	0.155	29.61	-14.541	98.95
7	0.28	9.33	0.135	29.64	-14.561	99.08
6	0.24	8.00	0.116	29.68	-14.580	99.21
5	0.20	6.66	0.097	29.72	-14.599	99.34
4	0.16	5.33	0.077	29.76	-14.618	99.47
3	0.12	4.00	0.058	29.80	-14.638	99.61
2	0.08	2.67	0.039	29.84	-14.657	99.737
1	0.039	1.33	0.019	29.881	-14.677	99.868
0.9	0.035	1.20	0.017	29.884	-14.679	99.882
0.8	0.032	1.07	0.015	29.889	-14.681	99.895
0.7	0.028	0.933	0.013	29.892	-14.682	99.908
0.6	0.024	0.800	0.012	29.896	-14.684	99.921
0.5	0.020	0.667	0.0097	29.900	-14.686	99.934
0.4	0.016	0.600	0.0087	29.904	-14.688	99.947
0.3	0.012	0.533	0.0077	29.908	-14.690	99.961
0.2	0.008	0.400	0.0058	29.912	-14.692	99.974
0.15	0.006	0.267	0.0039	29.914	-14.693	99.980
0.10	0.004	0.200	0.0029	29.916	-14.694	99.987
0.05	0.002	0.133	0.0019	29.918	-14.695	99.993
0	0	0	0	29.92	-14.696	100

1 Torr = 1 mm abs. = 1000 microns
Sea Level Barometric Pressure= 29.92 in. Hg; or, 760 torr

TEMPERATURE CONVERSIONS

°C	TEMP.	°F	°C	TEMP.	°F
-34.4	-30	-22	33.3	92	197.6
-28.9	-20	-4	34.4	94	201.2
-23.3	-10	14	35.6	96	204.8
-17.8	0	32	36.7	98	208.4
-16.7	2	35.6	37.8	100	212
-15.6	4	39.2	43	110	230
-14.4	6	42.8	49	120	248
-13.3	8	46.4	54	130	266
-12.2	10	50.0	60	140	284
-11.1	12	53.6	66	150	302
-10.0	14	57.2	71	160	320
-8.9	16	60.8	77	170	338
-7.8	18	64.4	82	180	356
-6.7	20	68.0	88	190	374
-5.6	22	71.6	93	200	392
-4.4	24	75.2	99	210	410
-3.3	26	78.8	104	220	428
-2.2	28	82.4	110	230	446
-1.1	30	86.0	116	240	464
0	32	89.6	121	250	482
1.1	34	93.2	127	260	500
2.2	36	96.8	132	270	518
3.3	38	100.4	138	280	536
4.4	40	104.0	143	290	554
5.6	42	107.6	149	300	572
6.7	44	111.2	154	310	590

7.8	46	114.8	160	320	608
8.9	48	118.4	166	330	626
10.0	50	122.0	171	340	644
11.1	52	125.6	177	350	662
12.2	54	129.2	182	360	680
13.3	56	132.8	188	370	698
14.4	58	136.4	193	380	716
15.6	60	140.0	199	390	734
16.7	62	143.6	204	400	752
17.8	64	147.2	210	410	770
18.9	66	150.8	216	420	788
20.0	68	154.4	221	430	806
21.1	70	158.0	227	440	824
22.2	72	161.6	232	450	842
23.3	74	165.2	238	460	860
24.4	76	168.8	243	470	878
25.6	78	172.4	249	480	896
26.7	80	176.0	254	490	914
27.8	82	179.6	260	500	932
28.9	84	183.2	266	510	950
30.0	86	186.8	271	520	968
31.1	88	190.4	277	530	986
32.2	90	194.0	282	540	1004

From known temperature, read left for °C, right for °F

°F = $^9/_5$ °C + 32

°C = $^5/_9$ (°F-32)

Rankin (°R) = °F + 460

Kelvin (°K) = °C + 273

CONVERSION FACTORS

PRESSURE CONVERSION *

psi	in. H_2O	in Hg	mm H_2O	Torr (mm Hg)	ATM.
1	27.73	2.036	704.49	51.71	0.06804
0.03605	1	0.0734	25.4	1.8627	0.00245
0.49116	13.623	1	346.02	25.4	0.03342
0.00142	0.03937	0.00289	1	0.07341	0.000097
0.01934	0.53632	0.03937	13.623	1	0.001316
14.696	407.61	29.921	10353	760	1

1 in. H_2O = 0.002487 bar

* This is a unit conversion only. Some pressure terms may be absolute, some relative (gauge), and some may be either.

FLOW CONVERSION

CFM	l/sec.	m^3/min.	m^3/hr.
1	0.47195	0.02832	1.6990
2.1189	1	0.06	3.6
35.314	16.666	1	60
0.58861 *	0.27778	0.01667	1

* **At 60 Hz.** When converting from m^3/hr. to CFM, be aware of motor frequency. Many m^3/hr. ratings are at 50 hz, while most CFM ratings are at 60 hz.

If the conversion is from m^3/hr. at 50 hz. to CFM at 60 hz the factor is 0.7063.

VELOCITY				
FT. / SEC.	FT. / MIN.	CM/ SEC.	METER/ SEC.	METER/ MIN.
1	60	30.48	0.3048	18.29
0.01667	1	0.5080	0.005080	0.3048
0.03281	1.9685	1	0.01	0.600
3.281	196.85	100	1	60
0.0547	3.281	1.667	0.01667	1

LENGTH				
FEET	INCHES	METERS	CENTI- METERS	MILLI- METERS
1	12	0.3048	30.48	304.8
0.0833	1	0.0254	2.54	25.4
3.281	39.37	1	100	1000
0.03281	0.3937	0.01	1	10
0.003281	0.03937	0.001	0.1	1

Instructions: Read down from the known factor to the "1", then across to the desired conversion factor. i.e., Pressure—1 in H_2O = 0.0734 in. Hg.

1643
Evangelista Torricelli duplicates Berti's experiment, but with mercury. Invents the barometer.

VOLUME				
Gallons	$ft.^3$	$in.^3$	m^3	cm^3
1	0.13368	231	0.0037854	3,785.4
7.4805	1	1,728	0.028317	28,317
0.004329	0.0005787	1	0.0000164	16.387
264.17	35.315	61,024	1	1,000,000
0.0002642	0.0000353	0.06102	0.000001	1

1 gallon = 3.785 liters

1 liter = 0.0353 ft^3

MISCELLANEOUS CONVERSIONS

PUMPING SPEED CONVERSIONS

1m^3/hr. (60hz) = 0.589 ft^3/min. (60hz)
1m^3/hr. (50hz) = 0.706 ft^3/min. (60hz)
1ft^3/min. (60hz) = 1.697 m^3/hr. (60hz)
1ft^3/min. (60hz) = 1.416 m^3/hr. (50hz)
1 liter/min. = 0.0353 ft^3/min.
1 liter/sec. = 2.12 ft^3/min.
1 liter/sec. = 3.6 m^3/hr.
1 m^3/hr. = 0.2778 liters/sec.
1 ft^3/min. = 0.472 liters/sec.
1 ft^3/min. = 28.33 liters/min.
1 mbar•l/sec. = 2.82 Torr•CFM
1 SCFM= 760 Torr•CFM

1 horsepower = 2546 BTU/hr.

$$3 \text{ ph. HP} = \frac{\text{Volts x Amps x eff. x P.F. x } 1.732}{746}$$

$$1 \text{ ph. HP} = \frac{\text{Volts x Amps x eff. x P.F}}{746}$$

MOTOR CYCLING GUIDELINES

Electric motors* have specific NEMA guidelines for the number of starts per hour and the period between stops and starts they can tolerate.

Motor Horsepower	Minimum Interval Between Starts	Minimum Off-Time
0.25 - 10	10 min.	3 min.
10 - 20	20	5
20 -50	30	7
50 - 100	40	7

* NEMA Type "A" thru "F" induction; Type "T" (50 HP or less)

NOISE

The sound pressure level, or noise, is measured on an exponential scale. An increase of 3 dB is a doubling of the noise. A 10 dB increase is 10 times noisier; 20 dB is 100 times noisier.

It takes a 3 dB sound level increase in order for it to be perceptable to the human ear.

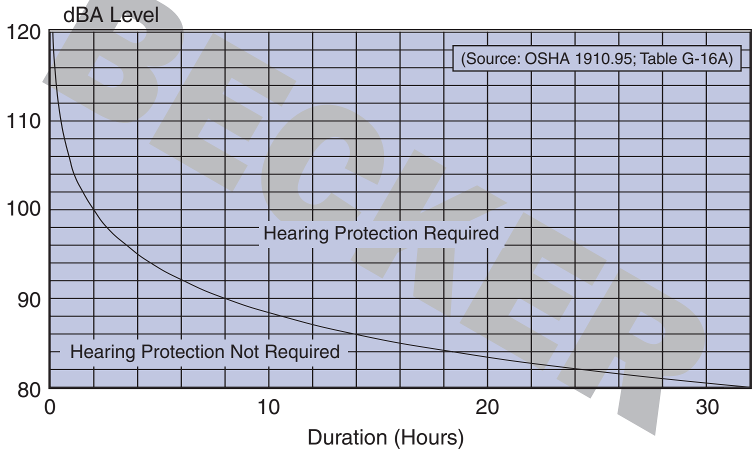
Exposure to different noise levels.

Exposure to different noise levels at different times requires that the sum of the exposure time percentages (actual time at each sound level divided by the permissible time at each sound level) cannot exceed unity (1). For example:

Exposure during 8 hour day:	Permissible exposure:	Exposure time percentages:
3 hrs. @ 85dBA	unlimited	0
4 hrs. @ 92dBA	6 hours	4/6 = 0.66
1 hrs. @ 95dBA	4 hours	1/4 = 0.25
		Total = 0.91

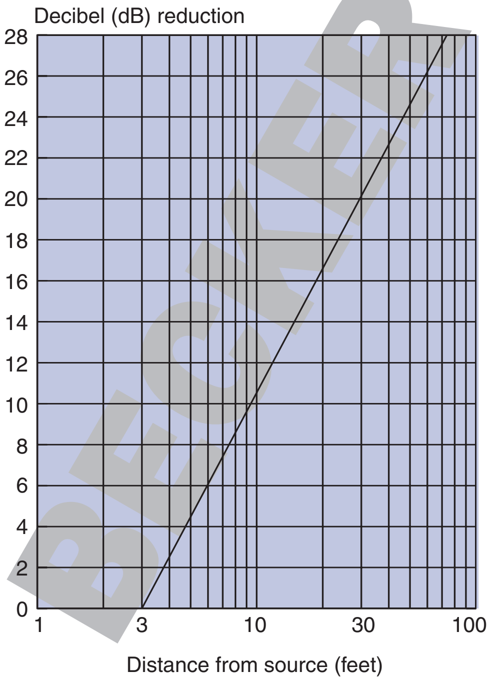
Since the total does not exceed 1, protection is not required. If it exceeds 1, protection is required.

DURATION OF EXPOSURE TO SOUND LEVELS

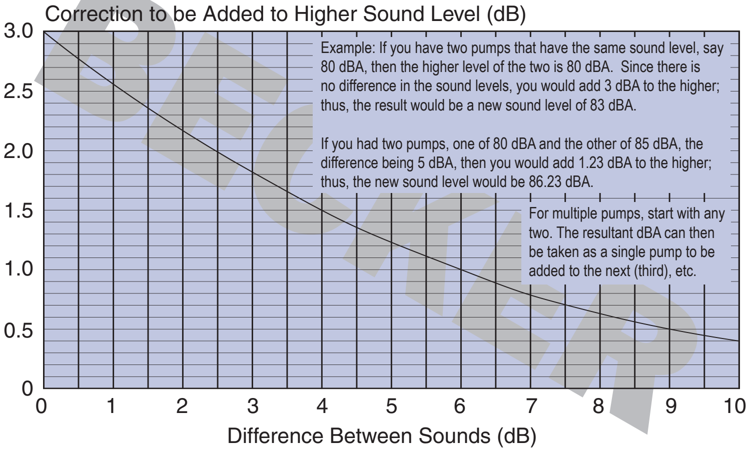


DECIBEL REDUCTION

For distance in a free field



ADDING TWO SOUND LEVELS



ALTITUDE -vs- BAROMETRIC PRESSURE

ALTITUDE (Feet)	BAROMETRIC PRESSURE (in. Hg)	ALTITUDE (Feet)	BAROMETRIC PRESSURE (in. Hg)
0	29.92	2700	27.11
100	29.81	2800	27.01
200	29.70	2900	26.91
300	29.60	3000	26.82
400	29.49	3200	26.62
500	29.38	3400	26.42
600	29.28	3600	26.23
700	29.17	3800	26.03
800	29.07	4000	25.84
900	28.96	4200	25.65
1000	28.86	4400	25.46
1100	28.75	4600	25.27
1200	28.65	4800	25.08
1300	28.54	5000	24.90
1400	28.44	5200	24.71
1500	28.33	5400	24.52
1600	28.23	5600	24.34
1700	28.13	5800	24.16
1800	28.02	6000	23.98
1900	27.92	6500	23.53
2000	27.82	7000	23.09
2100	27.72	7500	22.65

2200	27.62	8000	22.22
2300	27.52	8500	21.80
2400	27.42	9000	21.39
2500	27.32	9500	20.98
2600	27.21	10000	20.58

To determine the equivalent sea level pressure (%):

$$P_{SL} = \frac{(P_B - V)\ 29.92}{P_B}$$

P_{SL} = Sea level reference pressure (in. Hg Abs.)
P_B = Barometric Pressure at altitude (in. Hg Abs.)
V = Operating vacuum level at altitude (in. Hg)

To determine the equivalent sea level flow:

$$Q_{SL} = Q_O \times \frac{29.92}{P_B} \qquad Q_O = \frac{Q_{SL}}{\frac{29.92}{P_B}}$$

Q_{SL} = Sea level airflow (SCFM)
Q_O = Airflow at altitude (SCFM)
P_B = Barometric Pressure at alt. (in. Hg Abs., or PSIA)

NOTE: When selecting pumps for operation at high altitudes, it is often necessary to use motors with larger horsepower due to the inefficiencies of cooling fans, etc. Contact the motor manufacturer for specific details and technical help.

"We live submerged at the bottom of an ocean of air"
Evangelista Torricelli, CA 1644

ALTITUDE CORRECTION FOR REGENERATIVE BLOWERS

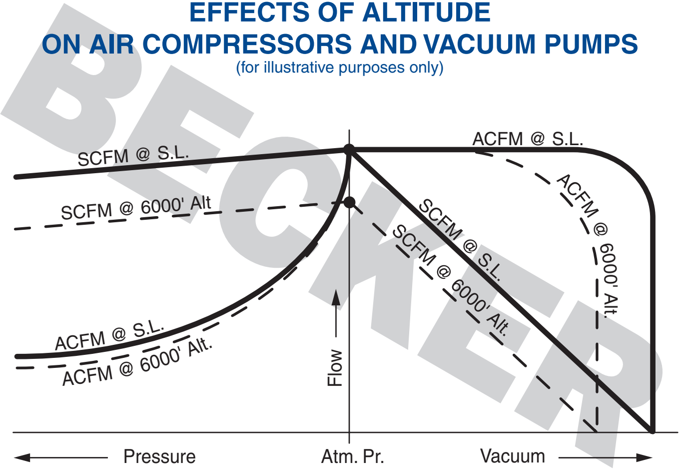
A given percentage decrease in density due to altitude, equals the same percentage decrease of pressure, but the same ACFM.

i.e., A blower that produces 110 ACFM at 40 in. H_2O at sea level = 110 ACFM at 35.72 in. H_2O at an altitude of 3000 feet (26.62 in. Hg Bar. Pr.):
[40 x 0.107 = 4.28; 40 - 4.28 = 35.72]

Density Change	
@ 1,000 ft. = -3.8%	@ 10°F = +13%
@ 2,000 ft. = -7.4%	@ 20°F = +10%
@ 3,000 ft. = -10.7%	@ 30°F = +8%
@ 4,000 ft. = -13.8%	@ 40°F = +6.4%
@ 5,000 ft. = -16.7%	@ 50°F = +4%
@ 6,000 ft. = -20%	@ 60°F = +2%
@ 7,000 ft. = -23.1%	@ 70°F = 0%
@ 8,000 ft. = -25.9%	@ 80°F = -2%
@ 9,000 ft. = -28.6%	@ 90°F = -4%
@ 10,000 ft. = -31%	@ 100°F = -5.7%

EFFECTS OF ALTITUDE ON AIR COMPRESSORS AND VACUUM PUMPS

(for illustrative purposes only)



HOLDING FORCE: ROUND SUCTION CUPS

Cup dia. (in.)	Area (in^2)	Holding force (lbs.) In. Hg (Vac): 5	10	15	20	25	29
.375	0.11	0.27	0.54	0.81	1.08	01.36	1.57
.5	0.2	0.48	0.96	1.45	1.93	2.41	2.8
625	0.31	0.75	1.51	2.26	3.01	3.77	4.37
.75	0.44	1.08	2.17	3.25	4.34	5.42	6.29
.875	0.6	1.48	2.95	4.43	5.91	7.38	8.56
1	0.79	1.93	3.86	5.79	7.72	9.64	11.2
1.25	1.23	3.01	6.03	9.04	12.1	15.1	17.5
1.5	1.77	4.34	8.68	13	17.4	21.7	25.2
1.75	2.41	5.91	11.8	17.7	23.6	29.5	34.3
2	3.14	7.72	15.4	23.1	30.9	38.6	44.7
2.25	3.98	9.76	19.5	29.3	39.1	48.8	56.6
2.5	4.91	12.1	24.1	36.2	48.2	60.3	69.9
2.75	5.94	14.6	29.2	43.8	58.3	72.9	84.6
3	7.07	17.4	34.7	52.1	69.4	86.8	101
3.5	9.62	23.6	47.3	70.9	94.5	118	137
4	12.6	30.9	61.7	92.6	123	154	179
4.5	15.9	39.1	78.1	117	156	195	227
5	19.6	48.2	96.4	145	193	241	280
5.5	23.8	58.3	117	175	233	292	338
6	28.3	69.4	139	208	278	347	403
6.5	33.2	81.5	163	244	326	407	473
7	38.5	94.5	189	284	378	473	548
7.5	44.2	108	217	325	434	542	629
8	50.3	123	247	370	494	617	716
8.5	56.7	139	279	418	557	697	808
9	63.6	156	312	469	625	781	906
9.5	70.9	174	348	522	696	870	1010
10	78.5	193	386	579	772	964	1119
11	95	233	467	700	934	1167	1354
12	113	278	555	833	1111	1389	1611

SQUARE SUCTION CUPS

Cup Size (in.)	Area (in²)	Holding force (lbs.) In. Hg (Vac): 5	10	15	20	25	29
.375	0.14	0.35	0.69	1.04	1.38	1.73	2
.5	0.25	0.61	1.23	1.84	2.46	3.07	3.56
625	0.39	0.96	1.92	2.88	3.84	4.8	5.56
.75	0.56	1.38	2.76	4.14	5.53	6.91	8.01
.875	0.77	1.88	3.76	5.64	7.52	9.4	10.9
1	1	2.46	4.91	7.37	9.82	12.3	14.2
1.25	1.56	3.84	7.67	11.5	15.3	19.2	22.3
1.5	2.25	5.53	11.1	16.6	22.1	27.6	32
1.75	3.06	7.52	15	22.6	30.1	37.6	43.6
2	4	9.82	19.6	29.5	39.3	49.1	57
2.25	5.06	12.4	24.9	37.3	49.7	62.2	72.1
2.5	6.25	15.3	30.7	46	61.4	76.7	89
2.75	7.56	18.6	37.1	55.7	74.3	92.9	108
3	9	22.1	44.2	66.3	88.4	111	128
3.5	12.3	30.1	60.2	90.3	120	150	174
4	16	39.3	78.6	118	157	196	228
4.5	20.3	49.7	99.5	149	199	249	288
5	25	61.4	123	184	246	307	356
5.5	30.3	74.3	149	223	297	371	431
6	36	88.4	177	265	354	442	513
6.5	42.3	104	208	311	415	519	602
7	49	120	241	361	481	602	698
7.5	56.3	138	276	414	553	691	801
8	64	157	314	472	629	786	912
8.5	72.3	177	355	532	710	887	1029
9	81	199	398	597	796	995	1154
9.5	90.3	222	443	665	887	1108	1285
10	100	246	491	737	982	1228	1424
11	121	297	594	891	1189	1486	1723
12	144	354	707	1061	1415	1768	2051

Equivalent Dia. = $1.128\sqrt{a}$; where: a = area (in.^{2})

VACUUM SYSTEM SIZING

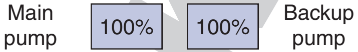
MULTIPLEX SYSTEMS

The majority of central vacuum systems are designed with redundancy included. The following method is the most common.

The Peak Calculated Load (PCL) is the maximum anticipated load the sysem is expected to meet.

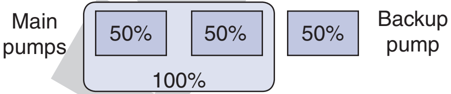
DUPLEX

Each pump is sized for 100% of PCL



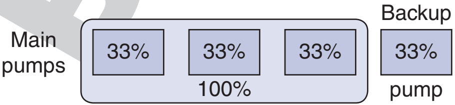
TRIPLEX

Each pump is sized for 50% of PCL



QUADRUPLEX

Each pump is sized for 33% of PCL



CONDUCTANCE (C)

Conductance (C) is the reciprocal of resistance, or pressure drop (ΔP), expressed in terms of volumetric flow. When designing a system, the calculated conductance should be at least ten times the ACFM (i.e., if the volumetric flow at the operating pressure is 150 ACFM, the conductance of the system should be at least 1500 ACFM).

Conductance of components
in series:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots$$

Conductance of components
in parallel:

$$C = C_1 + C_2 + C_3 \ldots$$

$$C = \frac{Q}{\Delta P}$$

$$Q = C \bullet \Delta P$$

$$\Delta P = \frac{Q}{C}$$

1660
Otto von Guericke demonstrates the power of the force of atmospheric pressure in Magdeburg. A vacuum was created in two close fitting hemispheres, and two teams of horses could not pull them apart. When a valve was opened, the hemispheres fell apart.

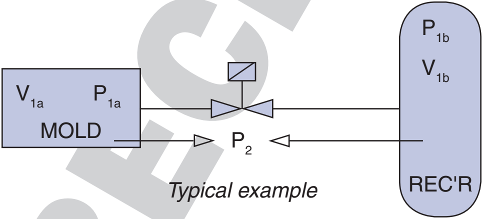
RECEIVERS

Sizing a receiver to equalize pressure

$$V_{1b} = \frac{(V_{1a} \times P_{1a}) - (V_{1a} \times P_2)}{P_2 - P_{1b}}$$

Calculating the final equalized pressure (P_2)

$$P_2 = \frac{(P_{1a} \times V_{1a}) + (V_{1b} \times P_{1b})}{V_{1b} + V_{1a}}$$



Typical example

Where: P_1 = Initial pressure (Torr)
P_2 = Final, equalized pressure (Torr)
V_1 = Initial volume (ft^3)
subscript a = high pressure (low vacuum) chamber
subscript b = low pressure (high vacuum) chamber

PUMP DOWN CALCULATIONS

To find the required pump speed (ACFM):

$$S = \frac{V}{T} \ln \frac{P_1}{P_2} \quad \text{-or-} \quad S = 2.3 \frac{V}{T} \log \frac{P_1}{P_2}$$

To find the time required:

$$T = \frac{V}{S} \ln \frac{P_1}{P_2} \quad \text{-or-} \quad T = 2.3 \frac{V}{S} \log \frac{P_1}{P_2}$$

To find the volume of a system:

$$V = \frac{S\ \ T}{\ln (P_1/P_2)} \quad \text{-or-} \quad V = \frac{S\ \ T}{2.3 \log (P_1/P_2)}$$

Where:
- V = Volume of system (ft^3)
- P1 = Initial—high—pressure (Torr)
- P2 = Final—low—pressure (Torr)
- T = Pump down time (minutes)
- S = Pump speed, or capacity (*average* ACFM from P_1 to P_2)

PUMPDOWN TIME CORRECTION FACTORS*

Multiplier for use with $T = \frac{V}{S} \ln \frac{P_1}{P_2}$

From Atm. Press. to:	Pump Type/Ultimate Vacuum (Torr)				
	Oil-less		Lubricated		
	75	50	15	2	0.4
500 Torr	1.03	1.019	Less than 1%	Less than 1%	Less than 1%
475	1.033	1.022			
450	1.038	1.024			
425	1.043	1.027			
400	1.048	1.031			
375	1.055	1.035			
350	1.062	1.039	1.011		
325	1.07	1.044	1.012		
300	1.081	1.05	1.014		
275	1.092	1.057	1.015		
250	1.107	1.065	1.017		
225	1.125	1.076	1.02		
200	1.149	1.088	1.023		
175	1.182	1.106	1.027		
150	1.229	1.129	1.032		
125	1.307	1.164	1.039		
100	1.469	1.223	1.049		
90	1.611	1.26	1.055		
85	1.734	1.284	1.058		

75		1.351	1.066		
70		1.399	1.071		
65		1.466	1.077		
60		1.568	1.084		
55		1.757	1.092	1.01	
50			1.102	1.011	
45			1.114	1.012	
40			1.13	1.014	
35			1.152	1.016	
30			1.185	1.018	
25			1.238	1.021	
20			1.347	1.026	
18			1.442	1.028	
16			1.671	1.031	
14				1.035	
12				1.041	
10				1.048	
8				1.06	1.011
6		CORRECTION		1.08	1.014
5		FACTOR		1.098	1.016
4				1.129	1.019
3				1.195	1.025
2					1.037
1					1.078
0.8					1.102
0.6					1.155
0.5					1.219
0.4					

* Factors due to effect of ultimate vacuum on performance curve.

COMPRESSOR PUMP UP

To find the required compressor capacity, or time:

$$ACFM = \frac{(V\,(P_2 - P_1))\,/\,T}{P_O}$$

$$T = \frac{V\ \ (P_2 - P_1)}{P_O\ \ (ACFM)}$$

Where: V = Receiver or System Volume (ft3)
T = Time from P_1 to P_2 (minutes)
P_O = Atmospheric Pressure (PSIA)
P_1 = Initial Pressure (PSIA)
P_2 = Final Pressure (PSIA)

VENTING OF VACUUM VESSELS

Venting from Low Absolute Pressure to Atmospheric Pressure *Rapidly* :

$$t = \frac{V}{3\ \ d^2}$$

Venting from Low Absolute Pressure to Atmospheric Pressure *Slowly* :

$$t = \frac{V}{2.25\ \ d^2}$$

Venting from One Absolute Pressure to an Intermediate Absolute Pressure (other than atmospheric):

$$t = .28\ \frac{V}{d^2}\ (R_2 - R_1)$$

Note: For R_n factors, see graph below

Where:

t = Time (seconds)

V = Vessel volume (cu. ft.)

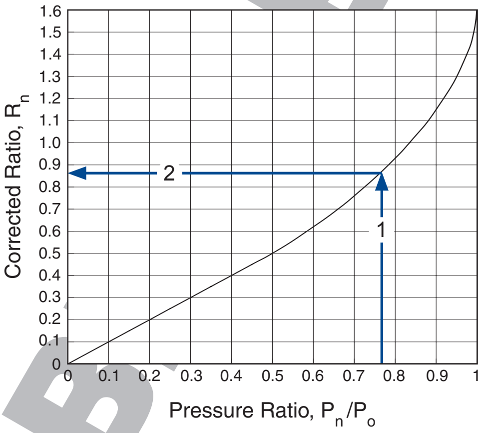
d = Diameter of opening (inches)

P_o = Abs. pressure on outside of vent valve (Torr)

P_1 = Initial absolute pressure in vessel (Torr)

P_2 = Final absolute pressure in vessel (Torr)

R_n = Corrected ratio



CRITICAL PRESSURE RATIO

Correction Factor

RULE OF THUMB

To reduce the *absolute* operating pressure by *half*, requires *twice* the pump capacity.

To pump the *same* load in *half* the time, requires *twice* the pump capacity.

INCREASING PUMP CAPACITY

To *increase flow* while maintaining the *same ultimate pressure*, place pumps in **parallel**.

To *decrease the ultimate pressure* while maintaining the *same flow*, place pumps in **series** (flow will be determined by the first pump in the series).

To *increase both flow and ultimate pressure*, place a rotary lobe (Roots-type) positive displacement blower as the first pump in a **series** with a Dekatorr type F pump.

"What is there in a vacuum that could make them afraid?"
Blaise Pascal, CA 1648

RECEIVER VOLUMES
(With Domed Heads)

Size—dia. x l. (inches)	Volume (ft.^{3}, Nom.)	Volume (Gallons, Nom.)
10 x 30	1.33	10
12 x 27	1.6	12
12 x 33	2.0	15
14 x 33	2.67	20
14 x 48	4.0	30
16 x 38	4.0	30
18 x 72	11.0	82
20 x 26	4.0	30
20 x 48	8.0	60
20 x 63	10.7	80
24 x 35	8.0	60
24 x 48	10.7	80
24 x 69	16.0	120
24 x 72	18.0	135
30 x 46	16.0	120
30 x 72	26.74	200
30 x 84	32.0	240
36 x 96	53.5	400
42 x 144	107.0	800
42 x 117	88.24	660
48 x 144	141.7	1060
54 x 166	207.2	1550

LEAKAGE IN VACUUM SYSTEMS

The following equation can be used to determine the amount of air in-leakage in vacuum systems:

$$L = \frac{0.15 \times V \times (P_2 - P_1)}{T}$$

Where: L = Leakage (lbs./hr.)

V = Volume ($ft.^3$)

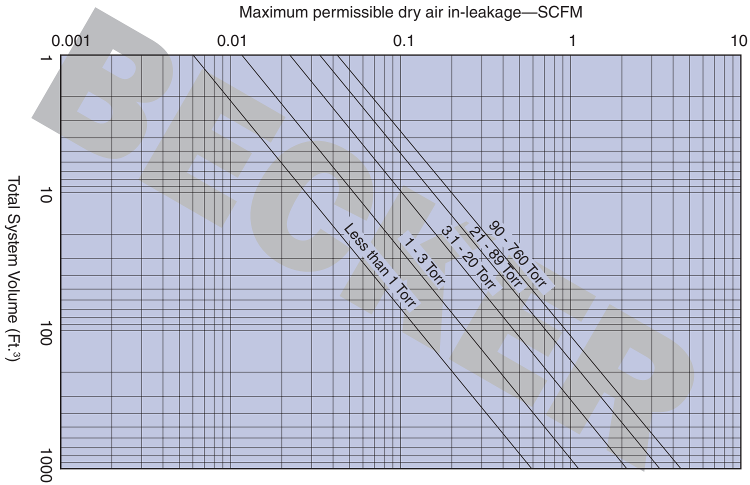
P_1 = Starting pressure (in. Hg Abs.)

P_2 = Ending Pressure (in. Hg Abs.)

T = Time (min.)

The maximum recommended allowable in-leakage of atmospheric air, when designing a vacuum system, may be determined by the following methods:

Inlet Pressure Range		Pumping Speed Multiplier
Torr	In. Hg Abs.	
760 - 100	29.92 - 4	1.0
100 - 10	4 - 0.4	1.25
10 - 0.5	0.4 - 0.02	1.5
0.5 - 0.05	—	2.0
0.05 - 0.0005	—	4.0


Maximum permissible dry air in-leakage—SCFM
0.001
0.01
0.1
1
10
Total System Volume (Ft.³)
1
10
100
1000
Less than 1 Torr
1 - 3 Torr
3.1 - 20 Torr
21 - 89 Torr
90 - 760 Torr

CALCULATING AIR LEAKS

To determine the amount of air in-leakage in an existing vacuum system, the following equation may be used:

$$Q = \frac{P \bullet V}{T}, \text{ or, } \textit{TorrACFM}$$

If the system volume (**V**=ft.^{3}) is known, monitor the time (**T**=min.) it takes for the pressure (**P**=Torr) to rise from the *starting* absolute pressure to the *final* absolute pressure, using the difference in pressure (i.e., P = 100-35 = 65).

Do not exceed 400 Torr.

To determine the amount of in-leakage (ACFM) *at the operating pressure*, divide "Q" by the operating pressure (Torr).

For an explanation of "Q", see page 9.

For an alternative equation see page 40.

For an easy way to find vacuum leaks, wrap Saran Wrap™, or other "sticky" plastic kitchen wrap, around pipe fittings. It will draw in if a leak is present.

USING A PUMP AS A FLOW METER

(Based on the principle that all* positive displacement pumps have linear mass flow curves).

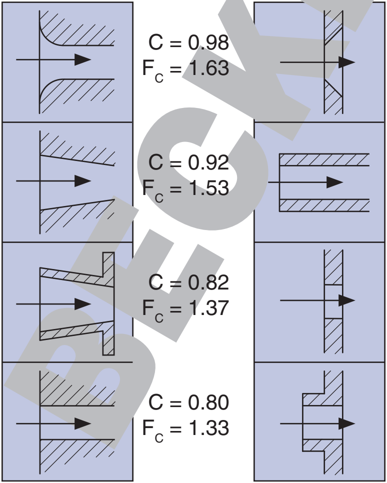
- Set any pump control switches to "manual", or, if none are used, place jumpers across the vacuum switch contacts. The pumps must not cycle on and off during this test. Only run one pump.
- Close the isolation valve at the inlet of the pump and measure the best (ultimate) vacuum it can produce. Use a good quality pressure gauge.
- Open the isolation valve and let the pump run until the vacuum reaches a stable level (does not rise or fall).
- Refer to the performance curve for the pump and read the flow produced at the vacuum level at which the system stabilized.

This is the total flow for the entire system at that moment. Monitor it using the same method at different times during the day and during different days to establish variations in the requirements. Note that some manufacturers rate their pumps in ACFM, while others rate theirs in SCFM. The equations on page 9 can be used to convert from one to the other.

* Liquid ring pumps can deviate slightly from this principle, due to the characteristics of the ring of liquid that is the cylinder "wall".

ORIFICE FLOW COEFFICIENTS

The shape of an orifice determines the amount of gas that can pass through it. Gas flow (SCFM) increases from atmospheric pressure until it reaches sonic (speed of sound) velocity, which occurs at a pressure ratio (upstream pressure to downstream pressure) of 1:0.528 (approximately 400 Torr with atmospheric pressure on the upstream side of the orifice).



$C = 0.98$, $F_C = 1.63$	$C = 0.80$, $F_C = 1.33$
$C = 0.92$, $F_C = 1.53$	$C = 0.72$, $F_C = 1.20$
$C = 0.82$, $F_C = 1.37$	$C = 0.61$, $F_C = 1.00$
$C = 0.80$, $F_C = 1.33$	$C = 0.55$, $F_C = 0.87$

C = Flow Coefficient
F_C = Correction Factor*

* To be applied to the charts on pages 46 - 49.

NOTE: Dirt buildup on the edge of the orifice will affect the flow coefficient.

When air flows through an orifice and the diameter is constant, the pressure will vary as the square of the flow:

$$\frac{P}{P_1} = \frac{V^2}{V_1^{\,2}}$$

When the pressure is constant, the flow will vary as the square of the diameter:

$$\frac{V}{V_1} = \frac{D^2}{D_1^{\,2}}$$

When the flow is constant, the pressure will vary inversely as the fourth power of the diameter:

$$\frac{P}{P_1} = \frac{D_1^{\,4}}{D^4}$$

FLOW (SCFM) THROUGH A SQUARE

Orifice Dia. (inches)		Torr: / In. Hg:	735 / 1	709 / 2	684 / 3	659 / 4	633 / 5	608 / 6
3/64	.0468		.115	.181	.220	.246	.270	.291
1/16	.0625		.212	.321	.386	.439	.483	.523
5/64	.0781		.338	.494	.620	.701	.774	.831
3/32	.0938		.483	.718	.881	1.01	1.12	1.20
7/64	.1094		.666	.989	1.21	1.39	1.53	1.65
1/8	.125		.869	1.33	1.60	1.84	2.04	2.18
9/64	.140		1.10	1.63	2.01	2.30	2.53	2.72
5/32	.156		1.35	2.00	2.47	2.81	3.10	3.31
3/16	.188		1.88	2.85	3.51	3.99	4.37	4.68
7/32	.219		2.61	3.73	4.59	5.28	5.87	6.32
1/4	.250		3.38	4.76	5.89	6.80	7.54	8.15
9/32	.281		4.16	5.97	7.29	8.32	9.25	9.99
5/16	.313		5.12	7.28	8.73	9.96	11.07	11.99
3/8	.375		6.86	10.17	12.59	14.46	16.07	17.26
7/16	.438		9.96	14.55	17.54	19.92	22.07	23.82
1/2	.500		13.04	19.03	23.30	26.42	28.90	30.93
9/16	.563		17.59	25.00	30.32	34.39	37.72	40.53

For a well rounded orifice, multiply by: 1.59

To convert SCFM to lbs./hr.,

EDGED ORIFICE UNDER VACUUM

583	557	532	507	481	456	431	405	380—0*
7	8	9	10	11	12	13	14	15—30*
.312	.329	.344	.352	.360	.366	.370	.371	.372
.559	.591	.615	.633	.645	.658	.661	.663	.667
.873	.908	.950	.978	1.00	1.02	1.03	1.04	1.04
1.26	1.33	1.38	1.41	1.45	1.48	1.50	1.51	1.51
1.75	1.82	1.89	1.94	1.99	2.02	2.05	2.06	2.06
2.30	2.40	2.48	2.55	2.59	2.65	2.67	2.70	2.71
2.86	2.97	3.09	3.18	3.25	3.31	3.36	3.39	3.42
3.50	3.66	3.81	3.93	4.03	4.10	4.16	4.18	4.20
4.94	5.16	5.35	5.56	5.72	5.87	5.94	6.05	6.10
6.66	7.00	7.27	7.52	7.75	7.91	8.06	8.17	8.26
8.66	9.05	9.40	9.72	10.02	10.24	10.46	10.61	10.75
10.72	11.20	11.74	12.11	12.58	12.93	13.23	13.35	13.62
12.79	13.48	14.05	14.64	15.17	15.69	16.06	16.44	16.82
18.30	19.19	20.20	20.90	21.68	22.45	23.18	23.67	24.35
25.27	25.66	27.75	28.76	29.72	30.66	31.72	32.35	33.54
32.78	34.65	36.21	37.61	38.82	39.94	40.82	41.87	43.38
43.12	45.20	47.12	48.73	50.20	51.50	52.47	53.90	55.08

multiply by: 4.5 Flow Coefficient = 0.61 Critical Flow

FLOW (SCFM) THROUGH A SQUARE

Orifice Dia. (inches)		PSIG 1	2	3	4	5	6
3/64	.0468	0.173	0.275	0.35	0.40	0.44	0.49
1/16	.0625	0.296	0.48	0.6	0.70	0.77	0.86
5/64	.0781	0.48	0.75	0.95	1.1	1.22	1.34
3/32	.0938	0.67	1.07	1.35	1.56	1.75	1.93
7/64	.1094	0.99	1.5	1.89	2.14	2.4	2.63
1/8	.125	1.43	2.01	2.44	2.8	3.13	3.45
9/64	.140	1.6	2.42	3.06	3.57	4.02	4.41
5/32	.156	1.94	2.96	3.74	4.36	4.87	5.32
3/16	.188	3.06	4.3	5.27	6.12	6.86	7.53
7/32	.219	3.77	5.71	7.04	8.16	9.13	10.0
1/4	.250	4.7	7.14	9.08	10.61	12.04	13.26
9/32	.281	5.92	8.82	11.22	13.66	15.0	16.52
5/16	.313	7.24	10.4	13.16	15.4	17.44	19.48
3/8	.375	10.6	14.9	18.46	21.62	24.58	27.23
7/16	.438	13.77	20.6	25.5	29.27	33.25	36.82
1/2	.500	17.03	25.5	32.33	38.25	43.55	48.25
9/16	.563	22.85	34.07	42.02	48.96	55.5	61.8

For a well rounded orifice, multiply by: 1.59

EDGED ORIFICE UNDER PRESSURE

7	8	9	10	12	15	18	20	25
0.52	0.56	0.59	0.632	0.7	0.806	0.877	0.93	1.06
0.92	1.0	1.05	1.122	1.234	1.407	1.55	1.65	1.9
1.45	1.55	1.652	1.744	1.94	2.2	2.438	2.58	2.96
2.09	2.25	2.4	2.53	2.8	3.16	3.49	3.7	4.2
2.86	3.06	3.24	3.44	3.78	4.28	4.73	5.03	5.75
3.73	4.0	4.25	4.5	4.97	5.62	6.23	6.58	7.42
4.75	5.08	5.39	5.68	6.22	7.01	7.77	8.29	9.47
5.65	6.16	6.56	6.94	7.67	8.67	9.65	10.3	11.73
8.16	8.75	9.32	9.98	10.94	12.44	13.87	14.69	16.83
10.81	11.73	12.44	13.26	14.64	16.68	18.67	19.89	22.75
14.28	15.3	16.22	17.24	19.38	22.34	24.89	26.42	30.19
18.05	19.34	20.4	21.32	23.66	27.85	31.21	33.25	38.05
21.22	22.95	24.1	26.21	29.27	33.66	37.84	40.49	46.92
29.89	32.33	34.78	37.23	41.72	48.04	54.16	58.04	67.32
40.4	43.66	46.92	49.88	55.9	64.67	73.03	78.54	91.49
52.7	57.12	61.2	65.38	73.24	84.56	95.37	102.1	119
67.52	73.13	78.54	83.64	93.43	107.3	120.87	130.05	153

Flow Coefficient = 0.61

C_V RATINGS

C_V	Orifice Dia.
.04	3/64" (0.047)
.07	1/16" (0.063)
.11	5/64" (0.078)
.16	3/32" (0.094)
.21	7/64" (0.109)
.28	1/8" (0.125)
.36	9/64" (0.141)
.44	5/32" (0.156)
.53	11/64" (0.172)
.63	3/16" (0.189)
.74	13/64" (0.203)
.86	7/32" (0.219)
.99	15/64" (0.234)
1.125	1/4" (0.250)
1.42	9/32" (0.281)
1.76	5/16" (0.312)
2.12	11/32" (0.344)
2.53	3/8" (0.375)
2.97	13/32" (0.406)
3.44	7/16" (0.438)
3.96	15/32" (0.469)
4.5	1/2" (0.500)
5.7	9/16" (0.563)
17.92	1" (1.0)

Doubling the orifice diameter, quadruples the C_V

$$D_{eff} = \sqrt{\frac{C_V}{18}}$$

$$C_V = 18\ d^2$$

Where: D_{eff} = Effective orifice diameter (in.)

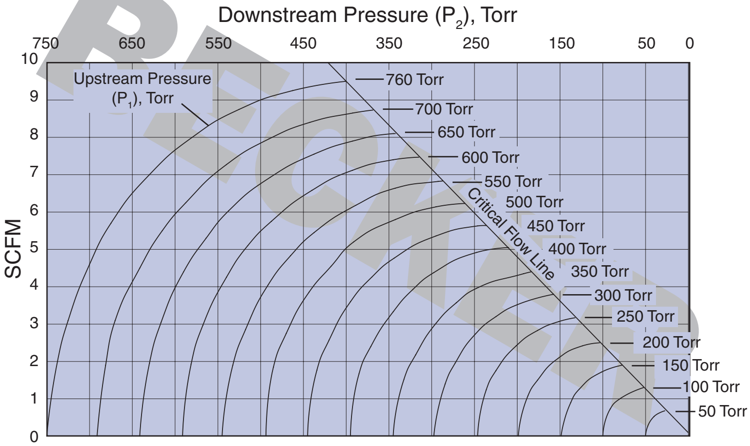
$$SCFM = 0.574\ C_V \sqrt{\frac{\Delta P\ (P_2)}{T_1\ (G)}}$$

Where: T_1 = °R
G = Specific Gravity, 1 (for Air)
ΔP = Pressure drop across the orifice
P_2 = Downstream Pressure (Torr)

C_V and SCFM are directly proportional

1660
Robert Boyle creates "Boyle's Law", $P_1V_1 = P_2V_2$. wherein, at a constant temperature, a volume of air varies with pressure according to it's inverse proportion.

MAX. FLOW FOR A DEVICE WITH A C_V OF 1



USING THE C_V GRAPH

1. Determine the C_V for the device (valve or orifice).
   (See page 46 for C_V values for orifices)

2. Correct the C_V for use with the chart at the right ($C_V = 1$).

3. Correct the SCFM for use with this chart.

4. Read down from Downstream Pressure, (P_2) (vertical) line to the corrected SCFM (horizontal) line. The curved line will be the upstream operating pressure (P_1) for the *original* device, because:

   C_V and SCFM are directly proportional.

$$\text{SCFM} = 0.574\, C_V \sqrt{\frac{\Delta P\ (P_2)}{T_1\ (G)}}$$

See page 51 for details.

Example

30 SCFM at 200 Torr

P_2 = 200 Torr
C_V = 10.125

$$\frac{1}{10.125} = 0.0988$$

0.0988 x 30 = 2.96

P_1 = 275 Torr

therefore:
ΔP = 75 Torr

C_V OF DEVICES IN SERIES

To determine the combined flow coefficient of two devices in series:

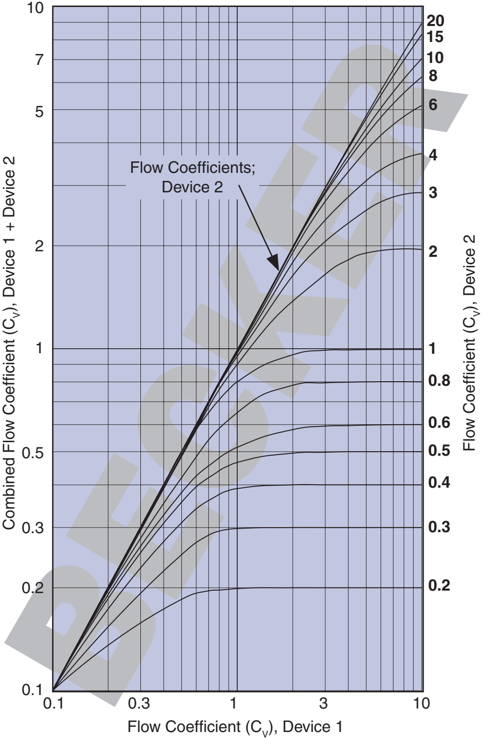
- Read up from the C_V of the first device to the intersection of the curved line indicating the C_V of the second device.

- Read left to find the resultant combined C_V of the two devices in series.

If there are more than two devices in series, the total combined C_V of the system can be found by taking any two devices as a sub-system and determining their combined C_V, which may then be combined with the next device in the series, and so on.

To determine the resultant flow coefficient when one device is removed from a series of devices:

- Read right from the combined C_V of the devices in series to the curved line representing the C_V of the device being removed.
- Read down to the resultant C_V of the remaining portion of the system.



10
7
5
2
1
0.5
0.3
0.2
0.1
0.1
0.3
1
3
10
20
15
10
8
6
4
3
2
1
0.8
0.6
0.5
0.4
0.3
0.2
Flow Coefficients; Device 2
Combined Flow Coefficient (C$_V$), Device 1 + Device 2
Flow Coefficient (C$_V$), Device 1
Flow Coefficient (C$_V$), Device 2

HOW TO USE THE PIPE SIZING CHART

- Read from the SCFM required at the operating pressure on the left scale, or for lbs./hr. at the operating pressure on the right side of the scale, to the diagonal line indicating the operating pressure.
- The closest diagonal pipe size line above the intersecting point is the first estimate for the appropriate pipe size. This will apply to lines about 100 to 150 feet long.
- To determine the estimated pressure rise (ΔP) for the selected pipe, find the intersection for the pipe size and the SCFM (or lbs./hr.) flow rate. This will usually be slightly different from the point in step 1.
- Read down to the ΔP_{760} number. This is the ΔP at 760 torr and must be corrected for the actual operating pressure (P_O).
- Multiply this number by the equation below (right) to read the ΔP at P_O.
- If the ΔP for all sections of pipe between the pump and the point of use exceeds 10% of the absolute operating pressure, select the next larger size pipe and recalculate. Be sure to include the ΔP through all devices in the system (i.e., filters, valves, etc.).
- ACFM may be calculated from the equation below (left)

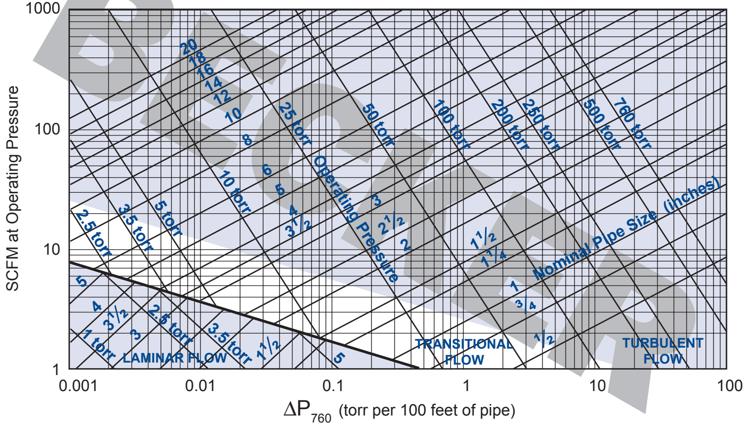
$$ACFM = SCFM \times \frac{760}{P_O} \times \frac{T_O + 460}{530}$$

$$\Delta P \text{ at } P_O = \Delta P_{760} \times \frac{760}{P_O} \times \frac{T_O + 460}{530}$$

Where: P_O = Operating Pressure (torr) ; T_O = Operating Temperature (˚F)

PIPE SIZING CHART—VACUUM

(Air at 760 torr, 68°F, 36% RH)



HOW TO USE THE PIPE SIZING CHART

1. Read from SCFM at the left over to the desired pipe size (diagonal lines).

2. Read down to the ΔP_{Atm} at the bottom of the chart.

3. Calculate the actual ΔP based on the air density at the operating pressure.

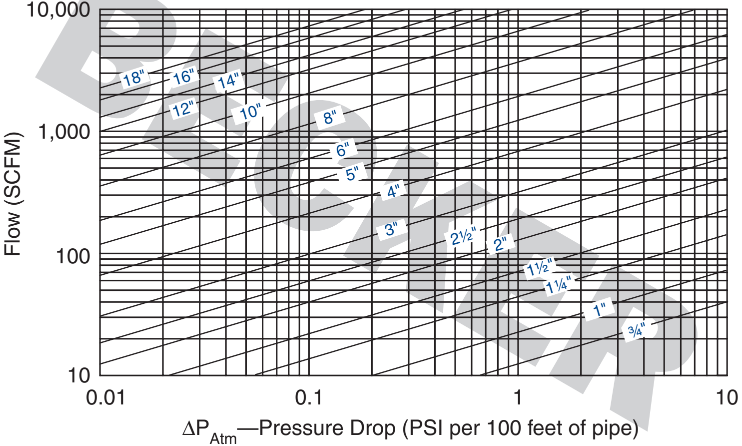
"For the air-pump weakens and dispirits, but cannot wholly exhaust"
Christopher Smart, Jubilate Agno, 1759

Data based upon air flow through schedule 40 steel pipe.

Air density of 0.075 lbs./ft^3.

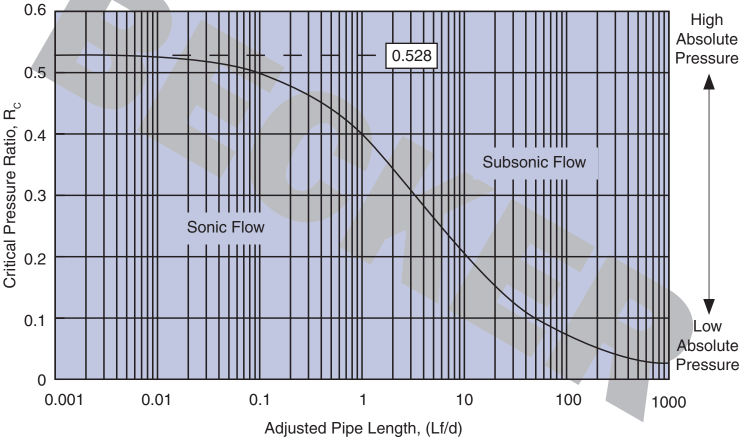
Friction loss is directly proportional to air density.

PIPE SIZING CHART—PRESSURE



EFFECT OF PIPE LENGTH ON CRITICAL RATIO

(Also refer to “Percent of Sonic Flow at Subcritical Pressures”, page 62)



Using the Graph

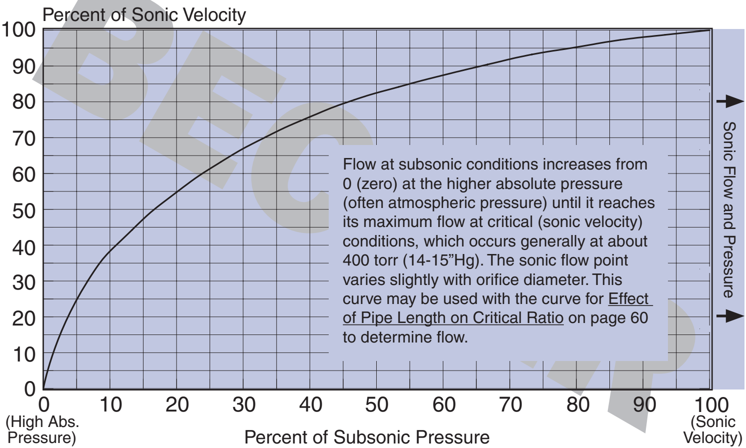
A long length of the pipe increases the resistance to flow due to friction between the air and the pipe wall. This flow resistance paradoxically increases flow velocity until the critical ratio (downstream absolute pressure divided by the upstream absolute pressure) is reached, at which sonic velocity occurs, depending on pipe length and pressure difference. Unlike an orifice, where the length is shorter than the diameter, and a nozzle, both of which where the critical ratio is constant, in piping the critical ratio is not constant, but decreases as pipe length increases.

The graph at the right illustrates the effect that the adjusted pipe length (Lf/d) has on the critical pressure ratio (R_C). The friction factor (f) will vary with the pipe surface roughness, pipe diameter and Reynolds number*.

Where:	L = Pipe length (ft.)
	f = friction factor, (0.02)
	d = pipe diameter (ft.)

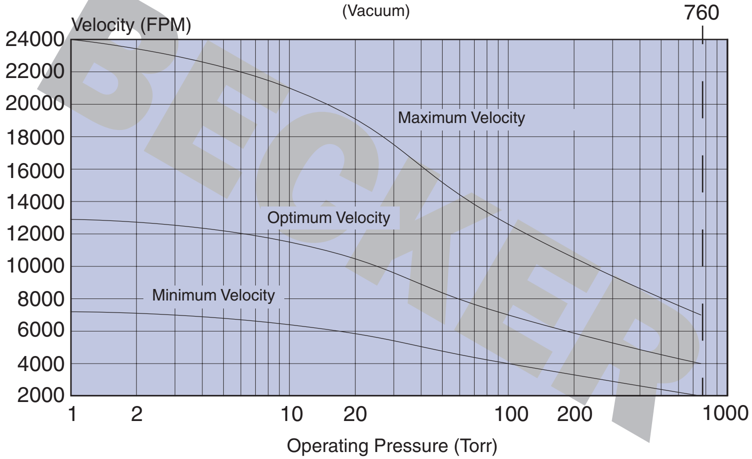
* See: Process Vacuum System Design and Operation, by James Ryans and Daniel Roper, McGraw-Hill, pg. 33

PERCENT OF SONIC FLOW AT SUBCRITICAL PRESSURES



DESIGN FLOW VELOCITY

(Vacuum)



FRICTION LOSSES IN PIPE FITTINGS

Equivalent Length of straight pipe (feet)

Type of Fitting / Size	1"	1¼"	1½"	2"	3"	4"	6"
Elbow—Std. 90°	2.7	3.7	4.3	5.5	8	11	16
Elbow—45°	1.25	1.6	2	2.5	3.7	5	7.5
Elbow—Med. sweep	2.25	3	3.6	4.5	7	9	13.5
Elbow—Long sweep	1.75	2.3	2.7	3.5	5.1	7	11
Elbow—Square	5.7	7.5	9	12	16	21	34
Tee—Straight thru	1.75	2.3	2.7	3.5	5.1	7	11
Tee—Thru side	5.5	7.5	9	12	16	21	34
Check Valve—Swing	7	9	10	13	19	25	40
Globe Valve—Open	30	39	45	58	82	115	170
Gate Valve—Open	0.6	0.7	0.95	1.2	1.7	2.25	3.5
Gate Valve—3/4 open	3.5	4.5	5.5	7	10	13	20
Gate Valve—1/2 open	18	23	26	34	50	68	100
Gate Valve—1/4 open	70	100	120	150	210	290	410

VOLUME OF PIPE

Pipe Size	Schedule 40 Steel / PVC / CPVC			Schedule 80 Steel / PVC / CPVC		
	Area	Volume/Ft.		Area	Volume/Ft.	
	(In.^{2})	Ft.^{3}	Gal's	(In.^{2})	Ft.^{3}	Gal's
1/4"	0.1	0.0007	0.005	0.07	0.0005	0.0037
3/8"	0.19	0.0013	0.01	0.14	0.001	0.0075
1/2"	0.3	0.0021	0.016	0.23	0.0016	0.012
3/4"	0.53	0.0037	0.028	0.43	0.003	0.224
1"	0.86	0.006	0.045	0.72	0.005	0.037
1 1/4"	1.5	0.0104	0.078	1.28	0.009	0.067
1 1/2"	2.04	0.0142	0.106	1.77	0.012	0.092
2"	3.36	0.0233	0.174	2.95	0.051	0.153
2 1/2"	4.79	0.0333	0.249	4.24	0.03	0.22
3"	7.39	0.0513	0.384	6.61	0.046	0.343
4"	12.73	0.0884	0.661	11.5	0.08	0.598
5"	20.01	0.139	1.04	18.19	0.126	0.945
6"	28.89	0.201	1.501	26.07	0.181	1.354
8"	50.03	0.347	2.599	45.66	0.317	2.372
10"	78.85	0.548	4.1	71.81	0.499	3.73
12"	111.9	0.777	5.814	101.6	0.716	5.278
14"	135.3	0.939	7.027	122.7	0.852	6.375
16"	176.7	1.227	9.18	160.9	1.117	8.357
20"	278	1.930	14.44	252.7	1.755	13.13
24"	402	2.792	20.88	365.2	2.536	18.97

Note: PVC / CPVC pipe in the shaded area is not recommended, but its use may be possible depending on operating conditions including vacuum level and ambient temperature. Contact factory for details.

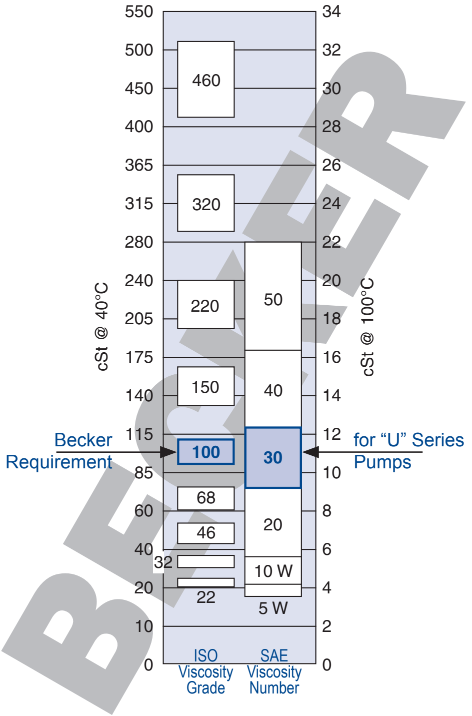
OIL CAPACITY of "U" SERIES PUMPS

MODEL	OIL RESERVOIR CAPACITY (Qts.)
U3.6	0.21
U1.16	0.9
U3.10-3.16	0.52
U4.20	0.5
U3.25-3.40	1.0
U2.70-2.100	2.0
U4.70-4.100	2.1
U2.165-2.250	4
U4.165-4.250	7.4
U4.400-4.630	14.8

Becker Vacuum Pump Oils

	SS-100	PS-100	FO-100
Viscosity @100°F (Cst)	120.8	119.2	92.39
Viscosity @210°F (Cst)	12.5	13.76	8.41
Viscosity Index	100	123	54
Flash Point	510°F	510°F	490°F
Pour Point	10°F	-55°F	—
Vapor Pressure @ 100°F	3.2×10^{-4}	8.4×10^{-12}	—
Vapor Pressure @ 210°F	1.3×10^{-5}	1.0×10^{-6}	—

All Becker "U" Series pumps are shipped with an initial supply of SS-100 Vacuum Pump Oil



ISO and SAE VISCOCITY GRADE COMPARISON

Becker SS-100 Semi-Synthetic Vacuum Pump Oil

Property	Units	Limits		
		New Oil	Cautionary	Condemning
Viscosity @ 40°C	cSt	90-110	50-90 & 110-130	<50 & >130
Antioxidant Level	% Remaining	100	10	<10
Acid Number	mg KOH/g	0.2	1.0	>1.0
Phosphorus	PPM	0	10-20	>20
Zinc	PPM	0	10-20	>20
Calcium	PPM	0	10-20	>20
Barium	PPM	0	10-20	>20
Iron	PPM	0	5-10	>10
Copper	PPM	0	5-10	>10
Lead	PPM	0	5-10	>10
Tin	PPM	0	5-10	>10
Aluminum	PPM	0	5-10	>10
Silicon	PPM	0	10-15	>15
Molybdenum	PPM	0	10-20	>15
Water Content	PPM	<100	200-300	>300
Particle Count	Micron	ISO Code 19/15	ISO Code xx/19	ISO Code xx/19

TESTING LIMITS

Becker PS-100 Premium Synthetic Vacuum Pump Oil

Property	Units	Limits		
		New Oil	Cautionary	Condemning
Viscosity @ 40°C	cSt	95-105	32-80 & 115-120	3250 & >120
Antioxidant Level	% Remaining	100	10	<10
Acid Number	mg KOH/g	0.1*	0.7	>1.0
Phosphorus	PPM	0	20	>20
Zinc	PPM	0	20	>20
Calcium	PPM	0	20	>20
Barium	PPM	0	20	>20
Iron	PPM	0	10	>10
Copper	PPM	0	10	>10
Lead	PPM	0	10	>10
Tin	PPM	0	10	>10
Aluminum	PPM	0	10	>10
Silicon	PPM	0	10	>15
Molybdenum	PPM	0	20	>20
Water Content	PPM	<100	300	>300
Particle Count	Micron	ISO Code 17/15	ISO Code xx/19	ISO Code xx/19

* This parameter is not relevant to the condition of the oil; however, it may show acidity of the gas stream.

VAPOR PRESSURE TABLE

Gas	PRESSURE (Torr) 760	200	100	40	10	1
	Temperature (°C)					
Acetic Acid	118	80	63	43	17.5	-17.2
Acetone	56.2	39.5*	7.7	-9.4	-31.1	-59.4
Air	–	–	–	–	–	–
Ammonia	-33.6	-57.0	-68.4	-79.2	-91.9	-109.1
Argon	-185.6	-195.6	-200.5	-204.9	-210.9	-218.2
Benzene	80.1	42.2	26.1	7.6	-11.5	-36.7
Benzyl Alcohol	204.7	183	141.7	119.8	92.6	58
Bromine	58.2	24.3	9.3	-8.0	-25.0	-48.7
n-Butane	-0.5	-31.2	-44.2	-59.1	-77.8	-101.5
Carbon Dioxide	-78.2	-93.0	-100.2	-108.6	-119.5	-134..3
Carbon Disulphide	46.5	10.4	-5.1	-22.5	-44.7	-73.8
Carbon Tetrachloride	76.7	38.3	23	4.3	-19.6	-50
Carbon Monoxide	-191.3	-201.3	-205.7	-210	-215	-222
Chlorine	-33.8	-60.2	-71.7	-84.5	-101.6	-118
Ethane	-88.6	-110.2	-119.3	-129.8	-142.9	-159.5
Ethanol	78.3	63.5*	34.9	19	2.3	-31.3
Ethyl Chloride	12.3	-18.6	-32	-47	-65.8	-89.8
Ethylene	-103.7	-123.4	-131.8	-141.3	-153.2	-168.3
Ethylene Glycol	197.2	178.5*	141.8	120	92.1	53

Fluorine	-187.9	-198.3	-202.7	-207.7	-214.1	-223
Helium	-268.6	-269.8	-270.3	-270.7	-271.3	-271.7
n-Hexane	68.7	31.6	15.8	-2.3	-25	-53.9
Hydrogen	-252.5	-256.3	-257.9	-259.6	-261.3	-263.3
Hydrogen Chloride	-84.8	-105.2	-114	-123.8	-135.6	-150.8
Hydrogen Sulphide	-60.4	-82.3	-91.6	-102.3	-116.3	-134.3
Methane	-161.5	-175.5	-181.4	-187.7	-195.5	-205.9
Methanol	64.5	49.9*	21.2	5	-16.2	-44
Methyl Chloride	-24	-51.2	-63	-76	-92.4	–
Neon	-246	-249.7	-251	-252.6	-254.6	-257.3
Nitric Oxide	-151.7	-162.3	-166	-171.7	-178.2	-184.5
Nitrogen	-195.8	-205.6	-209.7	-214	-219.1	-226.1
Nitrous Oxide	-85.5	-103.6	-110.3	-118.3	-128.7	-143.4
Oxygen	-183.1	-194	-198.8	-204.1	-210.6	-219.1
n-Pentane	36.1	1.9	-12.6	-29.2	-50.1	-76.6
Propane	-42.1	-68.4	-111.7	-87.7	-57	-17.5
Propylene	-47.7	-73.3	-84.1	-96.5	-112.1	-131.9
Sulphur Dioxide	-10	-35.4	-46.9	-60.5	-76.8	--95.5
Toluene	110.7	89.5*	51.9	31.8	6.4	-26.7
Vinyl Chloride	-13.8	-41.3	-53.2	-66.8	-83.7	-105.6
Water	100	83*	51.6	34.1	11.3	-17.3

* Data at 400 Torr

Note: Inclusion on this list does not constitute approval of the use of these chemicals in Becker pumps. Contact the factory.

PROPERTIES OF GASES

Gas	Chemical Formula	Mol. Wt. (mol.)	Vapor Density	Density (lbs./ft.^{3})	C_p/C_v (k)
Acetic Acid	$C_2H_4O_2$	60.05	2.07		
Acetone	C_3H_6O	58.08	2.0		
Air	—	28.96	1.0	0.08072	1.406
Ammonia	NH_3	17.03	0.5963	0.0481	1.317
Argon	A	39.94	1.3787	0.1113	1.667
Benzene	C_6H_6	78.11	—	—	1.1
Benzyl Alcohol	C_7H_8O	108.13	3.734		
Bromine	Br_2	159.83	5.519		
n-Butane	C_4H_{10}	58.12	—	—	1.108
Carbon Dioxide	CO_2	44.01	1.529	0.1234	1.3
Carbon Disulphide	CS_2	76.12	—	—	1.205
Carbon Tetrachloride	$C\ Cl_4$	153.83	—	—	1.18
Carbon Monoxide	CO	28.01	0.9671	0.0781	1.403
Chlorine	Cl_2	70.91	2.486	0.2007	1.336
Ethane	C_2H_6	30.07	1.0493	0.0847	1.224
Ethanol	C_2H_6O	46.07	1.59		
Ethyl Chloride	C_2H_5Cl	64.50	—	—	1.13
Ethylene	C_2H_4	28.03	0.9749	0.0787	1.255
Ethylene Glycol	$C_2H_6O_2$	62.07	2.143		

Fluorine	F_2	38.00	1.312		
Helium	He	4.00	0.1381	0.0111	1.66
n-Hexane	C_6H_{14}	86.17	—	—	1.08
Hydrogen	H_2	2.02	0.06952	0.0056	1.408
Hydrogen Chloride	H Cl	36.47	1.2678	0.1023	1.405
Hydrogen Sulphide	H_2S	34.08	1.190	0.0961	1.324
Methane	CH_4	16.04	0.554	0.0447	1.316
Methanol	CH_4O	32.04	1.106		
Methyl Chloride	CH_3Cl	50.49	1.785	0.1441	1.2
Neon	Ne	20.18	0.696	0.0562	1.642
Nitric Oxide	N O	30.01	1.0366	0.0837	1.394
Nitrogen	N_2	28.02	0.9672	0.0781	1.41
Nitrous Oxide	N_2O	44.02	1.529	0.1234	1.303
Oxygen	O_2	32.00	1.1053	0.0892	1.4
n-Pentane	C_5H_{12}	72.14	—	—	1.086
Propane	C_3H_8	44.09	1.562	.1261	1.153
Propylene	C_3H_6	42.05	1.453	0.1173	—
Sulphur Dioxide	SO_2	64.06	2.2638	0.1827	1.256
Toluene	C_7H_8	92.13	3.18		
Vinyl Chloride	C_2H_3Cl	62.50	2.158		
Water	H_2O	18.02	—	—	1.3

Note: Inclusion on this list does not constitute approval of the use of these chemicals in Becker pumps. Contact the factory.

PUMPING CONDENSIBLES

1-Determine the temperature (T_{VI}) of the vapor at the inlet of the pump.

2-Determine the vapor pressure (P_{VI}) of the gas at its temperature at the inlet of the pump (use a vapor pressure table).

3-Estimate the pressure (P_O) at which you will be bleeding in the sweep gas (dry air). This will be the actual operating pressure of the process.

4-Calculate the maximum percentage of the gas.

$$\frac{P_{VI}}{P_O} \times 100 = \%Max.$$

5-Determine the maximum discharge pressure (P_D) the gas will see. This should be the maximum back pressure on the exhaust filters, stated in Torr (i.e., 3 PSIG is 3 x 51.55 + 760 = 915 Torr).

6-Determine the partial pressure P_{PD} of the gas at the discharge:

$$P_D \times \frac{\%Max.}{100} = P_{PD}$$

7-Referring to the vapor pressure chart for the water, find the temperature that corresponds to the partial pressure (P_{PD}) of the gas at the discharge.

This is the temperature at which you need to keep the oil and the exhaust box to prevent condensation.

GAS MIXTURES

$$MW_{AVG} = \frac{W_T}{\frac{W_1}{MW_1} + \frac{W_2}{MW_2} + \frac{W_N}{MW_N}}$$

$$SCFM = \frac{W_T}{60} \times \frac{379}{MW_{AVG}}$$

$$ACFM = SCFM \times \frac{760}{P_O} \times \frac{460 + T_O}{528}$$

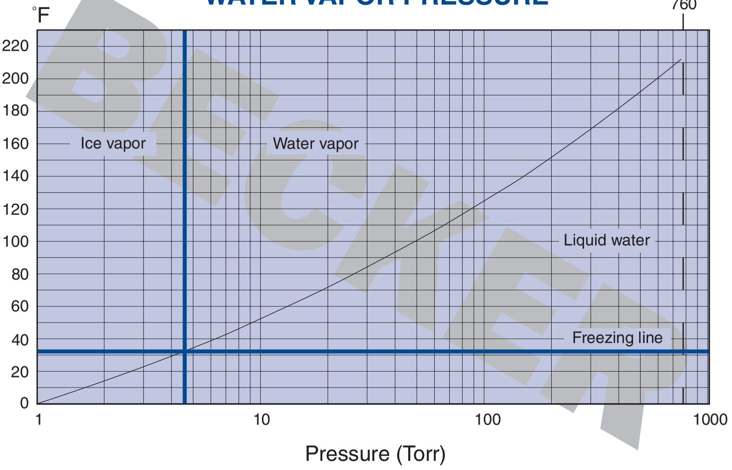
WHERE:
W_T = Total Gas Weight (#/hr.)
$MW_1 \ldots MW_N$ = Molecular Weight of Gas Component
$W_1 \ldots W_N$ = Weight of Gas Component
MW_{AVG} = Average Molecular Weight
P_O = Operating Pressure (Torr)
T_O = Operating Temperature (^{o}F)

DID YOU KNOW?

If you removed one million molecules every second from those contained in a single cubic inch of air at atmospheric pressure:

It would take *140 million years*
to remove all the molecules!

WATER VAPOR PRESSURE



VAPORIZING WATER

The rate of evaporization is limited by the heat input.

The heat per unit of weight required to cause a transition from liquid to vapor is called the Latent Heat of Vaporization

The liquid's vapor pressure will be the limit of vacuum until the liquid has been totally evaporated.

The quantity of heat required to evaporate a given weight of water can be calculated by multiplying the Latent Heat of Evaporization by the weight of the water.

Latent Heat of Vaporization for Water

Temp. °C	Btu/lb.	Temp. °C	Btu/lb.
0	597.12	60	563.44
10	591.86	70	557.47
20	586.13	80	551.50
30	580.63	90	545.29
40	574.90	100	539.08
50	569.17		

Evaporate 20# of water in 10 minutes at 50 torr @ 80°C

ACFM* = 20 x 379/18 x 760/50 x [(460+176)/530] x 1/10

* See Page 9

Heat Required: 20 x 551.50
Heat Transfer Rate: 11030/10 - 1103 Btu/Min.

LIFTING FLUIDS BY VACUUM

Using Specific Gravity (S.G.) to determine lift.

Since water has a specific gravity of 1, and atmospheric pressure is 406.8 in.H_2O (33.9 feet H_2O), divide 406.8 by the S.G. of the fluid to be lifted to get the pressure of the atmosphere in terms of the fluid.

Divide the distance to be lifted by the atmospheric pressure of the fluid to get the percentage of atmospheric pressure required to lift the fluid.

Multiply the percentage by the atmospheric pressure in your working term (torr; in.Hg; etc.) to get the necessary differential pressure to lift the fluid.

Lift molten aluminum 48 inches into a mold

Solution

Aluminum S.G. = 2.708

406.8 / 2.708 = 150.22 in.Al

48 / 150.22 = 0.32 Atm.

0.32 x 29.92 in.Hg = 9.54 in.Hg Vac

9.54 in.Hg
is needed to lift molten aluminum 48 inches

Be sure to provide adequate protection at the inlet of the pump (knock-out-pots, heat exchangers, etc.)

ADDING BLEED AIR TO CONTROL INLET TEMPERATURE

When a process includes inlet gas at a temperature higher than that specified as maximum for a pump, the temperature must be reduced to a point at or below that limit. Air (or other gas) can be admitted into the inlet airstream in order to cool the hot process gases, via dilution.

$$V = \frac{(AB) - (DB)}{(D - C)}$$

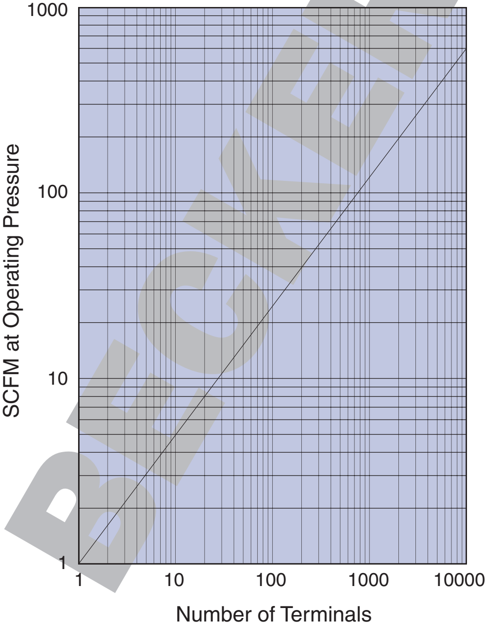
Where:

- A = Process (hot) Air Temperature (°F)
- B = Process Air Flow (air equivalent SCFM)
- C = Bleed Air Temp (°F)
- D = Final Desired Inlet Air Temperature (°F)
- V = Air Equivalent SCFM Needed for Bleed Air

He "has too much vacuum in his head"
Descartes, on Blaise Pascal, CA 1648

LABORATORY SIZING

General Laboratory Demand
Central System Sizing Chart

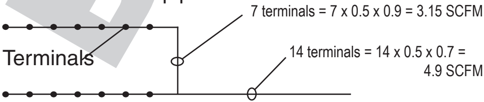


LABORATORY USE FACTOR CHART

No. of Terminals	Use Factor
1 - 5	100%
6 - 8	90%
9 - 12	80%
13 - 20	70%
21 - 35	60%
36 - 80	50%
81 - 160	40%
161 - 280	35%
281 - 500	30%
501 - 1000	25%
1001 - 2200	20%
2201 - 5000	15%
5001 +	10%

Sizing is based on 0.5 SCFM per terminal *at the operating pressure*.

When calculating pressure drop in laboratory piping systems, the use factor should be applied to the total number of terminals that are connected to the upstream side (farthest away from the pump) of that branch of pipe.



BECKER HOSPITAL SIZING CRITERIA
Usage Group A Terminals

Location	Recommended No. of Terminals
General Operating room	3
Orthopedic Surgery	3
Surgical Cystoscopy and Endoscopy	3
Critical Care	3
Isolation (Critical)	3
Coronary Critical Care	2
Pediatric Critical Care	3
Newborn Intensive Care	3
Cardio, Ortho, Neurological	3
Post-Anesthesia Care Unit	3
Caesarean/Delivery Room	3
Recovery Room	3
Labor/Delivery/Recovery (LDR)	2
Triage Area (Definitive Emergency Care)	1
Definitive Emergency Care, Exam/Treatment Room	1
Definitive Emergency Care, Holding Area	1
Trauma/Cardiac Room	3
Cardiac Catheterization Lab	2
Birthing Rooms	2
Special Procedures (Anesthetizing)	3
Special Procedures (Non-Anesthetizing)	2
Additional Anesthetizing Locations	3

Usage Group B Terminals

Location	Recommended No. of Terminals
Patient Rooms (Medical and Surgical)	1 (Accessable to each bed)
Exam and Treatment Rooms (Med., Surg., Postpartum Care)	1
Isolation (Infectious, Protective; Med., Surg.)	1
Security Room (Med., Surg., Postpartum)	1
Newborn Nursery (Full-Term)	1
Pediatric Nursery	1
Pediatric and Adolescent	1
Seclusion Treatment Room	—
Anesthesia Workroom	—
Outpatient Recovery	3
Labor/Delivery/Recovery/Postpartum(LDRP)	2
Postpartum Bedroom	1
Labor Room	1
Initial Emergency Management	1/Bed
Orthopedic and Cast Room	1
Autopsy Room	1/Workstation
Catheterization Labs	2
Surgical Excision Room	1
Dialysis Units	0.5/Bed
Respiratory Care	Convenience
Central Supply	Convenience
Equipment Repair, Calibration	Convenience
Teaching	Convenience

BECKER HOSPITAL SIZING CRITERIA

Vacuum Pump Size (SCFM*) =

$$(N_A \times UF_A \times 0.25) + (N_B \times UF_B \times 0.25) + (N_{OR} \times 1.5) + (N_{WAGD} \times 1.6)$$

Where:

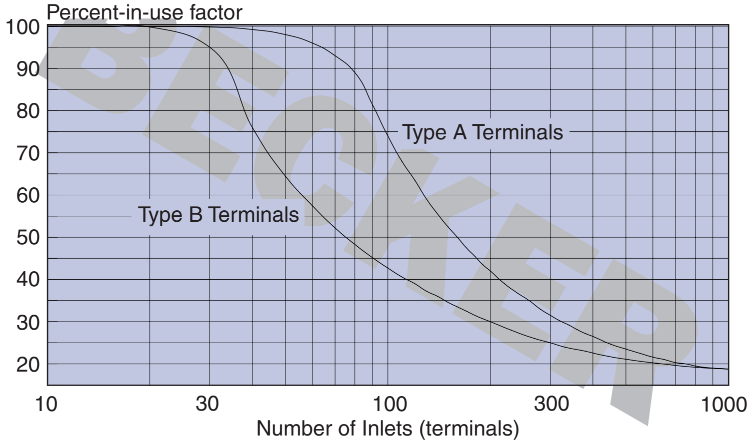
N_A = Number of A Type Terminals
N_B = Number of B Type Terminals
N_{OR} = Number of Operating Rooms
N_{WAGD} = Number of Waste Anesthetic Gas Disposal Terminals**
UF_A = Use Factor for A Type Terminals
UF_B = Use Factor for B Type Terminals

* SCFM at the lead vacuum switch set point of (typically) 19"Hg

** To be included only if WAGD is part of the central medical/surgical vacuum system

Note: NFPA 99 no longer recommends hospital sizing criteria. It is the responsibility of manufacturers and engineering organizations to determine proper pump sizing. This method is based on many years of experience, and incorporates capacity for recent equipment and usage developments.

SIMULTANEOUS USE FACTOR CURVES



AIR KNIVES

Design considerations:

Velocity
Slot size
Manifold size

VELOCITY

- Velocity depends on such factors as distance of air knife from the product, surface tension of the liquid, weight, and stability of the product.

- Velocity requirements may vary from 4000 FPM to over 20,000 FPM. The following equation may be used to determine velocity.

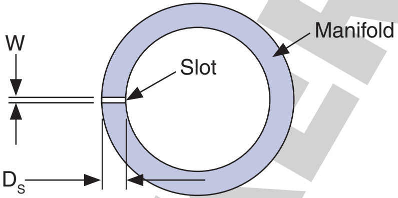
$$V = \frac{576 \times SCFM}{\pi D^2}$$

Where: D = Diameter of hole equal to total slot area.

SLOT SIZE

- A properly sized slot has a depth (D_S) to width (W) ratio of about 6:1.

- The length of the slot, relative to its width, should have a ratio between 1:100 to 200 for stability (i.e., a $^{1}/_{16}$" wide slot should be between 6" to 1' long).



MANIFOLD SIZE

- The area of the manifold should be approximately twice that of the total slot area. The following equation may be used to determine manifold I.D.

$$D = 2\sqrt{\frac{a}{\pi}}$$

Where: a = Total area of slot
D = Inside diameter of pipe or manifold

SIZING of SPAS and HOT TUBS

1— Determine the number of jets or orifices in the spa.

2— Calculate the total area of all the orifices:
Total area = (No. of holes) x π x radius^2

3— Select the proper blower from the following chart:
Find the number and size of the orifices (jets) in the spa. Read left to determine the proper Becker blower (Do not exceed the maximum water depth for the blower)

Orifice Area	
Orifice Dia.	Area (in^2)
$^1/_8$" (0.125)	0.012
$^5/_{32}$" (0.156)	0.019
$^3/_{16}$" (0.188)	0.028
$^7/_{32}$" (0.219)	0.038
$^1/_4$" (0.250)	0.049

Blower Selection Chart

SV Model	Max. water depth	No. of Jets	Orifice dia.	Min. no. of Orifices*	Min. total hole area (in²)
7.130/1	30"	3-5	1/8" 5/32" 3/16" 7/32" 1/4"	55 40 26 20 16	1.0
7.190/1	36"	5-10	1/8" 5/32" 3/16" 7/32" 1/4"	77 55 36 28 23	1.125
5.250/1	42"	7-12	1/8" 5/32" 3/16" 7/32" 1/4"	85 60 40 31 25	1.188
7.330/1	48"	12-18	1/8" 5/32" 3/16" 7/32" 1/4"	119 82 55 42 34	1.625

* Fewer orifices may cause excessive back pressure on the blower. Use of a pressure relief valve is recommended.

SIZING BLOWERS FOR TANK AGITATION

Becker regenerative blowers are used for tank agitation in applications such as plating tanks, cleaning tanks, and rinsing tanks. Both pressure and flow requirements must be calculated.

Pressure Requirements

$$P = 0.43\ D\ S + 0.75$$

Where:

- P = Pressure (PSIG)
- D = Solution Depth (feet)
- S = Specific Gravity of Solution (see table)

Flow Requirements

$$Q = A \bullet F$$

Where:

- Q = Flow Rate (SCFM)
- A = Tank Surface Area (ft^2)
- F = Agitation Factor (SCFM/ft^2, see table)

Rule of thumb: To suspend solids in a wastewater tank, you need 20 SCFM/1000 $ft.^3$ of H_2O

Blower Selection Chart

Solution	Agitation Factor (F) ($SCFM/ft^2$)	Specific Gravity (D)
Al Plating	1.0 - 1.8	1.2
Cu Plating	1.0 - 1.5	1.2
Ni Plating	1.2 - 2.0	1.2
Cleaning	1.0 - 1.5	1.1
Rinsing	0.5 - 1.5	1.0

TANK VENTILATION

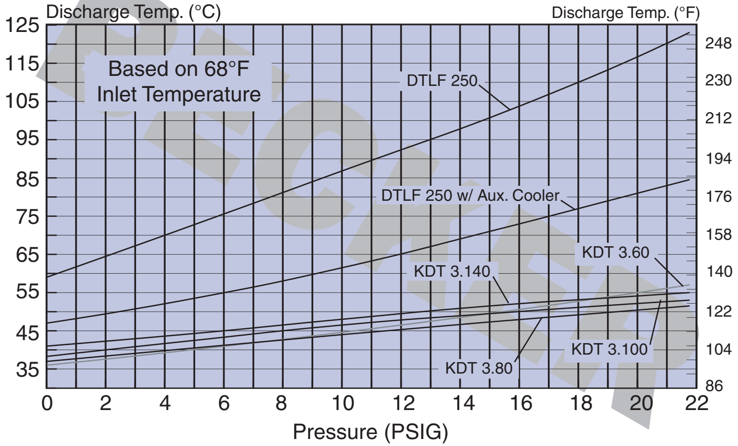
(Sizing blowers for ventilation of plating tanks)

Air is blown across the tank surface to carry the fumes to an exhaust system.

Air flow = 1 SCFM at 1 PSIG / foot of tank length

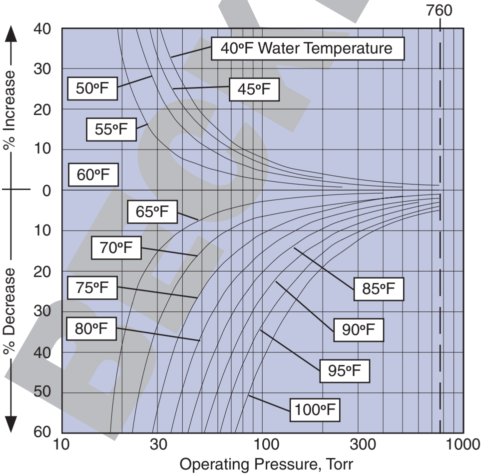
Orifices should be sized to provide an area equal to a $^{1}/_{8}$" diameter orifice (0.012 in^2) per foot of pipe.

SPARGING COMPRESSOR DISCHARGE TEMPERATURE



WATER TEMPERATURE CORRECTION FACTORS For Liquid Ring Vacuum Pumps

The following graph shows a typical correction factor for the performance of liquid ring vacuum pumps due to the effect of water vapor pressure. The standard is 60ºF; colder water increases performance, while warmer water decreases performance. Performance may vary slightly depending on brand and model—contact factory.



MISCELLANEOUS RULES OF THUMB

- To clear condensate from the sump of a Dekatorr pump, run the pump with the inlet closed and the gas ballast open until vaporized (Note: not all pumps are equipped with gas ballasting).

- The term "Pressure" usually refers to absolute pressure (full vacuum = 0).

- The term "Vacuum" usually refers to a relative (gauge) pressure (atmospheric pressure = 0).

- Velocity of air through a pipe with a regenerative blower:

$$\text{Ft./Min.} = \frac{576 \times \text{SCFM}}{3.14 \times D^2}$$

- Maximum pressure drop through a pipe in a system should be about 10% of the <u>absolute</u> operating pressure, from point of use to the pump, including all devices in the line (A lower pressure drop could mean that you are paying more for the piping; a higher pressure drop could mean that you are paying more for the pump due to oversizing).

- To find a leak in vacuum piping, try placing Saran Wrap™ (or other "sticky" plastic wrap) around the pipe joints or devices, then watch to see if the wrap draws in tighter due to the leak being sealed or if the pressure changes on the gauge.

- Cooling pumps: The required exchange of air in a room in order to remove heat generated by the pump and keep the room at a temperature 10°F above the outside ambient is about 230 CFM/HP.

- For every 18F degrees increase in temperature, oil life is reduced by half.

- It costs about $333.00 per year to operate a 1 horsepower pump running 100% of the time with a cost of $0.05/kWh.

- 1 PPM (parts per million) is like 1 second in 11.6 days.
  1 PPB (parts per billion) is like 1 second in 31.7 years.

- A leak of about 1 drop of oil every 2 minutes = 1 cc/hr. = 1 quart every 39.5 days = 2.3 gallons/year.

- Surgical tubing makes a good vacuum chuck gasket.

- 1 in.^{3} @ 760 Torr contains about 4.4×10^{21} (4,400,000,000,000,000,000,000) molecules; at 1 micron there remain 5.79×10^{15} molecules.

- USDA oil ratings:
  H1—Incidental contact with food permitted.
  H2—No contact with food is permissible.

- A single fingerprint can have a load of 1 x 10^{-15} torr•l/sec, or 2.12 x 10^{-5} torr•CFM (2.7 x10^{-8} SCFM).

- The coldest ambient temperature in which a Becker oil-less pump should be placed is -5°C (23°F).

- The capture velocity for fume hoods is about 100 ft/min. (1.1 mph).

- Evaporating water: You will evaporate about 2/3 of your load in about half the total time.

- Condensers should be considered when the partial pressure of the vapor is greater than half the total pressure.

- HVLP (High Volume Low Pressure) paint spraying typically operates between 4.8 and 7.5 PSIG and needs about 20 SCFM at the gun.

- Cost of cooling (air conditioning) to offset heat generated by a pump (per year):
  $0.00157/BHP/hr. of operation/$0.01 per kWh

- For each 1 HP of pumps we save, we reduce the power required for air conditioning by 0.2 HP.

- Oral surgery requires 1 SCFM per terminal.

- Dental offices are sized by the number of operators (dentists or hygenists) that may use the equipment at a given time, not the number of suites.
  - Compressed air = 1-2 SCFM @ 40 PSIG
  - Vacuum = 7.0 SCFM @ 8 in. Hg (min.)

- Skilled nursing facilities require 1 SCFM per bed (due to open terminals).

Becker Pumps Corp.
100 East Ascot Lane
Cuyahoga Falls, Ohio 44223
(330) 928-9966

info@beckerpumps.com

www.beckerpumps.com

Written by David L. Brittain

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