BASIC COMPRESSOR TYPES

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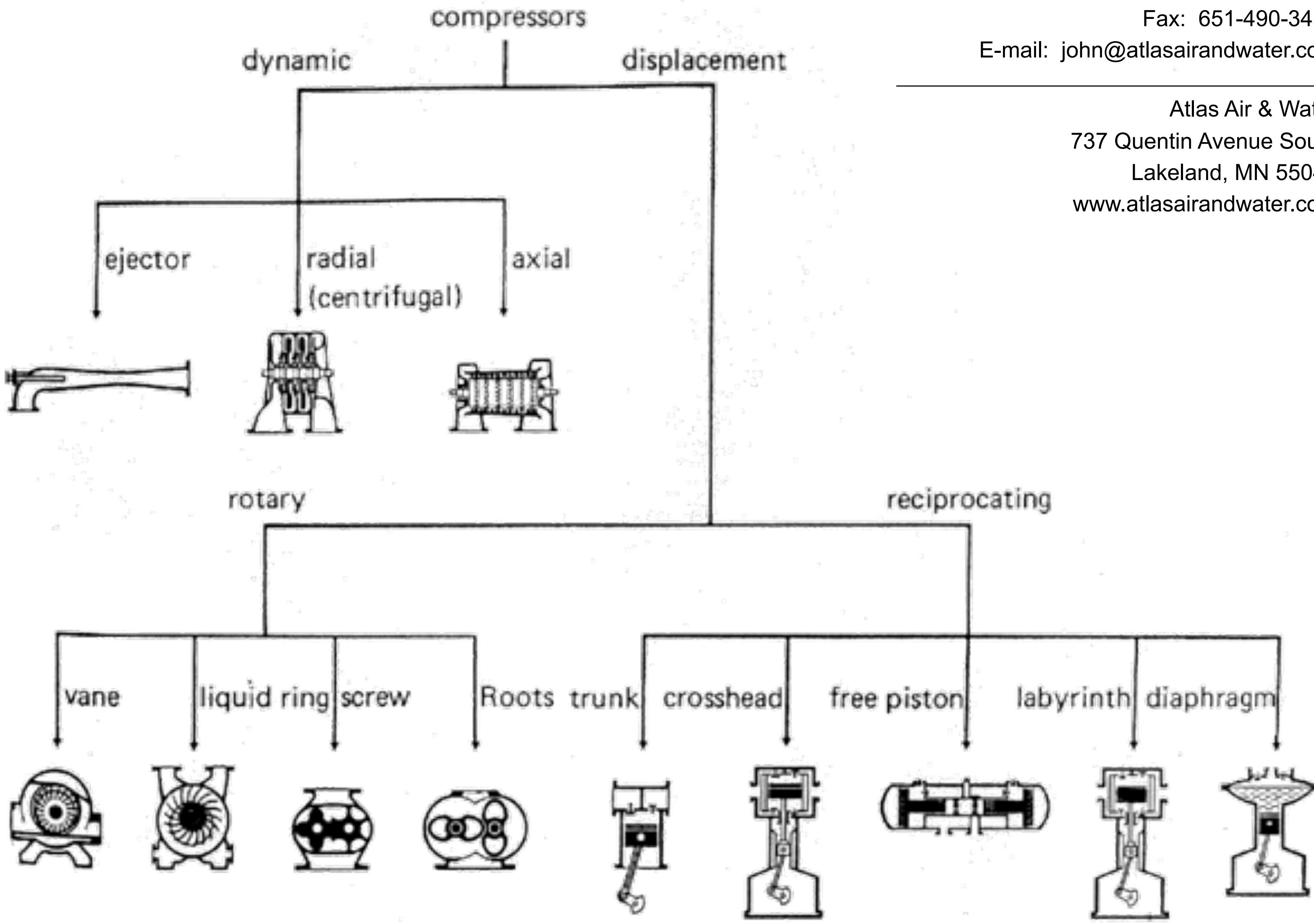


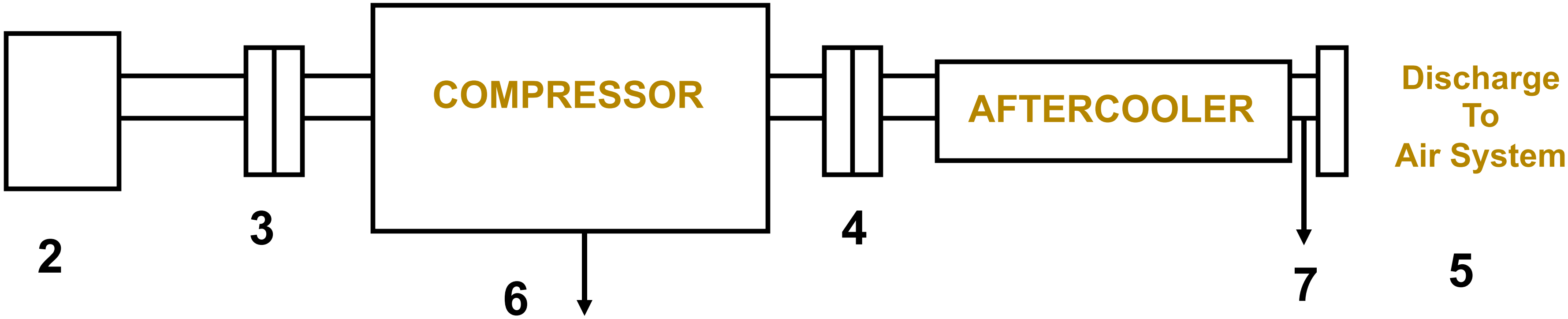
Electric Operating Cost

Motor Full Load KVA Operating Cost Per Year (8760) Hours at Stated Cost Per KWH ($)

Size HP	.03	.04	.05	.06	.07	.08	.09
10	$2,665	$3,553	$4,441	$5,330	$6,218	$7,106	$7,994
15	4,118	5,491	6,865	8,236	9,609	10,982	12,354
20	5,271	7,029	8,786	10,544	12,301	14,058	15,815
25	6,551	8,735	10,919	13,103	15,287	17,471	19,655
30	7,511	10,014	12,518	15,022	17,525	20,029	22,532
40	10,070	13,427	16,784	20,141	23,498	26,855	30,211
50	12,378	16,504	20,630	24,756	28,882	33,008	37,134
60	15,035	20,046	25,058	30,070	35,081	40,093	45,104
75	18,685	24,913	31,142	37,370	43,599	49,827	56,055
100	23,944	31,925	39,908	47,887	55,869	63,850	71,831
125	31,134	41,512	51,890	62,268	72,646	83,024	93,402
150	36,942	49,256	61,570	73,884	86,198	98,511	110,825
200	49,577	66,103	82,629	99,154	115,680	132,206	148,732

ABSOLATE PRESSURE	Is the arithmetic sum of gauge and atmospheric pressures. It must be used in all calculations involving the basic gas laws.
ABSOLUTE TEMPERATURE	Is the temperature of a body referred to the absolute zero, at which point the volume of an ideal gas theoretically becomes zero. On the Fahrenheit scale this is minus 459.67°F; on the Centigrade scale it is minus 273.15°C, engineering values of minus 460°F and minus 273°C are used herein.
BRAKE HORSEPOWER	The total HP input required including gas horsepower and all frictional losses.
CAPACITY	Quantity of gas actually delivered, typically referred back to the inlet conditions at pressure, temperature and moisture: • ACFM • SCFM • ICFM • CFM • FAD
DEW POINT	The temperature of a gas at a given pressure, at which vapor will start to condense.
GAS HORSEPOWER	The actual work required to compress and deliver a quantity of gas, including thermodynamic, leakage and fluid losses, but not including mechanical losses.

INTERCOOLING	Cooling of the gas between stages of compression to: 1. Reduce the interstage temperature 2. Reduce the volume to the next stage 3. Liquify condensable vapors to reduce horsepower All of the above in order to reduce horsepower.
PRESSURE RATIO	The ratio of the absolute discharge pressure to the absolute inlet pressure
RELATIVE HUMIDITY	The ratio of the actual vapor pressure to the vapor pressure at saturation. Refer to tables to calculate relative differences.



1. Conditions 14.7 PSIA, 60 DEG. F., DRY
2. Ambient Conditions, Example 14.5 PSIA, 95 DEG. F., 70% RH
3. Inlet Flange Compressor
4. Discharge Flange of Compressor
5. Compressed Air to System
6. Seal Losses
7. Condensate Losses from Intercoolers and Aftercooler

FAD: Amount of compressed air measured at 5 related back to ambient 2

SCFM: Amount @ 4 or 5 referred back to standard (1)

ACFM: Amount @ 4 or 5 referred back to inlet flange (3)

ICFM: Amount of air expressed in cu. ft./min. flowing by inlet flange (3)

Definitions

The following definitions and principles are those applicable to multistage centrifugal compressors, and should be used in determining and specifying sizes and types of centrifugal compressors for various industrial applications.

ICFM OR INLET VOLUME IN CUBIC FEET PER MINUTE:

The volume of air in cubic feet per minute (cfm) actually entering the blower or exhauster inlet is designated ICFM.

SCFM OR STANDARD VOLUME IN CUBIC FEET OR AIR PER MINUTE:

The volume of air in cfm at 68F, 14.70 lbs. per sq. in absolute pressure and 36% relative humidity is designated SCFM

ABSOLUTE PRESSURE:

The total pressure measure from an absolute vacuum is the absolute pressure. It consists of the sum of the atmospheric pressure and the gage pressure. Where the gage pressure is expressed as suction, it is negative and must be subtracted from the atmospheric pressure to determine the absolute pressure, and where the gage pressure is expressed as pressure it must be added to the atmospheric pressure to determine the absolute pressure.

WE CAN NOW CONVERT FROM ONE RATING CONDITION TO ANOTHER OR FROM A RATING CONDITION TO A STANDARD CONDITION

<u>EXAMPLE</u>

I. GIVEN:

FAD CFM	=	657
PSIA	=	13.9
Temperature	=	90°F
RH	=	30%

Convert to SCFM using SPT Conditions

$$\frac{P_1 V_1}{T_1} = \text{Ambient Condition}$$

$$\frac{P_2 V_2}{T_2} = \text{Standard Condition Condition}$$

$$\textbf{SCFM} = V_2 = \frac{(P_1)}{(P_2)} \times \frac{(T_2)}{(T_1)} \times V_1$$

$$\textbf{SCFM} = \frac{(13.9 - (.698 \text{ X } .3))}{14.7} \times \frac{(460 + 60)}{(460 + 90)} \times 657$$

SCFM = 578

Determine SCFM

Using Combined Gas Law Formula:

$$\frac{P_1V_1}{T_1°R} = \frac{P_2V_2}{T_2°R}$$

Let all Subscript 1 be SCFM Ref.

Subscript 2 be Jobsite Condition.

To Correct for RH

P – (RH X Partial Vapor Press @ Temp)

Therefore:

$$\frac{(P_1 - (RH \times PVP))\ V_1}{T_1°R} = \frac{(P_2 - (RH \times PVP))\ V_2}{T_2°R}$$

Solving for SCFM

$$V_1 = V_2 \frac{(P_2 - (RH \times PVP))\ T_1°R}{(P_1 - (RH \times PVP))\ T_2°R}$$

II. GIVEN:

ICFM	=	1087
PSIA	=	14.7
Temperature	=	97°F
RH	=	80%

Convert ICFM to FED CFM

$$\mathbf{F.A.D.} = \frac{[\mathrm{ICFM\ X}\ (14.4 - (.8 \times 1.0078)]}{[14.7(.8 \times .8668)]} \times \frac{557 \quad - \quad (\mathrm{ICFM} \times \mathrm{Seal\ Loss})}{562}$$

Compensate for:

Press, drop through piping, .3 PSI, temperature increase from ambient 5° F, water vapor measured as volume seal losses 1.5%

FAD = 1029 $\therefore$

ICFM is inflated by 5.6%

or

A compressor rated at 1087 ICFM puts out the same amount of air as a unit rated at 1029 FAD CFM

Reciprocating Compressors

- Positive displacement machines, considered as constant – volume variable pressure
- Delivers pulsating compressed air, either entrained with lubricating oil or lubricating free
- Can be built as moderate duty or heavy duty units

Major Industrial Classifications

Single Acting, Trunk-Piston

- Typically air-cooled
- Single or two-stage
- Positive or splash lubricated
- Although can be built as heavy duty, not a continuous duty compressor
- Modern materials used in some designs to improve cooling characteristics
- Lubricated or non-lubricated cylinders
- Minimum foundation
- V-belt or direct drive

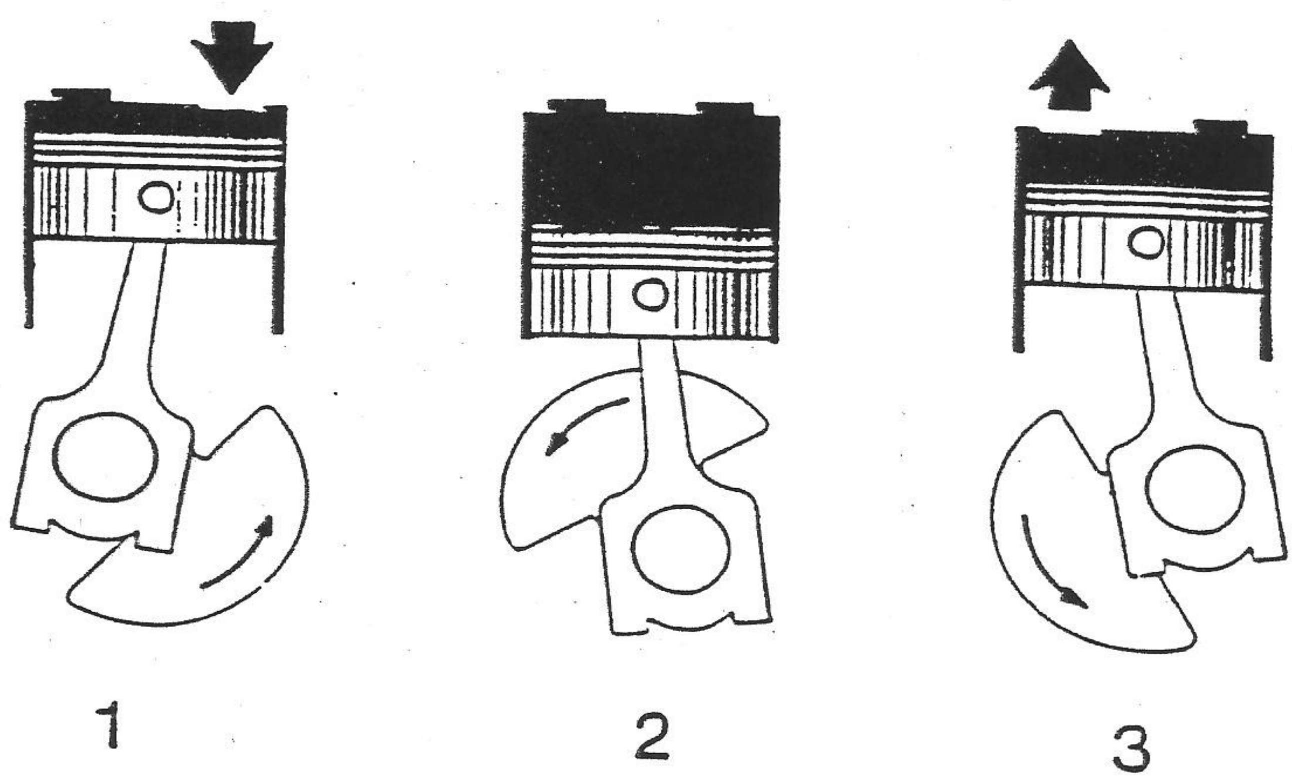
Range

- Fractional – 100 HP
- 35 PSIG – 5000 PSIG

SCFM REFERENCE POINTS

P_1 (PSIA)	14.696	14.7	14.7
T_1 (°F)	68	60	70
RH %	36	0	0

Single Action Design Pistons



Double Acting, Cross Head Design

- Air or water cooled
- Single or two-stag
- Typically positive lubrication
- Typically classified as heavy duty, continuous machines
- Lubricated or non-lubricated cylinder
- V-belt or direct drive

Range

- 60 – 700 HP
- 35 – 250 PSIG

Main Components or Reciprocating Compressor

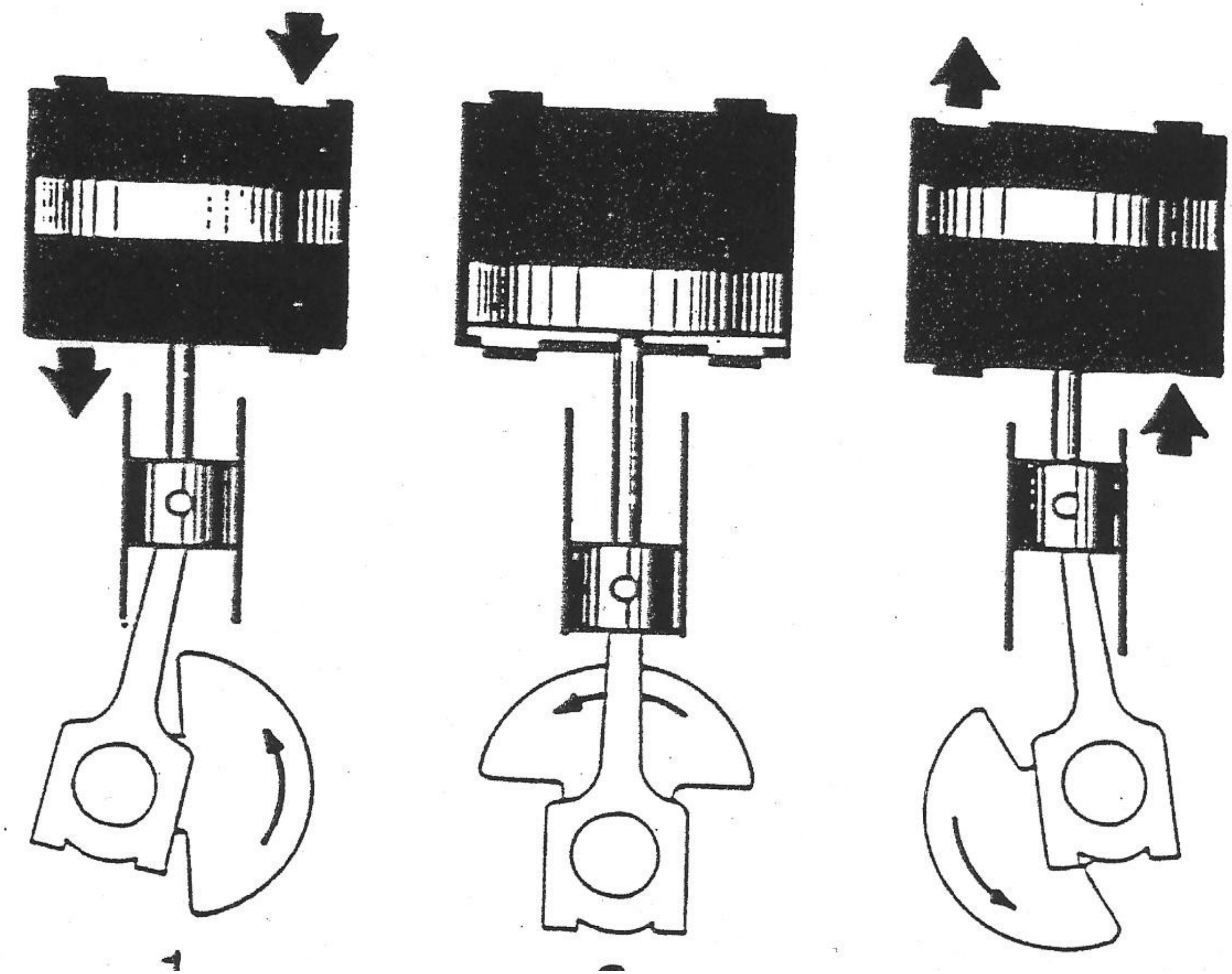
Frame and Running Gear

- Needs to be designed to withstand the maximum horsepower transmitted through the shaft and the pressure exerted upon it

Cylinders

- Cylinder arrangement and valve design are critical to overall efficiently and reliability of unit
- Different size cylinders are often placed on a given frame size to provide various sizes of compressors
- Houses the valves and rod packing

Double Action Cross Head Design Pistons



Rotary Compressors

- First introduced 40 years ago.
- Initial designs had symmetrical profile rotors with non-contracting rotors delivering oil-free air.
- This unit was efficient only at large flows (5,000 – 20,000 CFM)
- An asymmetric profile was developed. This reduced blow-by/leakage/slip and made low volume applications fairly efficient.
- Earliest applications were oil-flooded.
- The oil performed two functions:
  - Sealed between rotor and rotor lubricated rotors
  - Absorbed heat of compression
- Oil-flooded units were single-stage
- Oil-free rotaries are two-stage as heat of compression causes rotor growth and therefore discharges temperature needs to be limited. Also, two-stages improve efficiency.

ATLAS AIR & WATER
SERVICE QUALITY

Rotary Compressors

OIL-FLOODED SCREW

PRO

- Low initial cost
- Low to medium maintenance cost

Con

- Low efficiency

OIL-FREE SCREW

PRO

- Low Maintenance
- Good efficiency
- Efficient over wide ranges of conditions and load cycles
- Oil-free air

CON

- High initial cost

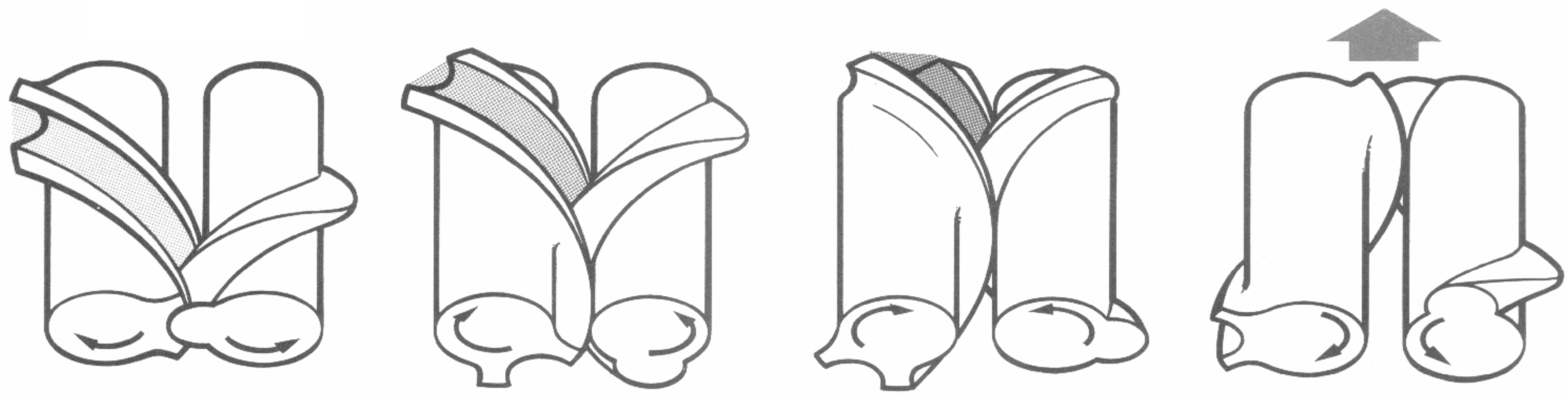
OIL-FREE LOBE

PRO

- Low maintenance
- Lower cost than oil free screw
- Stable over wide ranges of conditions and load cycles
- Oil-free air

CON

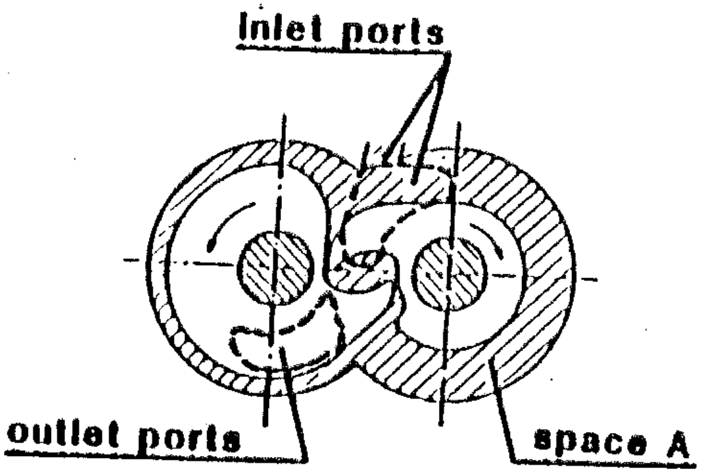
- Medium efficiency



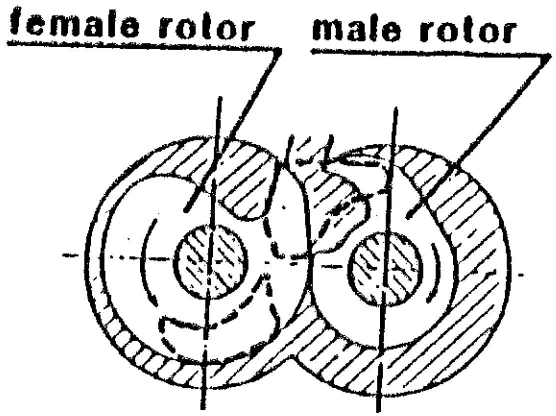
Rotary Lobe Compressors

- First introduced in 1982
- Straight profile design imparts compression around perimeter of rotor
- Thrust loads eliminated from rotors
- Lower speed operation and simpler profile allows for lower selling price

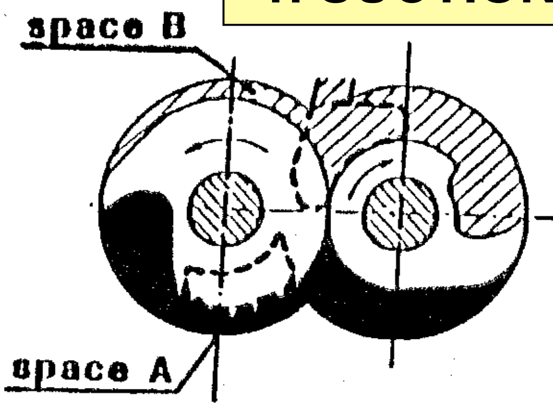
Rotary Lobe



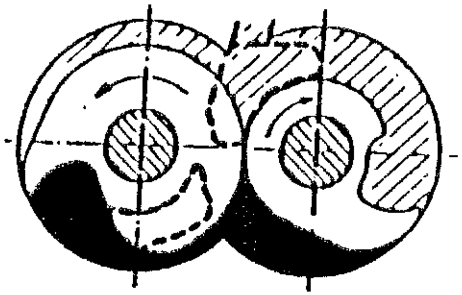
1. SUCTION



2. COMPRESSION STARTS

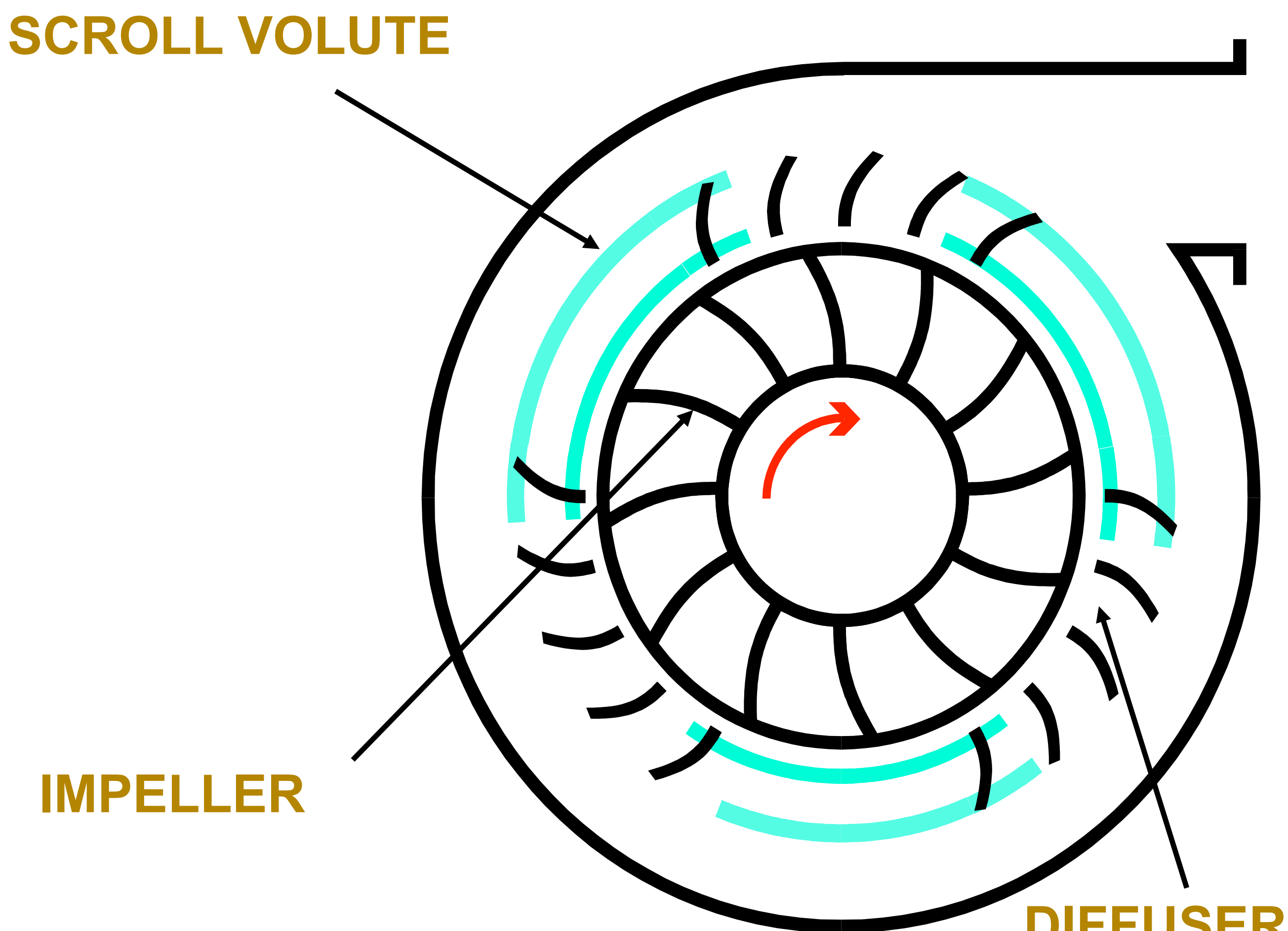


3. END OF COMPRESSION



4. DELIVERY

Centrifugal Compressor Terminology



Considerations For Centrifugal Compressors

- Capacity Requirements
- Lead Factors
- Ambient Factors:
  - Air temp and pressure
  - Water temp and cleanliness
  - Ambient air cleanliness

Centrifugals

- Pro
  - Reliable when properly applies
  - Oil-free air
- Con
  - Complicated operation
  - Performance greatly affected by ambient conditions
  - Unstable in varying load conditions

Centrifugal Compressors

- Capacity and horsepower change greatly with varying ambient conditions
- Increased air density due to reduced air and water temperatures increases flow and horsepower
- Specific flows and horsepowers should be checked for high, low, and average ambient conditions
- Reduce inlet air pressure due to altitude also reduces horsepower requirements
- For every 1,000 feet in elevation power requirement is reduced by approximately 1.8%
- Motor performance should also be checked at altitude
- Mass flow is reduced with increased elevation

Regulation Types

Load – Unload

- A compressor operating under this mode will provide the largest possible operational range of any control system. The compressor will also use the least amount of power.

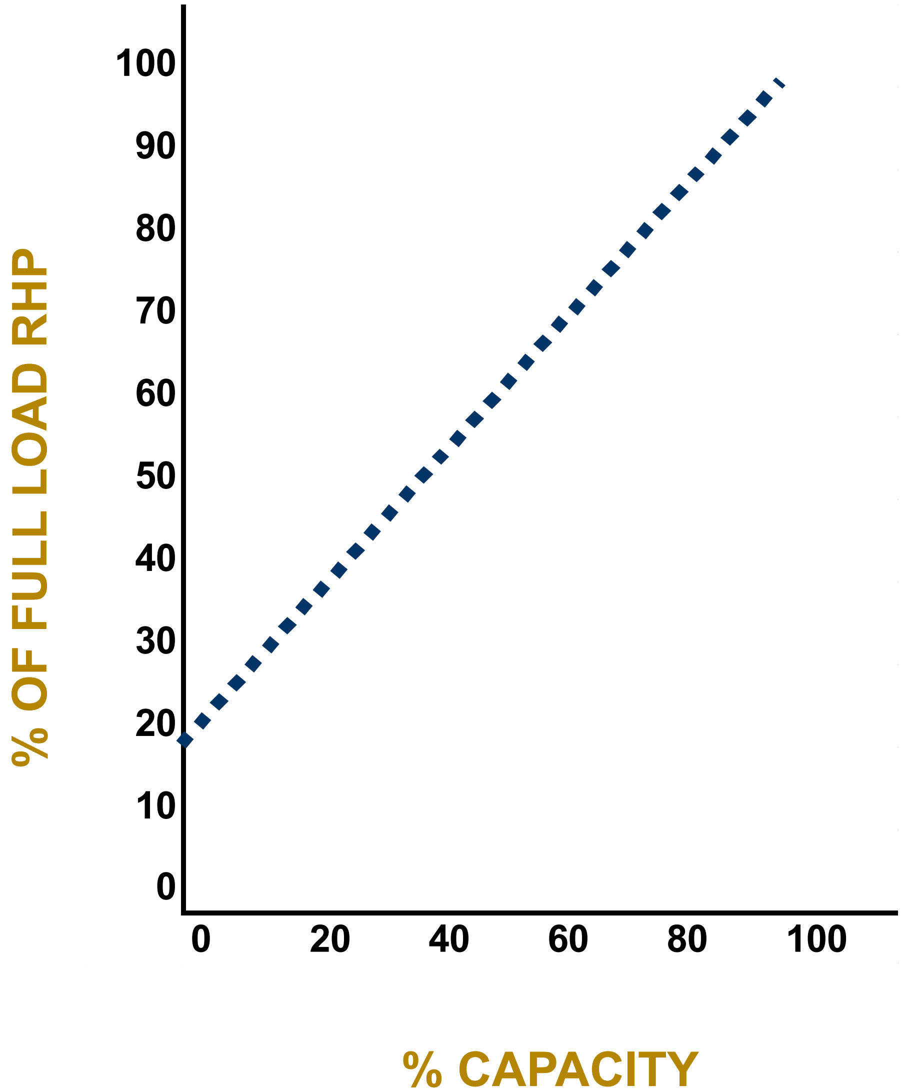
Modulation Control

- This method provides for a constant pressure by restricting the flow of air to the inlet of the compressor. Capacity can range from 0 – 100%, but this method of control is extremely inefficient.

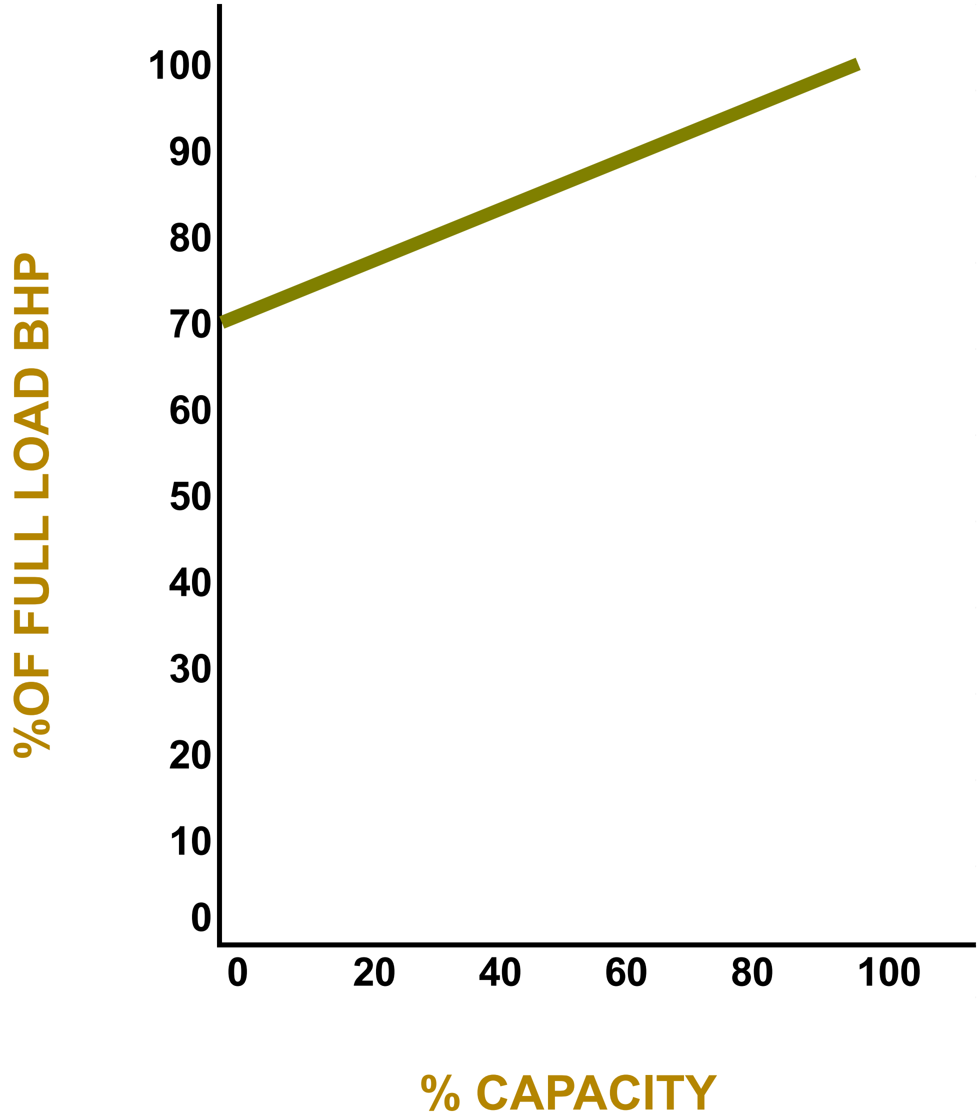
Auto Dual Control

- A combination of load-unload and timed delay shutdown creates the most effective and efficient control system. This control system will turn the compressor off after it has run unloaded for a predetermined time.

Full Load/No Load Capacity Control



Modulating Capacity Control



Screw Compressor Controls

modulation control

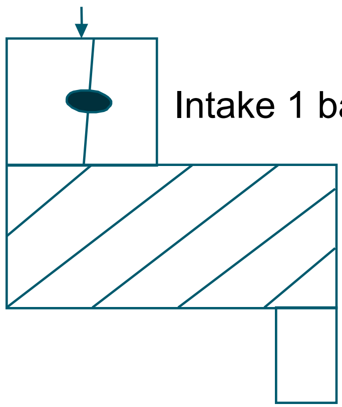
In a modulation control a butterfly valve regulates the intake.

Full load

- Butterfly valve is fully open with full flow of air
- Compressor operates at the built pressure ratio

Part load

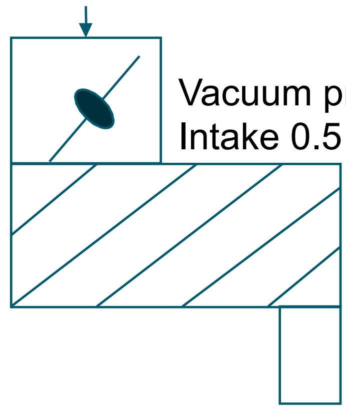
- Restriction at the inlet (vacuum)
- Outlet pressure remains the same (air net pressure)



Intake 1 bar(a)

Outlet 8 bar(a)

screw element



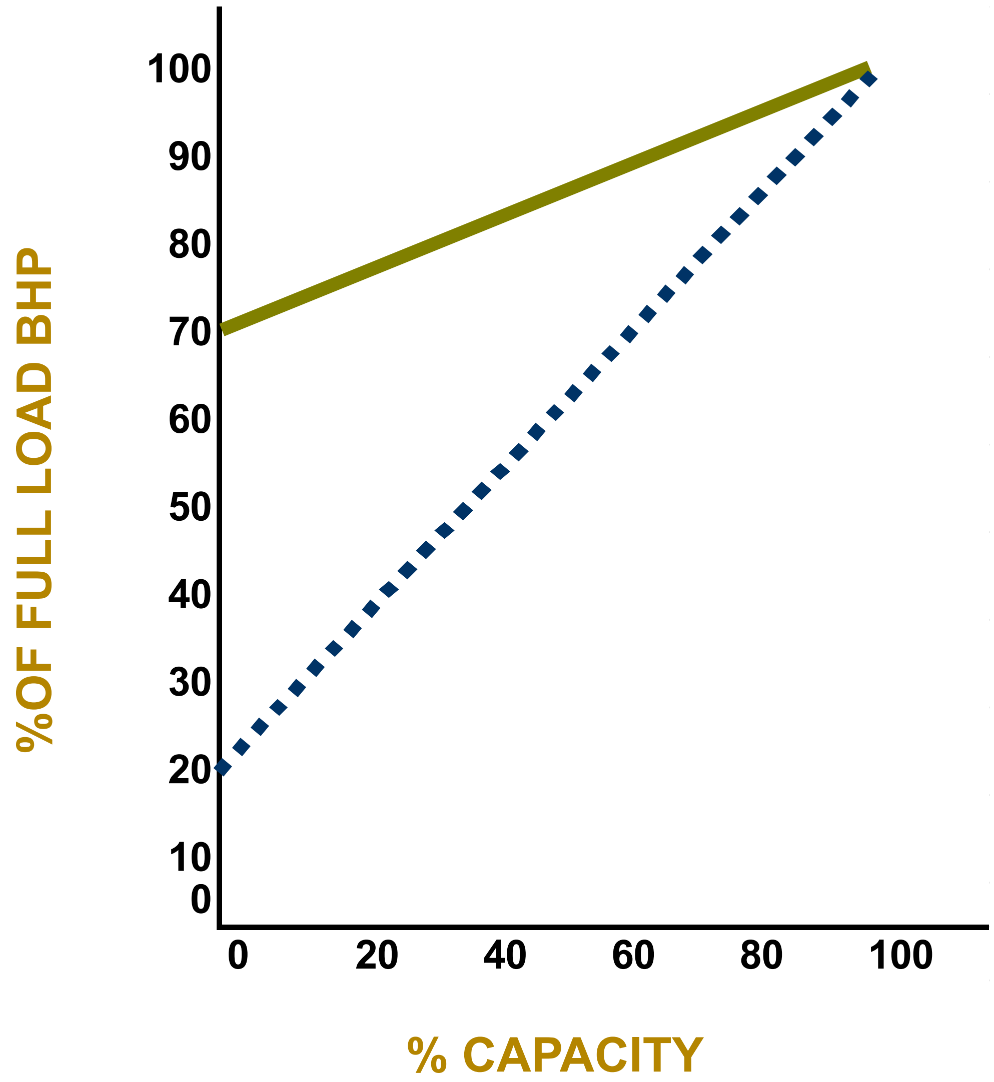
Vacuum prevails
Intake 0.5 bar(a)*

Outlet 8 bar(a)

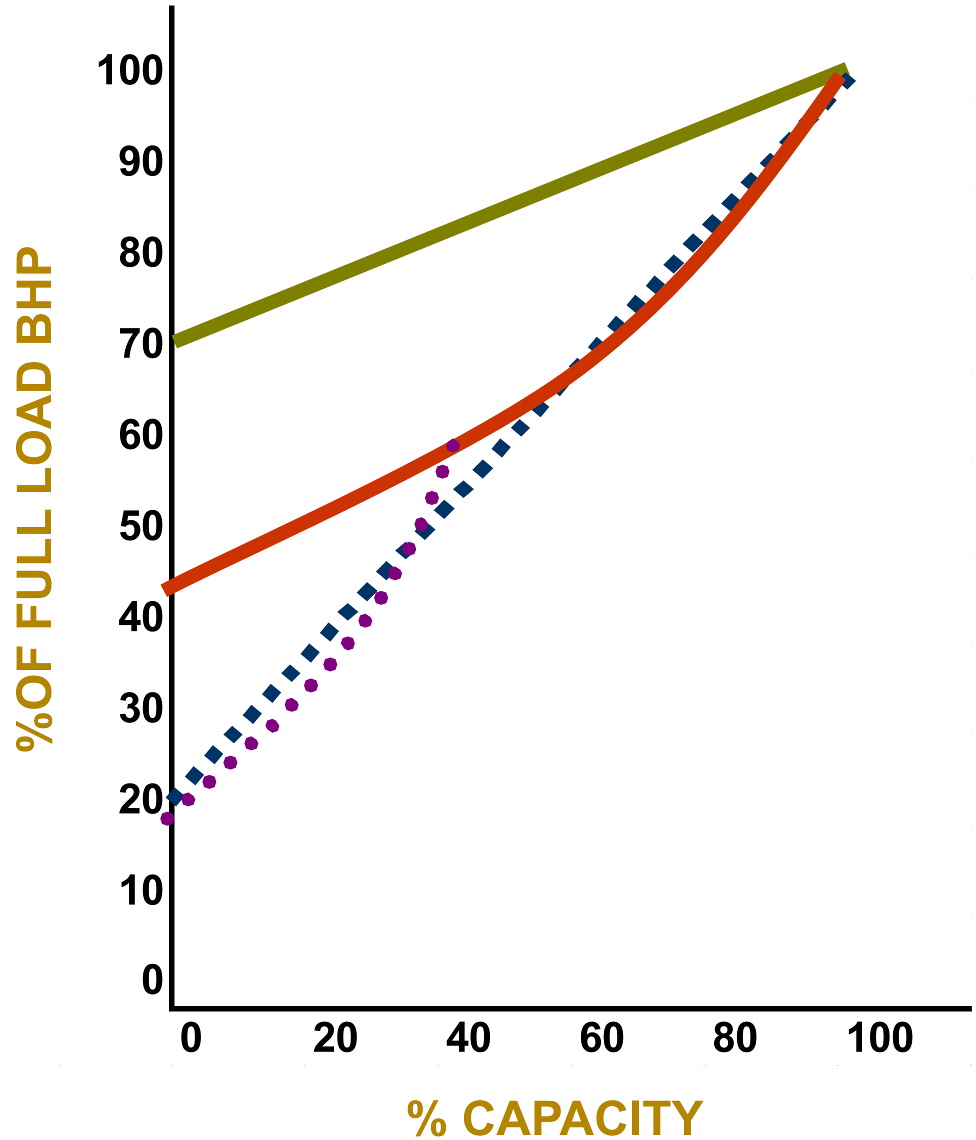
Pressure ratio = 8

Pressure ratio = 16 higher than the BIPR, hence inefficient at part loads

Full Load/No Load vs. Modulation Capacity Control



Turn Valve/Slide Valve vs. Full Load/No Load vs. Modulation

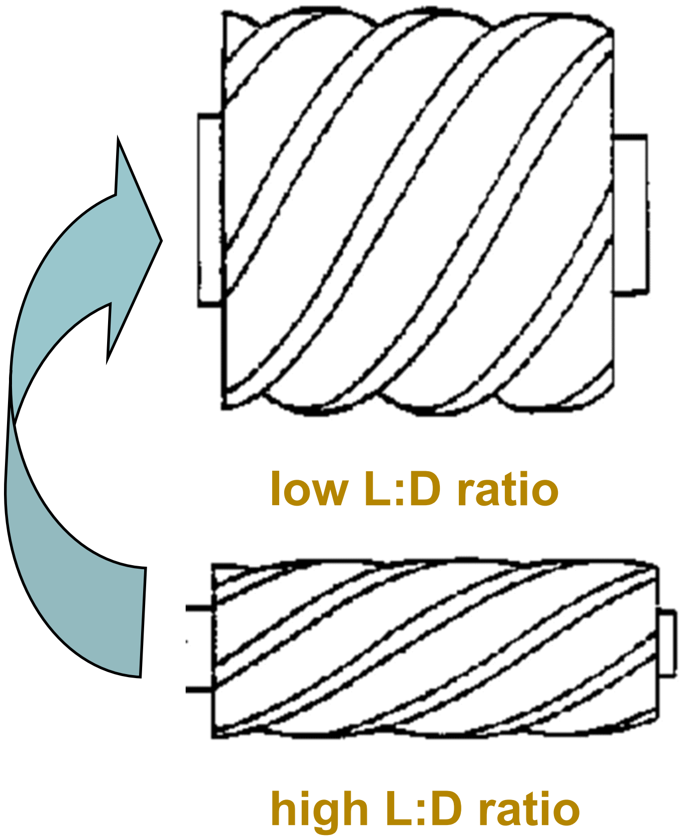


Rotor Length Adjustment

How it works ...

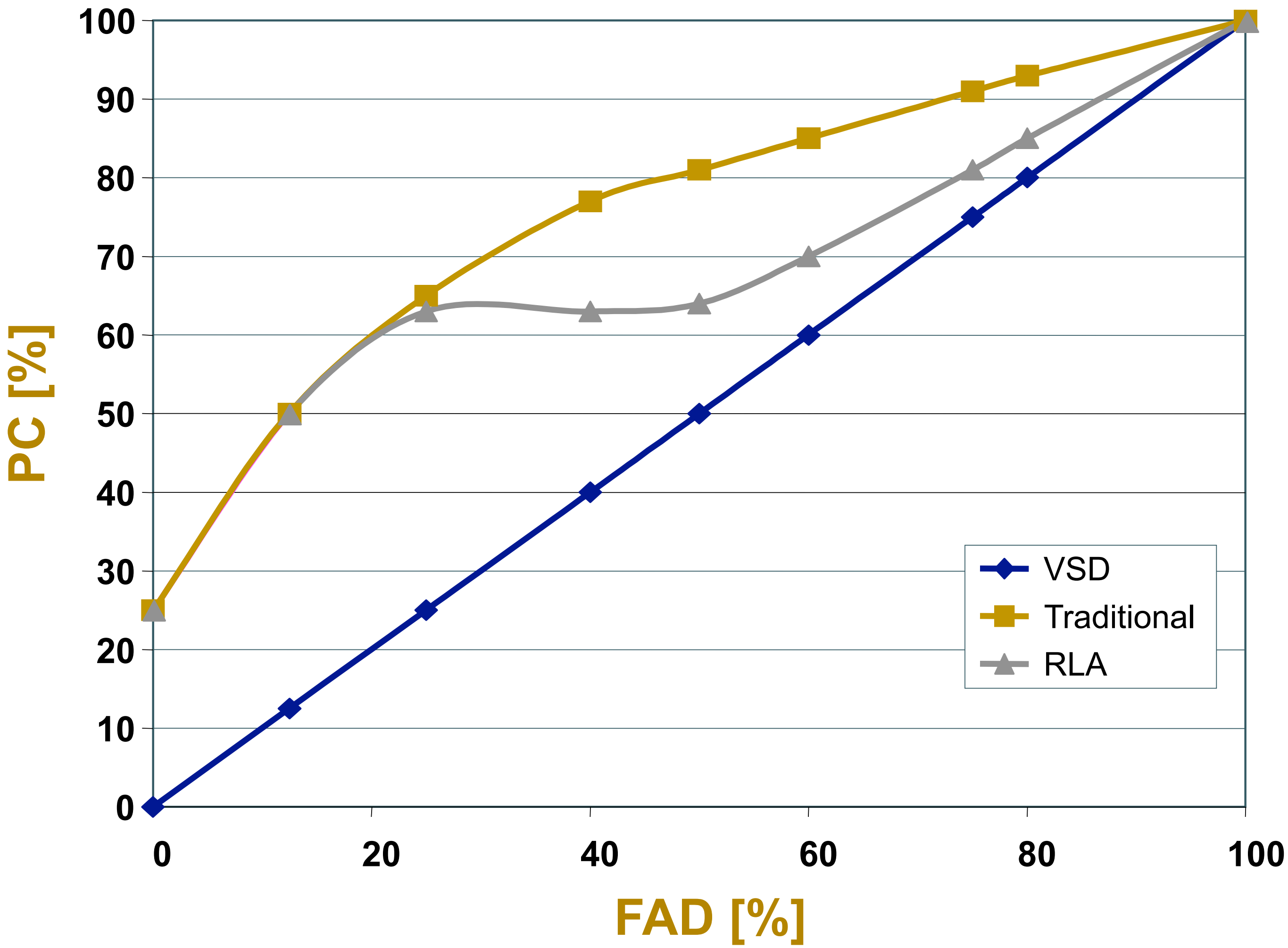
- Most common on higher kW machines
- Often called “turn valve”or slide valve”
- Effective rotor length is varied by moving the outlet port,hence adjusting the volume flow in relation to the demand
- 0.5-1 bar pressure band
- Inefficient at lower loads

Rotor Length Adjustment

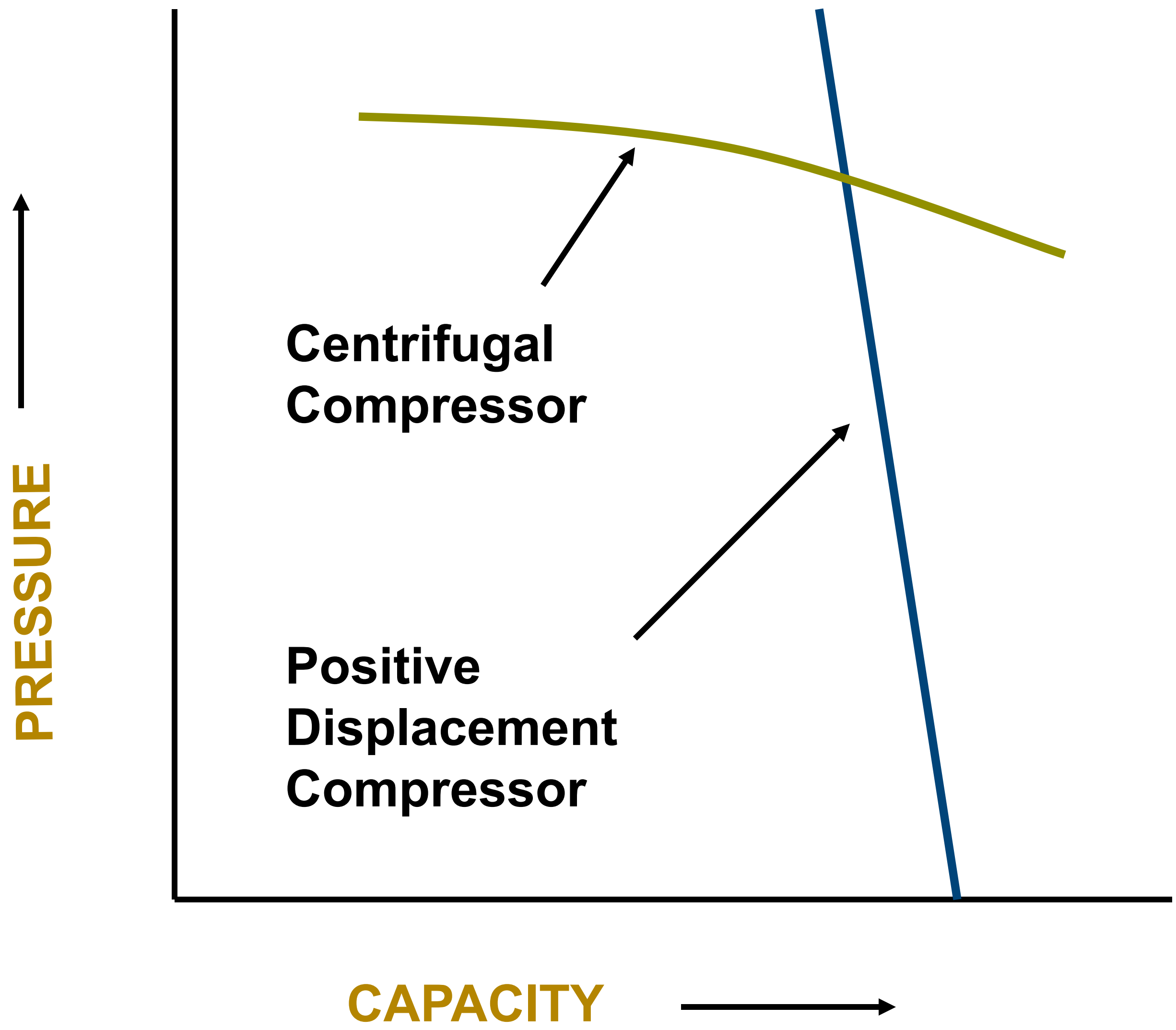


The optimal L/D ratio is changed resulting in substantial efficiency losses

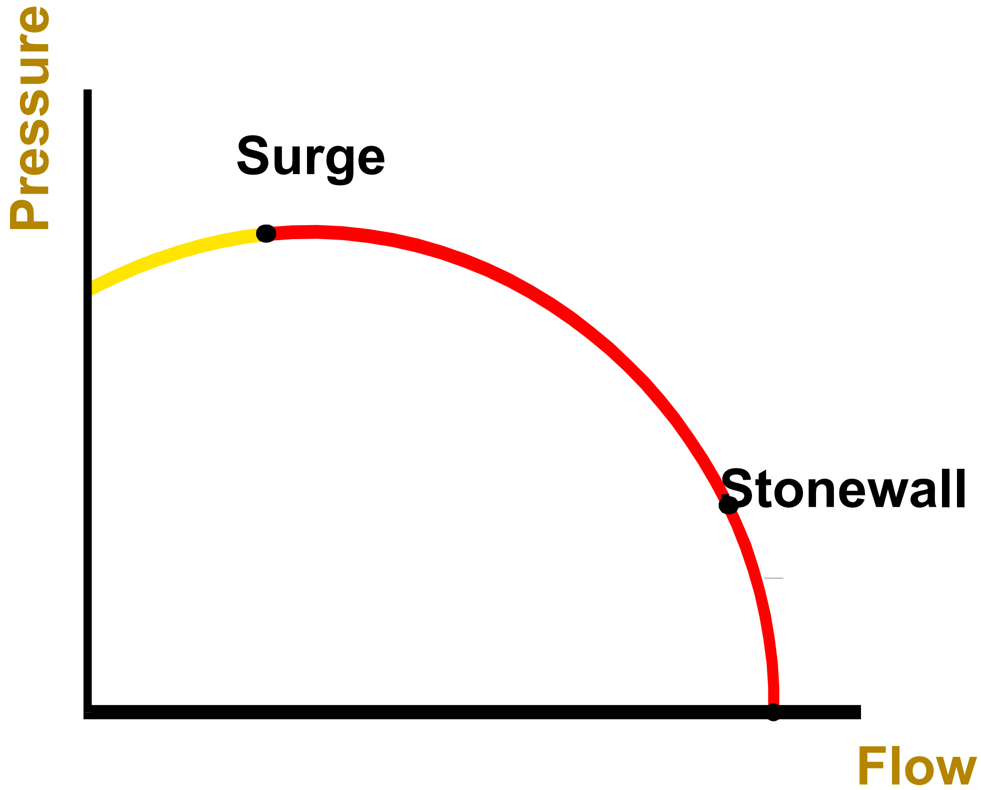
Comparison



PC [%]
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
FAD [%]
VSD
Traditional
RLA


Centrifugal Compressor
Positive Displacement Compressor
PRESSURE
CAPACITY

Centrifugal Compressor Fundamentals



The centrifugal compressor characteristic curve

Centrifugal Compressor Fundamentals

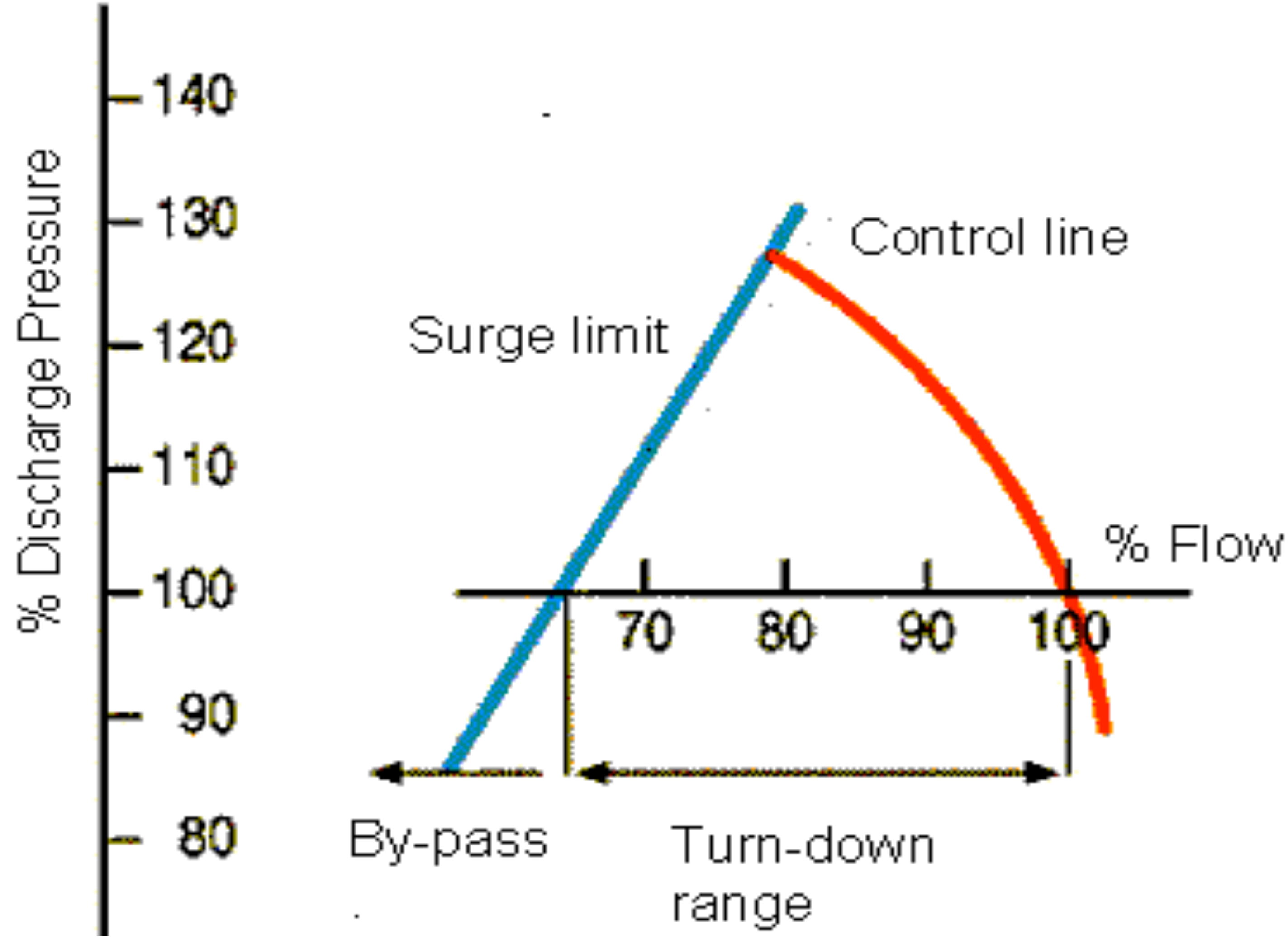
SURGE

Breakdown of airflow due to high back pressure (oscillation flow)

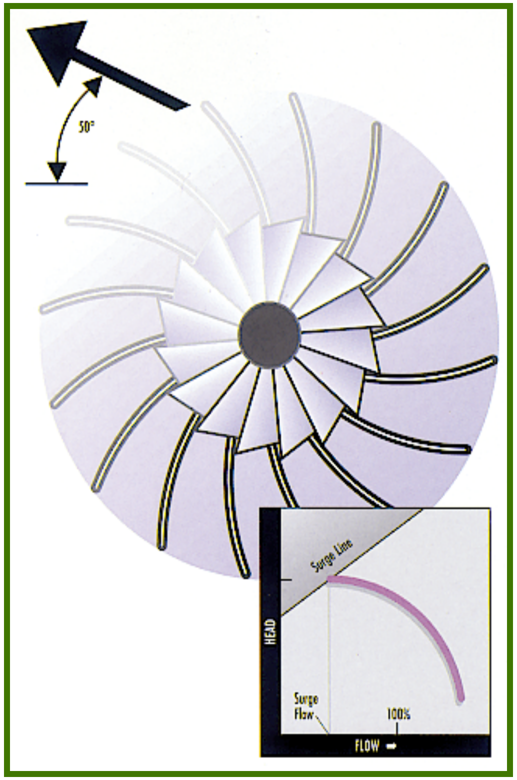
STONE WALL (choke)

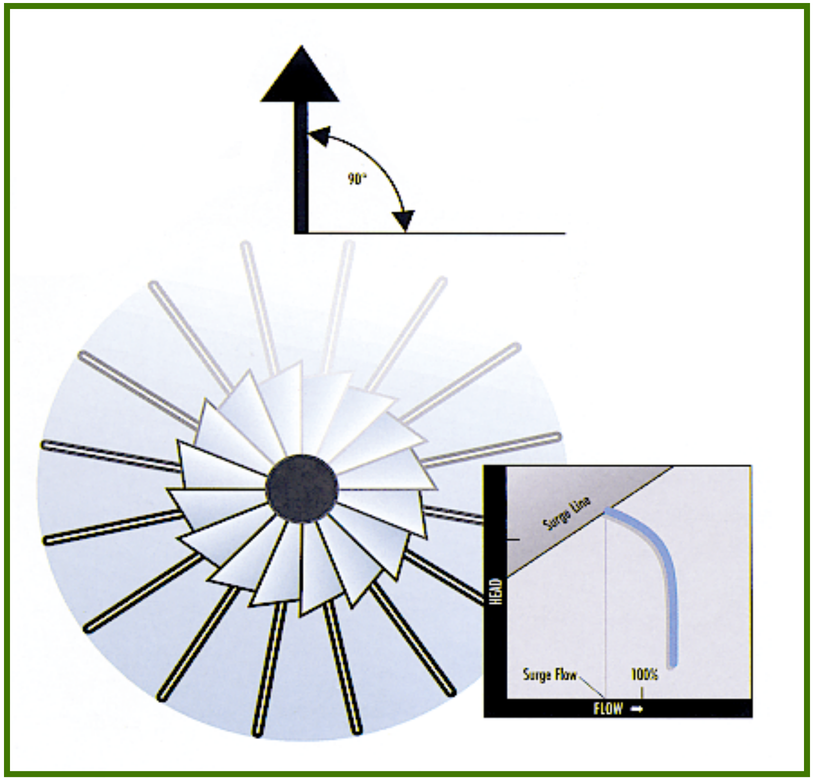
Maximum flow a compressor can handle at a given speed

Turndown Capacity



Impeller Geometry





Backward Leaning

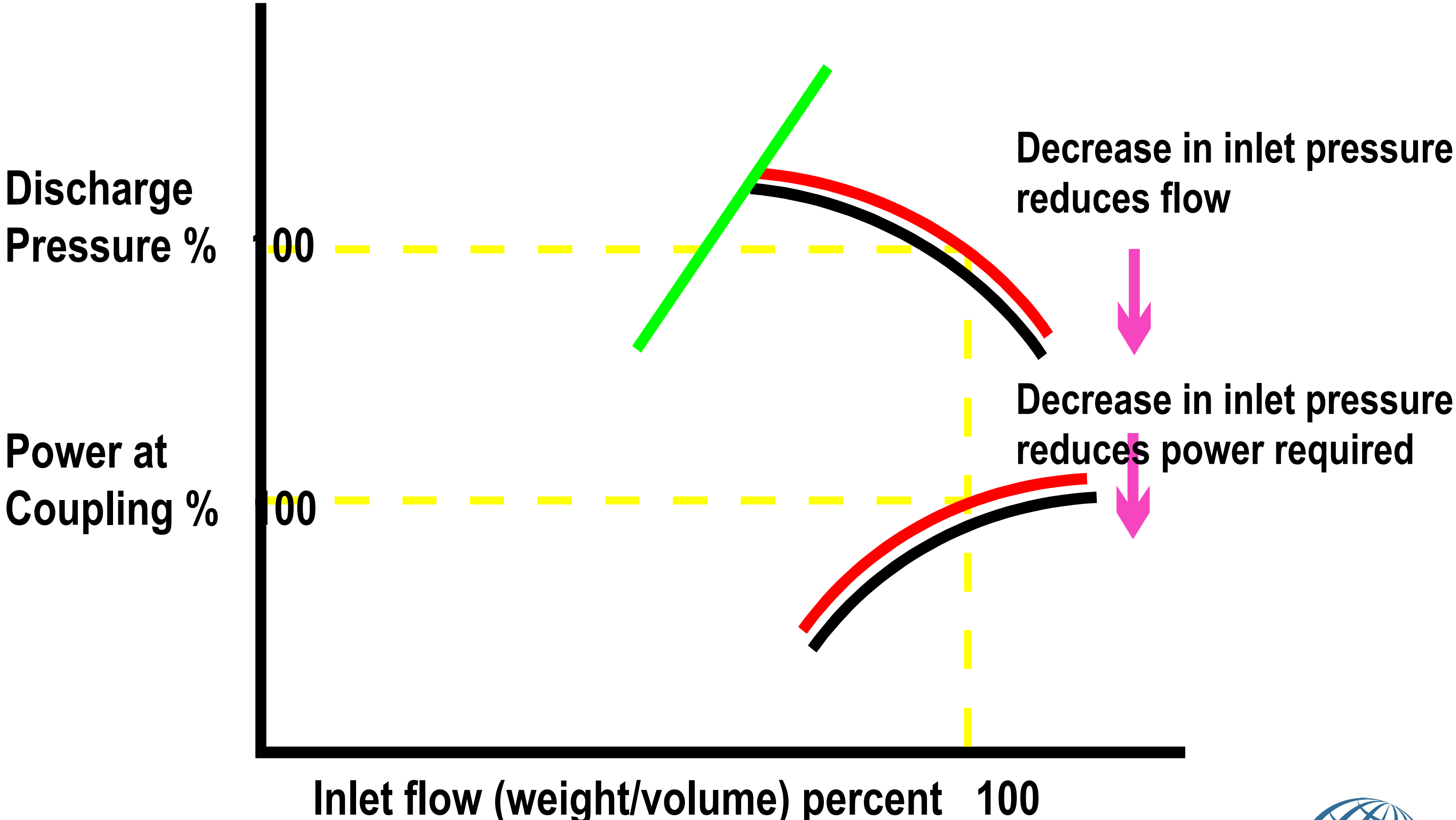
+ bigger turn-down
+ higher efficiency
- bigger diameter

Radial

+ smaller diameter
- limited turn-down

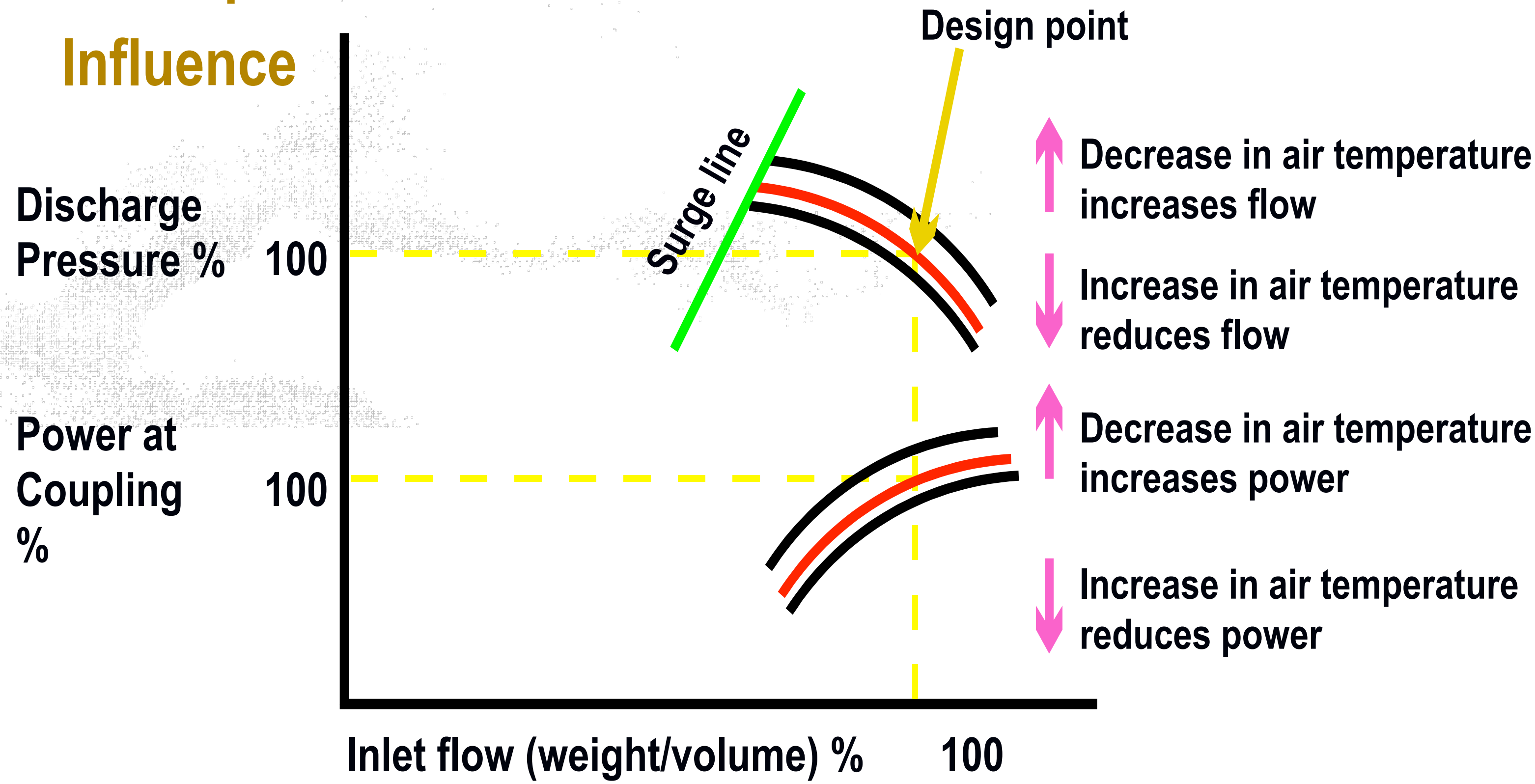
Centrifugal Compressor Fundamentals

Inlet Pressure



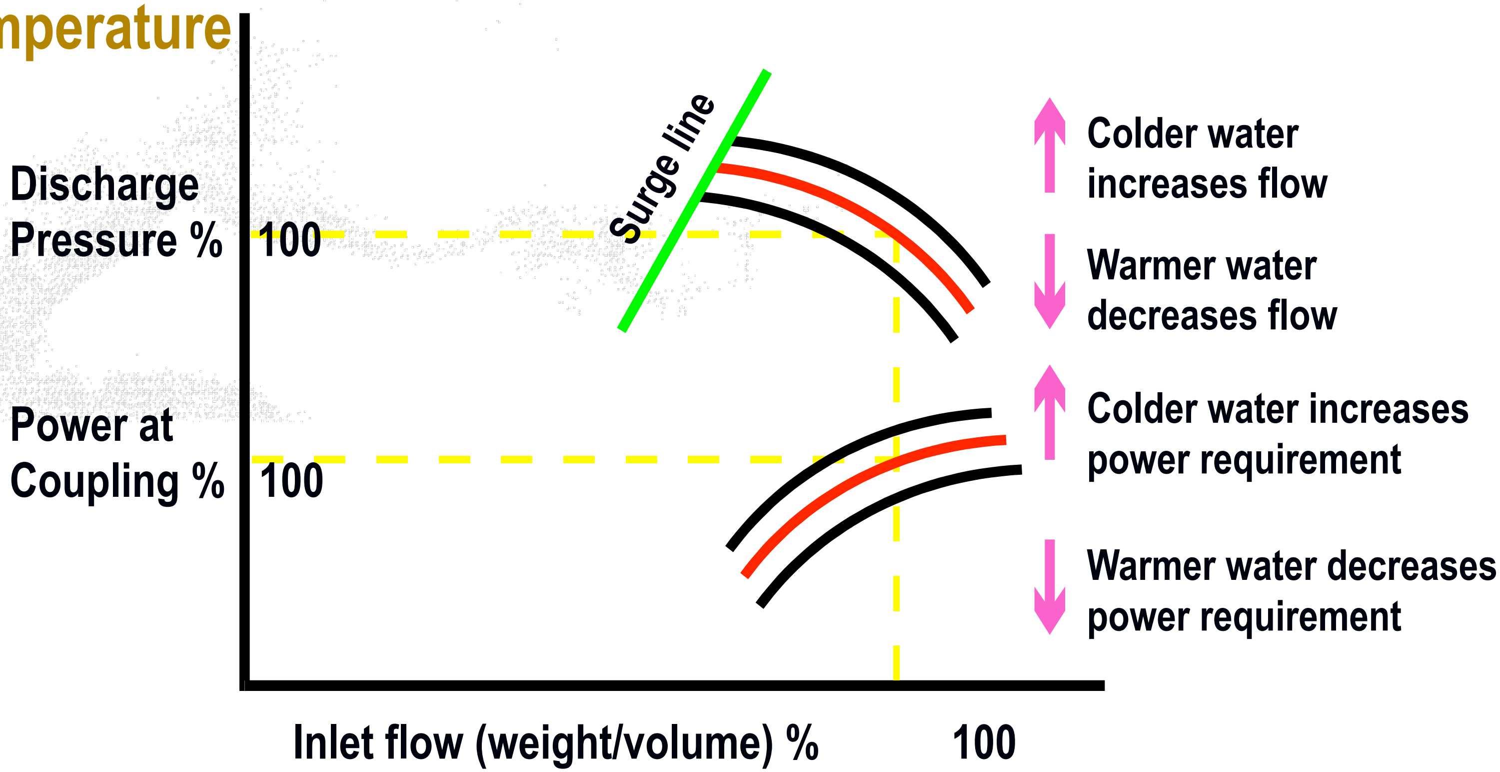
Centrifugal Compressor Fundamentals

Inlet Air Temperature Influence



Centrifugal Compressor Fundamentals

Cooling Water Temperature



Compressor Fundamentals

Variables Influencing Compressor Performance

Where: P : Power
P_1 : Inlet pressure
V_1 : Inlet volume
n : Adiabatic factor
P_2/P_1 : Pressure ratio

Variables influencing power:
P_1 = Inlet pressure
V_1 = Volume flow (not mass!)
P_2/P_1 = Pressure ratio

Positive Displacement Compressors

$$P = P_1 . V_1 . \frac{n}{n-1} . \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

Inlet air temperature and weight flow (density) have no effect on power

Compressor Fundamentals

Variables influencing compressor performance

Dynamic Compressors

$$H = R \cdot T_1 \cdot \frac{k}{k-1} \cdot \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} - 1 \right\}$$

Where:

H	:	Head
R	:	Gas constant
T_1	:	Inlet temperature
k	:	Spec heat ratio cp/cv
P_2/P_1	:	Pressure ratio

Compressor Fundamentals

Variables Influencing Centrifugal Compressor Performance

Power is calculated with formula:

$$P = \frac{H_p \, . m}{\eta_{is}}$$

Where: H_p : Head pressure
m : Mass flow
η_{is} : Isentropic efficiency

There are three variables that affect the power:

T_1 : Inlet temperature
m : Mass flow
P_2/P_1 : Pressure ratio

Compressor Fundamentals

Displacement Compressors

Variables:	P_1	=	Inlet pressure
	V_1	=	Volume flow
	P_2/P_1	=	Pressure ratio

Dynamic Compressors

Variables:	T_1	=	Inlet temperature
	m	=	Mass flow
	P_2/P_1	=	Pressure ratio

Be careful to obtain the proper part load horsepower for the type of compressor being reviewed.

Summer and winter can affect compressor performance differently depending what type of compressor is being considered:

EXAMPLE:

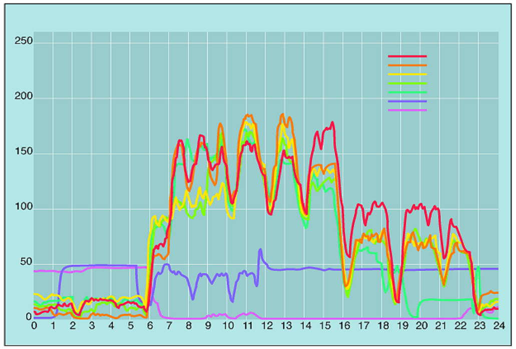
Efficiency for a positive displacement compressor is relatively the same in both summer and winder (BHP/ 100 CFM), on a mass flow basis, BHP/100 SCFM is much lower with lower inlet temperatures

Efficiency of a dynamic compressor is poorer in winter conditions than in summer conditions because it is a constant mass flow unit (BHP/100 SCFM)

ZR315 VSD

for the lowest cost compressed air

Most production facilities show a characteristic air demand profile, with fluctuations in air demand according to the hour of the day or the day of the week. Compressors with a traditional regulation system cannot precisely follow these varying demand patterns. Result: energy goes to waste. It shouldn’t have to. From the day you install the **ZR VSD** – Variable Speed Driven – compressor, your energy bill and the stability of your process will show a major difference.



A typical air demand profile, measured over one week.

A measurement box which is used for analysis of air demand and energy consumption in your plant. Based on these readings, the implementation of a VSD compressor in a typical installation can be stimulated by software. Future energy savings can be estimated.

Introducing the Atlas Copco oil-free ZR315 VSD. The perfect match between air supply and air demand.

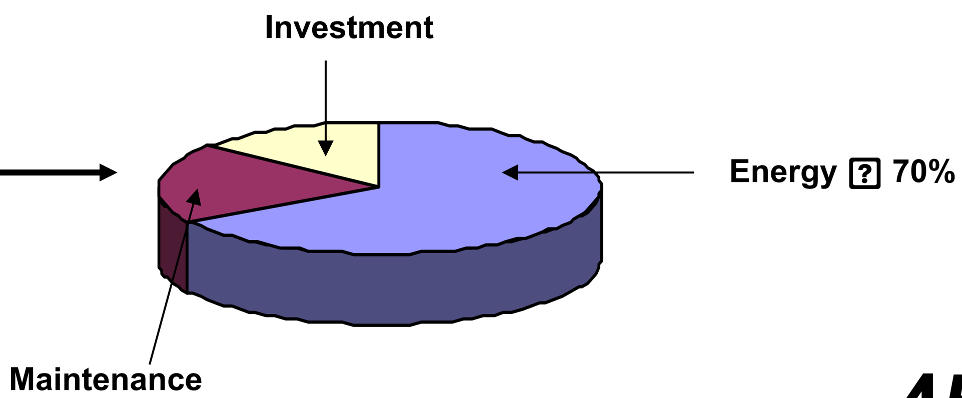
The integrated frequency converter of the ZR315 VSD will vary the speed of the compressor to closely follow the air demand, thereby saving enough energy to payback the additional investment in possibly one to two years, demanding on the energy tariffs and the demand patterns.

Call upon the expertise of Atlas Copco to assess your process and give you an estimation of energy savings possibly for your factory.

Operating range ZR315 VSD

Total compressor life cycle cost

Because in the total life cycle cost of a standard compressor, energy consumption represents over 70%, the VSD approach has a significant impact on the total cost structure.



VSD – Variable Speed Drive

= caring for energy

= caring for nature

Lowest possible running cost

- Air supply = Air demand
- With a varying air demand pattern, motor speech regulation is the most efficient compressor control method
- Energy savings at partial load
- Extended component lifetime

Constant pressure

- Process stability improvement

Low starting currents

- Lower investments in electrical systems
- No peak current penalties
- Smooth starting

Motor and VSD, on brand

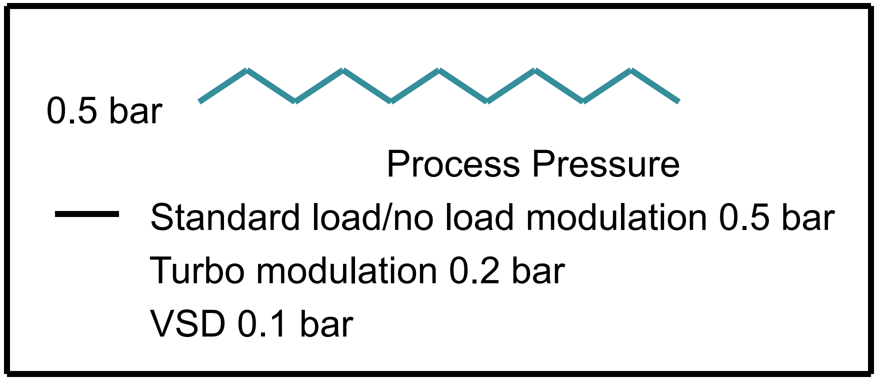
- Highest possible efficiency in the speed range
- Consolidated warranty for the entire system
- Worldwide service availability

VSD – a Very Smart Decision

No current peaks

Compressor starts are even smoother than with so called “soft starters.” This greatly simplifies the electrical installation. No current peaks. No risk of penalties from the utility company. Investment in the electrical system can be reduced.

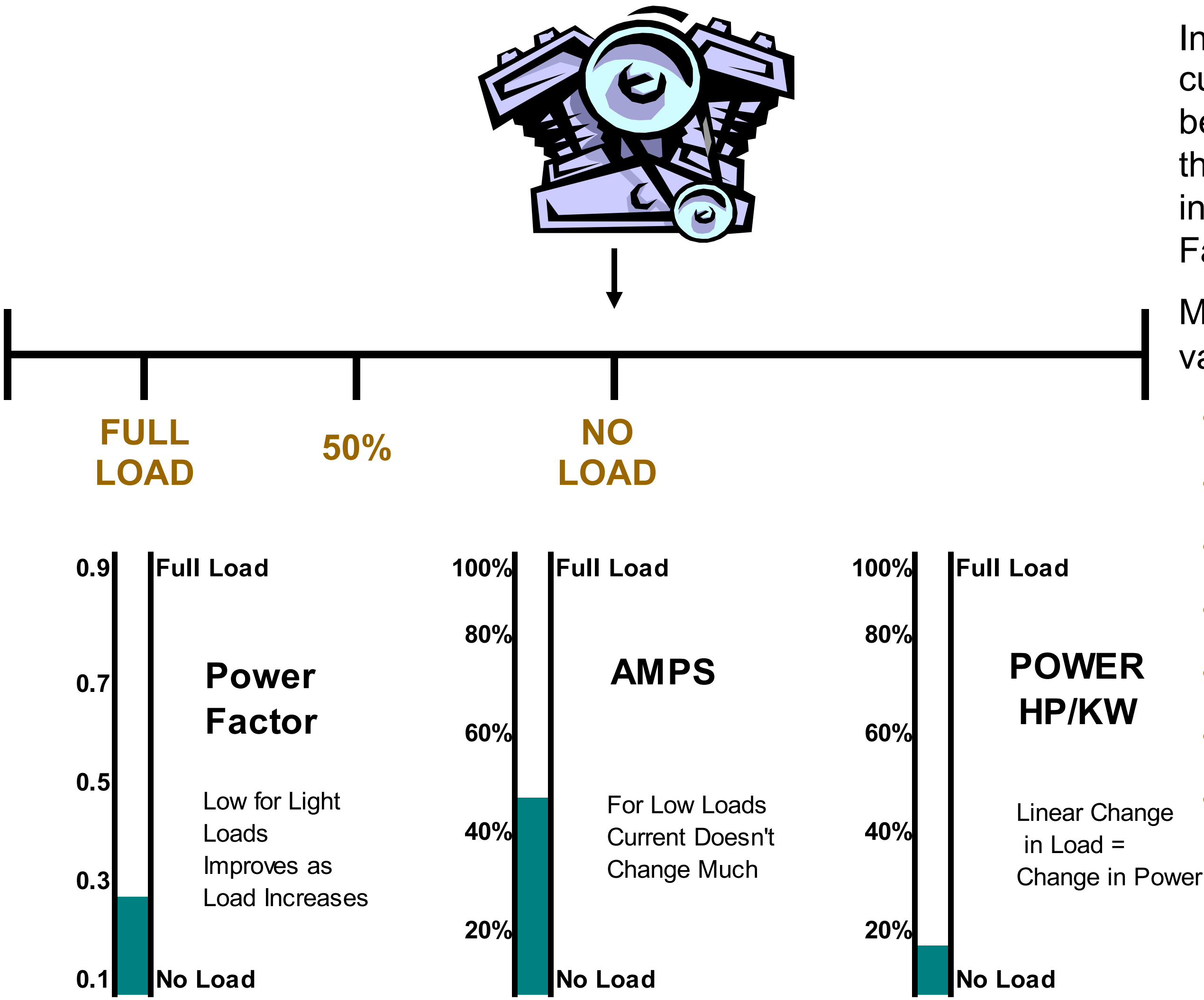
The frequency converter is integrated within the compressor package.



Constant pressure

The output pressure is virtually constant over a wide capacity range (narrow pressure band within 0.1 bar). Unlike traditional regulation systems, it optimizes energy consumption and ensures high process stability.

Motor Load vs. Power Factor, AMPS, Power



In an induction motor, the current (amps) always lags behind the voltage. This lag is the Power Factor. As load increases and the Power Factor improve.

Monitoring Power gives you valuable information.

- Viscosity
- Tool Condition
- Pump or Fan Flow
- Beginning or End of Process
- Overload
- Loss of Load
- Optimum Feed Rate

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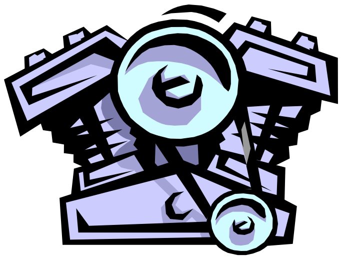

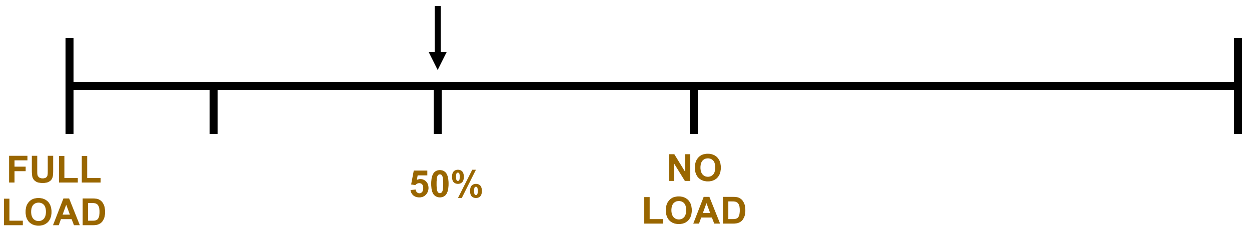

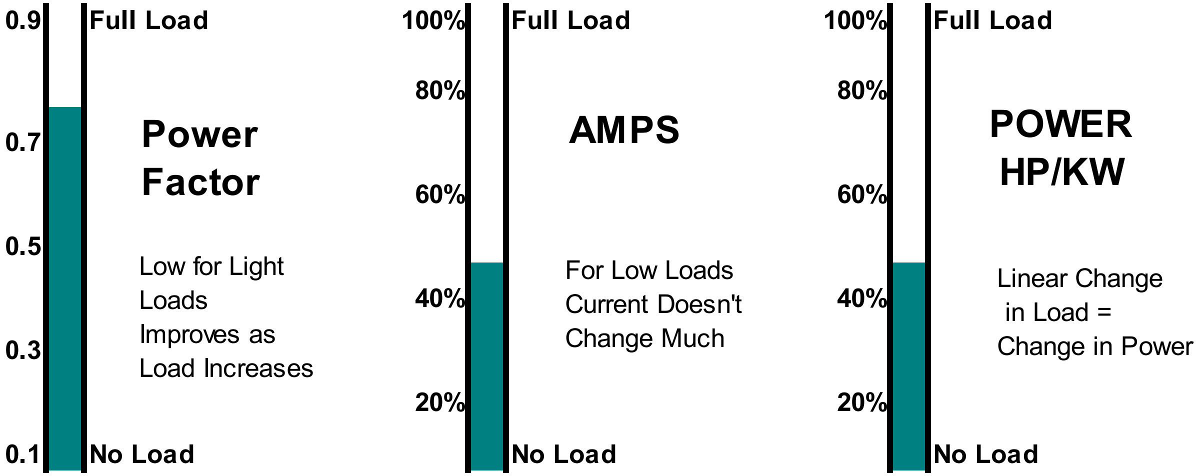

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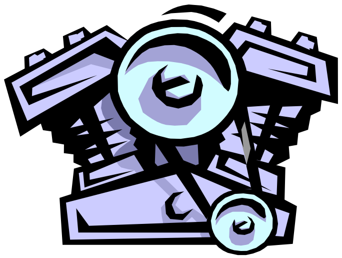

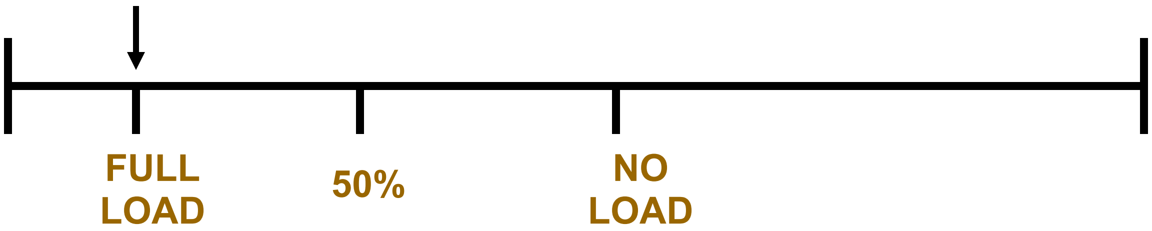

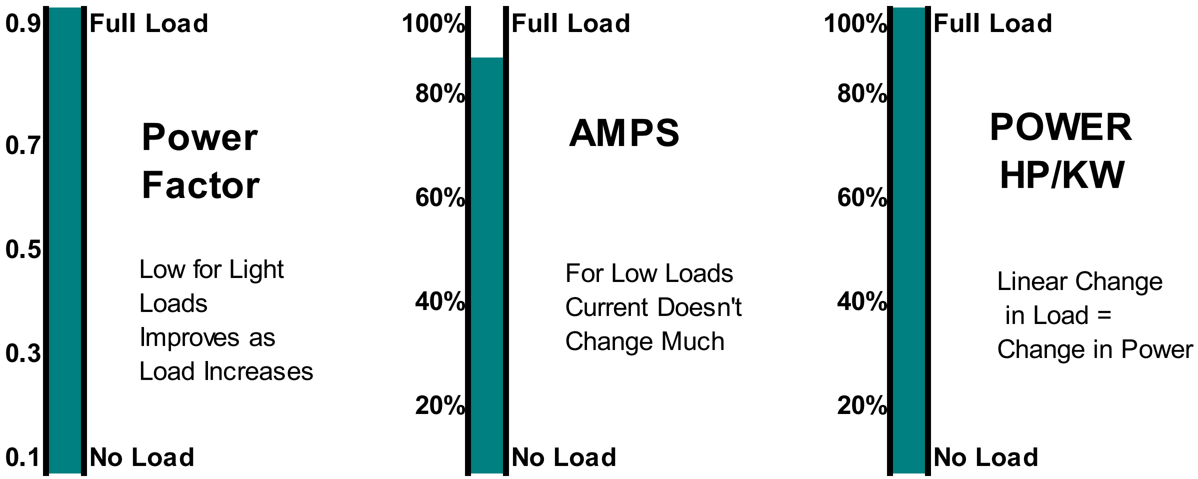

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- Viscosity
- Tool Condition
- Pump or Fan Flow
- Beginning or End of Process
- Overload
- Loss of Load
- Optimum Feed Rate

Air Cooled

1. **COMPRESSOR UNIT**

- The unit should be installed on a level floor capable of supporting the weight of the unit. Stated distance between walls are minimums. Recommended minimum distance between top of unit and ceiling is 4.0 feet (ventilation alternative).

2. **COMPRESSOR DISCHARGE VALVE**

3. **DISCHARGE PIPE**

- The size and length of the discharge pipe may be estimated using the formula stated below:

$$L = \frac{1470 \triangle P \times d^5 \times P}{O_C^{\ 1.85}}$$

Where: L = Length of discharge pipe (feet)

$\triangle P$ = Allowable pressure drop (PS) – Recommended 1.45 PSI Maximum

d = Inside diameter of discharge pipe (inches)

P = Absolute pressure at compressor outlet valve (PSIA)

O_c = Compressor capacity (CFM)

4. VENTILATION

- The inlet grill(s) and ventilation fm must be installed so there is no recirculation of the compressor cooling air.
- The air velocity through the inlet grill(s) should be limited to 15.0 feet per second.
- For ventilation alternatives 2, 3, and 4, the maximum allowed pressure drop over the cooling ducts is 0.12 inches of water.
- The temperature at the compressor unit intake should be maintained between 32° F and 104° F.
- The required ventilating air, for ventilation alternatives 1 and 2 may be estimated using the following formula:

$$\boxed{O_V = \frac{2875N}{\triangle T}}$$

Where O_V is ventilating air required (CFM)

N is nominal unit horsepower (HP)

$\triangle$T expected, or allowable temperature rise between the room and incoming air. remember intake air temperature to unit should be less than 104° F.

5. MOISTURE DRAIN

6. ELECTRICAL CONTROL CUBICLE WITH MONITORING PANEL

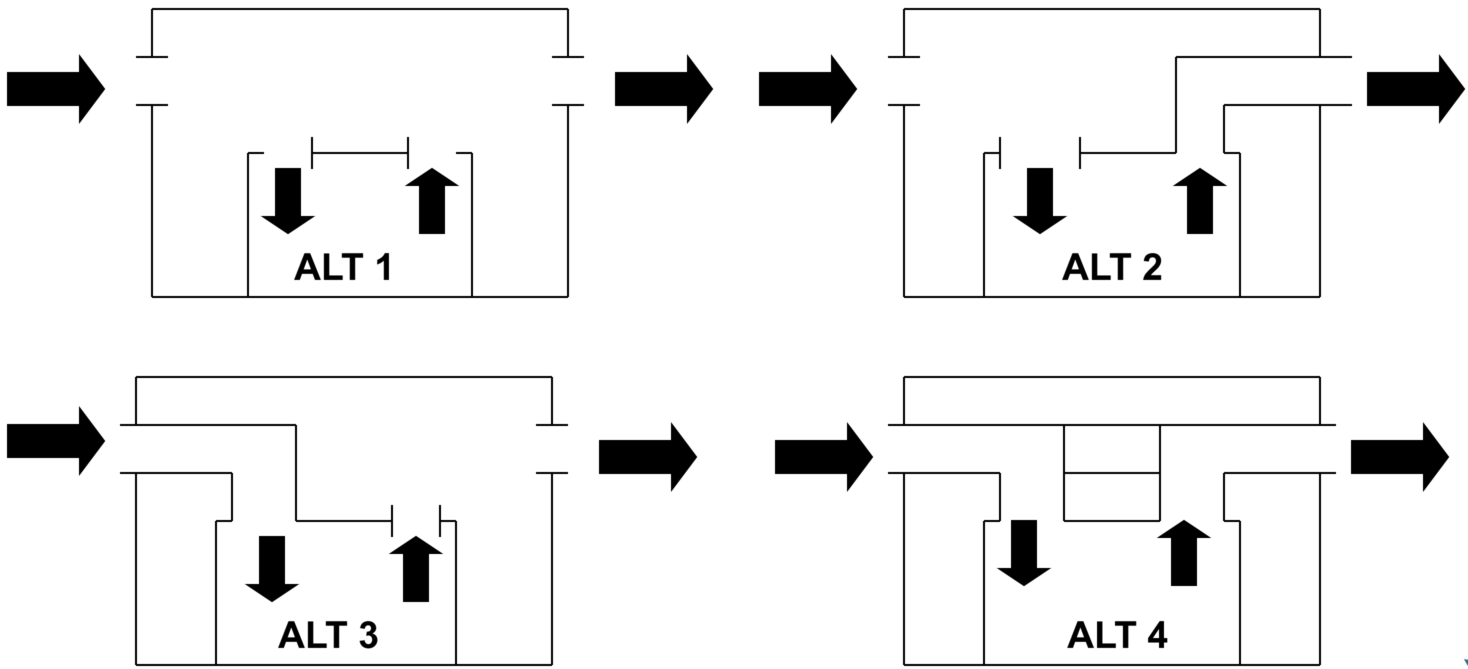
7. ELECTRICAL ENTRANCE PANEL

8. <u>ALL PIPING AND ELECTRICAL CONNECTIONS TO THE UNIT MUST BE STRESS FREE. THE UNIT SHOULD NOT SUPPORT THESE LOADS.</u>

9. <u>SEE GENERAL ARRANGEMENT FOR DIMENSIONS</u>

10. <u>FLOW DIAGRAM AVAILABLE</u>

VENTILATION PROPOSALS



Water Cooled

1. **COMPRESSOR UNIT**

- The unit should be installed on a level floor capable of supporting the weight of the unit. Stated distance between walls are minimums. Recommended minimum distance between top of unit and ceiling is 4.0 feet (ventilation alternative).

2. **COMPRESSOR DISCHAREGE VALVE**

3. **DISCHARGE PIPE**

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Where: L = Length of discharge pipe (feet)

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- The air velocity through the inlet grill(s) should be limited to 15.0 feet per second.
- For ventilation alternatives 2, 3, and 4, the maximum allowed pressure drop over the cooling ducts is 0.12 inches of water.
- The temperature at the compressor unit intake should be maintained between 32° F and 104° F.
- The required ventilating air, for ventilation alternatives 1 and 3 may be estimated using the following formula:

$$\boxed{O_V = \frac{310N}{\triangle T}}$$

Where O_V is ventilating air required (CFM)

N is nominal unit horsepower (HP)

$\triangle T$ expected, or allowable temperature rise between the room and incoming air. remember intake air temperature to unit should be less than 104° F.

5. MOISTURE DRAIN

6. ELECTRICAL CONTROL CUBICLE WITH MONITORING PANEL

7. ELECTRICAL ENTRANCE PANEL

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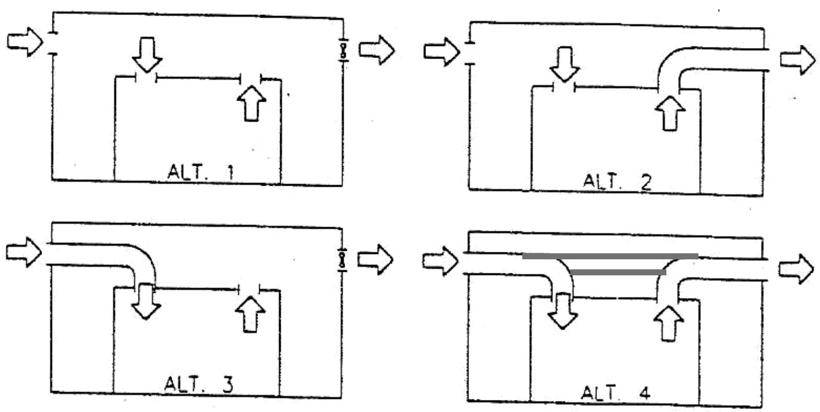
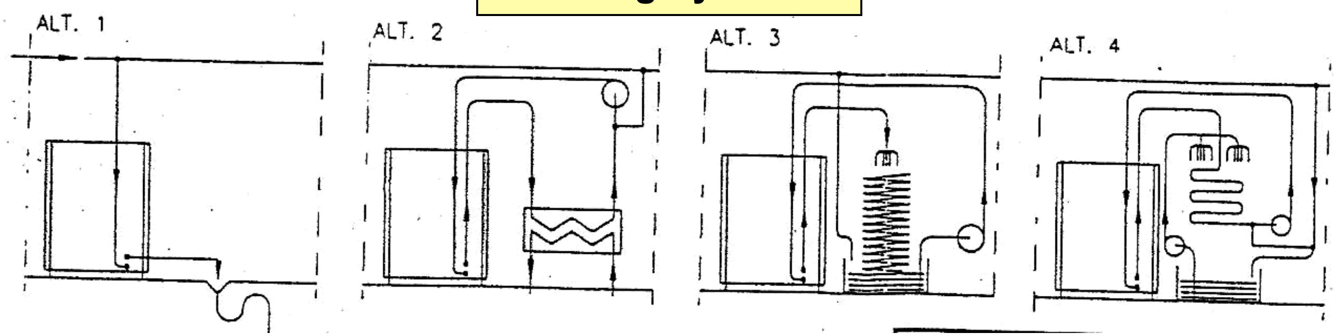


Cooling Systems



Effect of Ambient Conditions on Compressor Performance

Positive Displacement Compressors

- Affected minimally by ambient temperature
- Reduced inlet temperature increases mass flow
- For every 5° F reduction in temperature, mass flow increases 1%

Reduced Inlet Pressure Reduces Output Flow Slightly

- One PSI drop in inlet pressure reduces capacity by slightly more than one CFM, free air or 6.8% in mass flow
- One PSI is approximately 2000 feet

Effect of Initial or Intake Temperature on Delivery of Air Compressors Based on a Normal Intake Temperature of 60°F

Initial Temperatures		Initial Temperatures	
°F	Relative Delivery	°F	Relative Delivery
-20	1.180	70	0.980
-10	1.155	80	0.961
0	1.130	90	0.944
10	1.104	100	0.928
20	1.083	110	0.912
30	1.061	120	0.896
32	1.058	130	0.880
40	1.040	140	0.866
50	1.020	150	0.852
60	1.000	160	0.838

Water Temperature

- Relative difference between ambient air temperature and water temperature affects horsepower.
- Compressor performance is normally based on perfect inter cooling, i.e., inlet temperature to second stage is the same as inlet temperature to the first stage.
- Horsepower is reduced when second stage inlet temperatures lower.
- For every 12° F reduction in water temperature from perfect inter cooling, horsepower is reduced by 1%

Weight of Dry Air at Various Pressures and Temperatures at Sea Level

Temperature of Air		Gauge Pressure, Pounds																					
		0	5	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	175	200	225	250	300
*F	*C	Weight in Pounds per Cubic Foot																					
-20	-28.9	0.0900	0.1205	0.1515	0.2125	0.2744	0.3360	0.3970	0.4580	0.5190	0.5800	0.6410	0.702	0.7635	0.825	0.886	0.948	1.010	1.165	1.318	1.465	1.625	1.930
-10	-23.3	0.0882	0.1184	0.1485	0.2090	0.2685	0.3283	0.3880	0.4478	0.5076	0.5674	0.6272	0.687	0.747	0.807	0.868	0.928	0.989	1.139	1.288	1.438	1.588	1.890
0	-17.8	0.0864	0.1160	0.1455	0.2040	0.2630	0.3215	0.3800	0.4385	0.4970	0.5555	0.6140	0.672	0.731	0.790	0.849	0.908	0.968	1.114	1.260	1.406	1.553	1.850
10	-12.2	0.0846	0.1136	0.1425	0.1995	0.2568	0.3145	0.3720	0.4292	0.4863	0.5433	0.6006	0.658	0.716	0.774	0.832	0.889	0.947	1.090	1.233	1.376	1.520	1.810
20	-6.7	0.8280	0.1112	0.1395	0.1955	0.2516	0.3071	0.3645	0.4205	0.4770	0.5330	0.5890	0.645	0.701	0.757	0.813	0.869	0.927	1.067	1.208	1.348	1.489	1.770
30	-1.1	0.0811	0.1088	0.1366	0.1916	0.2465	0.3015	0.3570	0.4121	0.4672	0.5221	0.5771	0.632	0.687	0.742	0.797	0.852	0.908	1.046	1.184	1.322	1.406	1.735
40	4.4	0.0795	0.1067	0.1338	0.1876	0.2415	0.2954	0.3503	0.4038	0.4576	0.5114	0.5652	0.619	0.673	0.727	0.781	0.835	0.890	1.025	1.161	1.296	1.431	1.701
50	10.0	0.0780	0.1045	0.1310	0.1939	0.2367	0.2905	0.3432	0.3960	0.4487	0.5014	0.5541	0.607	0.660	0.713	0.766	0.819	0.873	1.006	1.139	1.271	1.403	1.668
60	15.6	0.0764	0.1025	0.1283	0.1803	0.2323	0.2840	0.3362	0.3882	0.4402	0.4927	0.5447	0.596	0.649	0.700	0.752	0.804	0.856	0.988	1.116	1.245	1.376	1.636
70	21.1	0.0750	0.1005	0.1260	0.1770	0.2280	0.2791	0.3302	0.3808	0.4316	0.4824	0.5331	0.584	0.635	0.686	0.737	0.788	0.839	0.967	1.095	1.223	1.350	1.604
80	26.7	0.0736	0.0988	0.1239	0.1738	0.2237	0.2739	0.3242	0.3738	0.4234	0.4729	0.5224	0.572	0.622	0.673	0.723	0.774	0.824	0.949	1.074	1.199	1.325	1.573
90	32.2	0.0723	0.0970	0.1218	0.1707	0.2195	0.2688	0.3182	0.3670	0.4154	0.4639	0.5122	0.561	0.611	0.660	0.709	0.759	0.809	0.932	1.054	1.177	1.300	1.544
100	37.8	0.0710	0.0954	0.1197	0.1676	0.2155	0.2638	0.3122	0.3602	0.4079	0.4555	0.5033	0.551	0.599	0.648	0.696	0.745	0.794	0.914	1.035	1.155	1.276	1.517
110	43.3	0.0698	0.0937	0.1176	0.1645	0.2115	0.2593	0.3070	0.3542	0.4011	0.4481	0.4950	0.542	0.589	0.637	0.685	0.732	0.780	0.899	1.017	1.135	1.254	1.491
120	48.9	0.0686	0.0092	0.1155	0.1618	0.2080	0.2549	0.3018	0.3481	0.3944	0.4403	0.4866	0.533	0.579	0.626	0.673	0.720	0.767	0.884	1.001	1.118	1.234	1.465
130	54.4	0.0674	0.0905	0.1135	0.1590	0.2045	0.2505	0.2966	0.3446	0.3924	0.4296	0.4770	0.524	0.570	0.616	0.662	0.708	0.754	0.869	0.984	1.099	1.214	1.440
140	60.0	0.0663	0.0889	0.1115	0.1565	0.2015	0.2465	0.2915	0.3364	0.3813	0.4262	0.4711	0.516	0.561	0.606	0.651	0.696	0.742	0.855	0.968	1.081	1.194	1.416
150	65.6	0.0652	0.0874	0.1096	0.1541	0.1985	0.2425	0.2865	0.3308	0.3751	0.4193	0.4636	0.508	0.552	0.596	0.640	0.685	0.730	0.841	0.953	1.064	1.175	1.392
175	79.4	0.0626	0.0840	0.1054	0.1482	0.1910	0.2335	0.2755	0.3181	0.3607	0.4033	0.4450	0.488	0.531	0.573	0.616	0.658	0.701	0.808	0.914	1.021	1.128	1.337
200	93.3	0.0603	0.0809	0.1014	0.1427	0.1840	0.2248	0.2655	0.3054	0.3473	0.3882	0.4291	0.470	0.511	0.552	0.592	0.633	0.674	0.776	0.879	0.982	1.084	1.287
225	107	0.0581	0.0779	0.0976	0.1373	0.1770	0.2163	0.2555	0.2949	0.3344	0.3738	0.4120	0.452	0.491	0.531	0.570	0.609	0.649	0.747	0.846	0.944	1.043	1.240
250	121	0.0560	0.0751	0.0941	0.1323	0.1705	0.2085	0.2466	0.2845	0.3232	0.3602	0.3981	0.436	0.474	0.513	0.551	0.589	0.627	0.722	0.817	0.912	1.007	1.197
275	135	0.0541	0.0726	0.0910	0.1278	0.1645	0.2011	0.2378	0.2745	0.3111	0.3478	0.3844	0.421	0.458	0.494	0.531	0.568	0.605	0.697	0.789	0.881	0.972	1.155
300	149	0.0523	0.0707	0.0881	0.1237	0.1592	0.1945	0.2300	0.2654	0.3008	0.3363	0.3716	0.407	0.442	0.478	0.513	0.549	0.585	0.673	0.762	0.852	0.940	1.118
350	177	0.0491	0.0658	0.0825	0.1160	0.1495	0.1828	0.2160	0.2492	0.2824	0.3156	0.3488	0.382	0.415	0.449	0.482	0.516	0.549	0.632	0.715	0.799	0.883	1.048
400	204	0.0463	0.0621	0.0779	0.1090	0.1405	0.1720	0.2035	0.2348	0.2661	0.2974	0.3287	0.360	0.391	0.423	0.454	0.486	0.517	0.596	0.674	0.753	0.831	0.987
150	232	0.0437	0.0586	0.0735	0.1033	0.1330	0.1628	0.1925	0.2220	0.2515	0.2810	0.3105	0.340	0.369	0.399	0.429	0.458	0.488	0.562	0.637	0.711	0.786	0.934
500	260	0.0414	0.0555	0.0696	0.0978	0.1260	0.1540	0.1820	0.2100	0.2380	0.2660	0.2940	0.322	0.351	0.379	0.407	0.435	0.463	0.534	0.604	0.675	0.746	0.885
550	288	0.0394	0.0528	0.0661	0.0930	0.1198	0.1464	0.1730	0.1996	0.2262	0.2528	0.2794	0.306	0.333	0.359	0.386	0.413	0.440	0.507	0.573	0.641	0.709	0.841
600	316	0.0376	0.0504	0.0631	0.0885	0.1140	0.1395	0.1650	0.1904	0.2158	0.2412	0.2668	0.292	0.317	0.343	0.368	0.393	0.419	0.483	0.547	0.611	0.675	0.801

Based on perfect gas laws and air weight of 08071 lbs. Per cu. Ft. at 32° F and barometric pressure of 14696 lbs. Per sq. in.

Altitude and Atmospheric Pressures

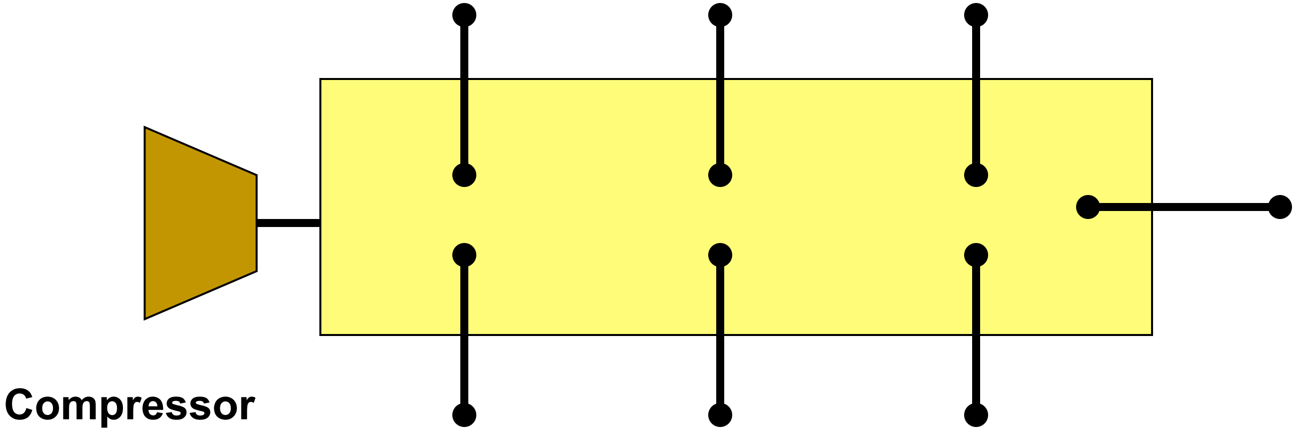
Altitude Above Sea Level Feet	Barometer Inches Hg. Abs.	Atmospheric Pressure PSIA
0	29.92	14.69
250	29.65	14.56
500	29.38	14.43
750	29.12	14.30
1,000	28.86	14.16
1,250	28.60	14.05
1,500	28.33	13.91
1,750	28.08	13.79
2,000	27.82	13.66
2,250	27.57	13.54
2,500	27.32	13.41
2,750	27.07	13.30
3,000	26.82	13.17
3,250	26.58	13.05
3,500	26.33	12.93
3,750	26.09	12.81
4,000	25.84	12.69
4,250	25.61	12.58
4,500	25.37	12.46
4,750	25.14	12.35
5,000	24.90	12.23
5,250	24.67	12.12
5,500	24.44	12.00
5,750	24.21	11.89
6,000	23.99	11.78

Relative Humidity of Air from Readings of Wet and Dry Bulb Thermometers

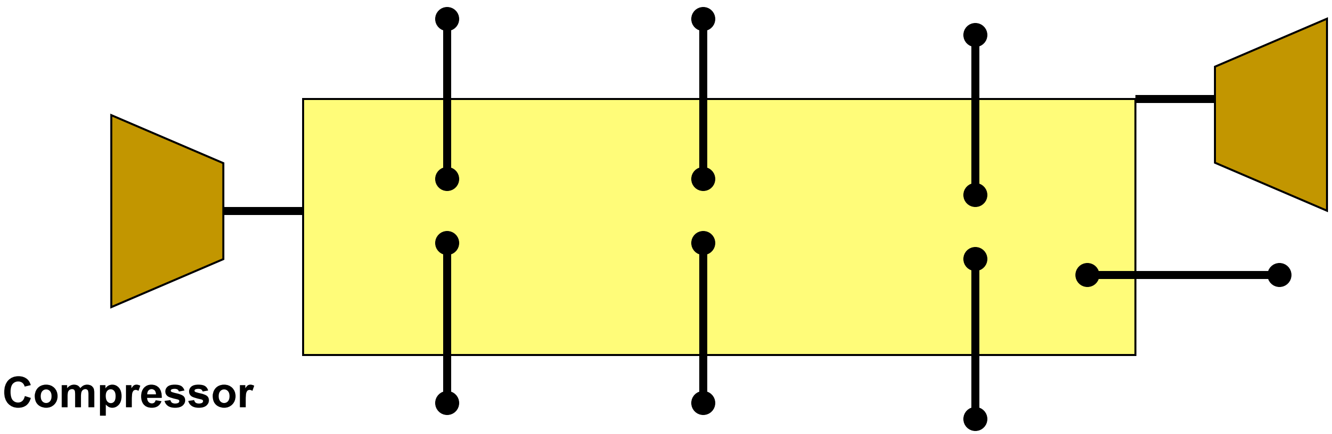
Temperature of air degrees F	Difference between wet and dry bulb Thermometer Degrees Fahrenheit																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
-10	46																								
0	67	33																							
10	78	56	34	13																					
20	85	70	55	40	26	12																			
30	89	78	67	56	46	36	26	15	6																
32	89	79	69	59	49	39	30	20	11	2															
35	91	81	72	63	54	45	36	27	19	10	2														
40	92	83	75	68	60	52	45	37	29	22	15	7	0												
45	93	86	78	71	64	57	51	44	38	31	25	18	12	6											
50	93	87	80	74	67	61	55	49	43	38	32	27	21	16	10	5	0								
55	94	88	82	76	70	65	59	54	49	43	38	33	28	23	19	14	9	5	0						
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1				
62	94	89	84	79	74	69	64	59	54	50	45	41	36	32	28	24	20	16	12	8	4	1			
64	95	90	84	79	74	70	65	60	56	51	47	43	38	34	30	26	22	18	15	11	7	4	0		
66	95	90	85	80	75	71	66	61	57	53	48	44	40	36	32	29	25	21	17	14	10	7	3	0	
68	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	31	27	23	20	16	13	10	6	3	
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3
72	95	91	86	82	77	73	69	65	61	57	53	49	45	42	38	34	31	28	24	21	18	15	12	9	6
74	95	91	86	82	78	74	69	65	51	58	54	50	47	43	39	36	33	29	26	23	20	17	14	11	8
76	96	91	87	82	83	74	70	66	62	59	55	51	48	44	41	38	34	31	28	25	22	19	16	13	11
78	96	91	87	83	83	75	71	67	63	60	56	53	49	46	43	39	36	33	30	27	24	21	18	16	13
80	96	91	87	83	84	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15
82	96	92	88	84	84	76	72	69	65	61	58	55	51	48	45	42	39	36	33	30	28	25	22	20	17
84	96	92	88	84	84	76	73	69	66	62	59	56	52	49	46	43	40	37	35	32	29	26	24	21	19
86	96	92	88	84	85	77	73	70	66	63	60	57	53	50	47	44	42	39	36	33	31	28	26	23	21
88	96	92	88	85	85	77	74	70	67	64	61	57	54	51	48	46	43	40	37	35	32	30	27	25	22
90	96	92	89	85	85	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24
92	96	92	89	85	85	78	75	72	68	65	62	59	56	53	50	48	45	42	40	37	35	32	30	28	25
94	96	93	89	85	85	79	75	72	69	66	63	60	57	54	51	49	46	43	41	38	36	33	31	29	27
96	96	93	89	86	86	79	76	63	69	66	63	61	58	55	52	50	47	44	42	39	37	35	32	30	28
98	96	93	89	86	86	79	76	63	70	67	64	61	58	56	53	50	48	45	43	40	38	36	34	32	29
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30

Condensed from Circular F of the U.S. Weather Bureau

Distribution System Piping Diagram

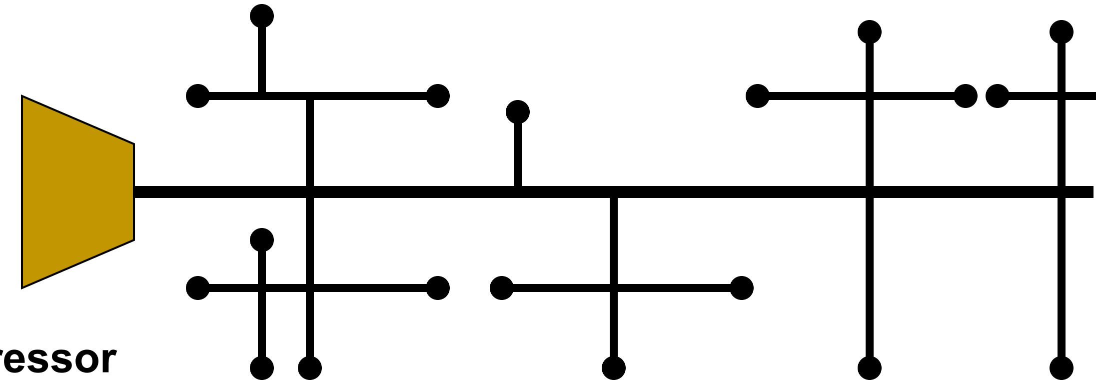


A. Loop - Most Energy Efficient



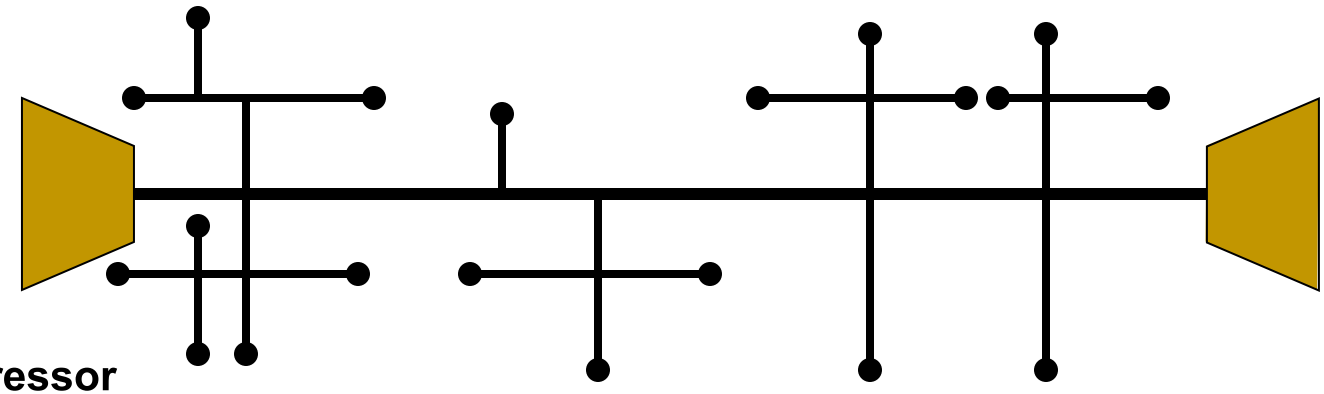
B. Unit - Fair Energy Efficiency

Distribution System Piping Diagram



Compressor

C. Grid - Good Energy Efficiency



Compressor

A. Loop - Least Energy Efficient

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	15	20	30	40	50	75	100	125	150	200	250	300	350
1/2" Schedule 40	10		1.45	1.24	0.96	0.79	0.67	0.48	0.38	0.31	0.26	0.20	0.16	0.14	0.12
	15			2.58	2.08	1.70	1.43	1.04	0.81	0.67	0.57	0.43	0.35	0.30	0.25
	20				3.60	2.94	2.48	1.80	1.41	1.15	0.98	0.75	0.61	0.51	0.44
	30						5.40	3.90	3.05	2.50	2.12	1.63	1.32	1.11	0.96
	40							6.80	5.31	4.37	3.70	2.84	2.30	1.94	1.67
	50								8.20	6.75	5.70	4.37	3.55	2.99	2.58
	60								11.70	9.61	8.16	6.25	5.08	4.27	3.68
	80										14.40	11.00	8.95	7.52	6.50
	100											17.10	13.90	11.70	10.10
3/4" Schedule 40	10	0.42	0.35	0.30	0.23	0.19	0.16	0.12							
	20	1.57	1.31	1.32	0.87	0.71	0.60	0.43	0.34	0.28	0.24	0.18	0.15	0.12	0.11
	35			3.22	2.50	2.04	1.72	1.25	0.98	0.80	0.68	0.52	0.42	0.35	0.31
	50				4.95	4.05	3.42	2.47	1.93	1.59	1.35	1.03	0.84	0.71	0.61
	65						5.71	4.12	3.23	2.65	2.25	1.72	1.40	1.18	1.01
	80							6.19	4.74	3.98	3.37	2.58	2.10	1.76	1.52
	100							9.60	7.53	6.40	5.25	4.02	3.26	2.74	2.37
	125								11.70	9.70	8.12	6.22	5.05	4.25	3.67
	150									12.60	11.50	8.85	7.16	6.03	5.20
	200											15.60	12.60	10.60	9.14
	250												19.70	16.60	14.30

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	15	20	30	40	50	75	100	125	150	200	250	300	350
1" Schedule 40	20	0.45	0.38	0.32	0.25	0.20	0.17	0.13	0.10						
	35	1.25	1.07	0.92	0.71	0.58	0.49	0.35	0.28	0.23	0.19	0.15	0.12	0.10	
	50			1.81	1.40	1.15	0.97	0.70	0.55	0.45	0.38	0.29	0.24	0.20	0.17
	75				3.10	2.53	2.14	1.54	1.21	0.99	0.84	0.65	0.52	0.44	0.38
	100					4.39	3.70	2.68	2.09	1.72	1.46	1.12	0.91	0.76	0.66
	125						5.70	4.10	3.22	2.64	2.24	1.72	1.39	1.17	1.01
	150							5.88	4.60	3.78	3.20	2.46	1.99	1.68	1.45
	200								8.05	6.61	5.61	4.30	3.49	2.94	2.53
	250									10.30	8.87	6.72	5.45	4.59	3.96
	300										12.60	9.66	7.85	6.60	5.70
	400											17.20	14.00	11.70	10.10
	500												21.8	18.30	15.80
1 1/2" Schedule 40	50	0.31	0.25	0.22	0.17	0.14	0.12								
	75	0.65	0.54	0.46	0.36	0.29	0.25	0.18	0.14	0.12	0.10				
	100	1.13	0.94	0.80	0.62	0.51	0.43	0.31	0.24	0.24	0.20	0.17	0.13	0.11	
	125		1.44	1.24	0.96	0.78	0.66	0.48	0.37	0.31	0.26	0.20	0.16	0.14	0.12
	150			1.75	1.35	1.11	0.94	0.68	0.53	0.43	0.37	0.28	0.23	0.19	0.17
	200			3.04	2.36	1.93	1.63	1.18	0.92	0.76	0.64	0.49	0.40	0.34	0.29
	250				3.68	3.01	2.54	1.83	1.44	1.18	1.00	0.77	0.62	0.52	0.45
	300					4.29	3.62	2.62	2.05	1.74	1.43	1.09	0.89	0.75	0.64
	400						6.35	4.58	3.59	2.94	2.50	1.92	1.55	1.31	1.13
	500							7.12	5.59	4.59	3.89	2.98	2.42	2.03	1.76
	600								8.00	6.55	5.55	4.26	3.46	2.91	2.51
	700								10.80	8.89	7.55	5.78	4.70	3.95	3.40
	800									11.60	9.80	7.50	8.10	5.12	4.42
	1000										15.20	11.70	9.45	7.95	6.86
	1200											16.40	13.30	11.20	9.61
	1400											22.90	18.60	15.60	13.50

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	15	20	30	40	50	75	100	125	150	200	250	300	350
2" Schedule 40	75	0.19	0.16	0.13	0.10										
	100	0.28	0.24	0.20	0.16	0.13	0.11								
	150	0.69	0.57	0.49	0.38	0.31	0.26	0.19	0.15	0.12	0.10				
	200	1.20	1.00	0.85	0.66	0.54	0.46	0.33	0.26	0.21	0.18	0.14	0.11		
	250		1.53	1.31	1.02	0.83	0.70	0.51	0.40	0.33	0.26	0.21	0.17	0.15	0.13
	300			1.89	1.47	1.20	1.01	0.73	0.57	0.47	0.40	0.31	0.26	0.21	0.18
	400				2.50	2.04	1.73	1.25	0.98	0.80	0.68	0.52	0.42	0.36	0.31
	500				3.87	3.16	2.67	1.93	1.51	1.24	1.05	0.81	0.65	0.55	0.48
	600					4.50	3.81	2.75	2.15	1.77	1.50	1.05	0.93	0.79	0.58
	800							4.87	3.82	3.13	2.66	2.04	1.65	1.39	1.20
	1000							7.55	5.90	4.85	4.12	3.16	2.56	2.16	1.86
	1250								9.12	7.49	6.35	4.87	3.96	3.32	2.87
	1500									10.80	9.17	7.02	5.70	4.80	4.14
	1750										12.50	9.54	7.74	6.50	5.62
	2000										16.30	12.50	10.10	8.50	7.35
	2250											15.80	12.80	10.80	9.30
	2500											19.40	15.80	13.30	11.40

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	15	20	30	40	50	75	100	125	150	200	250	300	350
2 1/2" Schedule 40	150	0.29	0.24	0.22	0.18	0.13	0.11								
	200	0.50	0.42	0.36	0.28	0.23	0.19	0.14	0.11						
	250	0.80	0.64	0.55	0.43	0.35	0.29	0.21	0.17	0.14	0.12				
	300	1.08	0.90	0.77	0.60	0.49	0.41	0.30	0.23	0.19	0.16	0.13	0.10		
	400		1.57	1.34	1.04	0.85	0.72	0.52	0.41	0.33	0.20	0.22	0.18	0.15	0.13
	500			2.07	1.60	1.31	1.11	0.80	0.63	0.51	0.44	0.33	0.27	0.23	0.20
	600			2.95	2.28	1.87	1.58	1.14	0.89	0.73	0.67	0.48	0.39	0.33	0.28
	800				4.00	3.27	2.76	2.00	1.56	1.28	1.09	0.83	0.68	0.57	0.49
	1000					5.17	4.30	3.19	2.43	1.99	1.69	1.30	1.05	0.88	0.76
	1250						6.78	4.89	3.83	3.14	2.66	2.04	1.66	1.39	1.20
	1500							6.85	5.36	4.40	3.73	2.87	2.32	1.95	1.68
	2000								9.40	7.82	6.55	5.02	4.07	3.42	2.96
	2500									12.10	10.30	7.86	6.39	5.36	4.62
	3000										14.70	11.30	9.13	7.70	6.62
	3500											15.40	12.50	10.50	9.02
	4000											20.00	16.30	13.70	11.80
3" Schedule 40	300	0.36	0.30	0.26	0.20	0.16	0.13	0.10							
	500	0.94	0.78	0.67	0.52	0.43	0.36	0.26	0.20	0.17	0.14	0.11			
	750		1.69	1.44	1.12	0.92	0.78	0.56	0.44	0.36	0.30	0.23	0.19	0.16	0.14
	1000			2.50	1.94	1.59	1.34	0.97	0.76	0.62	0.53	0.41	0.33	0.28	0.24
	1500				4.30	3.52	2.96	2.15	1.68	1.38	1.17	0.90	0.73	0.61	0.53
	2000						5.29	3.81	2.99	2.47	2.08	1.60	1.30	1.09	0.94
	2500							5.96	4.67	3.83	3.26	2.50	2.02	1.70	1.47
	3000							8.58	6.71	5.51	4.68	3.58	2.91	2.45	2.11
	3500								9.15	7.50	6.37	4.89	3.96	3.34	2.88
	4000								11.90	9.80	9.31	6.36	5.16	4.35	3.76
	4500									12.40	10.50	8.06	6.55	5.50	4.75
	5000									15.30	13.00	9.95	8.07	6.80	5.86
	6000											14.30	11.60	9.78	8.45
	7000											19.50	15.90	13.40	11.50

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	15	20	30	40	50	75	100	125	150	200	250	300	350
4" Schedule 40	500	0.24	0.20	0.17	0.13	0.11									
	750	0.52	0.43	0.37	0.29	0.23	0.20	0.14	0.11						
	1000	0.90	0.75	0.64	0.50	0.41	0.34	0.25	0.19	0.16	0.14	0.10			
	1500		1.64	1.41	1.09	0.89	0.75	0.54	0.43	0.35	0.30	0.23	0.18	0.16	0.13
	2000			2.46	1.91	1.56	1.32	0.95	0.75	0.61	0.52	0.40	0.32	0.27	0.23
	2500				2.96	2.42	2.04	1.47	1.16	0.95	0.80	0.62	0.50	0.42	0.34
	3000				4.20	3.44	2.91	2.10	1.64	1.35	1.14	0.88	0.71	0.60	0.52
	4000						5.15	3.11	2.90	2.38	2.02	1.55	1.26	1.06	0.91
	5000							5.75	4.50	3.70	3.14	2.40	1.95	1.64	1.42
	6000							8.22	6.45	5.30	4.50	3.44	2.79	2.35	2.03
	7000								8.77	7.20	6.10	4.68	3.80	3.20	2.76
	8000								11.50	9.40	8.00	6.11	4.95	4.17	3.60
	10,000									14.70	12.50	9.55	7.75	6.52	5.02
	12,000											13.80	11.80	9.40	8.10
	14,000											18.80	15.20	12.80	11.00
5" Schedule 40	1000	0.29	0.24	0.20	0.18	0.16	0.14	0.13	0.11						
	1500	0.62	0.52	0.44	0.39	0.34	0.31	0.28	0.24	0.21	0.16	0.13	0.11		
	2000	1.09	0.91	0.78	0.68	0.60	0.54	0.49	0.42	0.36	0.28	0.24	0.19	0.16	0.13
	2500		1.39	1.19	1.04	0.92	0.83	0.75	0.54	0.55	0.44	0.36	0.30	0.25	0.19
	3000		1.98	1.69	1.48	1.31	1.18	1.07	0.91	0.79	0.62	0.51	0.42	0.36	0.27
	4000			2.99	2.61	2.32	2.08	1.89	1.60	1.39	1.09	0.90	0.74	0.63	0.48
	5000				4.02	3.68	3.22	2.92	2.47	2.14	1.69	1.40	1.15	0.97	0.75
	6000						4.50	4.18	3.64	3.07	2.42	2.00	1.64	1.39	1.07
	8000								6.24	5.40	4.26	3.53	2.90	2.46	1.88
	10,000									8.40	6.62	5.47	4.50	3.82	2.92
	12,000										9.50	7.88	6.47	5.50	4.20
	14,000											10.70	8.80	7.46	5.72
	16,000												11.50	9.75	7.47
	18,000												14.50	12.40	9.45
	20,000													15.20	11.70

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	15	20	30	40	50	75	100	125	150	200	250	300	350
6" Schedule 40	1500	0.25	0.20	0.18	0.15	0.14	0.12	0.11							
	2000	0.43	0.36	0.31	0.27	0.24	0.21	0.19	0.16	0.14	0.11				
	2500	0.66	0.55	0.47	0.41	0.36	0.33	0.30	0.25	0.22	0.17	0.14	0.12	0.10	
	3000	0.94	0.78	0.67	0.58	0.52	0.47	0.42	0.36	0.31	0.24	0.20	0.17	0.14	0.11
	4000		1.36	1.16	1.01	0.90	0.81	0.74	0.62	0.54	0.43	0.35	0.29	0.25	0.19
	5000			1.80	1.58	1.40	1.26	1.14	0.97	0.84	0.66	0.53	0.45	0.38	0.29
	6000			2.58	2.26	2.00	1.80	1.64	1.38	1.20	0.95	0.78	0.64	0.55	0.42
	8000				3.98	3.54	3.18	2.89	2.44	2.12	1.67	1.38	1.13	0.96	0.74
	10,000						4.90	4.45	3.77	3.26	2.57	2.13	1.75	1.48	1.14
	12,500								5.85	5.06	4.00	3.30	2.71	2.30	1.76
	15,000									7.30	5.75	4.75	3.90	3.32	2.54
	17,500										7.82	6.47	5.30	4.50	3.46
	20,000											8.45	6.95	5.88	4.51
	25,000												10.80	9.20	7.05
	30,000													13.30	10.20
8" Schedule 40	3000	0.23	0.19	0.17	0.14	0.13	0.10								
	4000	0.40	0.34	0.29	0.25	0.22	0.18	0.15	0.13	0.12	0.11				
	5000	0.57	0.47	0.41	0.35	0.31	0.26	0.22	0.19	0.17	0.15	0.13	0.12	0.11	0.10
	7500	1.37	1.14	0.98	0.85	0.74	0.62	0.52	0.45	0.40	0.36	0.32	0.30	0.27	0.24
	12,000		2.00	1.71	1.50	1.33	1.08	0.92	0.80	0.70	0.63	0.57	0.52	0.48	0.43
	12,500			2.62	2.29	2.04	1.66	1.41	1.22	1.04	0.96	0.87	0.80	0.73	0.65
	15,000				3.30	2.94	2.39	2.02	1.75	1.55	1.38	1.25	1.14	1.06	0.94
	17,500					3.96	3.26	2.76	2.39	2.10	1.88	1.71	1.56	1.43	1.28
	20,000						4.22	3.56	3.09	2.73	2.44	2.21	2.02	1.85	1.66
	25,000							5.58	4.83	4.26	3.81	3.45	3.16	2.90	2.59
	30,000								6.90	6.08	5.45	4.92	4.50	4.15	3.69
	35,000									8.30	7.40	6.70	6.12	5.64	5.03
	40,000										9.64	8.74	8.00	7.35	6.55
	45,000											11.10	10.20	9.35	8.33

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	15	20	30	40	50	75	100	125	150	200	250	300	350
10" Schedule 40	5000	0.20	0.16	0.14	0.12	0.11									
	7500	0.43	0.36	0.31	0.27	0.24	0.19	0.16	0.14	0.13	0.11				
	10,000	0.75	0.63	0.54	0.47	0.42	0.34	0.29	0.25	0.22	0.20	0.18	0.16	0.15	0.13
	12,500	1.16	0.97	0.83	0.72	0.64	0.52	0.44	0.38	0.34	0.30	0.27	0.25	0.23	0.21
	15,000		1.38	1.18	1.03	0.91	0.75	0.63	0.55	0.48	0.43	0.39	0.36	0.33	0.29
	17,500		1.87	1.50	1.40	1.24	1.01	0.86	0.74	0.66	0.59	0.53	0.49	0.45	0.40
	20,000			2.07	1.81	1.60	1.31	1.11	0.96	0.85	0.76	0.69	0.63	0.58	0.50
	25,000				2.82	2.50	2.05	1.73	1.50	1.32	1.18	1.07	0.98	0.90	0.80
	30,000					3.58	2.92	2.47	2.14	1.89	1.69	1.53	1.40	1.28	1.15
	35,000						3.98	3.37	2.92	2.58	2.30	2.08	1.90	1.75	1.54
	40,000						5.20	4.40	3.80	3.55	3.00	2.72	2.48	2.28	2.04
	50,000								5.90	5.20	4.65	4.20	3.85	3.54	3.16
	60,000									7.50	6.70	6.07	5.55	5.10	4.55
	70,000										9.13	8.25	7.55	6.95	6.20
	80,000											10.80	9.85	9.05	8.10

Pressure Loss in Pounds for Each 100 Feet of Straight Pipe

Nominal Pipe Size	CFM Free Air	Line Pressure - PSIG													
		10	12.5	15	17.5	20	25	30	40	50	60	70	80	90	100
12" Schedule 40	7500	0.18	0.15	0.13	0.11	0.10									
	10,000	0.31	0.26	0.22	0.19	0.17	0.14	0.12	0.10						
	12,500	0.48	0.40	0.34	0.30	0.26	0.22	0.18	0.16	0.14	0.12	0.11	0.10		
	15,000	0.68	0.57	0.49	0.43	0.38	0.31	0.26	0.23	0.20	0.18	0.16	0.15	0.14	0.12
	17,500	0.92	0.77	0.64	0.58	0.51	0.42	0.35	0.31	0.27	0.24	0.22	0.20	0.18	0.16
	20,000	1.20	1.00	0.85	0.75	0.66	0.54	0.46	0.40	0.35	0.31	0.28	0.26	0.24	0.21
	25,000		1.57	1.34	1.17	1.04	0.85	0.72	0.62	0.55	0.49	0.45	0.41	0.37	0.33
	30,000			1.89	1.85	1.47	1.20	1.01	0.88	0.77	0.69	0.63	0.57	0.53	0.47
	35,000			2.54	2.24	1.98	1.62	1.37	1.19	1.05	0.94	0.85	0.77	0.71	0.64
	40,000				2.91	2.59	2.12	1.79	1.55	1.37	1.22	1.11	1.01	0.93	0.83
	50,000					4.00	3.27	2.78	2.39	2.11	1.89	1.71	1.56	1.44	1.28
	60,000						4.69	3.96	3.43	3.03	2.71	2.45	2.24	2.06	1.84
	80,000								6.10	5.37	4.80	4.35	3.97	3.66	3.28
	100,000									8.40	7.51	6.61	6.21	5.71	5.10
	125,000											10.70	9.70	8.95	7.98

Pressure Loss In Pounds For Lengths Other Than 100 Feet

The friction loss in pipe lengths shorter than 100 feet may be calculated proportional to the length. That is: for 50 feet, ½ the tabular figure; for 25 feet, ¼ the tabular figure, etc.

In pipe runs of more than 100 feet, the proportional method may be used providing the resultant friction loss does not exceed 9 or 10 psi. If it is greater, a more accurate check may prevent undersizing of pipes. Use the following method, based on the Fanning Equations from which these tables were derived:

Calculate first a conversion figure "K":

$$K = \frac{F_{100}\,(P \bullet \tfrac{1}{2} F_{100})}{100}$$

Then:

$F_1 = P - \boxed{?}P^2 * 2KL$

Where:

F_{100} = tabular friction loss figure for 100 ft.

F_1 = friction loss for length "L"

L = length of pipe in feet

and P = upstream pressure in pipe, psia

Friction of Air in Hose

Size of Hose, coupled each end (in.)	Cage Pressure at line (lb.)	Cubic Feet Free Air Per Min. Passing through 50 Feet Lengths of Hose											
		20	30	40	50	60	70	80	90	100	110	120	130
		Loss of Pressure (psi) in 50 Feet Lengths of Hose											
1/2	50	1.8	5.0	10.1	18.1								
	60	1.3	4.0	8.4	14.8	23.4							
	70	1.0	3.4	7.0	12.4	20.0	28.4						
	80	0.9	2.8	6.0	10.8	17.4	25.2	34.8					
	90	0.8	2.4	5.4	9.5	14.8	22.0	30.5	41.0				
	100	0.7	2.3	4.8	8.4	13.3	19.3	27.2	36.6				
	110	0.6	2.0	4.3	7.6	12.0	17.6	24.6	33.3	44.5			
3/4	50	0.4	0.8	1.5	2.4	3.5	4.4	6.5	8.5	11.4	14.2		
	60	0.3	0.6	1.2	1.9	2.8	3.8	5.2	6.8	8.6	11.2		
	70	0.2	0.5	0.9	1.5	2.3	3.2	4.2	5.5	7.0	8.8	11.0	
	80	0.2	0.5	0.8	1.3	1.9	2.8	3.6	4.7	5.8	7.2	8.8	10.5
	90	0.2	0.4	0.7	1.1	1.6	2.3	3.1	4.0	5.0	6.2	7.5	9.0
	100	0.2	0.4	0.6	1.0	1.4	2.0	2.7	3.5	4.4	5.4	6.6	7.9
	110	0.1	0.3	0.5	0.9	1.3	1.8	2.4	3.1	3.9	4.9	5.9	7.1
1	50	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2.0	2.6	3.5	4.8	7.0
	60	1.1	0.2	0.3	0.4	0.6	0.8	1.2	1.5	2.0	2.6	3.3	4.2
	70		0.1	0.2	0.4	0.5	0.7	1.0	1.3	1.6	2.0	2.5	3.1
	80		0.1	0.2	0.3	0.5	0.7	0.8	1.1	1.4	1.7	2.0	2.4
	90		1.1	0.2	0.3	0.4	0.6	0.7	0.9	1.2	1.4	1.7	2.0
	100		1.1	0.2	0.2	0.4	0.5	0.6	0.8	1.0	1.2	1.5	1.8
	110		0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.5

Friction Loss of Air in Pipe Fittings

(Expressed in Terms of Equivalent Feet of Straight Pipe)

Nominal Pipe Size Inches	Schedule Number	Inside Diameter		Globe Valve	Angle Valve	Gate Valve	Swing Check Valve	Plug Cock	45° Std. Elbow	90° Std. Elbow	90° Long Radius Elbow	Standard Tee		Close Return Brand	90° Welding Elbow	
												Run of Tee	Side Outlet			
		IN.	FT.	L/D = 340	L/D = 145	L/D = 13	L/D = 135	L/D = 18	L/D = 16	L/D = 30	L/D = 20	L/D = 20	L/D = 60	L/D = 30	Short Radius	Long Radius
½	40	0.622	0.0518	17.6	7.5	.67	7.0	.93	.83	1.55	1.04	1.04	3.11	2.59		
¾	40	0.824	0.0685	23.3	9.9	.89	9.2	1.23	1.10	2.06	1.37	1.37	4.11	3.43		
1	40	1.049	0.0872	29.7	13.6	1.14	11.8	1.57	1.40	2..62	1.74	1.74	5.20	4.36	1.4	1.1
1 ½	40	1.610	0.134	45.5	19.4	1.74	18.1	2.41	2.14	4.02	2.68	2.68	8.10	6.70	2.1	1.6
2	40	2.067	0.172	59.0	25.0	2.24	23.2	3.10	2.75	5.20	3.44	3.44	10.30	9.60	2.8	2.1
2 ½	40	2.469	0.206	70.0	29.9	2.68	27.8	3.70	3.30	6.20	4.12	4.12	12.40	10.30	3.3	2.5
3	40	3.068	0.256	87.0	37.1	3.32	34.6	4.60	4.10	7.70	5.10	5.10	15.40	12.80	4.1	3.1
4	40	4.026	0.335	114.0	48.5	4.35	45.2	6.00	5.40	10.10	6.70	6.70	20.10	16.80	5.4	4.0
5	40	5.047	0.420	143.0	61.0	5.50	57.0	7.60	6.70	12.60	9.40	8.40	25.20	21.00	6.7	5.1
6	40	6.065	0.505	172.0	73.0	6.60	68.0	9.10	8.10	15.10	10.10	10.10	30.30	25.30	8.1	6.1
8	40	7.981	0.665	226.0	96.0	8.70	90.0	12.00	10.70	19.90	13.30	13.30	40.00	33.30	11.0	8.0
10	40	10.020	0.836	284.0	121.0	10.90	11.3	15.00	13.40	25.10	16.70	16.70	50.20	41.80	13.0	10.0
12	40	11.938	0.995			13.00	13.4	17.90	15.90	29.80	19.90	19.90	60.00	50.00	16.0	12.0
14	30	13.250	1.104			14.30	149.0		17.70	33.20	22.10	22.10	64.00	55.00	18.0	13.0
16	30	15.250	1.270			16.50	171.0		20.30	38.20	25.40	25.40	76.00	64.00	20.0	15.0
18	30	17.124	1.430			18.60	193.0		22.80	43.20	28.60	28.60	86.00	72.00	23.0	17.0
20	20	19.250	1.600			20.80	216.0		25.60	48.00	32.00	32.00	96.00	80.00	25.0	19.0
24	20	23.250	1.940			25.20	262.0		31.00	58.00	38.80	38.80	117.00	97.00	30.0	23.0

All valves and cocks to be fully open.

Check valves pressure 0.50 PSI pressure loss to open fully.

Welding elbow data from Midwest Piping Catalog 61 (1961).

L/D valves from Crone Co. Technical Paper No. 410 (1957). Both L and D in feet.

Discharge of Air Through an Orifice

In cubic feet of free air per minute at standard atmospheric pressure of 14.7 lb. Per square inch absolute and 70° F

Gauge Pressure before Orifice in Pounds per sq. in.	Diameter of Orifice										
	1/64"	**1/32"**	**1/14"**	**1/8"**	**1/4"**	**3/8"**	**1/2"**	**1/8"**	**3/4"**	**7/8"**	**1"**
	Discharge in cubic feet at free air per minute										
1	0.028	0.112	0.450	1.80	7.18	16.2	28.7	45.0	64.7	88.1	115
2	0.040	0.158	0.633	2.53	10.1	22.8	40.5	63.3	91.2	124	162
3	0.048	0.194	0.775	3.10	12.4	27.8	49.5	77.5	111.0	152	198
4	0.056	0.223	0.892	3.56	14.3	32.1	57.0	89.2	128.0	175	228
5	0.062	0.248	0.993	3.97	15.9	35.7	63.5	99.3	143.0	195	254
6	0.068	0.272	1.09	4.34	17.4	39.1	69.5	109	156	213	278
7	0.073	0.293	1.17	4.68	18.7	42.2	75.0	117	168	230	300
9	0.083	0.331	1.32	5.30	21.2	47.7	84.7	132	191	260	339
12	0.095	0.379	1.52	6.07	24.3	54.6	97.0	152	218	297	388
15	0.105	0.420	1.68	6.72	26.9	60.5	108	168	242	329	430
20	0.123	0.491	1.96	7.86	31.4	70.7	126	196	283	385	503
25	0.140	0.562	2.25	8.98	35.9	80.9	144	225	323	440	575
30	0.158	0.633	2.53	10.1	40.5	91.1	162	253	365	496	648
35	0.176	0.703	2.81	11.3	45.0	101	180	281	405	551	720
40	0.194	0.774	3.10	12.4	49.6	112	198	310	446	607	791
45	0.211	0.845	3.38	13.5	54.1	122	216	338	487	662	865
50	0.229	0.916	3.66	14.7	58.6	132	235	366	528	718	938
60	0.264	1.06	4.23	16.9	67.6	152	271	423	609	828	1082
70	0.300	1.20	4.79	19.2	76.7	173	307	479	690	939	1227
80	0.335	1.34	5.36	21.4	85.7	193	343	536	771	1050	1371

Discharge of Air Through an Orifice

In cubic feet of free air per minute at standard atmospheric pressure of 14.7 lb. Per square inch absolute and 70° F

Gauge Pressure before Orifice in Pounds per sq. in.	Diameter of Orifice										
	1/64"	1/32"	1/14"	1/8"	1/4"	3/8"	1/2"	1/8"	3/4"	7/8"	1"
	Discharge in cubic feet at free air per minute										
90	0.370	1.48	5.92	23.7	94.8	213	379	592	853	1161	1516
100	0.406	1.62	6.49	26.0	104	234	415	649	934	1272	1661
110	0.441	1.76	7.05	28.2	113	254	452	705	1016	1383	1806
120	0.476	1.91	7.62	30.5	122	274	488	762	1097	1494	1951
125	0.494	1.98	7.90	31.6	126	284	506	790	1138	1549	2023
150	0.582	2.37	9.45	37.5	150	338	600	910	1315	1789	2338
200	0.761	3.10	12.35	49.0	196	441	784	1225	1764	2401	3136
250	0.935	3.80	15.18	60.3	241	542	964	1508	2169	2952	3856
300	0.995	4.88	18.08	71.8	287	646	1148	1795	2583	3515	4592
400	1.220	5.98	23.81	94.5	378	851	1512	2360	3402	4630	6048
500	1.519	7.41	29.55	117.3	469	1055	1876	2930	4221	5745	7504
750	2.240	10.98	43.85	174.0	696	1566	2784	4350	6264	8525	11136
1000	2.985	14.60	58.21	231.0	924	2079	3696	5790	8316	11318	14784

Table is based on 100% coefficient of flow. For well rounded entrance multiply values by 0.97. For sharp edged orifices a multiplier of 0.61 may be used for approximate results.

Values for pressures from 1 to 15 lbs. Gauge calculated by standard adiabatic formula.

Values for pressures above 15 lbs. Gauge calculated by approximate formula proposed by S.A. Moss.

$$W = 0.5303 \frac{AC_{P1}}{\boxed{?}\ T_1}$$

Where:

- W = Discharge in lbs. Per set
- A = Area of orifice in sq. in.
- C = Coefficient of flow
- $_{P1}$ = Upstream total pressure in lbs. Per sq. in. absolute
- T_1 = Upstream temperature in F. abs.

Values used in calculating above table were; C = 1.0, $_{p1}$ = gauge pressure + 14.7 lbs./sq.in. T_1 = 530°F. abs.

Weights (W) were converted to volume using density factor of 0.07494 lbs./cu. ft. This is correct for dry air at 14.7 lbs. Per sq. in. absolute pressure and 70° F.

Formula cannot be used where $_{p1}$ is less than two times the downstream pressure.

CFM vs. Pressure for Various Orifices

Flow is expressed in cubic feet per minute, and is assumed to take place from a receiver or other vessel, in which air is contained under pressure, into the atmosphere at sea level. Temperature of air in receiver is assumed at 60° F. This table is only correct for orifices with narrow edges; flow through even a short length of pipe would be less than that given below.

Receiver Gage Pressure Lbs.	Flow of Free Air (Cu. Ft. Per Min.) through Orifices of Various Diameters							
	1/64 "	1/32 "	3/64 "	1/16 "	3/32 "	1/8 "	3/16 "	1/4 "
1	0.027	0.107	0.242	0.430	0.97	1.72	3.86	6.85
2	0.038	0.153	0.342	0.607	1.36	2.43	5.42	9.74
3	0.046	0.188	0.471	0.750	1.68	2.98	6.71	11.90
5	0.059	0.242	0.545	0.965	2.18	3.86	8.71	15.40
10	0.084	0.342	0.770	1.360	3.08	5.45	12.30	21.80
15	0.103	0.418	0.940	0.167	3.75	6.65	15.00	26.70
20	0.119	0.485	1.070	1.930	4.25	7.70	17.10	30.80
25	0.133	0.540	1.210	2.160	4.75	8.60	19.40	34.50
30	0.156	0.632	1.400	2.520	5.60	10.00	22.50	40.00
35	0.173	0.710	1.560	2.800	6.20	11.20	25.00	44.70
40	0.190	0.770	1.710	3.070	6.80	12.30	27.50	49.10
45	0.208	0.843	1.900	3.360	7.60	13.40	30.30	53.80
50	0.225	0.914	2.050	3.640	8.20	14.50	32.80	58.20
60	0.260	1.050	2.350	4.200	9.40	16.80	37.50	67.00
70	0.295	1.190	2.680	4.760	10.70	19.00	43.00	76.00
80	0.330	1.330	2.970	5.320	11.90	21.20	47.50	85.00
90	0.364	1.470	3.280	5.870	13.10	23.50	52.50	94.00
100	0.400	1.610	3.660	6.450	14.50	25.80	58.30	103.00
110	0.430	1.760	3.950	7.000	15.70	28.00	63.00	112.00
120	0.470	1.900	4.270	7.580	17.00	30.20	68.00	121.00
130	0.500	2.040	4.570	8.130	18.20	32.40	73.00	130.00
140	0.540	2.170	4.870	8.680	19.50	34.50	78.00	138.00
150	0.570	2.330	5.200	9.200	20.70	36.70	83.00	147.00
175	0.660	2.650	5.940	10.600	23.80	42.10	95.00	169.00
200	0.760	3.070	6.900	12.200	27.50	48.70	110.00	195.00

Air Receivers

SIZING:

A rule of thumb is:

- The receiver should be sized as a minimum for 10% of the compressor capacity (cubic feet).

Formula for Calculating Exact Size

$$T = \frac{V \ \text{x} \ \text{Delta P}}{\text{Patm} \ \text{Xx} \ (\text{Qin} - \text{Qout})} \ \text{x} \ 60$$

Where:

T	= 1 Load Cycle (sec.)
V	= Air Network Volume (cubic feet)
Delta P	= Difference Between Cut In and Cut Out Pressure (PSI)
Patm	= Jobsite Ambient Pressure (PSIA)
Qin	= Flow Into Receiver (CFM)
Qout	= Flow Out of Receiver (CFM)

Note: The worst case is at a 50% load factor (Qin/2).

Standard American Receiver Sizes

Diameter IN.	Length FT.	Volume CU. FT.
24	6	19
30	7	34
36	8	57
42	10	96
48	12	151
54	14	223
60	16	314
66	18	428

Example:

Select an air receiver for a 1250 CFM air compressor.

- Using rule of thumb, min. capacity should be 125 cubic feet from standard size receivers. Select the size that meets this minimum requirement (151 cubic feet).
- Using the formula, assume the following:

T = 10 Sec. (3 cycles/min)

Delta P = 10 PSI

50% Load Factor

Therefore:

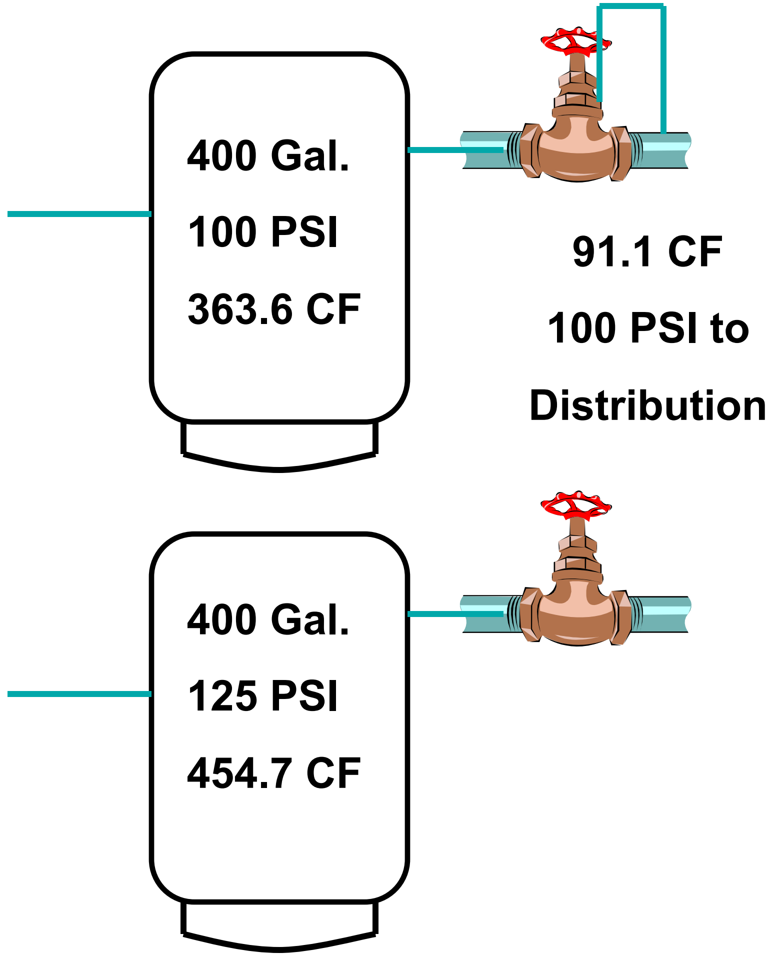
$$\boxed{10 = \frac{V \times 10 \times 60}{14.7 \times (1250/2)}}$$

V = 153 Cubic Feet in the Network (Receiver + Piping)

The full storage is the volume which can be drawn off the tank at a stored pressure until the pressure is reduced to the regulated pressure you are removing it at. Example: If you were to store air in a 400 gallon tank at 125 PSIG, how much volume would be removed before the tank pressure was at the discharge regulated pressure of 100 PSIG?

The useful storage is dependent on a control differential.

If air is taken out of this system at the same pressure that it is compressed, there is no storage regardless of the size or number of tanks. The only storage is present when the system is started and first turned on which may help prevent the compressors from going into drawdown initially. Without regulation either at the discharge of the receivers or at all use points, there is no storage and air is taken directly off the compressor head or airend. This causes the owner to interpret the HP requirements higher than would be necessary with a balanced system. It also causes maintenance and operating problems in the system.



Compresses Air Receiver Storage Capacity

The chart below indicates how much free air is stored at various pressures for different size tanks. It does not indicate that this is the useful storage.

Tank Dimensions	Capacity Gallons	Capacity in cubic feet of free air @ Gauge shown @ 14.7 PSIA BP								
		ATMS 1	4.5	7.8	9.5	11.2	12.9	14.6	18	21.4
		PSIG 0	50	100	125	150	175	200	250	300
14" X 36"	20	2.7	9.2	18.2	23	27.5	32.1	36.7	45.9	55.1
15" X 36"	30	4.0	13.6	27.2	34	40.8	47.6	54.4	68	81.6
20" X 48"	60	8.0	27.2	54.4	68	81.6	95.2	108.8	136.1	163.2
20" X 63"	80	10.7	36.4	72.8	91	109.1	127.3	145.5	181.9	218.3
24" X 68"	120	16.0	54.4	108.8	136	163.2	190.4	217.6	272	326.4
30" X 84"	240	32.0	108.8	217.6	272	326.4	380.8	435.2	544	652.8
36" X 96"	400	53.5	181.8	363.6	454.7	545.4	636.3	727.2	908.9	1090.8
42" X 117"	660	88.2	299.9	599.9	749.9	899.9	1049.9	1199.9	1499.9	1799.9
48" X 144"	1060	141.7	479.4	963.6	1204.5	1445.4	1686.3	1927.3	2409.1	2890.7
54" X 166"	1150	207.2	704.5	1409.1	1761.4	2113.6	2465.9	2818.2	3522.7	4227.3

Storage Capacity Worksheet

Average PSI																	
150	0.34	0.68	1.02	1.36	1.7	2.04	2.38	2.72	3.06	3.4	3.74	**4.08**	4.42	4.76	5.1	5.44	5.78
145		0.34	0.68	1.02	1.36	1.7	2.04	2.38	2.72	3.06	3.4	**3.74**	4.08	4.42	4.76	5.1	5.44
140			0.34	0.68	1.02	1.36	1.7	2.04	2.38	2.72	3.06	**3.4**	3.74	4.08	4.42	4.76	5.1
135				0.34	0.68	1.02	1.36	1.7	2.04	2.38	2.72	**3.06**	3.4	3.74	4.08	4.42	4.76
130					0.34	0.68	1.02	1.36	1.7	2.04	2.38	**2.72**	3.06	3.4	3.74	4.08	4.42
125						0.34	0.68	1.02	1.36	1.7	2.04	**2.38**	2.72	3.06	3.4	3.74	4.08
120							**0.34**	**0.68**	**1.02**	**1.36**	**1.7**	**2.04**	**2.38**	**2.72**	**3.06**	**3.4**	**3.74**
115								0.34	0.68	1.02	1.36	**1.7**	2.04	2.38	2.72	3.06	3.4
110									0.34	0.68	1.02	**1.36**	1.7	2.04	2.38	2.72	3.06
105										0.34	0.68	**1.02**	1.36	1.7	2.04	2.38	2.72
100											0.34	**0.68**	1.02	1.36	1.7	2.04	2.38
95												**0.34**	0.68	1.02	1.36	1.7	2.04
90													0.34	0.68	1.02	1.36	1.7
85														0.34	0.68	1.02	1.36
80															0.34	0.68	1.02

Capacity Required (1) Minute Event

Storage in Gallons

5.78	129	259	388	518	647	776	906	1035	1165	1294	1424	1553	1682	1812	1941	2071	2200
5.44	138	275	413	550	688	825	963	1100	1238	1375	1513	1650	1788	1925	2063	2200	2338
5.1	147	293	440	587	733	880	1027	1173	1320	1467	1613	1760	1907	2053	2200	2347	2493
4.76	157	314	471	629	786	943	1100	1257	1414	1571	1729	1886	2043	2200	2357	2514	2671
4.42	169	338	506	677	846	1015	1185	1354	1523	1692	1862	2031	2200	2369	2538	2708	2877
4.08	183	367	550	733	917	1100	1283	1467	1650	1833	2017	32200	2383	2567	2750	2933	3117
3.74	200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400
3.4	220	440	660	880	1100	1320	1540	1760	1980	2200	2420	2640	2860	3080	3300	3520	3740
3.06	244	489	733	978	1222	1467	1711	1956	2200	2444	2689	2933	3178	3422	3667	3911	4156
2.72	275	550	825	1100	1375	1650	1925	2200	2475	2750	3025	3300	3575	3850	4125	4400	4675
2.38	314	629	943	1257	1571	1886	2200	2514	2829	3143	3457	3771	4086	4400	4714	5029	5343
2.04	**367**	**733**	**1100**	**1467**	**1833**	**2200**	**2567**	**2933**	**3300**	**3667**	**4033**	**4400**	**4767**	**5133**	**5500**	**5867**	**6223**
1.7	440	880	1320	1760	2200	2640	3080	3520	3960	4400	4840	5280	5720	6160	6600	7040	7480
1.36	550	1100	1650	2200	2750	3300	3850	4400	4950	5500	6050	6600	7150	7600	8250	8800	9350
1.02	733	1467	2200	2933	3667	4400	5133	5867	6600	7333	8067	8800	9533	10267	11000	11733	12467
0.68	1000	2100	3200	4300	5400	6500	7600	8700	9800	10900	12000	13100	14200	15300	16400	17500	18600
0.34	2200	4400	6600	8800	11000	13200	15300	17600	19800	22000	24200	26400	28500	30700	33000	35200	37400
Event Cu'	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700

Capacity Required (1) Minute Event

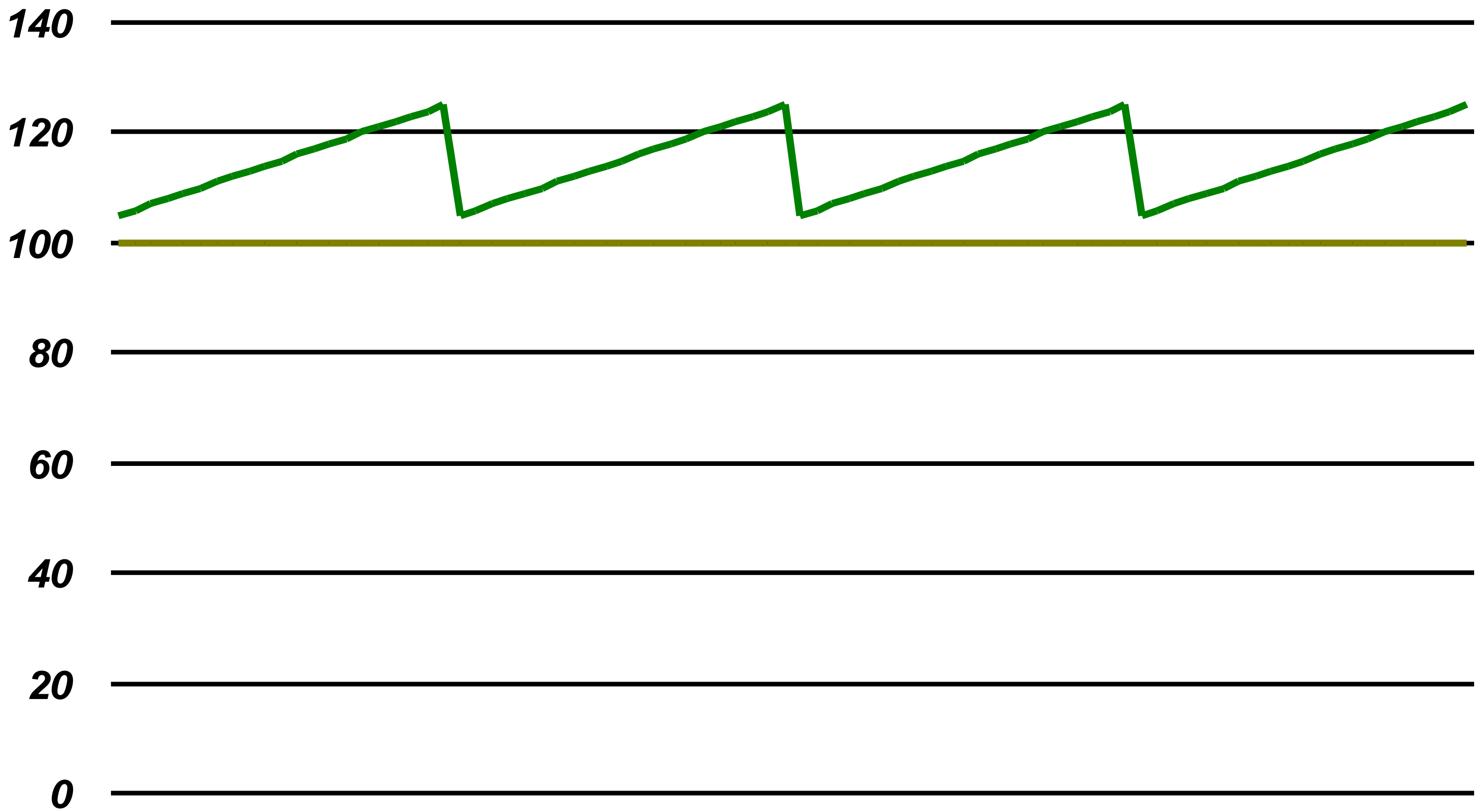
Storage in Cubic Feet

5.78	17	35	52	69	87	104	121	138	156	173	190	208	225	242	260	277	294
5.44	18	37	55	74	92	110	129	147	165	184	202	221	239	257	276	294	313
5.1	20	39	59	78	98	118	137	157	176	196	216	235	255	275	294	314	333
4.76	21	42	63	84	105	126	147	168	189	210	231	252	273	294	315	336	357
4.42	23	45	68	90	113	136	158	181	204	226	249	271	294	317	339	362	385
4.08	25	49	74	98	123	147	172	196	221	245	270	294	319	343	368	392	417
3.74	27	53	80	107	134	160	187	214	241	267	294	321	348	374	401	428	455
3.4	29	59	88	118	147	176	206	235	265	294	324	353	382	412	441	471	500
3.06	33	65	98	131	163	196	229	261	294	327	359	392	425	458	490	523	556
2.72	37	74	110	147	184	221	257	294	331	368	404	441	478	515	551	588	625
2.38	42	84	126	168	210	252	294	336	378	420	462	504	546	588	630	672	714
2.04	**49**	**98**	**147**	**196**	**245**	**294**	**343**	**392**	**441**	**490**	**539**	**588**	**637**	**686**	**735**	**784**	**833**
1.7	59	118	176	235	294	353	412	471	529	588	647	706	765	824	882	941	1000
1.36	74	147	221	294	368	441	515	588	662	735	809	882	956	1029	1103	1176	1250
1.02	98	196	294	392	490	588	686	784	882	980	1078	1176	1275	1373	1471	1569	1667
0.68	147	294	441	588	735	882	1029	1176	1324	1471	1618	1765	1912	2059	2206	2353	24X0
0.34	294	588	882	1176	1471	1765	2059	2353	2647	2941	3235	3529	3824	4118	4412	4706	5000
Event Cu'	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700

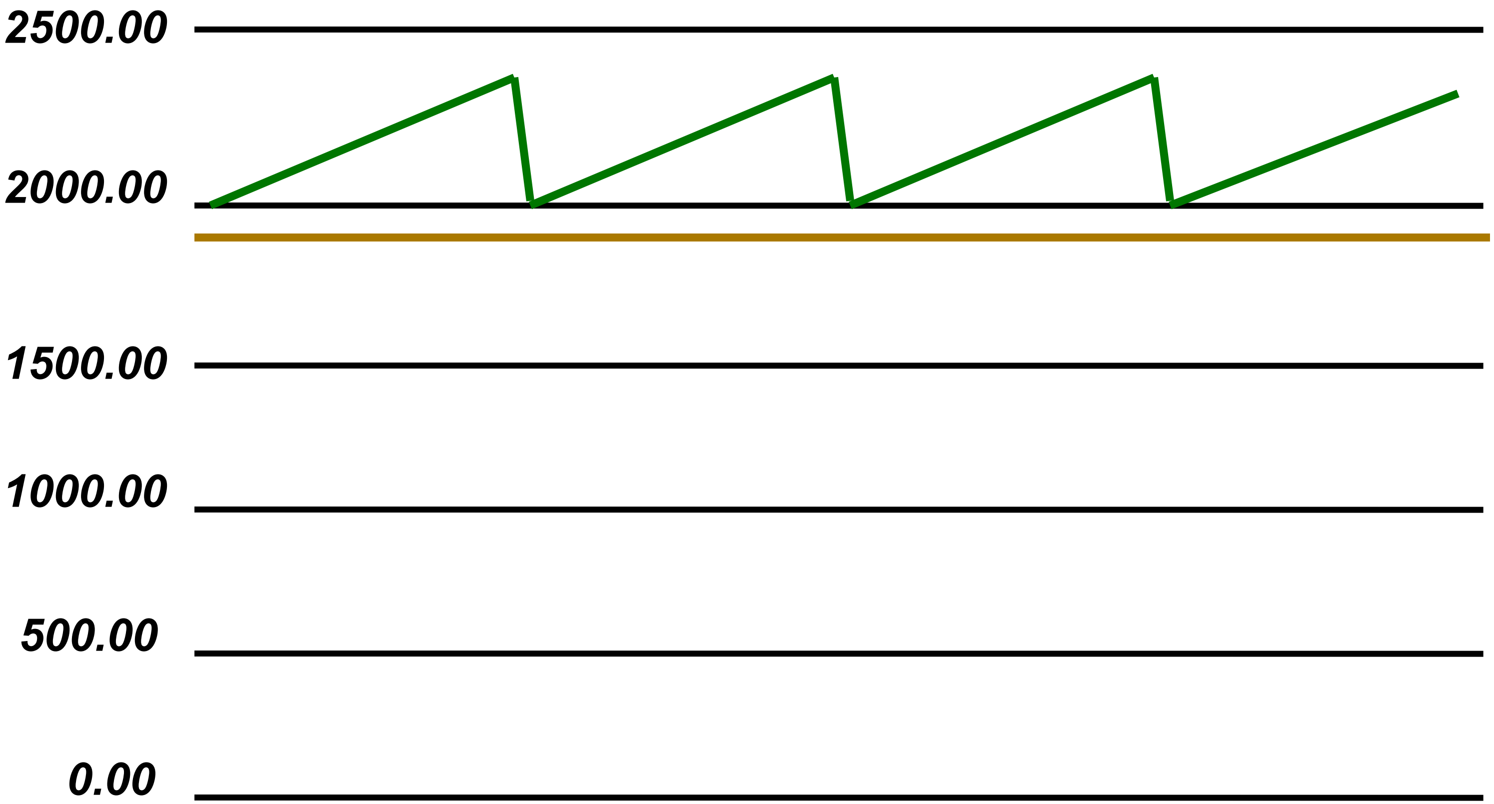
ATLAS AIR & WATER

SERVICE QUALITY

Air Pressure With & Without Pressure Control



SCFM Demand
With & Without Pressure Control



Compressed Air Demand Reduction

- With compressed air pressure set at 100 PSI the compressed air demand is held constant at 1915 scfm. This represents a compressed air demand reduction of 273 scfm from the previous average compressed air demand of 2278 scfm

Operating Cost Reduction

- With compressor delivering compressed air at only 15 cents per 1000 cubic feet a demand reduction of 273 scfm equals 273 x 60 x 8760 / 1000 x .15 = $ 21,523.00 annually.

Optimize Air Storage

- Ideal operating pressure > 90 psi
- Compressor operating pressure 105-125 psi
- Ideal receiver capacity 4 gal. / scfm or 1915 x 4 = 7660 gallons (7500)
- Usable storage 1723.5 cubic feet

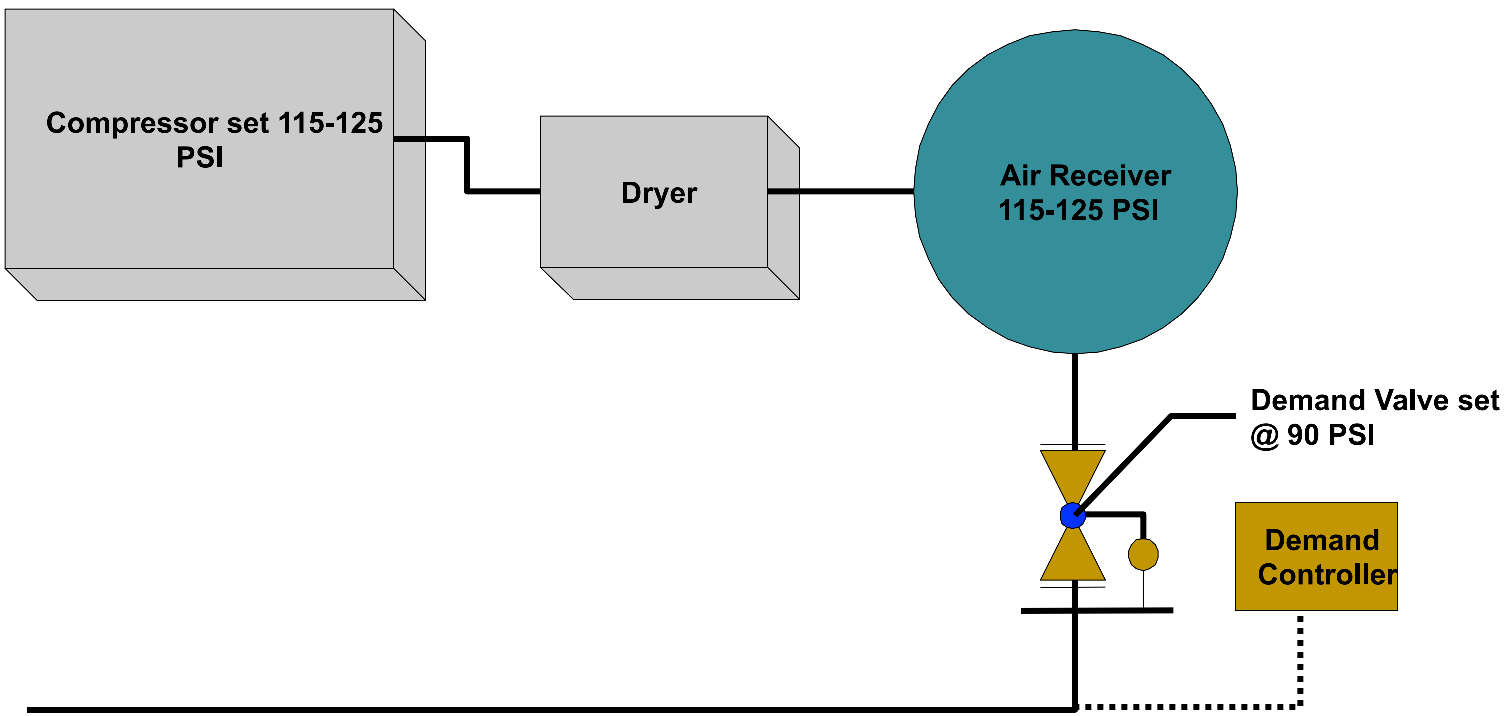
Load Shifting Capacity

- Effective stored compressed air 1723.5 cubic feet
- Compressed air demand spikes of up to 2372 + 1723.5 = 4095.5 scfm for up to one minute without any additional air compressors!!!
- Air pressure is maintained @ 90 psi

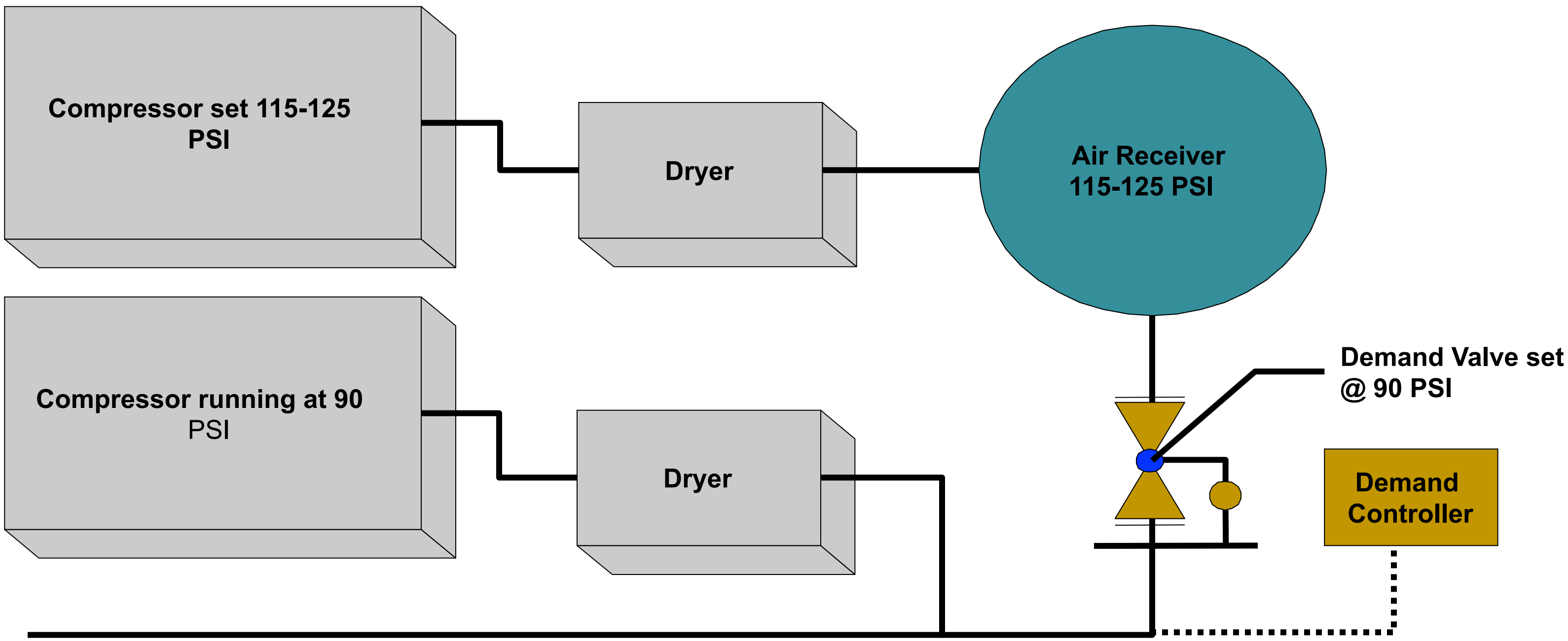
Compressor Controls

- Air storage allows for multiple compressor installation with a workable operating dead-band.
- Demand expansion systems provide a stable operating pressure for base loaded compressors

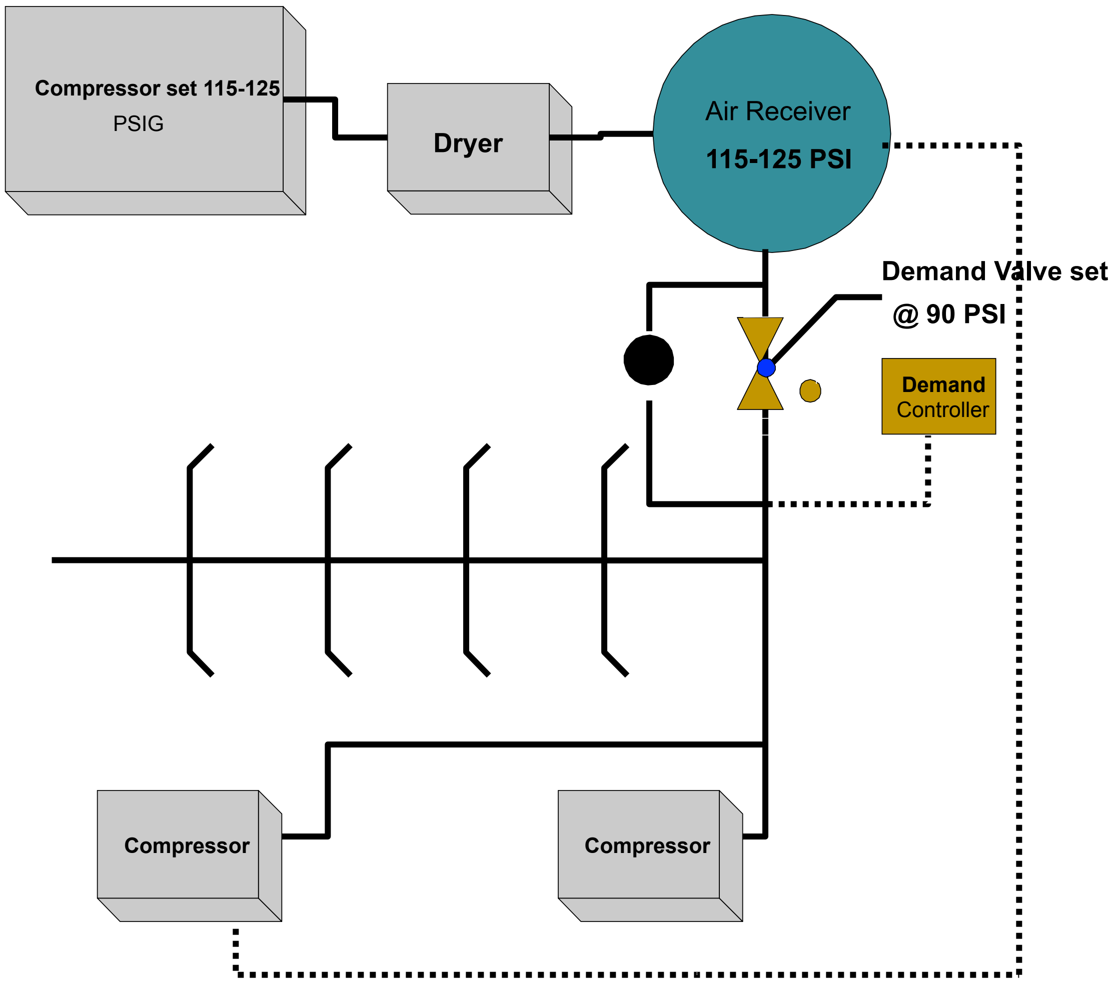
Typical Installation



Base Loaded Compressor Installation



Satellite Compressor Installation



Dew Points

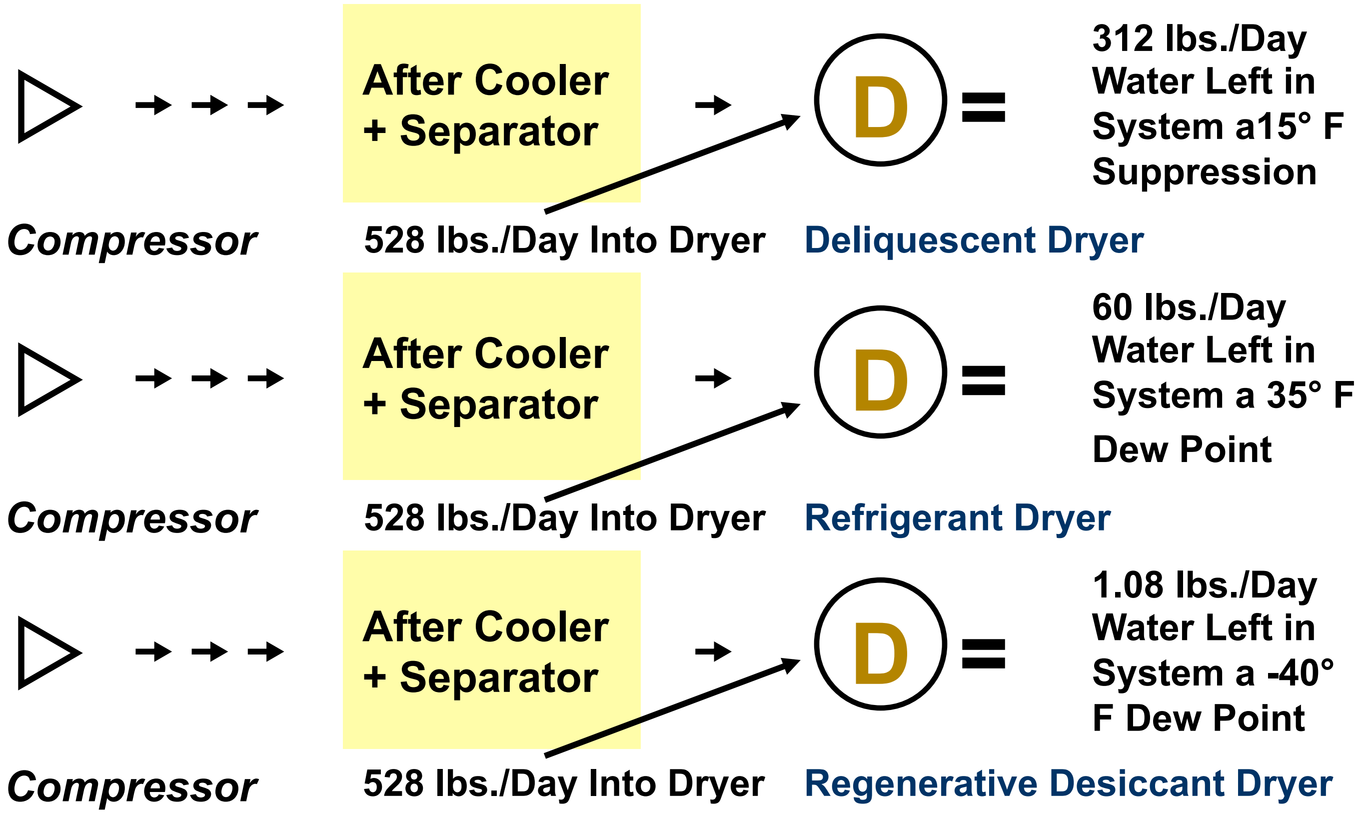
Definitions:

- Atmospheric Dew Point is the lowest temperature at which air will hold moisture at atmospheric pressure without condensation.
- Pressure Dew Point is the lowest temperature at which air will hold moisture at compressed pressures without condensation, a pop will always provide a lower atmospheric dew point, i.e., A + 35° F PDF a 100 PSI will yield an atmospheric dew point of -10° F.

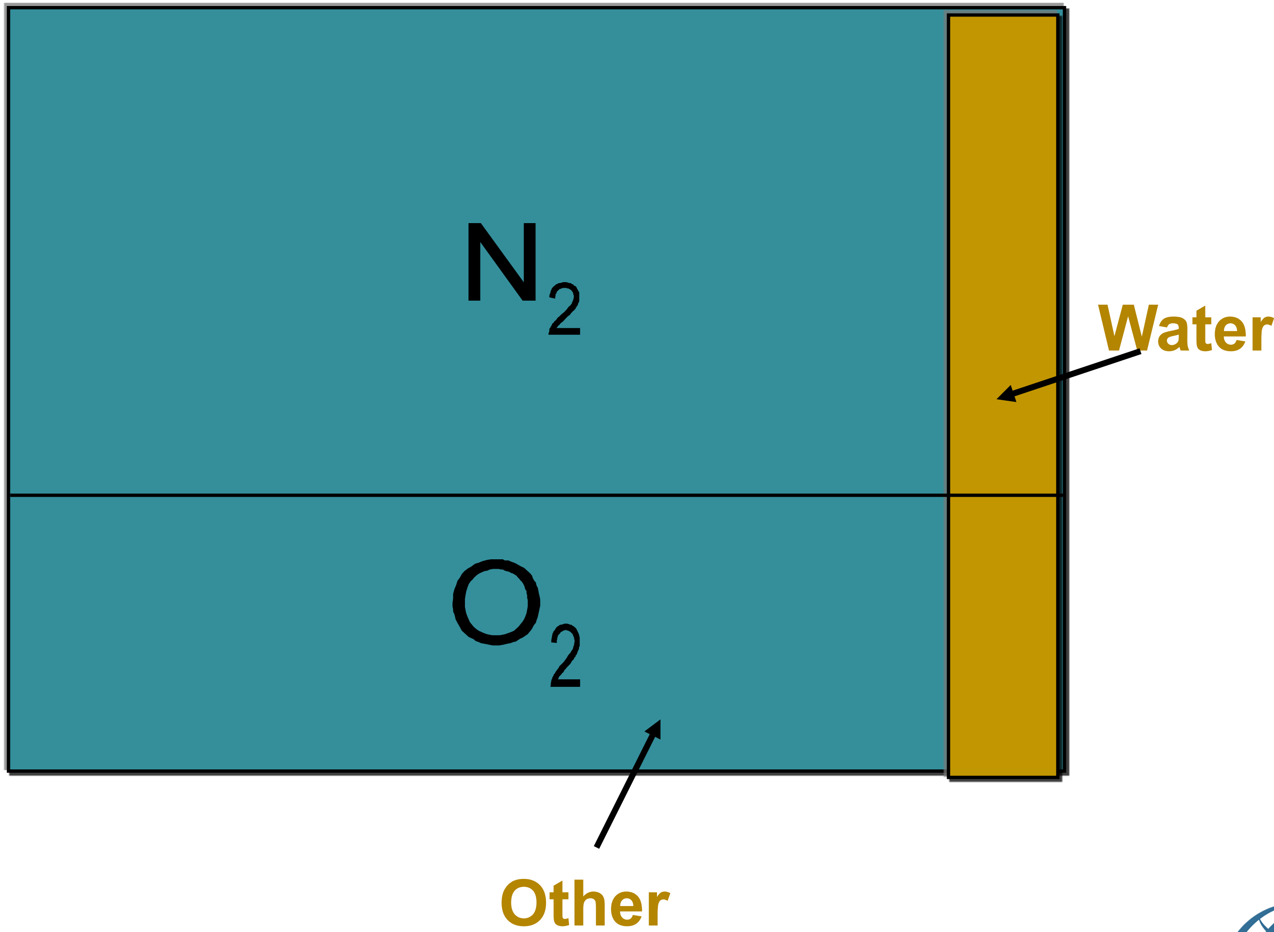
Technical Bulletin

In order to select one of the 3 basic designs that best suit a particular application, the degree of dryness required for each application must be determined. For comparison purposes, consider the following sketch pertaining to an application where 1000 SCFM of compressed air at 120 PSIG and 100° F. saturated is to be dried:

SYSTEM REQUIREMENTS:
1000 SCFM @ 120 PSIG
100° F From After Cooler



Composition of Air



What does relative humidity mean?

RH is defined as the ratio
between the actual water content
to the amount of water the air can possibly hold
at the same temperature

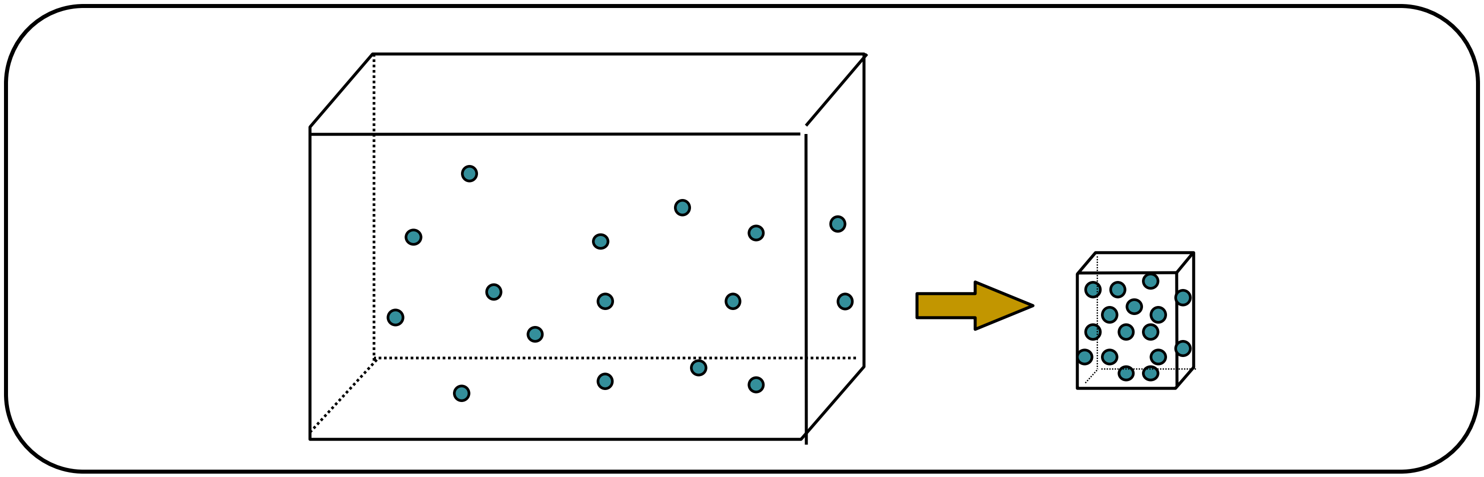
$$\frac{\text{Actual water content}}{\text{Max. possible water content}} = \text{RH (\%)}$$

What happens during compression?

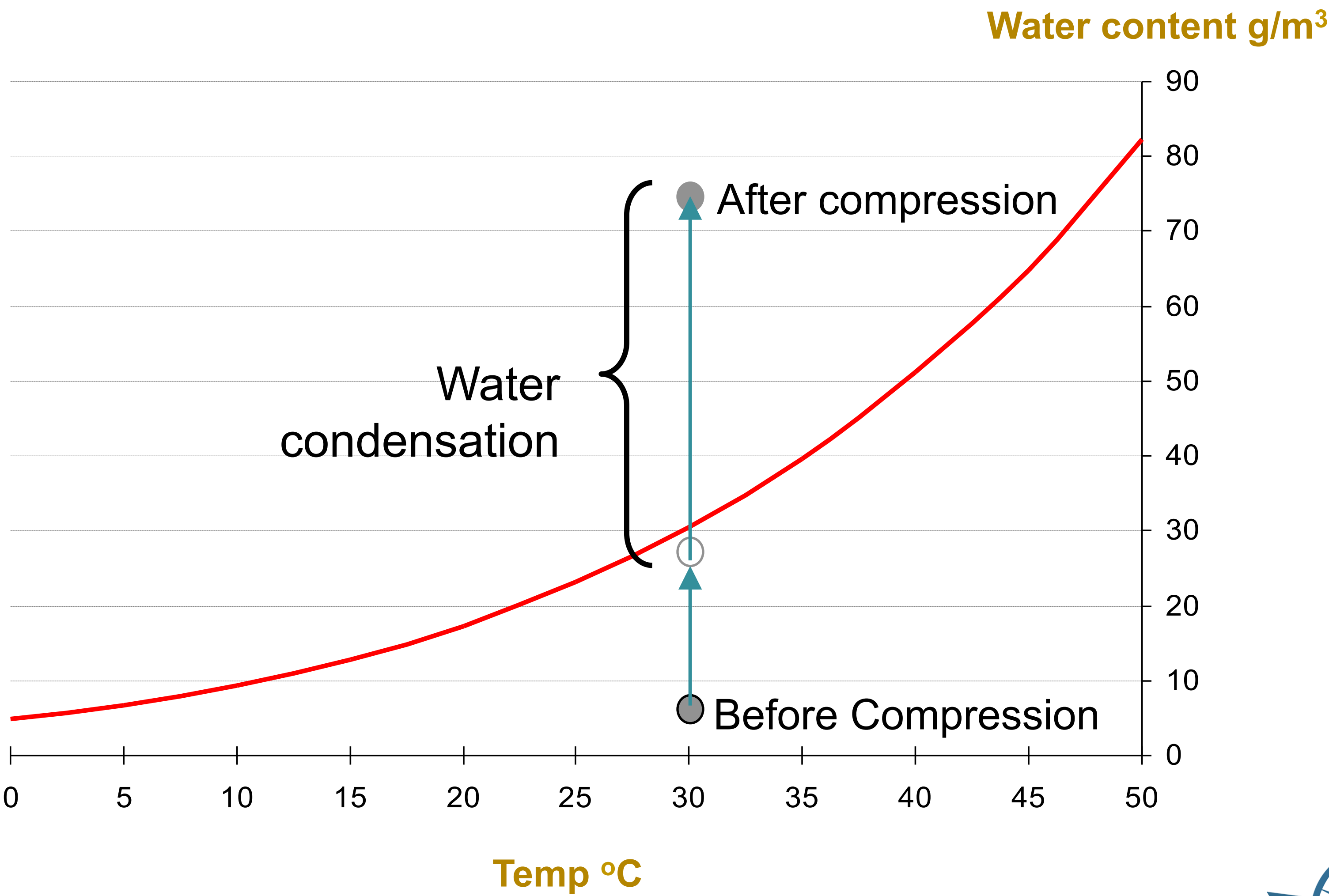
Air is compressible - Volume reduces (m^3) ↓

Water weight remains the same (g) =

Vapor density g/m^3 increases ↑

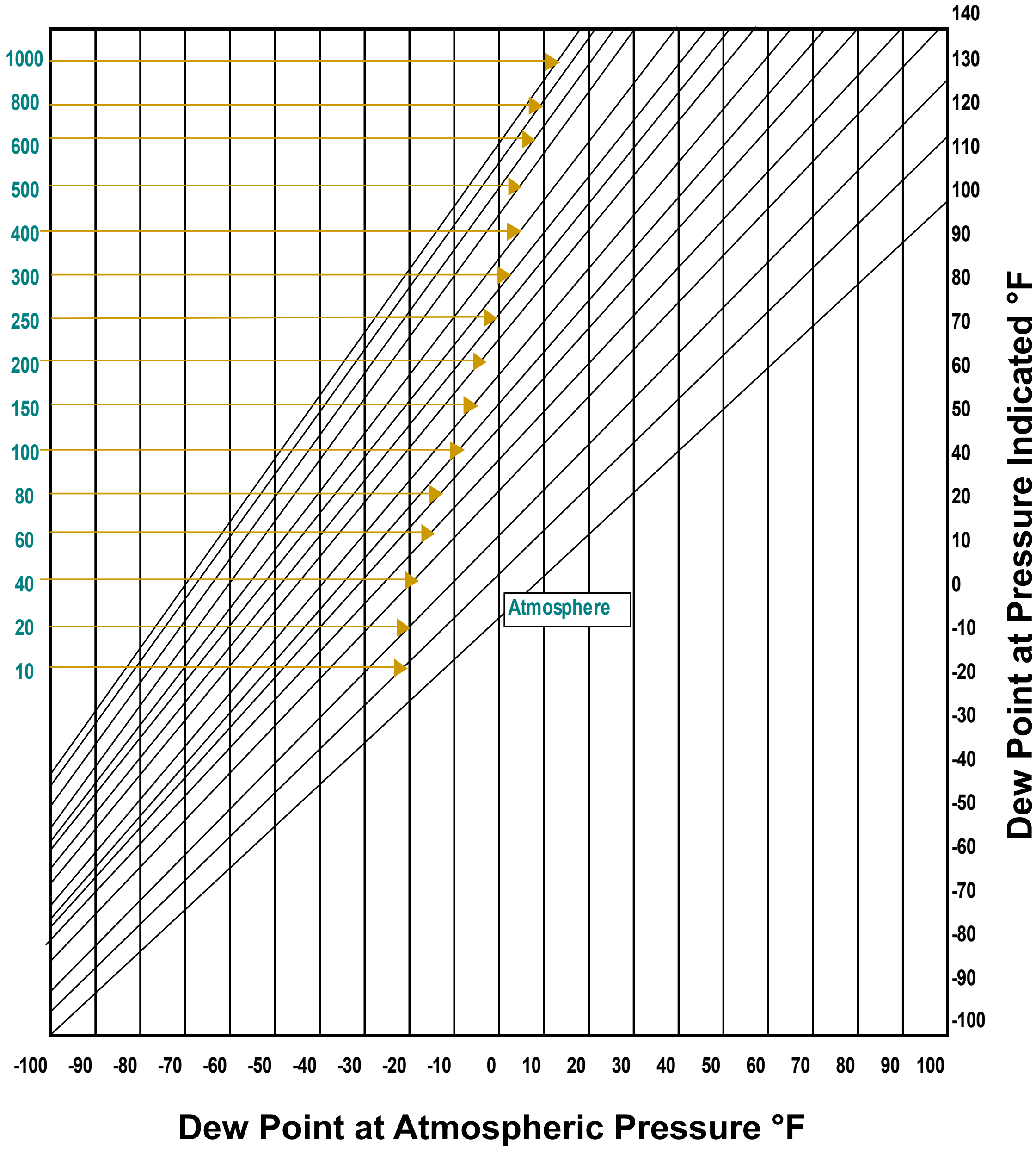


What happens during compression?



Note that all of these dryers are designed to remove water vapor but not entrained moisture. Filtering systems are used to remove contaminants other than moisture in the vapor state which include entrained liquids. They range from the basic entrainment separator which removes over 95% of entrained liquids by cyclonic action to the relatively sophisticated coalescing filters which are capable of removing down to 100% of particles 0.1 micron and larger. Coalescing is a filtering process where by liquid aerosols inpinge on the element and are agglomerated into larger and larger droplets and are drained away by gravity. An entrainment separator and/or coalescing filter is generally installed ahead of the drying unit to insure all entrained moisture has been removed from the compressed media before it passes through the dryer. Most dryer manufacturers recommend and supply the more efficient coalescing filters to provide maximum protection for their drying systems. It is best to allow the dryer manufacturer to specify or supply a “prefilter” in order to maximize dryer performance.

Dew Point Conversion Chart



Dew Point Conversion:

To obtain the dew point temperature expected if the gas were expanded to a lower pressure proceed as follows:

1. Using “dew point at pressure.” locate this temperature on scale at right hand side of chart.
2. Read horizontally to intersection of curve corresponding to the operating pressure at which the gas was dried.
3. From that point read vertically downward to curve corresponding to the expanded lower pressure.
4. From that point read horizontally to scale on right hand side of chart to obtain dew point temperature at the expanded lower pressure.
5. If dew point temperatures at atmospheric pressure are desired, after step 2 above read vertically downward to scale at bottom of chart which gives “Dew Point at Atmospheric Pressure.”

Capacity Correction Factors

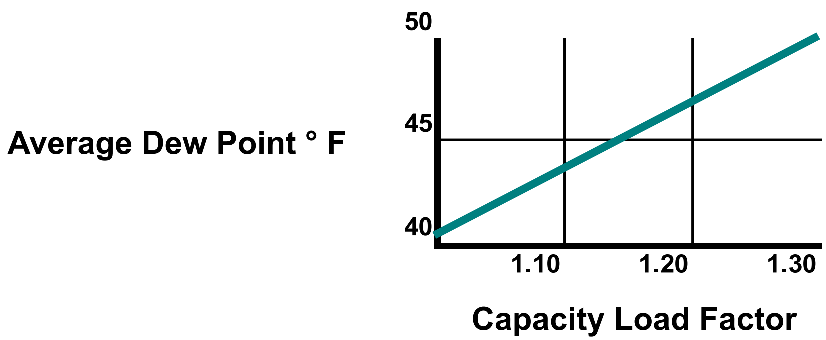
The following correction factors should be used if conditions vary from the nominal rating conditions of the dryers, which are 100° F Ambient, 100° F Inlet Air Temperature and 100 PSIG.

Correction Factor (K)

Ambient Temperature		Inlet Air Temperature		Inlet Air Pressure	
120° F	K = .84	120° F	K = .70	120 PSIG	K = 1.05
110	.92	110	.84	110	1.02
100	1.0	100	1.0	100	1.0
90	1.1	90	1.2	90	.97
80	1.2	80	1.5	80	.93
70	1.3			70	.90

Overload Effect on Dew Point

The curve below can be used to determine the approximate effect on dew-point when its rated capacity is exceeded at nominal conditions. This curve represents average performance of the entire FD Series line.



Example: What is the effect on dew point if an FD 608 is used for 600 cfm.

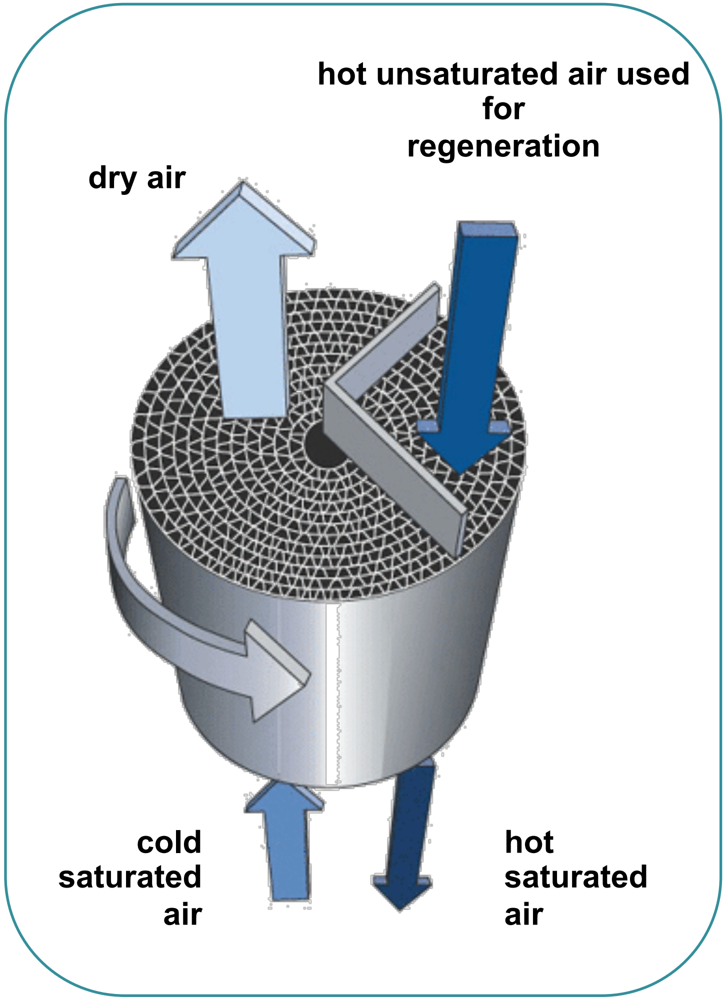
$$\frac{600}{520} = 1.15$$

From the curve the dew point would be approximately 45° F

Heat of Compression Dryers

- Heat of compression dryers use a desiccant to absorb the moisture in the compressed air. The desiccant is regenerated by using hot compressed air prior to an aftercooler. There is no purge loss. Dew points range from - 50° F to - 10° F. The dew point is proportional to the ambients.

MD Air Dryers



- Rotating drum: from 3 up to 10 r/h
- Regeneration air sector: 25%
  - Drying air sector: 75%
- Regeneration airflow:
  - 125°C - 220°C
  - 35% - 45%
- No air loss
  (MD guarantees100% compressor capacity)
- Pressure dewpoint:
  from -15°C to -40°C

Compressor Capacity

2065 CFM Power Cost (8760 HR. 7 Cents/KW) $203.145

Dryer	Refrig.	Heat of Compression	Heatless	H.R.	B.P.
Purge Loss, CFM	0	0	310	155	0
Power Cost $	8,217	100	100	18,396	40,576
Net Capacity	2,065	2,065	1,755	1,910	2,065
Power Cost (Comp. & Dryer)	211,362	203,245	203,245	221,541	243,721
Power Cost/CFM	102.35	98.42	115.81	115.99	118.02

Correction For Pressure Drop

Delta P (New Filter)	5	4	7	7	7
Power Increase %	2.5	2	3.5	3.5	3.5
$	5,079	4,063	7,110	7,110	7,110
Total Power Cost $	216,441	207,208	209,355	225,551	250,831
$/CFM	104.81	100.34	119.29	119.71	121.47
Difference %	+4.5		+18.9	+19.3	+21.1

Correction For Pressure Drop With Dirty Filter

Delta P (Average)	5	4	15	15	15
Power Increase %	0	0	4	4	4
$	0	0	8,126	8,126	8,126
Total Power Cost $	21,441	207,208	217,481	236,777	258,957
$/CFM	104.81	100.34	123.92	123.97	125.4
Difference %	+4.5		+23.5	+23.5	+25.0

Quality Standard for Instrument Air as Defined by The Instrument Society of America

Defines Dew Point as Follows:

4.1 Dew Point (At Line Pressure).

4.1.1 Outdoor installations (Where any part of the instrument air system is exposed to the outdoor atmosphere).

The dew point at line pressure shall be at least 10° C (18° F) below the minimum local recorded ambient temperature at the plant site.

4.1.2 Indoor installations (Where the entire instrument air system is installed indoors).

The dew point at line pressure shall be at least 10° C (18° F) below the minimum temperature to which any part of the instrument air system is exposed at any season of the year. In no case should dew point at line pressure exceed 2° C (Approximately 35° F).

Dryer Pre and After Filter

- Typically, dryer filters have a pressure drop of approximately 1-2 PSI when new. As the filters become contaminated, the pressure drop increase. Most dryer manufacturers suggest change @ a 8-10 PSI drop per filter.

A rule of thumb is that for every PSI drop, the power that is wasted is about ½%.

If the pressure drop is 8 PSI across each filter (16 PSI total), the increased power cost for the same pressure downstream of the filter will be approximately 8%.

Coolers

Intercoolers

- As the approach temperature of an intercooler increases due to dirty coolers, the power requirement increases. For every 11 degrees F deterioration, the power consumption will increase by 1%.

Aftercoolers

- For every 10 degrees F deterioration of the aftercooler approach temperature, the dryers' capacity is reduced by 16%.

Pressure

Cost of Increased Pressure

- For every 1 PSI increase the power requirement will increase by ½%.

Pressure Drops in the Air Distribution System

- Designing a piping system correctly can save many thousands of dollars in operating and maintenance costs
    1. Properly size lines
    2. Sloping the piping with low point drains and traps
    3. Branches of the main line should be from the top to prevent water from entering the branch
    4. Whenever possible, a loop system should be used to reduce the pressure drop
    5. If there is an intermittent user of larger volumes, a local receiver should be placed near the use point

Power Costs

Full load power costs are rather easy to calculate.

Power Cost = $BHP_{/Motor\ Eff}$ X .746 X Hrs. Operate X $Per KW

Example:

500 CFM

125 BHP

4200 Hrs/Year

$.06 KWH

Motor Eff. = 94%

Cost = $125_{/\ .94}$ X .746 X 4200 X .06

Cost = $25,000

However, if the compressor will be unloaded or modulate part of the time, the formula changes to:

Example:

$$P.C. = \%\text{ of Load} \times \frac{BHP \times}{EFF} .746 \times HRS \times \$/KW + \% \frac{\text{Unloaded BHP} \times}{\text{Motor Eff}} .746 + HRS \times \$/KW$$

$$P.C. = .80 \times \frac{125 \times}{.94} .746 \times 4200 \times .06 + .20 \times \frac{19 \times}{.90} .746 + 4200 \times .06 = \$20{,}793$$

- Basis ½% BHP Per 1 PSI Change
  - Down Stream Oil Coalescing Filters

    Delta P when New = 2 PSI = 1% BHP

    Delta P at Change Out = 10 PSI = 5% BHP
  - Down Stream Particulate Filters

    Delta P when New = 2 PSI = 1% BHP

    Delta P at Change Out = 10 PSI = 5% BHP
  - Refrigerated Air Dryer

    Delta P when New = 4 PSI = 2% BHP

Dollars to Overcome Filter and Dryer Restrictions

- Basis a 100 Horsepower Compressor:

$$\text{When New} = \frac{4 \text{ PSID} \times .746 \times .06 \times 8000}{92} = \$1{,}557$$

$$\text{When Replaced} = \frac{12 \text{ PSID} \times .746 \times .06 \times 8000}{92} = \$4{,}670$$

Preventative Maintenance

Effects on Performance

Inlet Air Filters

As the pressure drop across the inlet air filter increases, the compressor's capacity is decreased. For every 4 inches of water pressure drop (0.147 PSI) the mass flow is reduced by approximately 1%.

Example

What is the increased power cost for a 250 HP compressor operating with an air filter drop of 12 in. water.

Assume: Motor efficiency 94%, 6000, Hours/Year, $.07/KW

$$\$ = \frac{250 \times .746}{.94} \times 6000 \times .07 \times \frac{(12 \times 0.01)}{(4)} = \$2,500$$

Compressed Air Leaks

- Leaks should be kept generally between 5% - 10%
- When power costs are high, lower figures can still prove to be economical
- Generally, compressed air users do not realize how much air escapes through small leaks

Hole Diameter	Air Leakage At 100 PSI	Cost Per Year
IN.	CFM	$.06 KWH
1/32	1.62	158
1/16	6.5	633
1/8	26	2,532
1/4	104	$10,130

What do system leaks cost?

- Determine size of the leak either through calculation or actual size of orifice
- ¼ inch orifice can pass 103 CFM @ 100 PSIG
- A typical 25 horsepower oil flooded rotary screw air compressor
- At 6 cents a KW and 8000 hours of operation this can equal $9,946

What can be done to improve energy efficiency of a compressed air system?

- Walk the piping and listen
- If background noise is too loud, then an ultra sonic sun may be needed
- Classic soap and water
- Check defective tools, quick connection points, etc.
- Check and repair all drain traps. Do not leave them “cracked” open
- Determine through calculation

$$\text{CFM (Leakage)} = \frac{\text{(System Volume in Cu. Ft.) (Delta P Absolute) (60)}}{\text{(Bleed Down Time in Sec.) 14.7}}$$

$$102 \text{ CFM} = \frac{300\,(114.7 - 104.7)\,(60)}{120\,(14.7)}$$

Power Cost Calculation

$$\$ / \text{Year} = \frac{\text{BHP} \times .746 \times \$ \text{ Per KW} \times \text{Hours of Operation}}{\text{Motor Efficiency}}$$

$$\$ / \text{Year} = \frac{25 \times .746 \times .06 \times 8000}{90}$$

$ / Year = $9,946

Economical and Reliable Elektronikon® Compressor

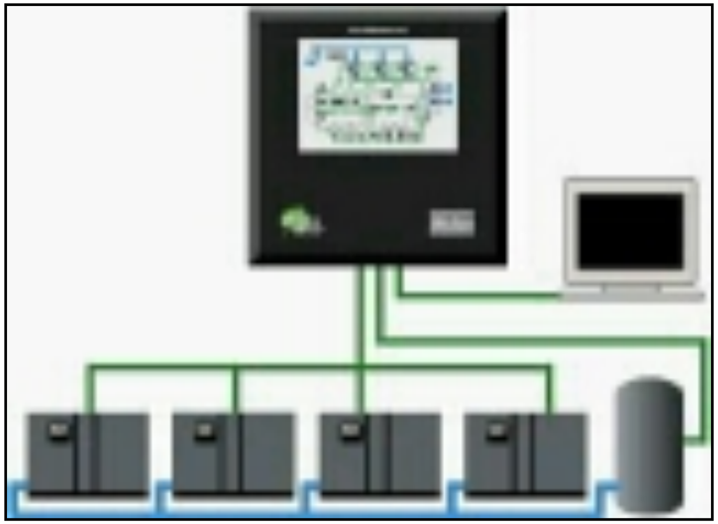
- Managing a multiple compressor installation used to be a complex art. With atlas *Copco’ ES – Energy Saver* air management systems, it has become a precise science.
- Built around the established Elektronikon microprocessor technology, *ES – Energy Saver* systems link the individual compressor controllers and optimize the total system for minimal pressure band, maximum savings, and easy-to-schedule maintenance.
- By providing compressed air in the right quantity and at the lowest possible cost, the *ES* systems let you concentrate on your business – instead of on compressed air or your power bill.

The Elektronikon® Experience

- Proven and trusted microprocessor technology
- The standard controller of most Atlas Copco compressors
- Language selection
- Constant monitoring of all compressor functions
- Minimum idling time for maximum savings
- Detailed warning and shutdown information
- Automatic restart after voltage failure
- Preventive maintenance assistance (indication of intervals)
- Lowest cost compressed air

Network Intelligence

- ES network links ES100 or ES300 central controller with individual Elektronikon Compressor controllers
- Comprehensive user interaction, either via ES control panel or from anywhere in the plant via ES400 remote monitoring software
- Real-time control and performance monitoring of each compressor on the network
- Minimal pressure band in the total compressed air system (lowest cost compressed air)
- Sequence shift option (equal wear and better preventive maintenance scheduling)



By reducing the pressure band width, Atlas Copco ES100 and ES300 Energy Savers **cut your electricity bill. Savings of 10%** are typical, and depending on the installation, even greater savings can be achieved.

The Clean & Clear CMS-OSD™ Condensate Filtration System

Clean & Clear CMS-OSD is the ultimate industrial water and condensate filtration system

ISO 14000 Compliant

The Clean & Clear Condensate Management System "CMS" & Oil/Water Separation Device "OSD" Filtration System removes both petroleum and synthetic lubricants/coolants from air compressor condensate to safe levels required by Federal and State Clean Water Regulations (below 15 ppm) and ISO 14000 environmental standards.

New Technology

The Clean & Clear CMS-OSD Filtration System utilizes patented new technology that is extremely efficient at trapping petroleum and synthetic lubricant/coolant while water flows cleanly through the OSD Filter. The OSD Filter removes all types of super refined petroleum, petroleum diesters, PAO's, polyglycols, PAG's, and liquid silicone fluids including: Sullube32, 24KT Fluid, Ultra Coolant, Aeon Fluids, QuinSyn, GA, FG, 4K, 8K, Roto Fluids and more. The CMS defuses and separates oily condensate/compressed air via a three step process.

The CMS Turbo separator spins the oily condensate/compressed air to the outside wall of the CMS where condensate collects. Liquid droplets and decompressed air flow through the diffuser plate to the outer separation chamber. Decompressed air changes direction from the outer chamber to the inner chamber and is released to atmosphere via the diffuser top plate. Condensate collects in the outer chamber and fills the inner chamber via the scavenge line. Dirt, rust and scale collect in the outer chamber preventing debris carry over to the inner chamber, CMS pump or OSD. Condensate from the inner chamber is drawn to the CMS pump via inner chamber scavenge tube, and delivered to the OSD.

Superior to Competition

The Clean & Clear OSD Filtration System is much more efficient, less expensive and easier to maintain than old fashioned gravity separators or boiler systems. Clean & Clear removes both petroleum based and synthetic based lubricant/coolant from condensate.

The Clean & Clear CMS-OSD™ Condensate Filtration System

Clean & Clear OSD filtration is simple and effective

Simple & Clean to Operate

No moving parts and no tools required for OSD Filter change. All hazardous wastes remain in the OSD Filter for easy and safe disposal. Change OSD Filter when replacement indicator moves from green to red. No spills, no mess, no contact with collected hazardous waste.

A complete system

The Clean & Clear CMS-OSD system maximizes the efficiency and life of the OSD Filter. The CMS removes compressed air from the condensate, eliminates excess oil, sludge, rust and particulates from the condensate. The CMS provides a controlled flow of condensate at a specific pressure to the OSD Filter. CMS-OSD are prepackaged. Just set CMS on the floor, plug in 115 volt power cord and connect oily condensate inlet to CMS. Attach CMS to OSD via connection tube provided. Connect clean water discharge from OSD to drain. The Clean & Clear CMS accepts multiple condensate sources and operates with any type of condensate drain. The CMS and OSD Filter have a small foot print, just 16 x 16 each. The CMS has a large 12 gallon collection sump. Field experience shows 10–14 months is typical OSD Filter life. The CMS is one time purchase.

Clean & Clear CMS-OSD System OSD Filters

Size	Part No.	Designed for:	Weight
3 x 30 OSD	#3030110OSD	5 hp–30 hp compressors	5.5 lbs.
6 x 26 OSD	#2660110OSD	40 hp–60 hp compressors	16 lbs.
6 x 36 OSD	#3660110OSD	75 hp–100 hp compressors	21 lbs.
6 x 44 OSD	#4460110OSD	125 hp–150 hp compressors	23 lbs.
8 x 26 OSD	#2680110OSD	200 hp–250 hp compressors	24 lbs.
8 x 36 OSD	#3680110OSD	250 hp–300 hp compressors	30 lbs.
8 x 52 OSD	#5280110OSD	350 hp and larger compressors	39 lbs.

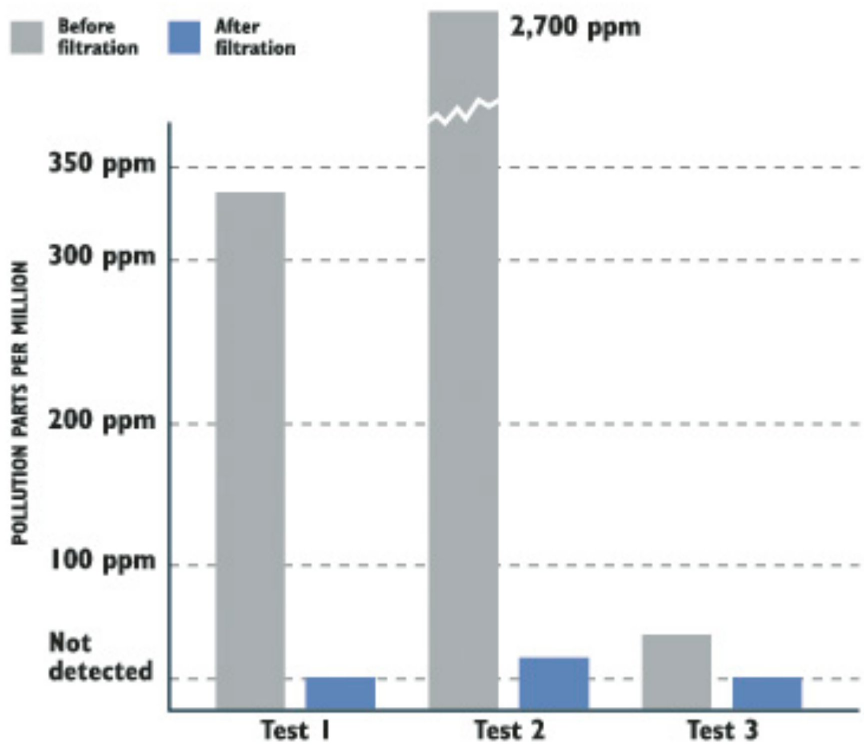
Delivery stock to five days.

CMS (Condensate Management System)

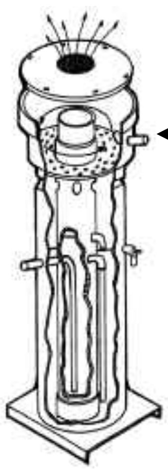
Floor stand is integral/included with CMS. Floor stand is option adder for OSD’s.

Size	Part No.		Weight
11 x 48	#CMS400	12 gallon sump, inlet and oulet connections are 3/4 NPT	64 lbs.

Clean & Clear OSD Test Results



Clean & Clear CMS



Sullair Sullube 32 Condensate
Before & After
Clean & Clear Filtration System

Compressor manufacturers advertise 1-3 ppm oil carry over to the compressed air header. However, the oil carry over from the air oil separator is 9-12 ppm. The compressor manufacturer relies on the after cooler, moisture separator to remove 8-11 ppm via condensate. The oil to condensate concentration varies summer to winter. As the amount of condensate is greater in summer than winter yet the oil carry over remains the same. Oil carry over will increase with poor maintenance of air oil separator, over filling oil sump (excess oil is pushed down stream), plugging of scavenge line.

CLEAN & CLEAR corporation

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ATLAS AIR & WATER

Laws & Regulations Pertaining to Disposal of Oily Condensate

Following is a list of the various laws and regulations that pertain to the disposal of oily condensate (as of March 13, 2002):

- Federal Water Pollution Control Act (USC Title 33, Section 1321 et.seq.).
- Resource Conservation and Recovery Act (USC Title 42 Section 6903 et.seq.).
- Clean Water Act (USC Title 33 Section 1251 et.seq.).
- Oil Pollution Recovery Act of 1990 (USC Title 33 Section 2702-2761).
- Pollution Prevention Act (USC Title 42 Section 13101 et.seq.).
- Toxic Substance Control Act (USC Title 15 Section 2601 et.seq.).

While all these statutes and the rules promulgated there under differ in some respects, they all prohibit the disposal of petroleum based solvents and synthetic based solvents into storm sewers, surface water, septic systems or into the ground.

If there is a oily sheen (approximately 10PPM or 10 mg/liter) it is a violation of these statutes. The fines can be as high as $10,000 per day plus clean up costs and criminal penalties for willful violations.

Most states have adopted the same standards with their pollution control acts and are mandated under federal law to enforce these standards. Inspections and permits are required in most states.

In addition, each local sewage disposal facility and regional waste disposal districts have adopted standards for the discharge of oily condensate into the sewage system. It varies from district to district, but our research indicates that the most common standards are 20ppm to 50ppm with both petroleum as well as synthetic based lubricants being classified as hazardous wastes

Heat Load Formulas

BTUH = 500 X GPM X TR

Where:

500 = Lbs. of Water/Hr.

GPM = Gallons Per Minute

TR = Temperature Rise

1 HP = 2545 BTUH

Therefore:

The total horsepower transmitted to the water is:

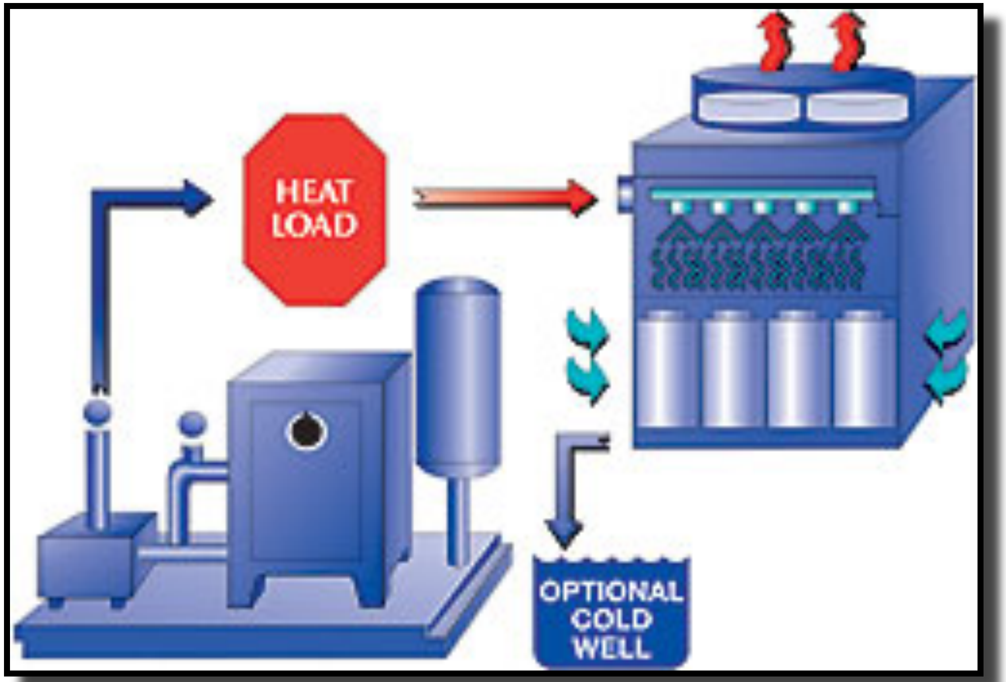
$$\boxed{HP = \frac{500 \times GPM \times TR}{2545}}$$

Approximately 4% of shaft HP remains in the compressed air. Approximately 2% of shaft HP is lost to radiation.

Therefore:

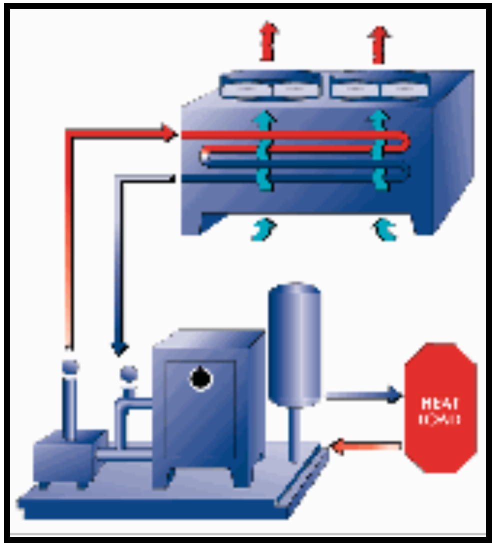
$$\boxed{SHAFT\ HP = \frac{500 \times GPM \times TR}{2545 \times .94}}$$

OE Open Evaporative Cooling



Dry Cooler

1. Closed loop dry cooling system.
2. Ethylene glycol solution eliminates all compressor cooler cleaning.
3. Temperature control of coolant by fan cycling.
4. Coolant temperatures to within 10 or 15 degrees F of ambient dry bulb.
5. Air elimination system eliminates all scale and corrosion.
6. Optional Dual pumps with automatic switch over with alarm.



CE Closed Loop Evaporative Cooling System

- Closed loop evaporative cooling system.
- Coolant temperatures to within 5 to 10 degrees F of ambient wet bulb.
- Temperature control by water spray and fan cycling.
- Requires a separate water supply for evaporation.

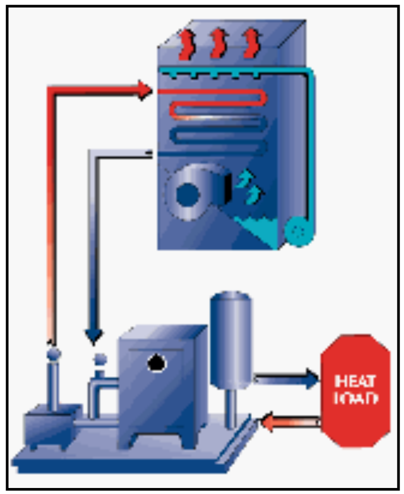
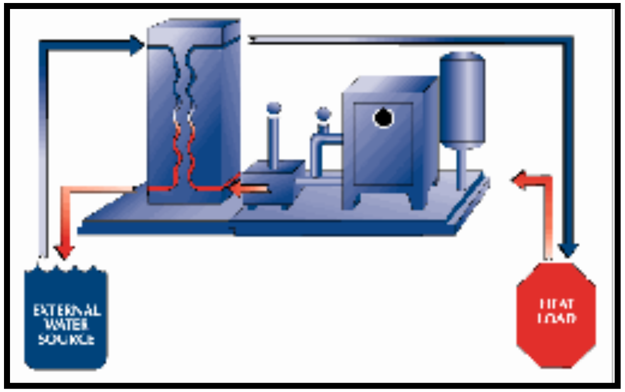


Plate and Frame

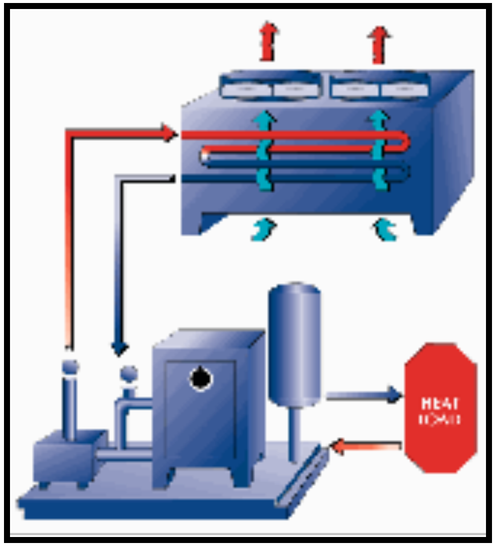
1. Closed loop cooling system for compressor
2. Ethylene glycol or demineralized water* for compressor cooling.

   *Provided system is installed indoors
3. Transfers heat to a raw water source, e.g., existing cooling tower (4), city water, pond, well, river or sea water.
4. Temperatures to within 5 to 10 degrees F of raw water supply.
5. Thermostatic control of raw water supply to reduce consumption.



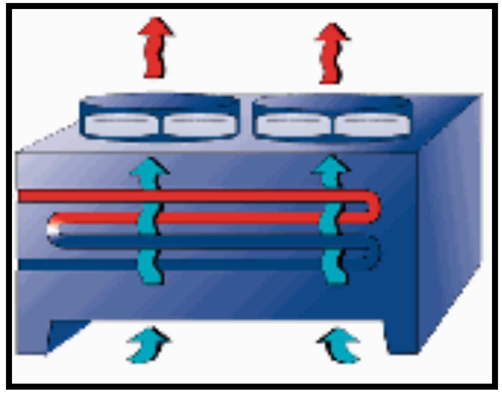
Dry Cooler With Trim Cooler

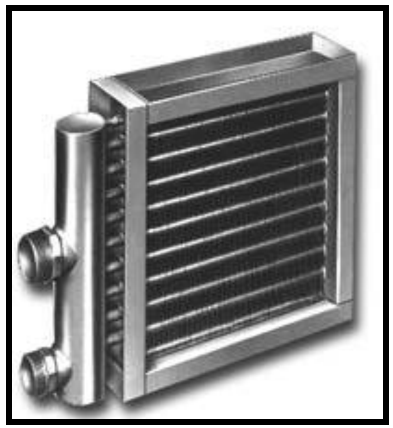
1. Combines benefits of dry cooler and plate and frame (Trim Cooler).
2. Trim cooler is only used during extreme summertime temperatures during the day.
3. Yearly external water consumption is less than an evaporative tower.
4. Temperatures to within 5 to 10 degrees F of raw water supply.
5. Thermostatic control of raw water supply to reduce consumption.



CW Chilled Water Cooling

HR Heat Recovery for CE and CD Systems





GPM Increase for Ethylene Glycol vs. Water for Same Heat Rejection