Egyptian Program for Promoting Industrial Motor Efficiency

Compressed Air Systems Optimisation
User Level Training Course

Trainers: Albert Williams & Siraj Williams
UNIDO Compressed Air Systems Optimisation Experts

Current Problem

In 2014, Egypt emitted 272.69 $MtCO_2$. Although only accounting for 0.6% of the total greenhouse gas (GHG) emissions worldwide, the country is one of the fastest growing emitters in the world and one of the most vulnerable places to climate change adversities. In fact, Egypt’s GHG emissions have grown by over 121% between 1990 and 2014. The GHG emissions growth rate is even higher for the electricity/heat consumption which grew by 244% over the same period.

Aim

The project aims to improve the efficiency of Electric Motor Driven Systems (EMDS) and accelerate the market penetration of energy efficient motors in the industrial sector and reduce GHG emissions through supporting low carbon technologies. The cost-effective motor system optimization measures and the replacement of inefficient motors expected to result in 40% reduction in energy use.

Visual Concept

Energy-Efficient motors possess a number of benefits since they are comprised of superior materials and elevated manufacturing techniques. They have increased reliability because of their longer bearing lives, lower waste heat output, higher service factors and less vibration.

As efficient electric motors achieve greater efficiency by reducing the losses the visual concept put along with the slogan “Save Today … Power Tomorrow” encourage target audience in the Egyptian Industrial Market to identify the opportunity of high energy efficient motor potentials.

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Outline

1. Introduction to Compressed Air Systems
2. Understanding Compressed Air
3. Supply Side: Compressors and their Application
4. Air Treatment
5. Demand Side - Eliminate Compressed Air Waste
6. Distribution
7. Pressure Profiles
8. Air Storage and System Energy Balance
9. System Controls
10. System Assessment
11. Data Collection
12. Maintenance
13. Heat Recovery

1. Introduction to Compressed Air Systems

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Introduction to Compressed Air Systems

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Compressed air has 3 primary uses

- **Power**
  - **As an energy source to perform work**

- **Process**
  - **Air becomes part of a process**

- **Control**
  - **To stop, start or regulate the operation of a machine**

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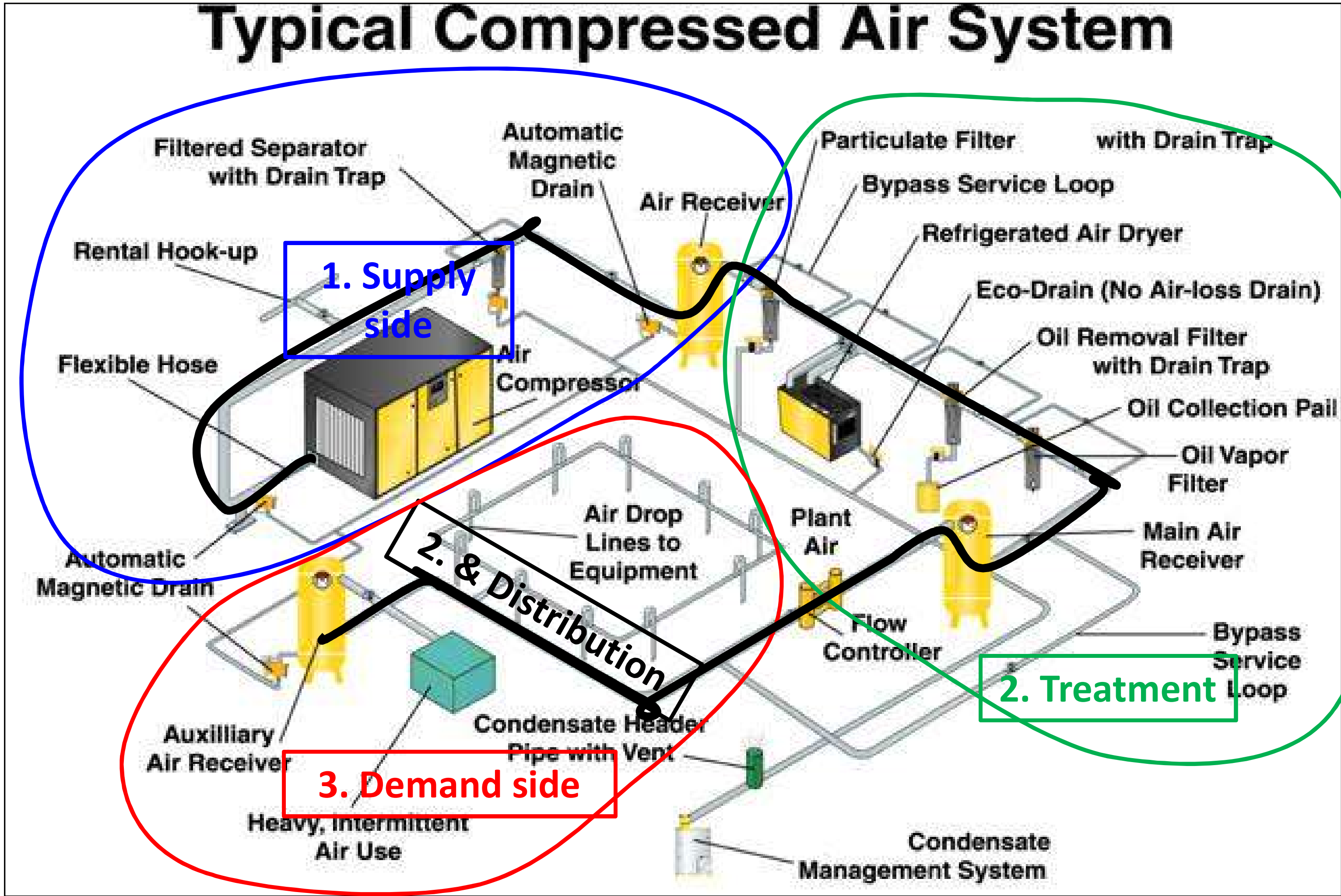
Introduction to Compressed Air Systems



Introduction to Compressed Air Systems

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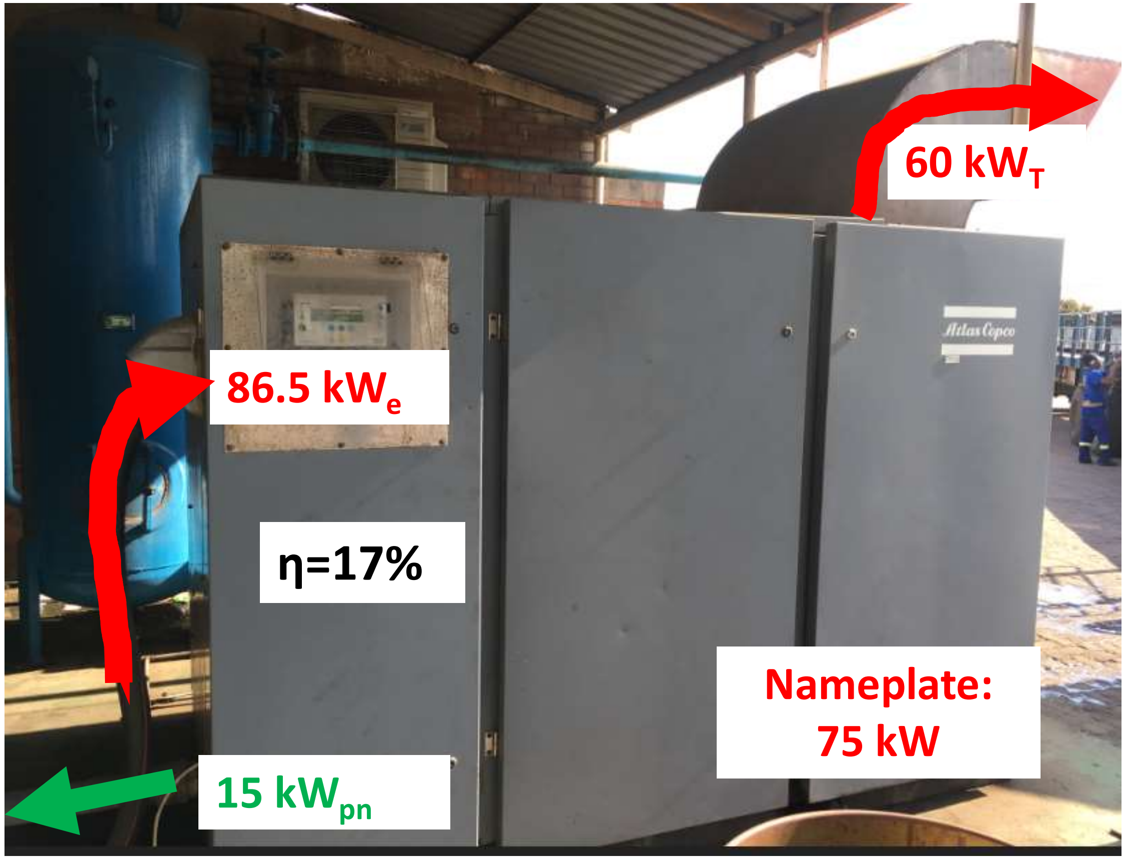
Compressed Air is **THE** most expensive source of energy

$$\eta = \frac{15\ kW\ out}{86.5\ kW\ in}$$

η = 17%



Source: Albert Williams

Introduction to Compressed Air Systems

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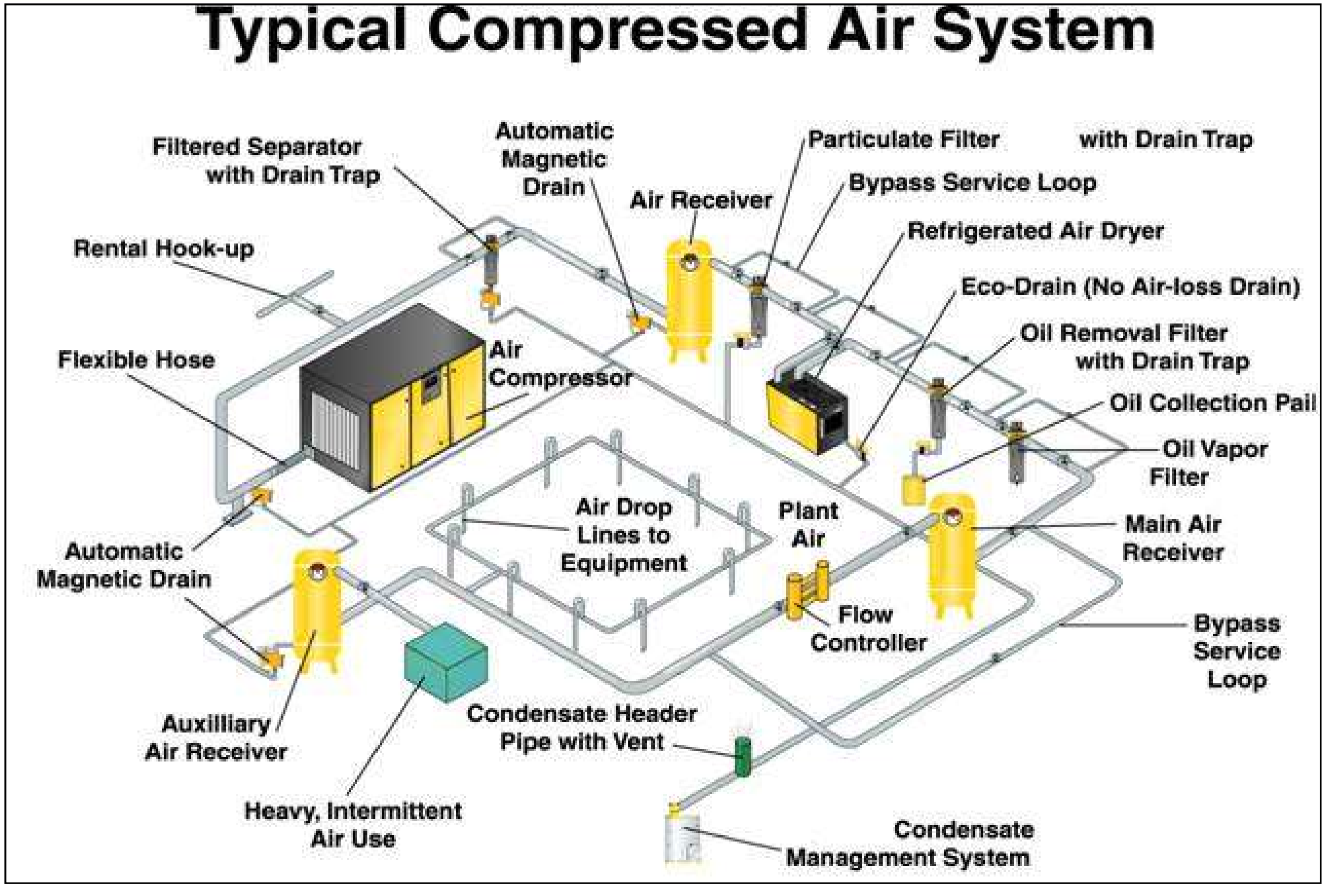
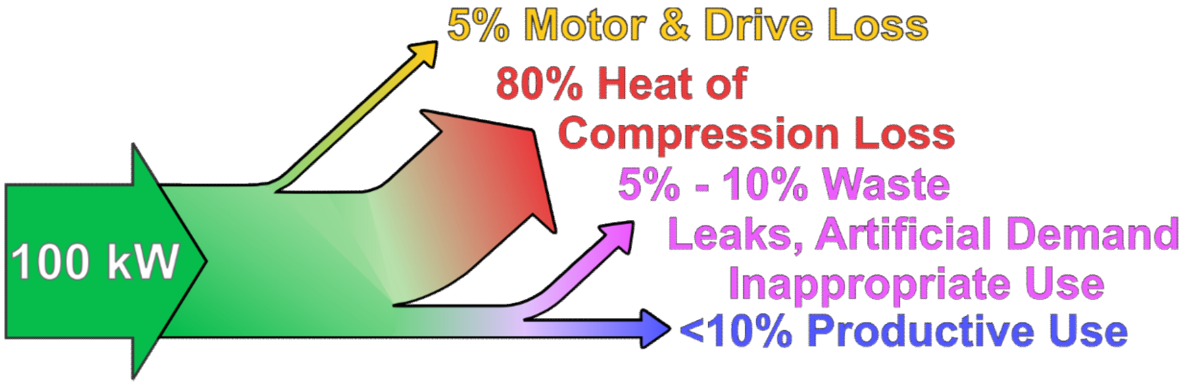


Source: Albert Williams

Introduction to Compressed Air Systems

Compressed Air Energy Flow



- Compressed air electrical energy conversion to pneumatic energy is very inefficient ~ 15%
- Typically 50% of the pneumatic energy is wasted
- The overall conversion efficiency < 10%

Introduction to Compressed Air Systems

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$$\eta = \frac{15\ kW\ out}{86.5\ kW\ in}$$

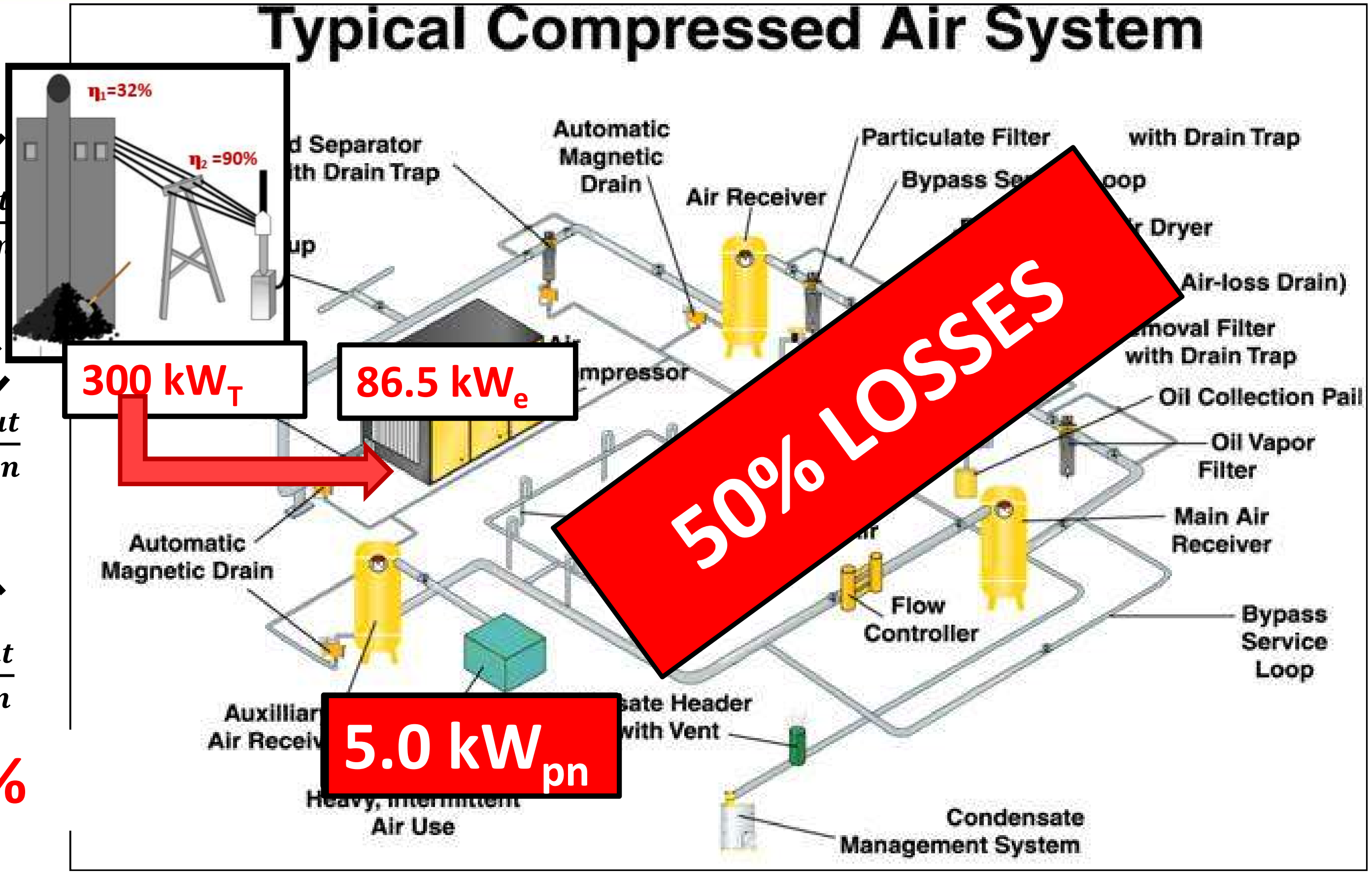
$\eta = 17\%$

$$\eta = \frac{7.5\ kW\ out}{86.5\ kW\ in}$$

$\eta = 8.7\%$

$$\eta \approx \frac{5.0\ kW\ out}{300\ kW\ in}$$

$\eta = 1\text{-}2\%$



Source: Albert Williams

Comparing 5 year life cycle costs

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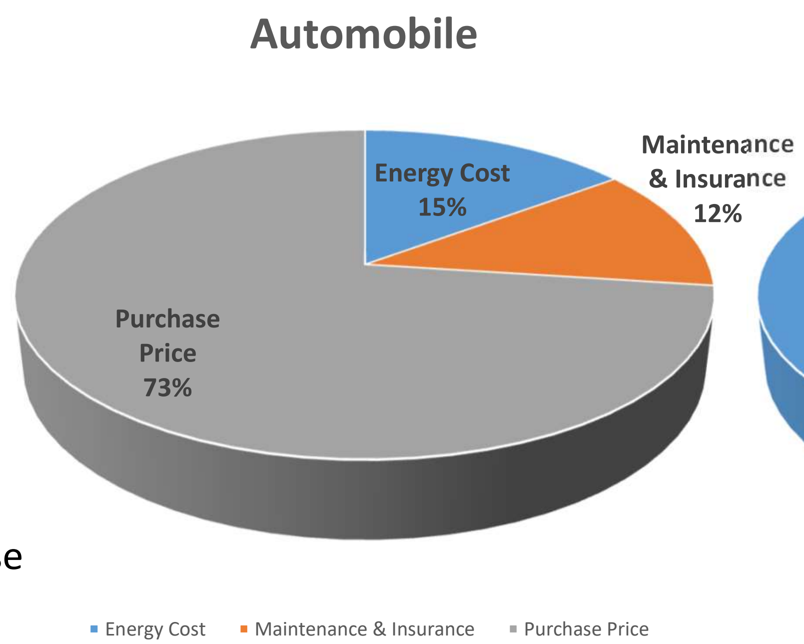
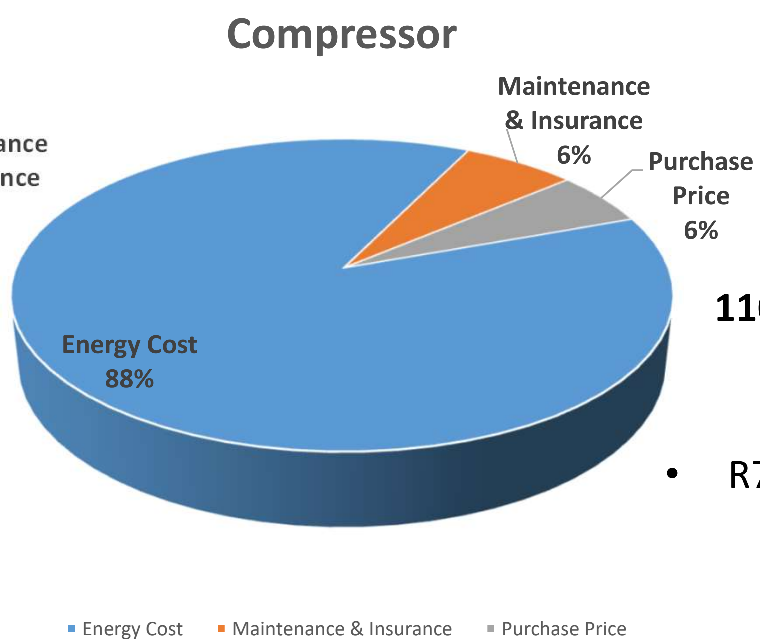




110 kW Automobile

- 20,000km/y
- Fuel = R16/liter
- 7 liter/100km
- R644,800 purchase

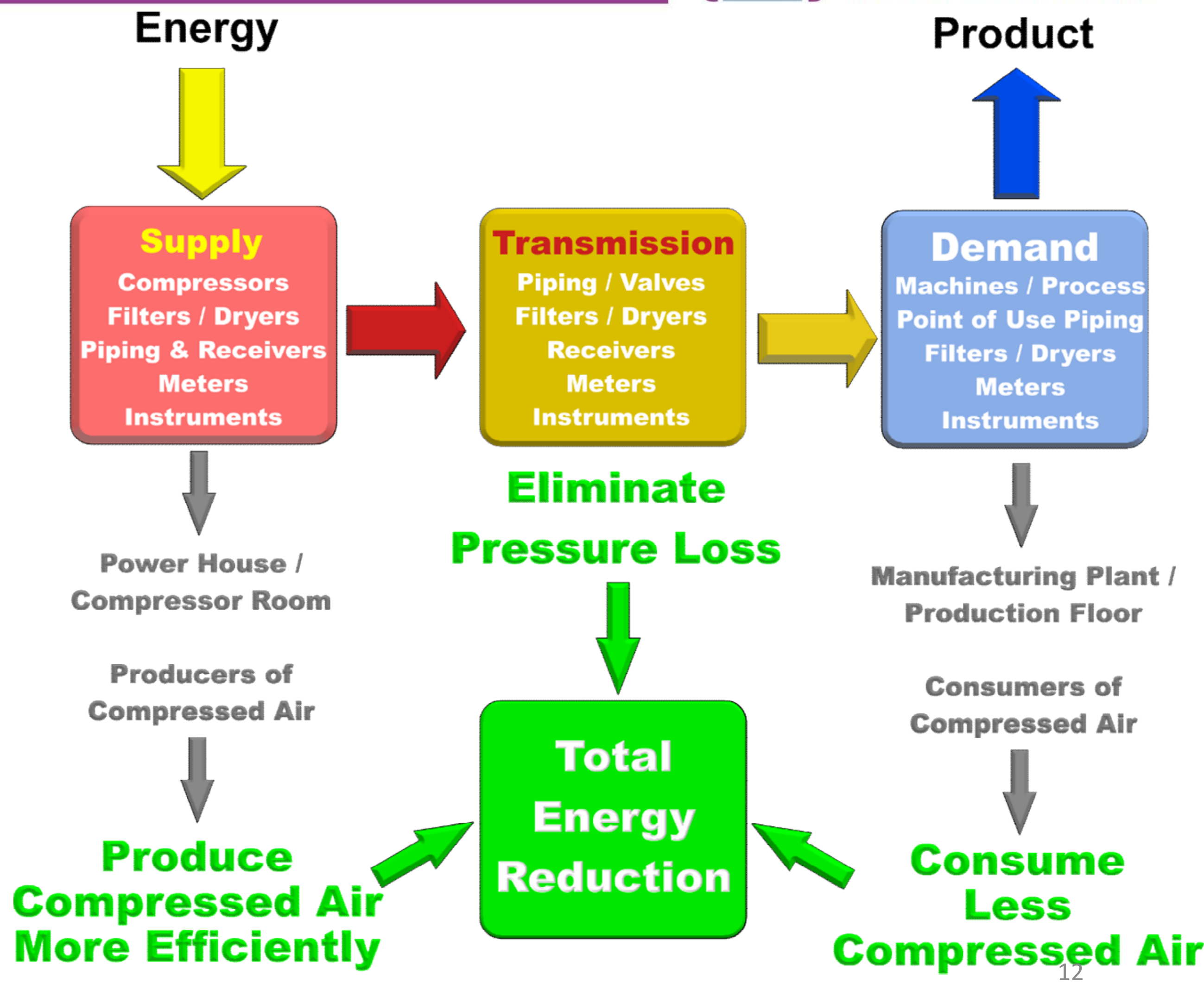
110kW Compressor

- 7000 hours/y
- R2.00/kWh
- R750,000 purchase

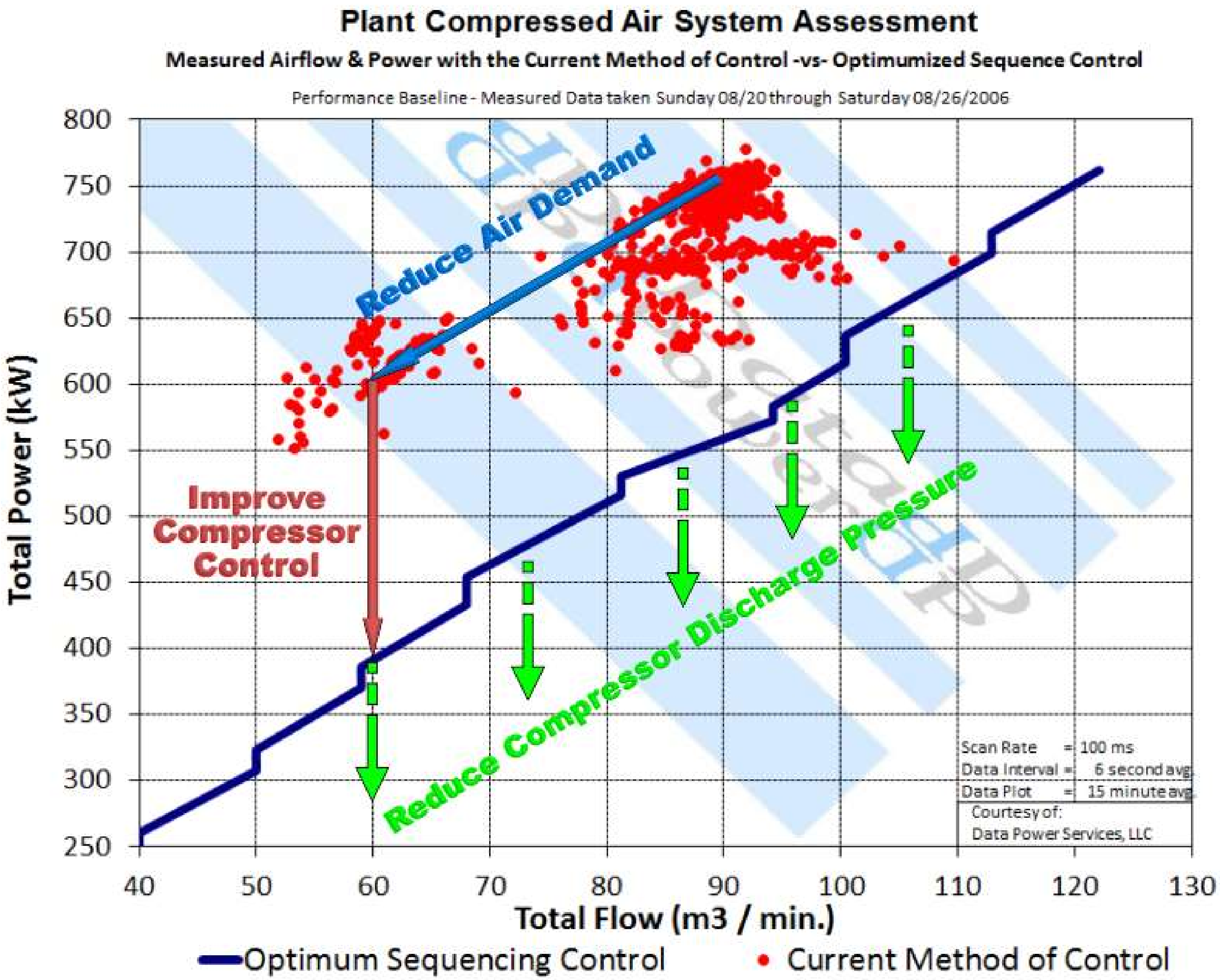
Common assumptions

- 8% discount rate
- Energy inflation rate 6%

The Systems Approach and Reducing Energy Consumption

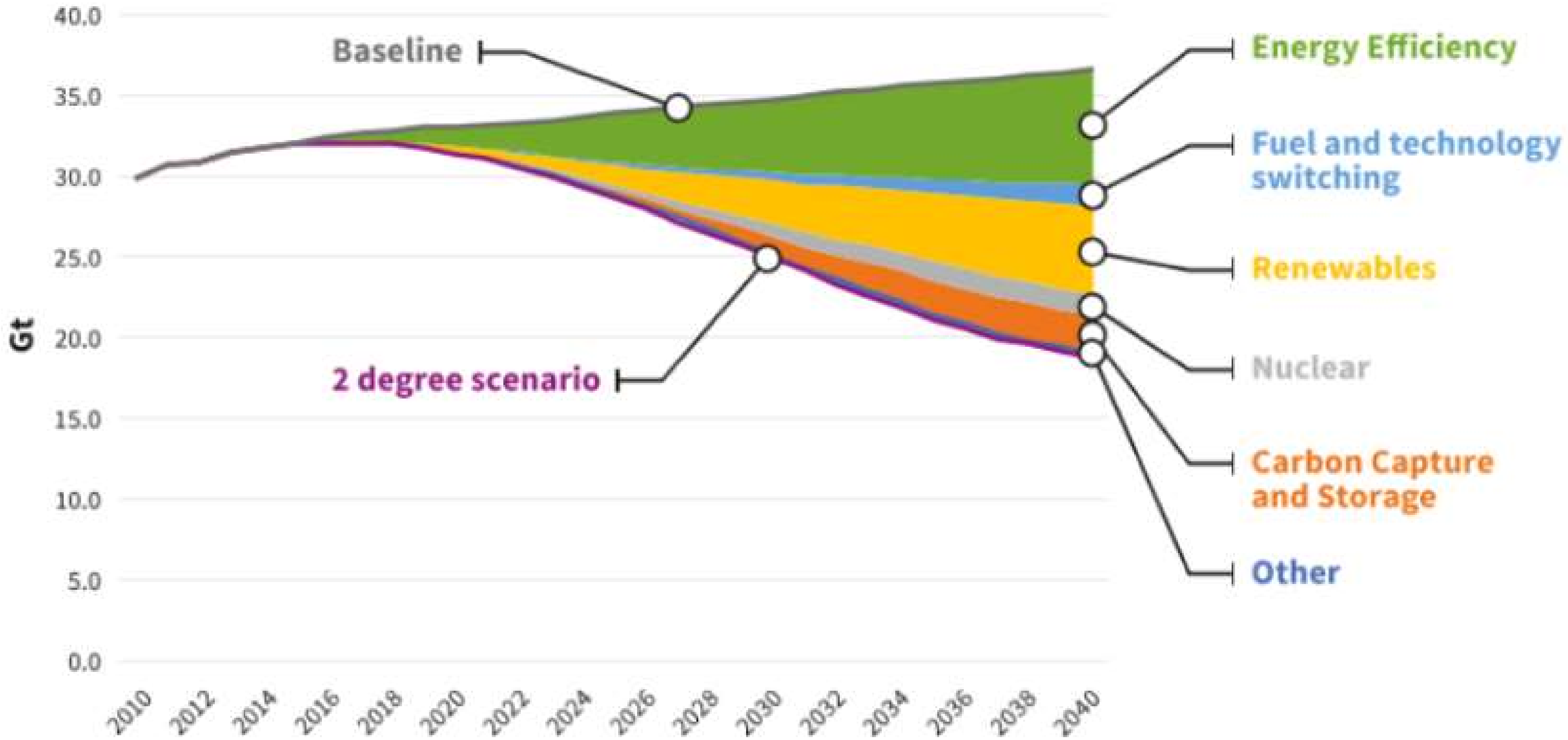


Optimizing Compressed Air System Efficiency



EE is #1 Global Strategy to Limit Temperature Increase

Figure 4. IEA *Global Energy Outlook* emissions scenario with temperature increase limited to 2 degrees



Key Learning Points

1. Compressed air is a necessary utility for industrial plants.
2. When compressed air is integral to the production process, it is a process variable.
3. System management must focus on productivity (controlling cost) rather than traditional goals.
4. The Systems Approach is an integrated approach, not component efficiency.
5. Energy cost is over 75% of the total life cycle cost to own and operate a compressed air system.
6. Generating compressed air is an inefficient energy conversion.
7. Avoiding the compression of air provides the greatest energy savings. Eliminate compressed air waste.
8. Many systems waste 50% or more of the compressed air that is consumed.
9. Including waste most compressed air systems have overall efficiency of < 10%.
10. Three basic opportunities to save energy include:
    - Generate compressed air more efficiently
    - Minimize pressure loss in the system
    - Reduce compressed air demand

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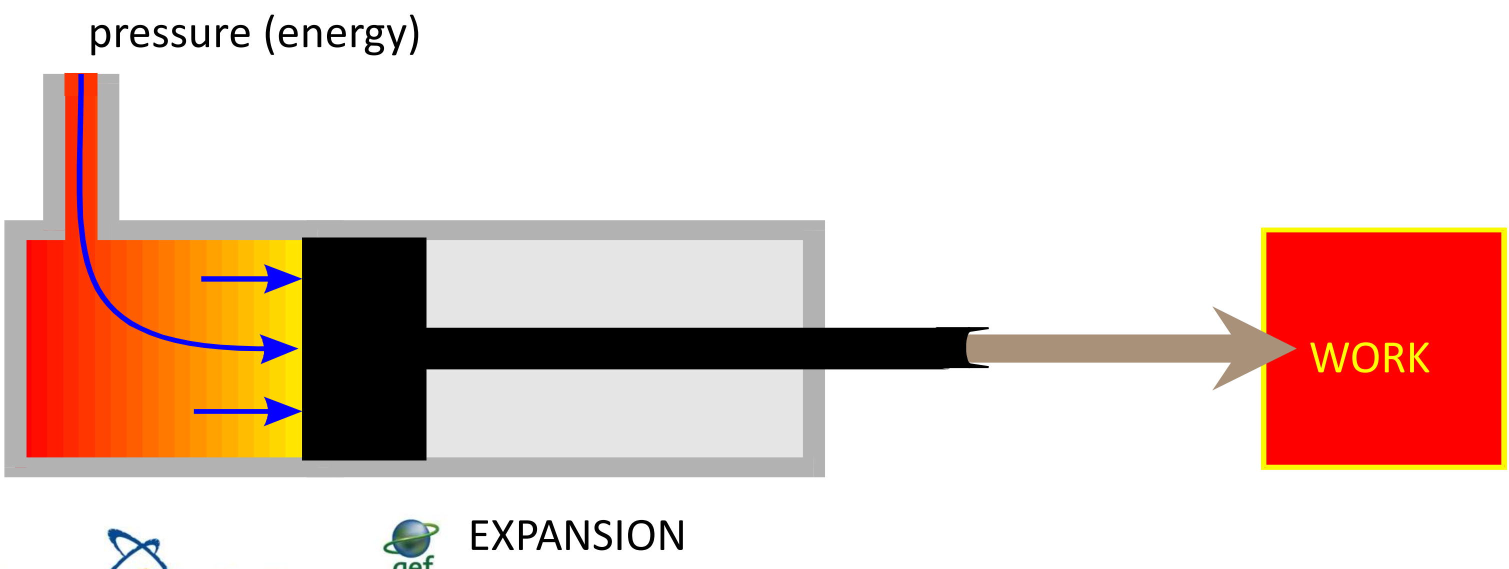
2. Understanding Compressed Air

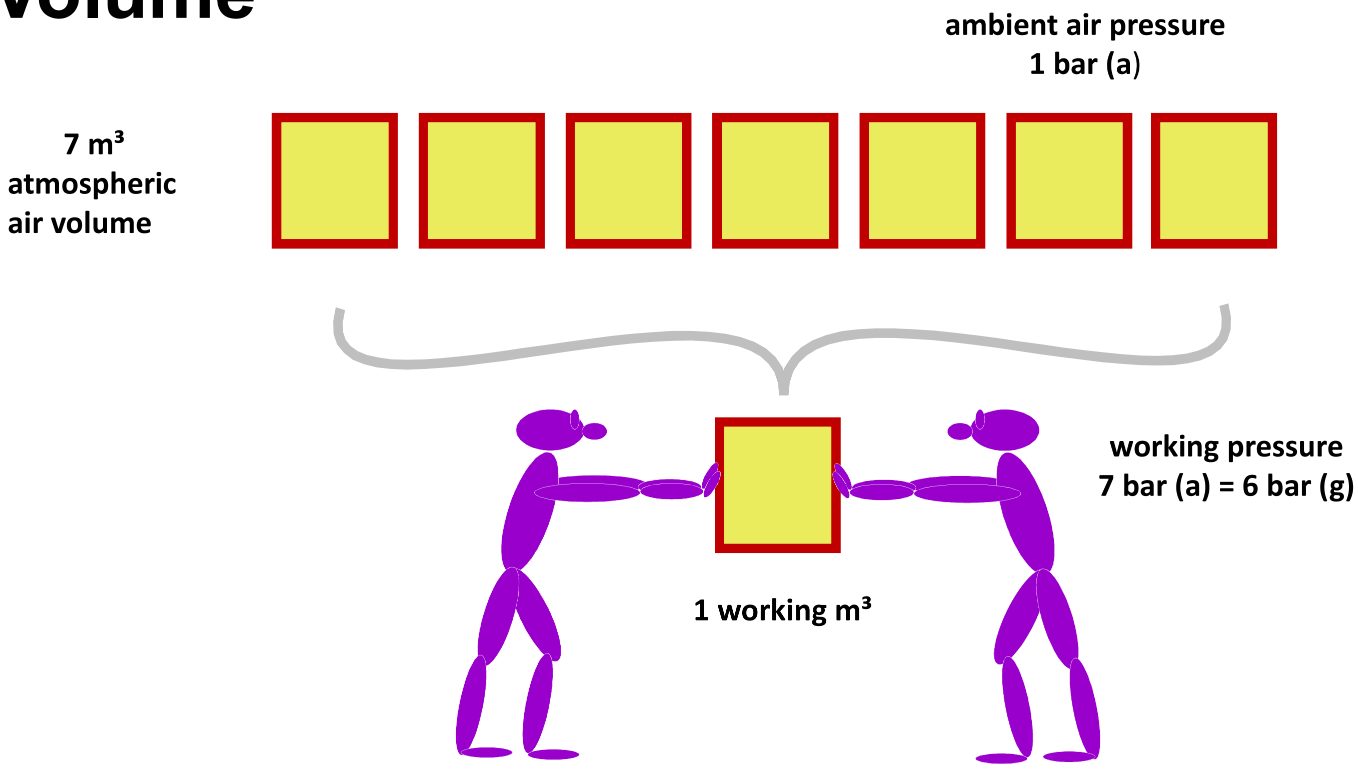
Physical laws

COMPRESSED AIR is atmospheric air under pressure.
That means energy is stored in the air.

When the compressed air expands again
this energy is released as WORK.



Volume


ambient air pressure
1 bar (a)
7 m³
atmospheric
air volume
working pressure
7 bar (a) = 6 bar (g)
1 working m³

FAD (Free Air Delivered) volume flow rate
FAD is the volume of air delivered at the discharge of an air compressor package. The volume flow rate is expressed at the prevailing ambient conditions of temperature, pressure, and relative humidity as they exist at the compressor intake.

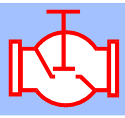
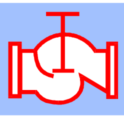
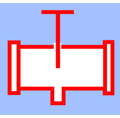
Nm^3/min (Normal cubic meters / minute)
Normal cubic meters / minute (Nm^3/min) is a weight or mass flow rate measurement. Although Nm^3/min and m^3/min sound similar, they are as different as liters and kilograms. Nm^3/min refers to the weight (or mass) of air that occupies one cubic meter of space under a defined (normal or standard) condition of temperature, pressure and humidity conditions.

Minimum diameters of pipes

FAD m³/min	working pressure 7.5 bar (g)			
	length of pipeline			
	up to 50 m	up to 100 m	up to 200 m	over 200 m
up to 12.5	2 1/2"	2 1/2"	3"	see straight-line graph
up to 15,0	2 1/2"	2 1/2"	3"	
up to 17.5	2 1/2"	3"	DN100	
up to 20.0	3"	3"	DN100	
up to 25.0	3"	DN100	DN100	
up to 30.0	3"	DN100	DN100	
up to 40.0	DN100	DN100	DN 125	

Flow resistance of fittings

expressed in equivalent pipe lengths

fitting example	equivalent pipe length in m						
	pipe inside diameter in mm						
	25	40	50	80	100	125	150
	6	10	15	25	30	50	60
	3	5	7	10	15	20	25
	0,3	0,5	0,6	1	1,3	1,6	1,9

Total pipe length: $L_{overall} = L_{straight} + L_{equivalent}$

or roughly: $L_{overall} = 1,6 \times L_{straight}$

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Pressure drop

If the normal working pressure of a pneumatic tool is 6 bar (g), any increase above that pressure costs money.

Example:
V = 30 m^3/min demand at 7 bar (g) 160 kW
At 8 bar (g) approximately 6% more power is required, i.e. around 9.4 kW more

Costs:
9.4 kW x 0.15 $/kWh x 8000 h/year = $11 280 /year!

Air main:
On a well designed air piping system a pressure drop of 0.1 bar is normally expected.

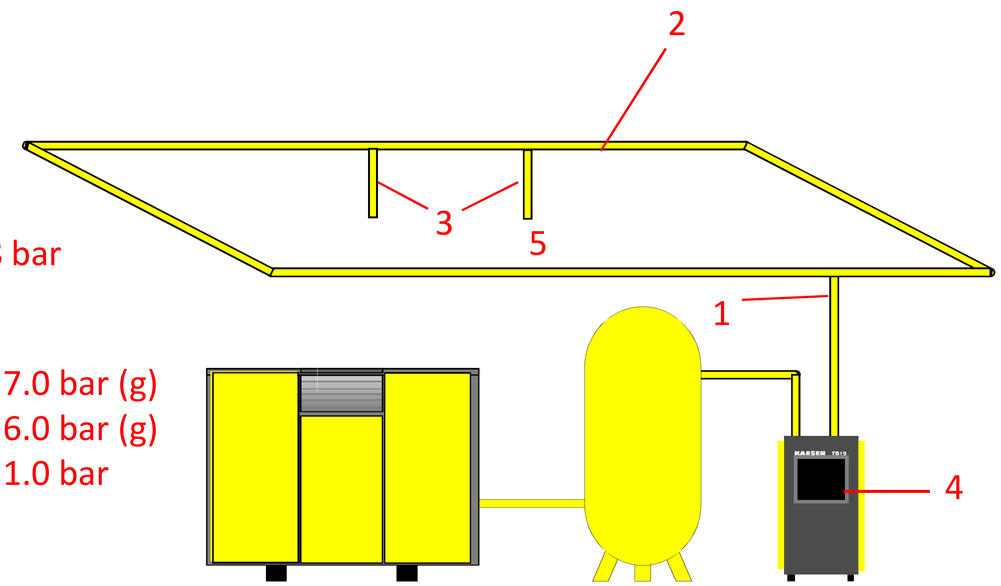
The maximum pressure drop in the air piping system should be no more than 1.5 % of the working pressure

Target Pressure Drop

1. Main piping	0.03 bar
2. Loop main (distribution)	0.03 bar
3. Connecting lines	0.04 bar
4. Refrigeration dryer	0.2 bar
5. FRL unit and hose	0.5 bar
max.	0.8 bar

Overall pressure drop 0.8 bar

Max. pressure at compressor	7.0 bar (g)
Pressure at consumer	6.0 bar (g)
Difference	1.0 bar



Key Learning Points

1. Compressed air is a common method of transmitting energy to pneumatic tools and devices.
2. The work accomplished by compressed air is dependent on the weight of air delivered to the end use equipment.
3. The weight of air is dependent on the conditions of pressure, temperature, and relative humidity.
4. Pressure, volume, and temperature are interrelated, in this relationship air is treated as an ideal gas.
5. As compressed air energy is transmitted from one location to another, pressure loss is an irrecoverable loss of energy.
6. The amount of pressure loss is related to the velocity in the compressed air pipeline

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3. Supply Side – Compressors and Their Application

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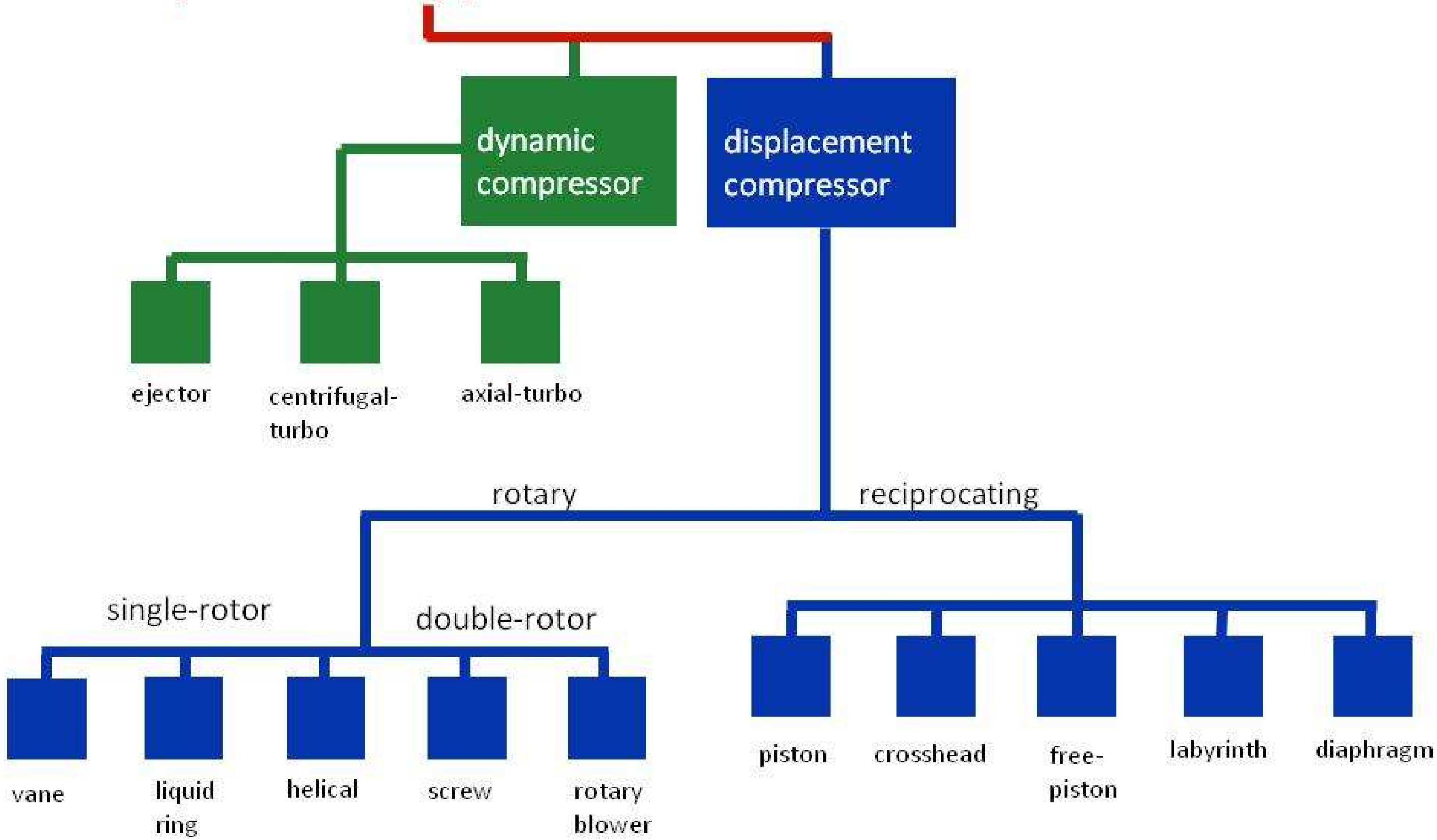
Compressor types



Specific Power for Various Compressor Types

Specific Power for Various Compressor Types (typical range)			
Volumetric flow rate (free air delivery)	kW / m^3/ min	kW / 100 l/sec	kW / 100 cfm
Recip. Single Acting (sgl stage)	7.8 - 8.5	47 - 51	22 - 24
Recip. Single Acting (2 stage)	6.4 - 8.1	38 - 49	18 - 23
Recip. Double Acting (sgl stage)	8.5 - 10.2	51 - 61	24 - 29
Recip. Double Acting (2 stage)	5.3 - 5.7	32 - 34	15 - 16
Lubricated Screw (sgl stage)	6.0 - 7.8	36 - 47	17 - 22
Lubricated Screw (2 stage)	5.7 - 6.7	34 - 40	16 - 19
Lubricant Free Screw (2 stage)	6.4 - 7.8	38 - 47	18 - 22
Centrifugal (3 stage)	5.7 - 7.1	34 - 42	16 - 20

Displacement Compressors

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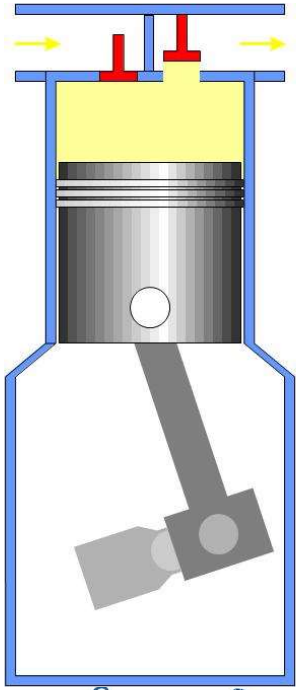
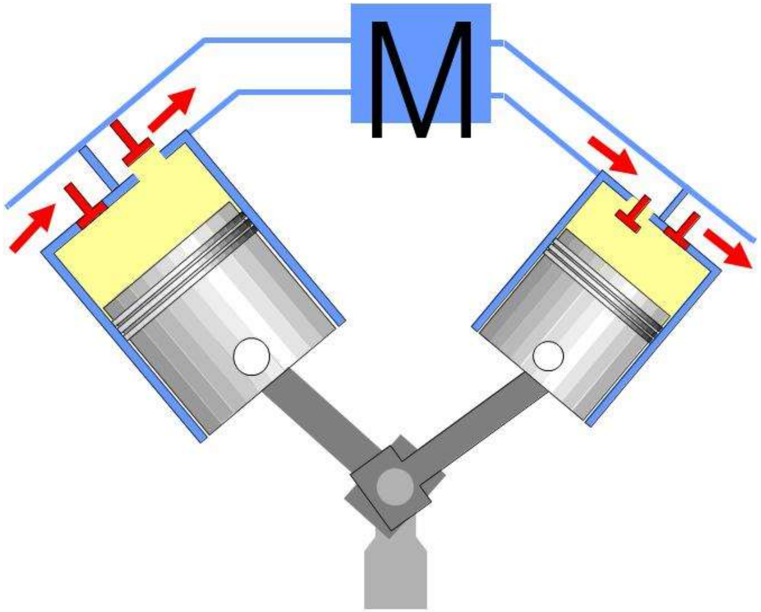
Reciprocating compressors

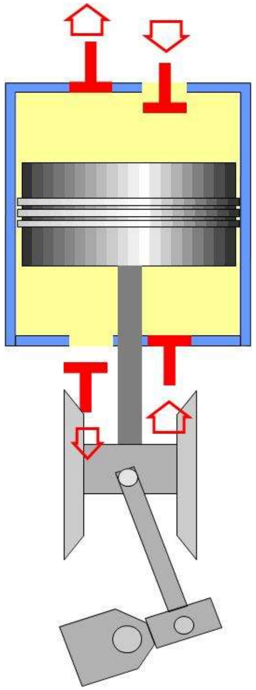
Single-acting, single-stage



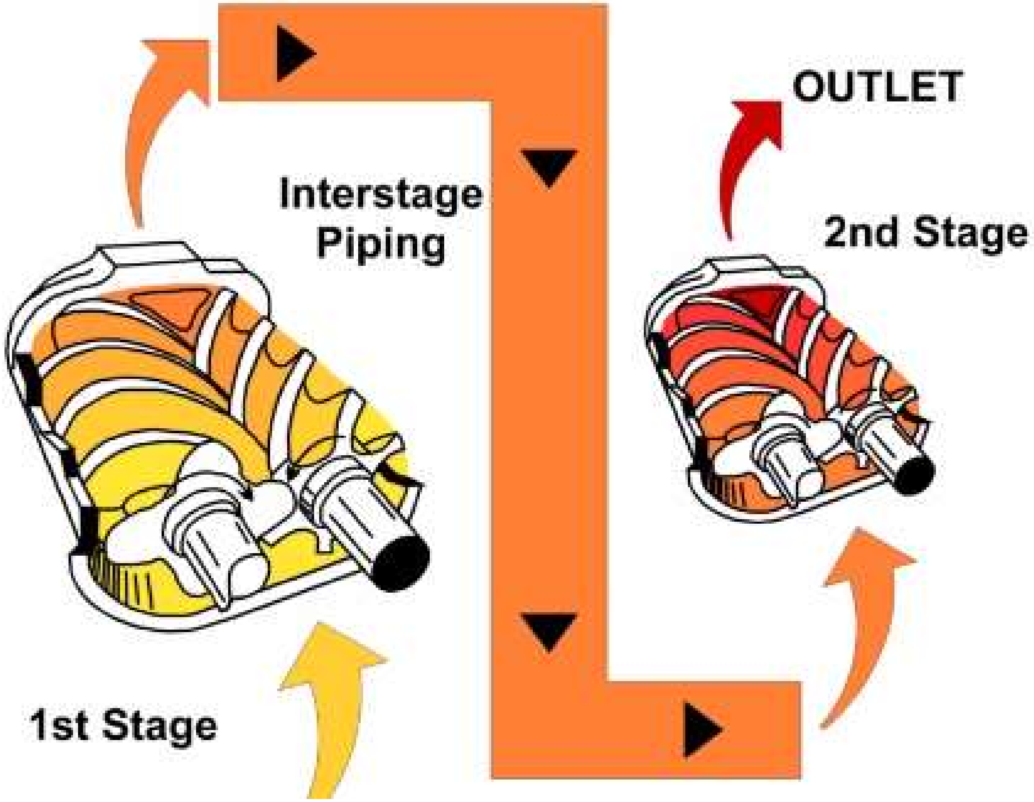
Single-acting, two- stage



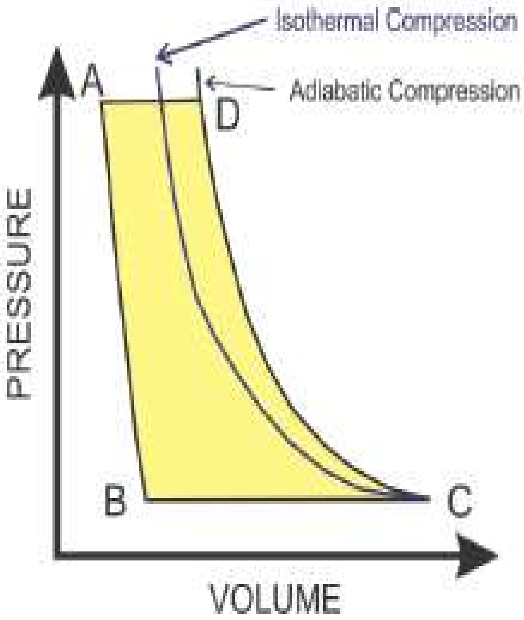
Double-acting, single- stage

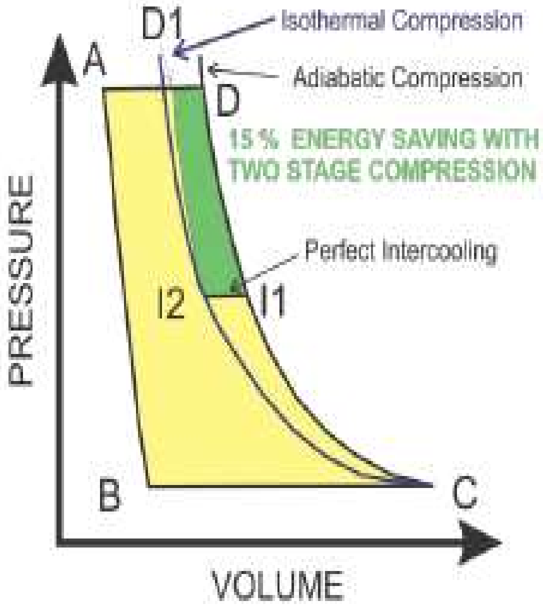


Multistage Compression

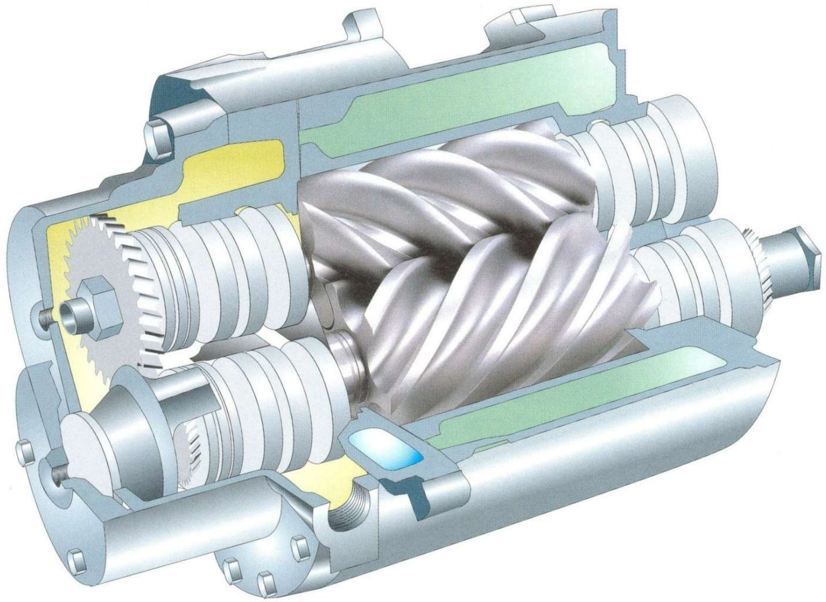


Stages of Compression: Single-stage, Two-stage, Multi-Stage

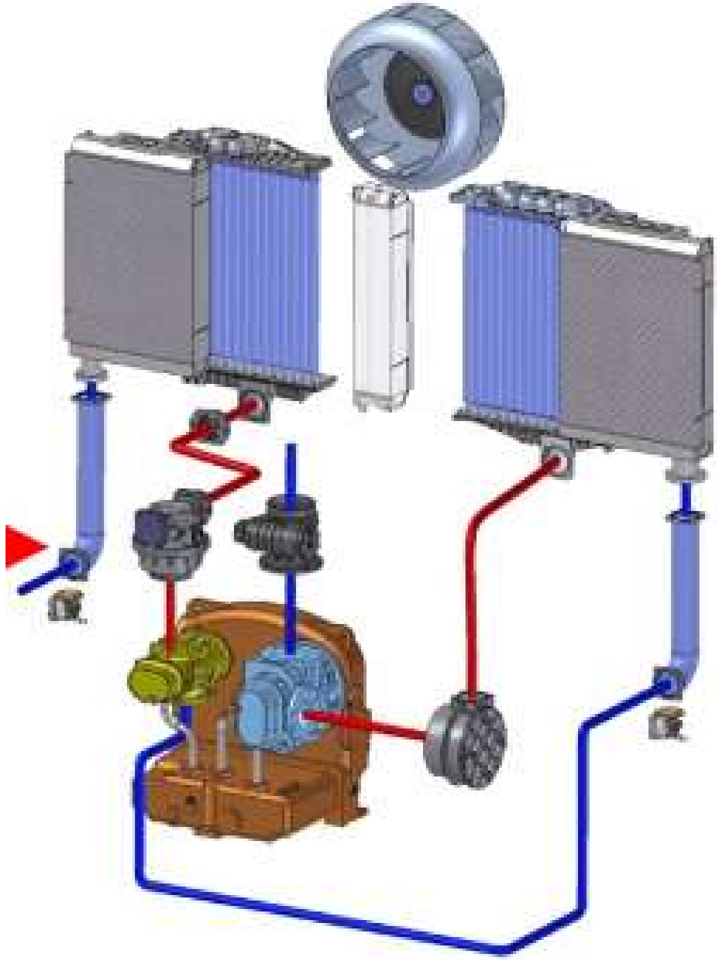




Oil Free Screw Compressor



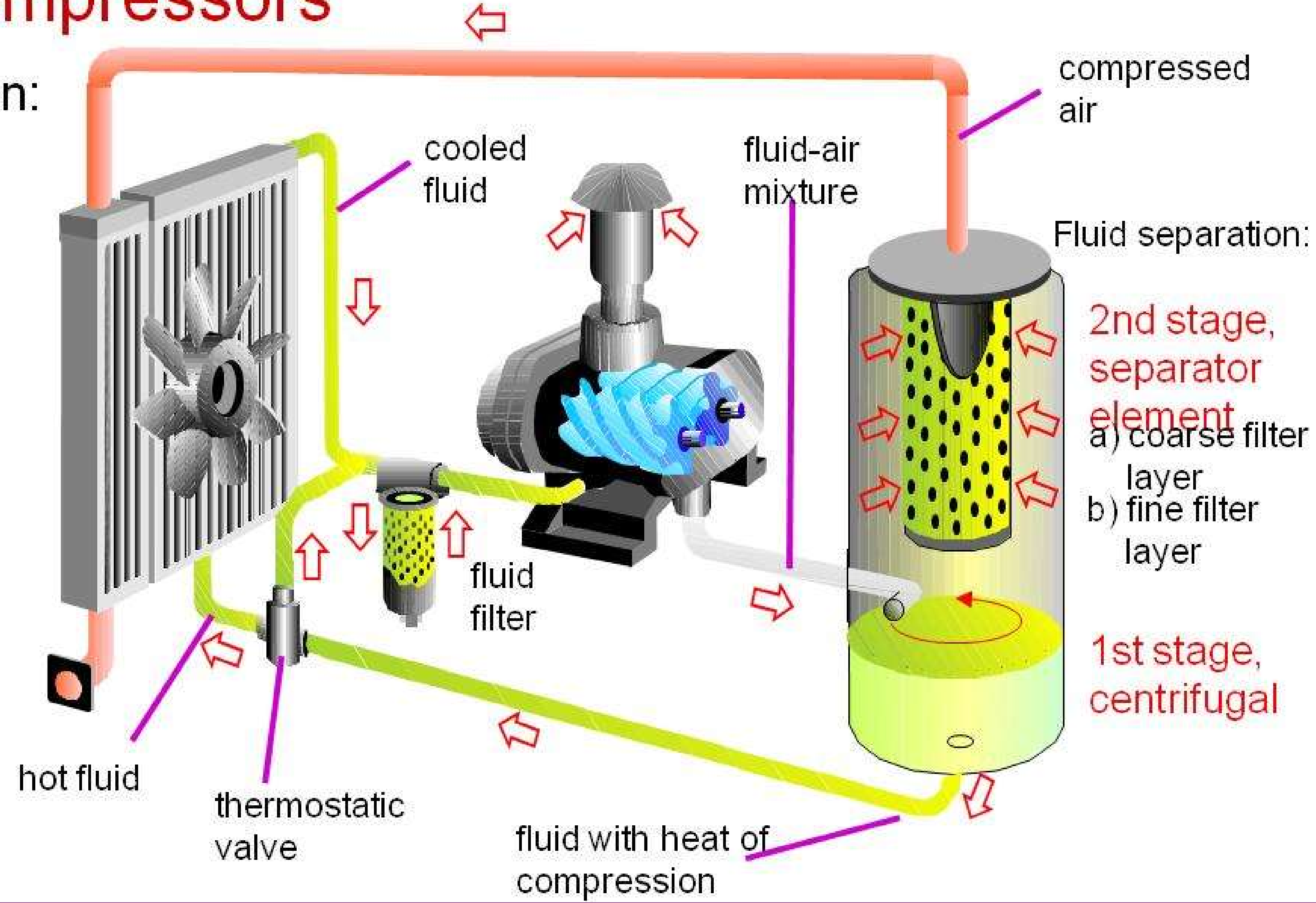
A stage in an oil-free screw compressor. Male and female rotors are journalled in the rotor housing, which here is water-cooled. The front rotor, with four lobes, is the male, this is connected to the gearbox. The distant rotor, with six lobes, is the female, this is held in place by the synchronising gear to the left.



Screw compressors

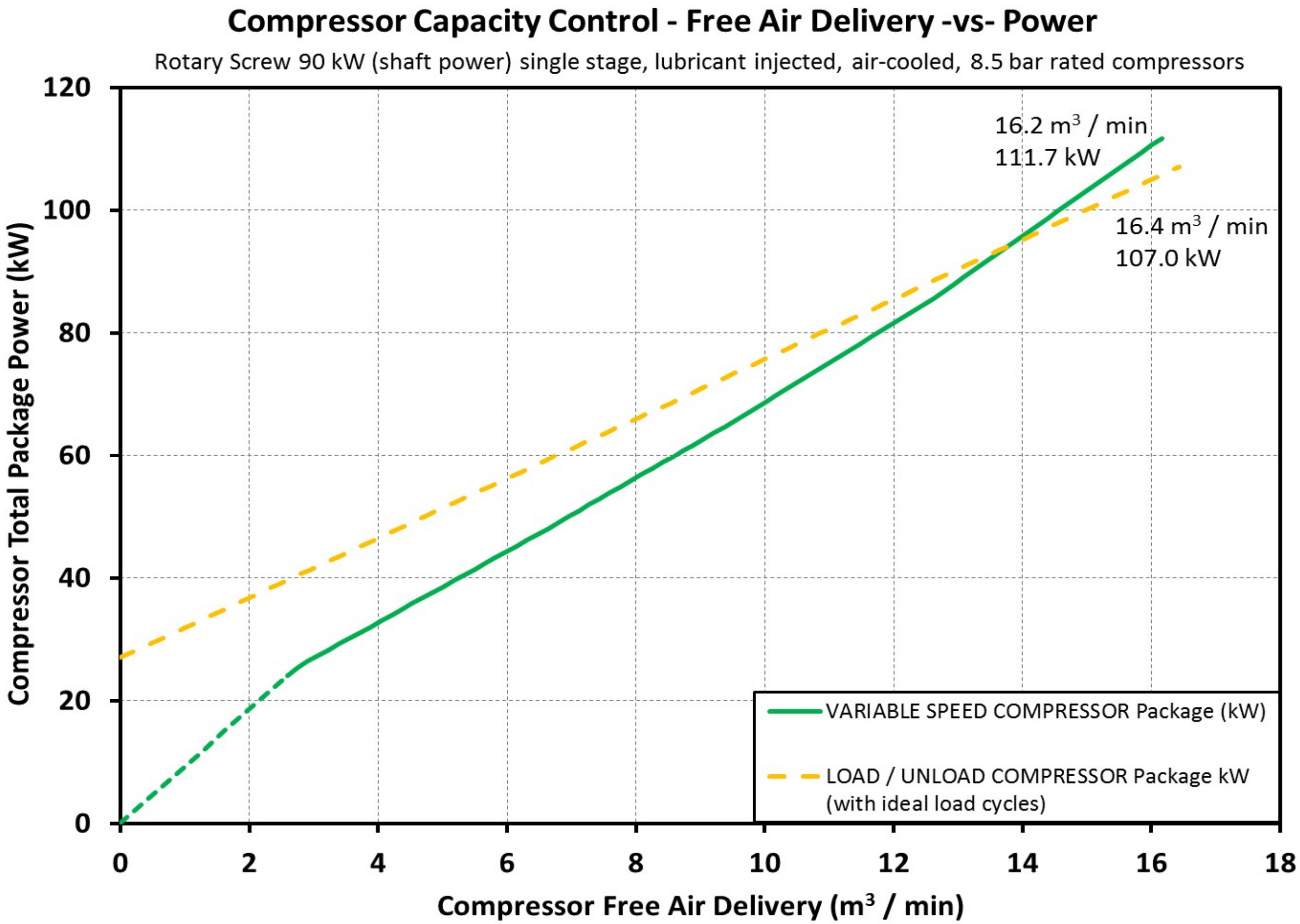
Construction:

Up to 85m³

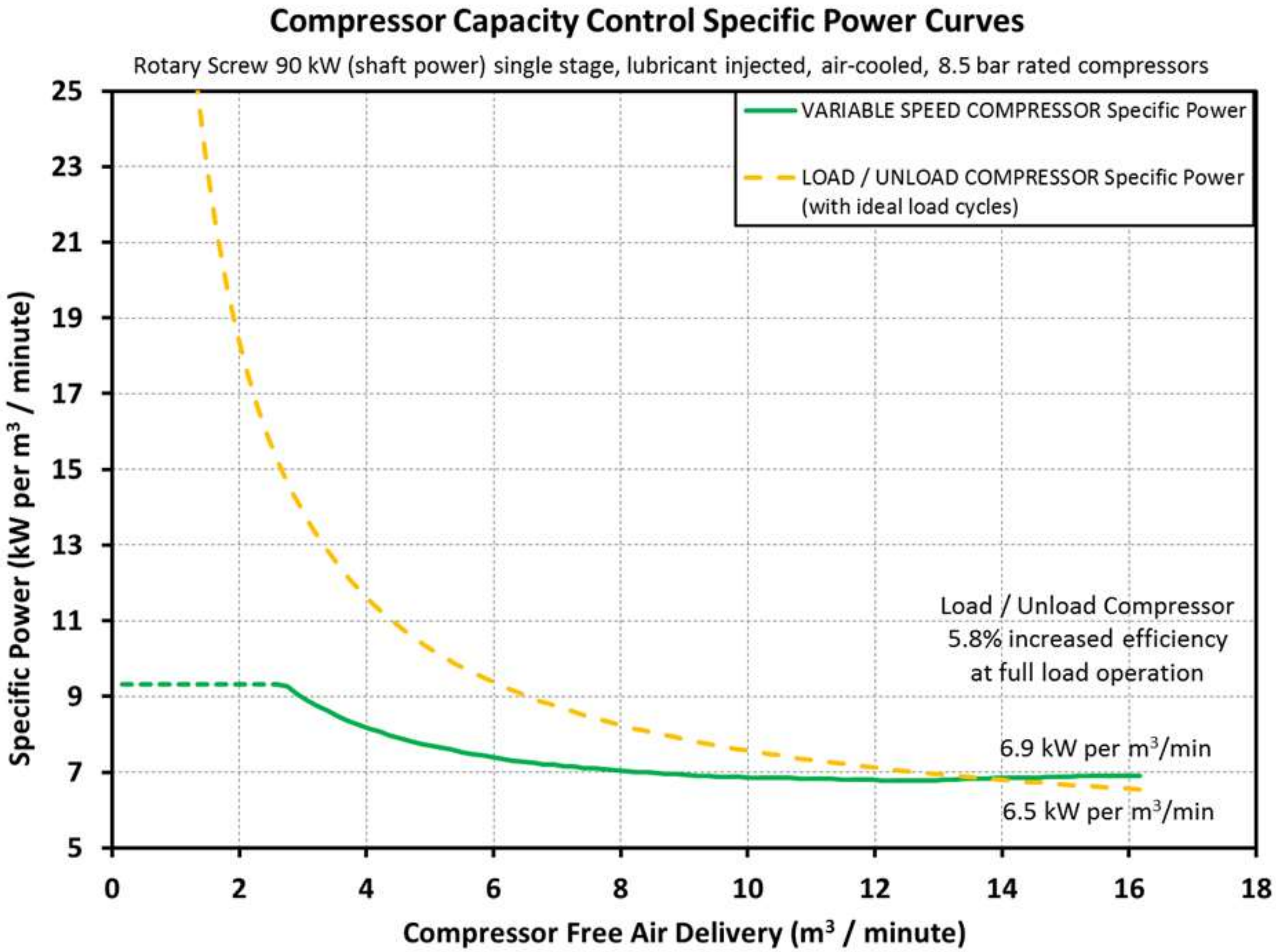


Compressor Performance Curves

Free Air Delivery -vs- Power



Compressor Performance Specific Power Curves



Load / Unload control

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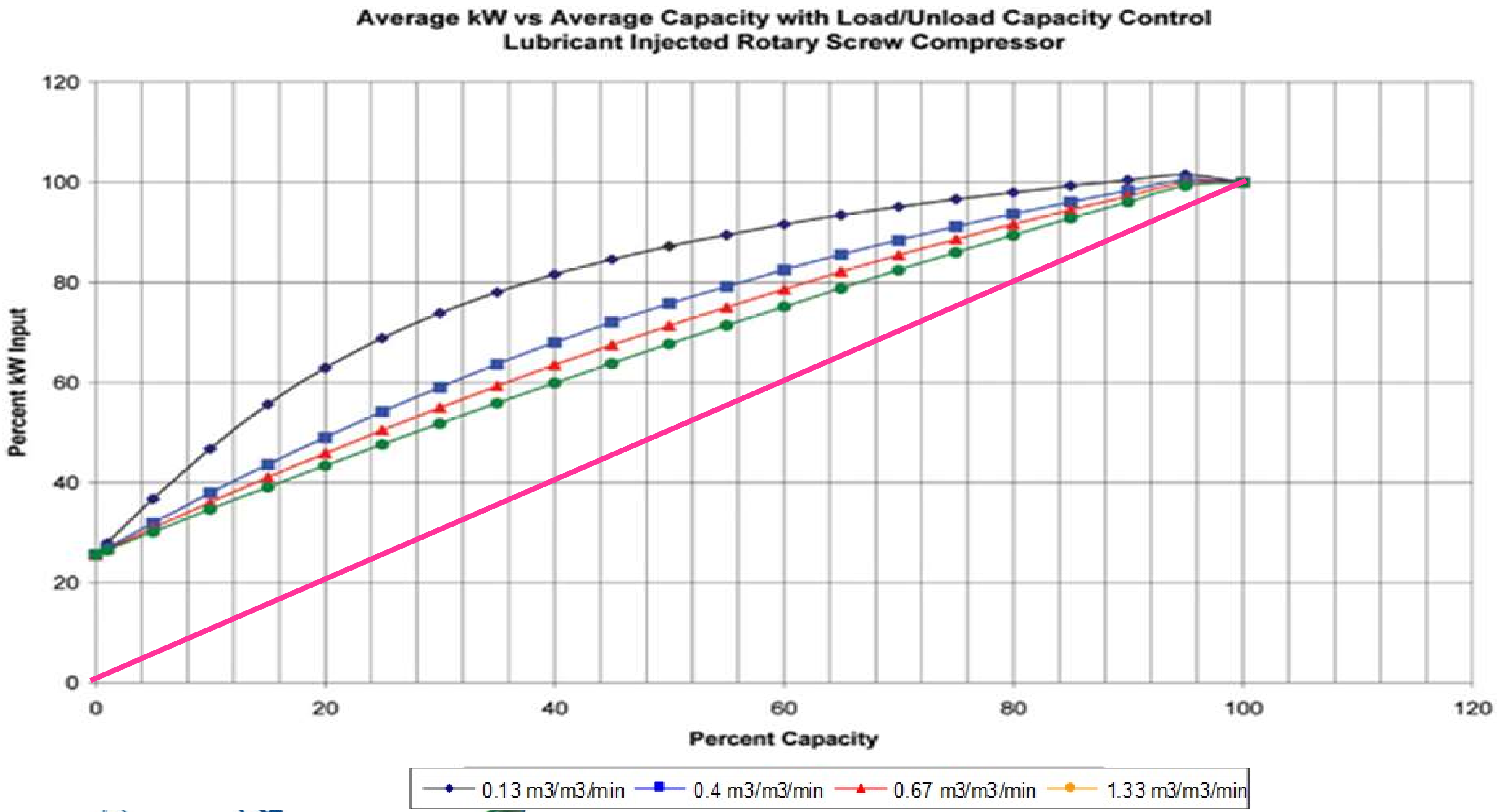
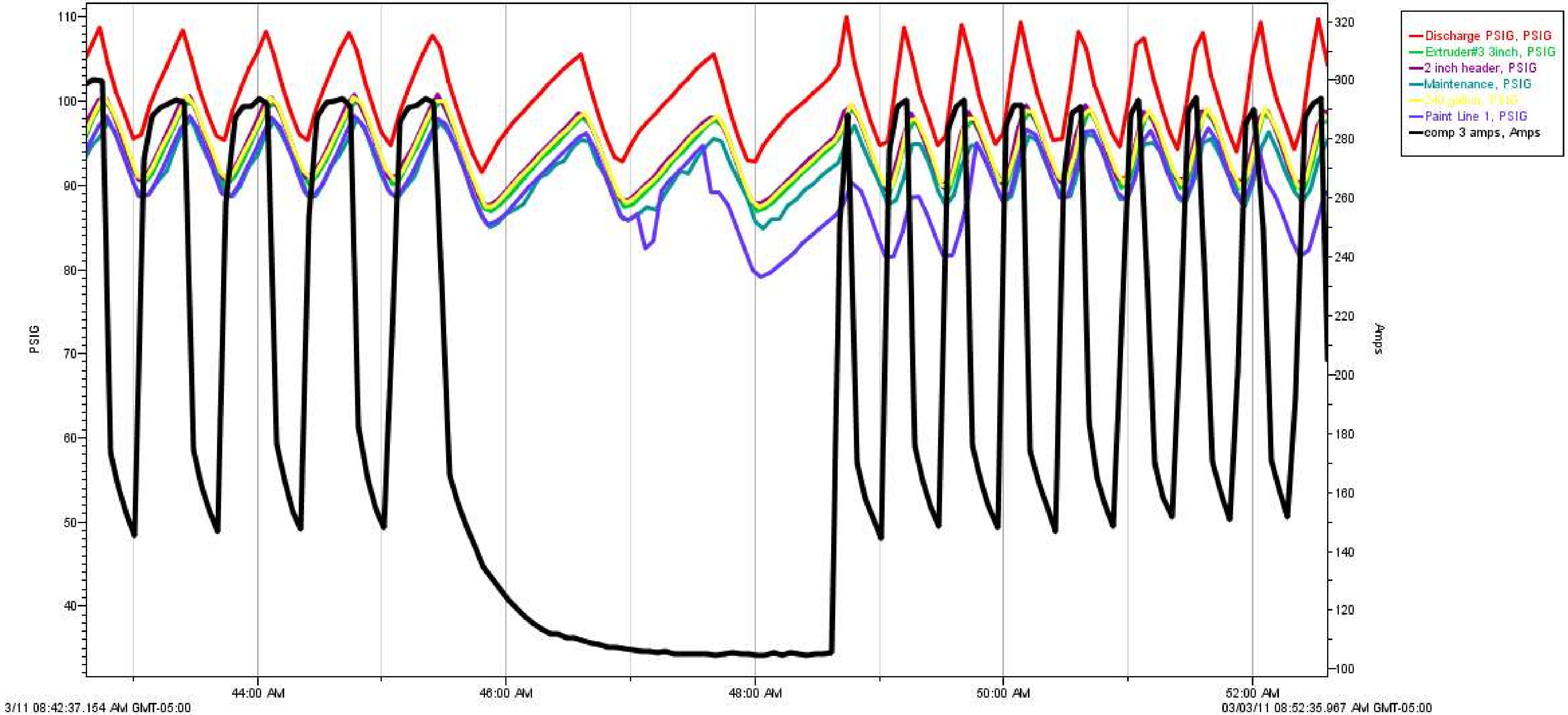
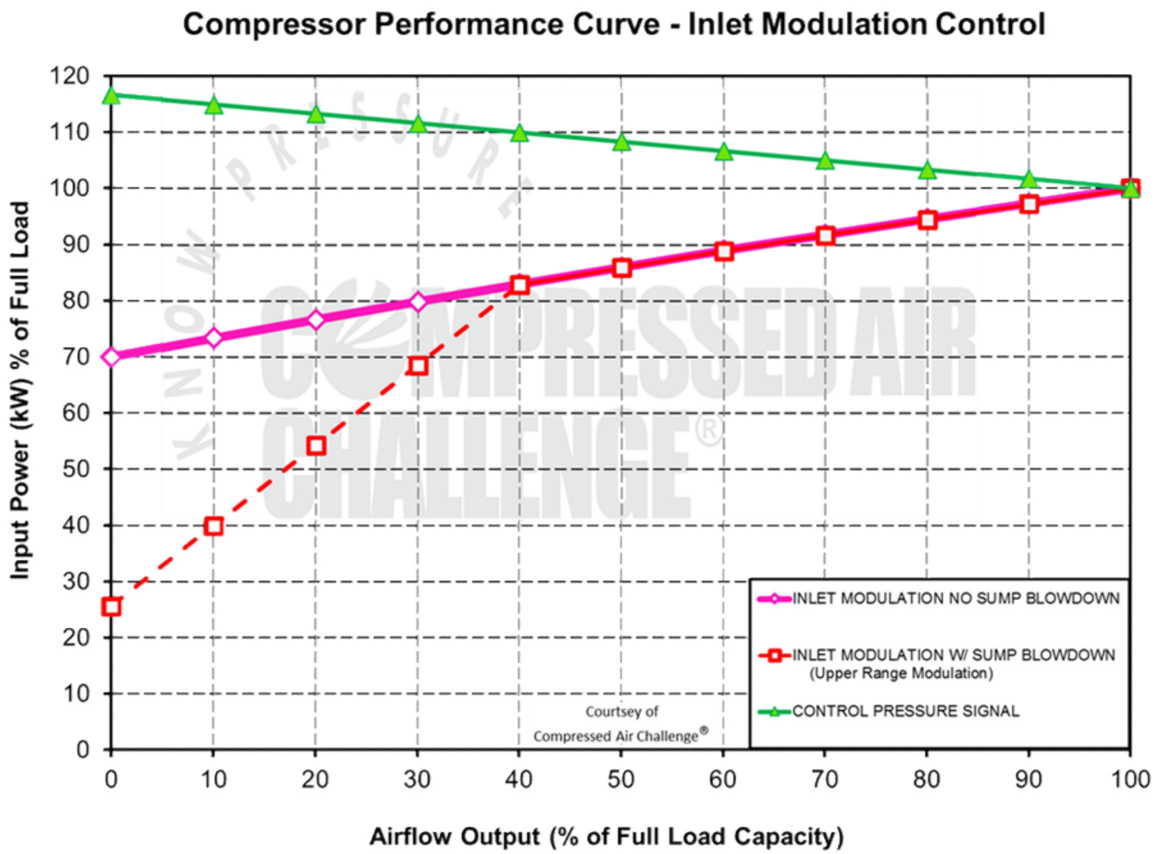
Load / Unload Control



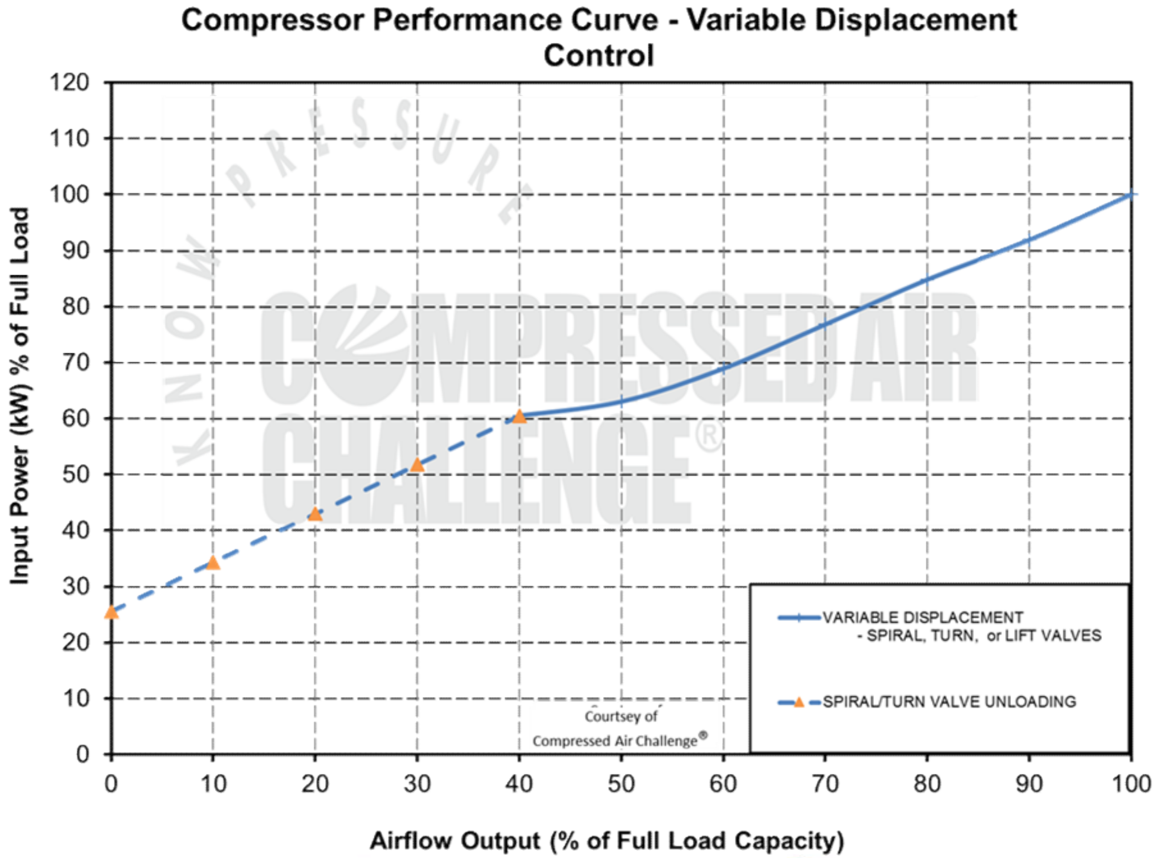
Load / Unload control

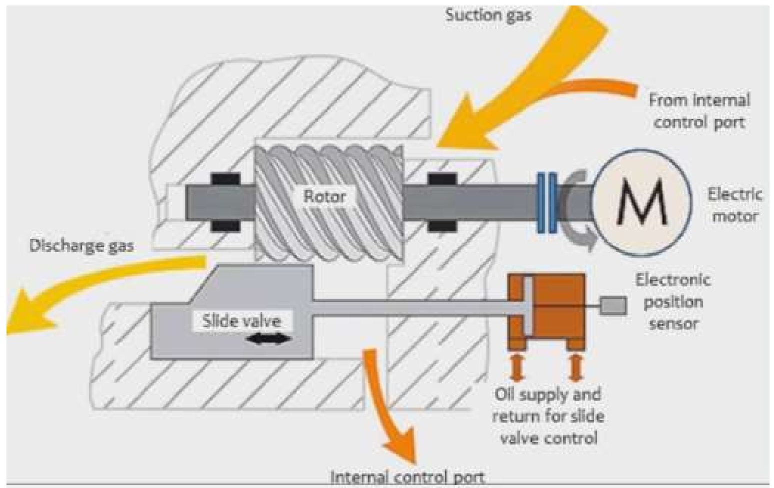


Inlet Modulation power curve
- rotary screw compressors



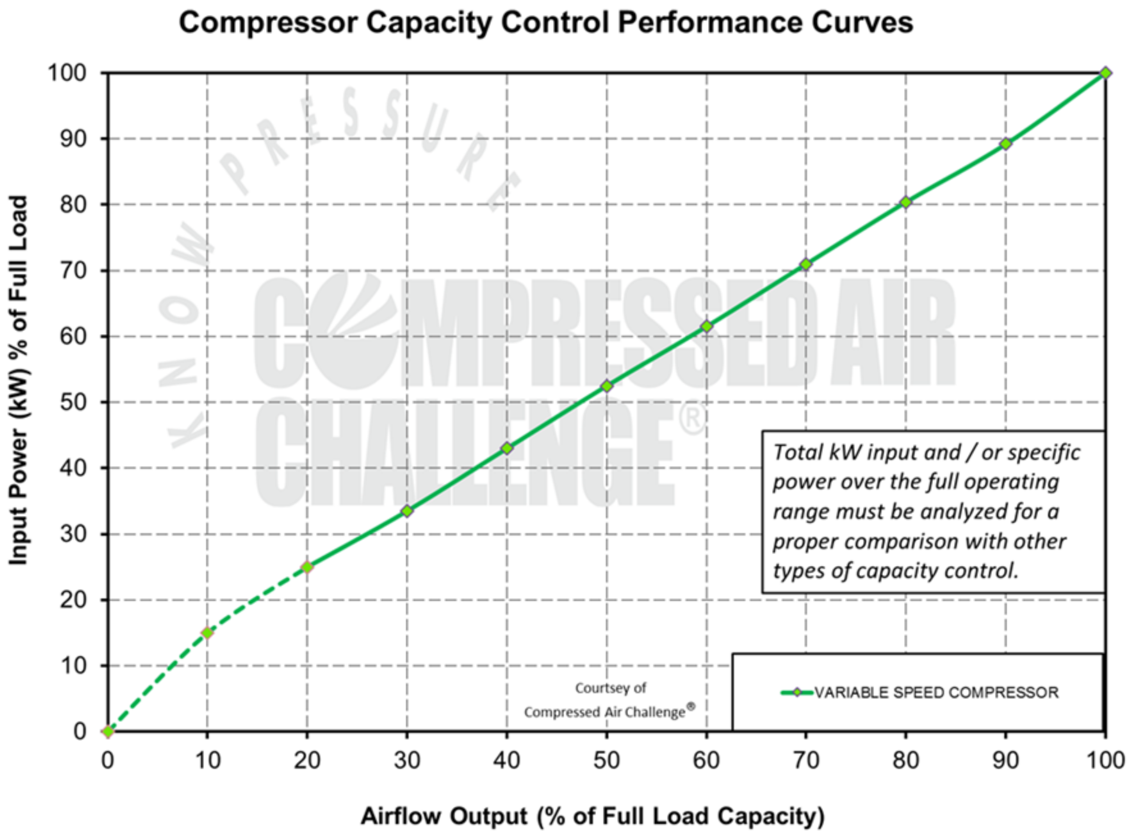
Variable displacement power curve - rotary screw compressors





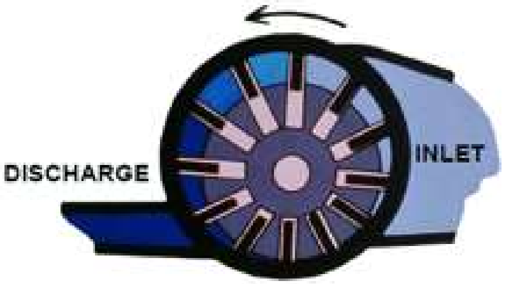
Variable speed drive power curve

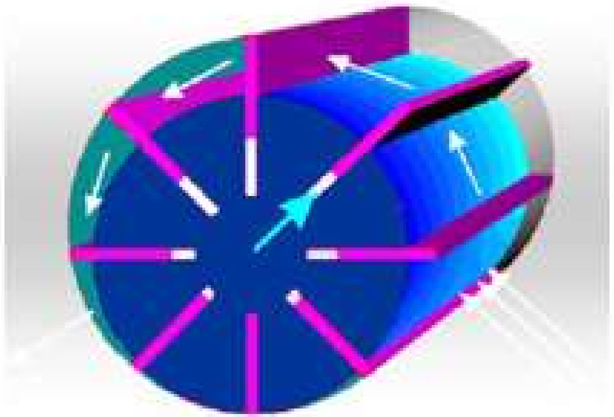
- rotary screw compressors

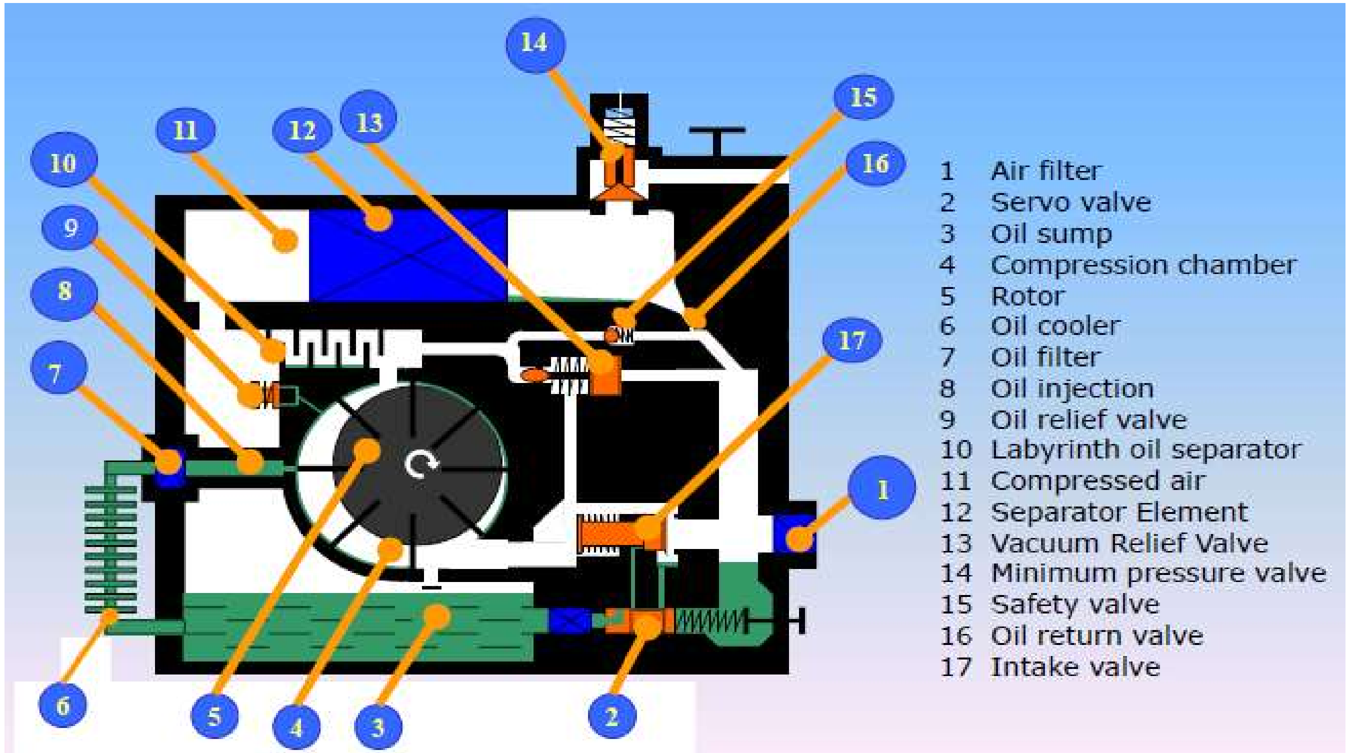


Displacement Compressors

Rotary Vane Compressors







Axial Compressors

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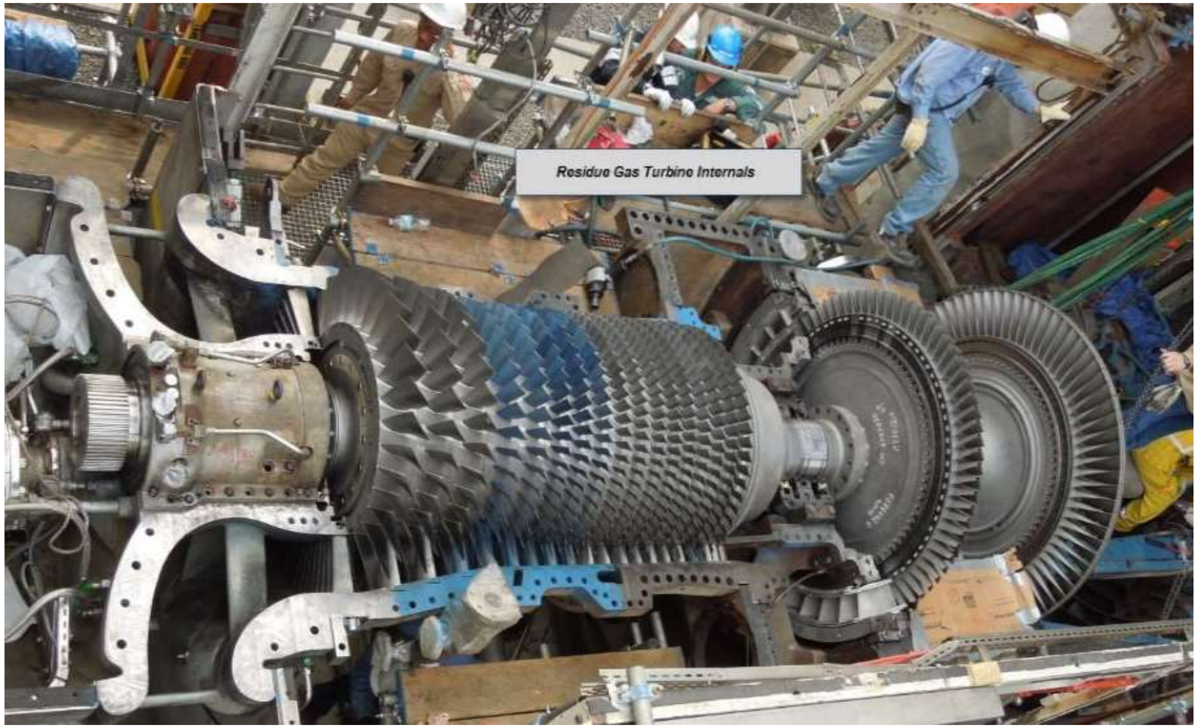
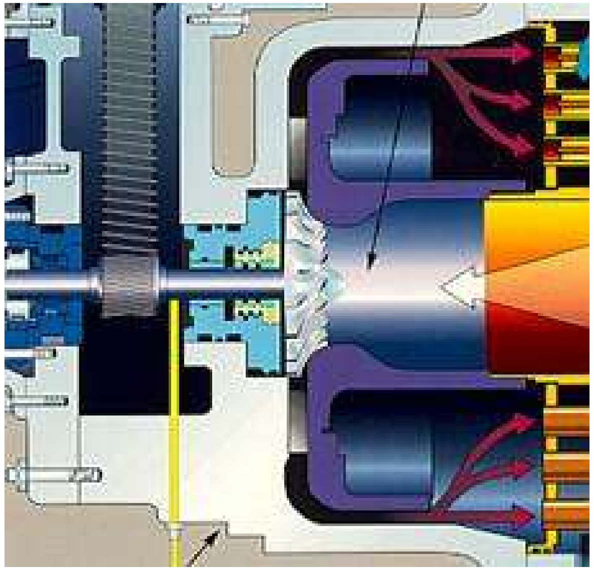
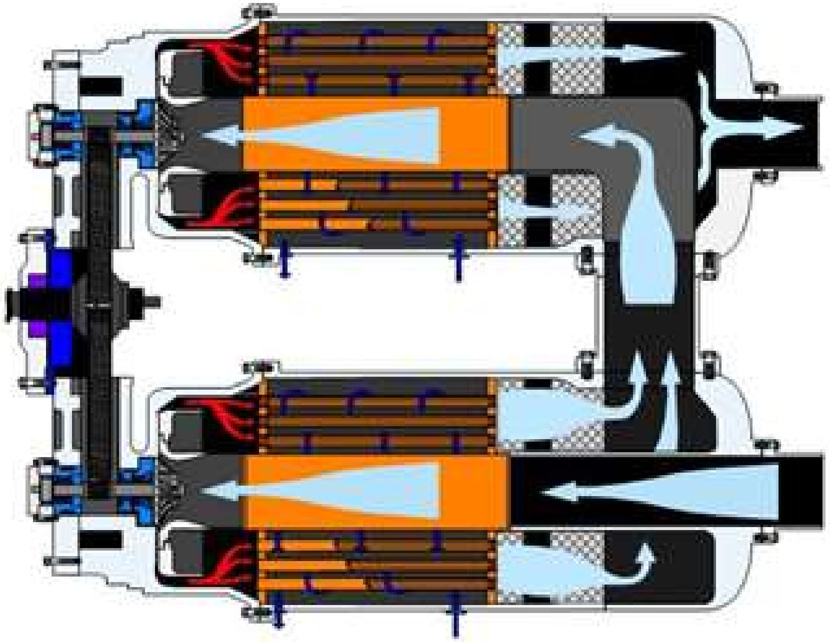


Dynamic Compressors

Centrifugal Turbo Compressors





Characteristics:

Capacity: 35 - 1200 m^3/min

Stages: 1 - 6

Pressure range: 3 - 40 bar (g)

Speed range: 3000 - 80000 min^{-1}

Centrifugal Compressors

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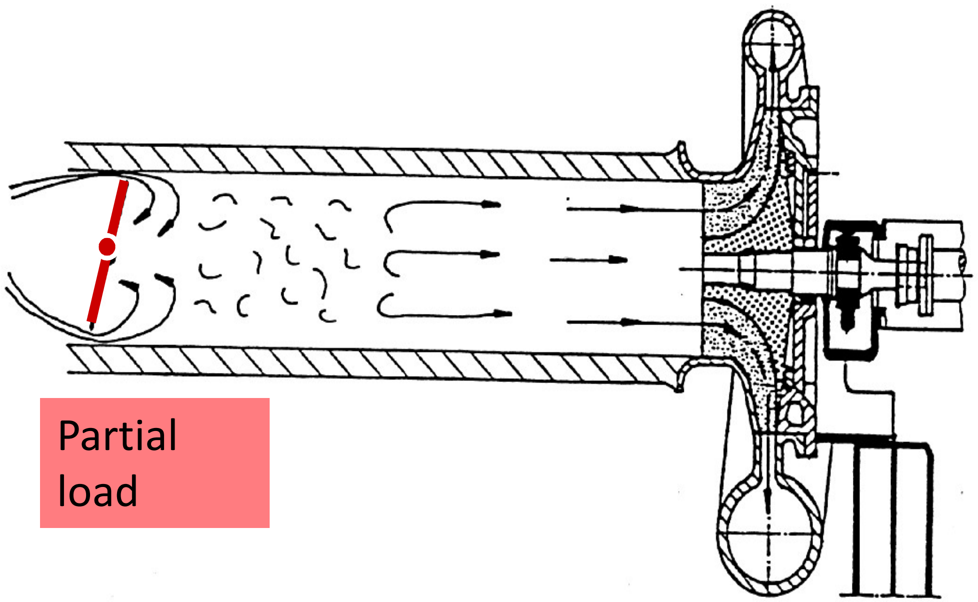
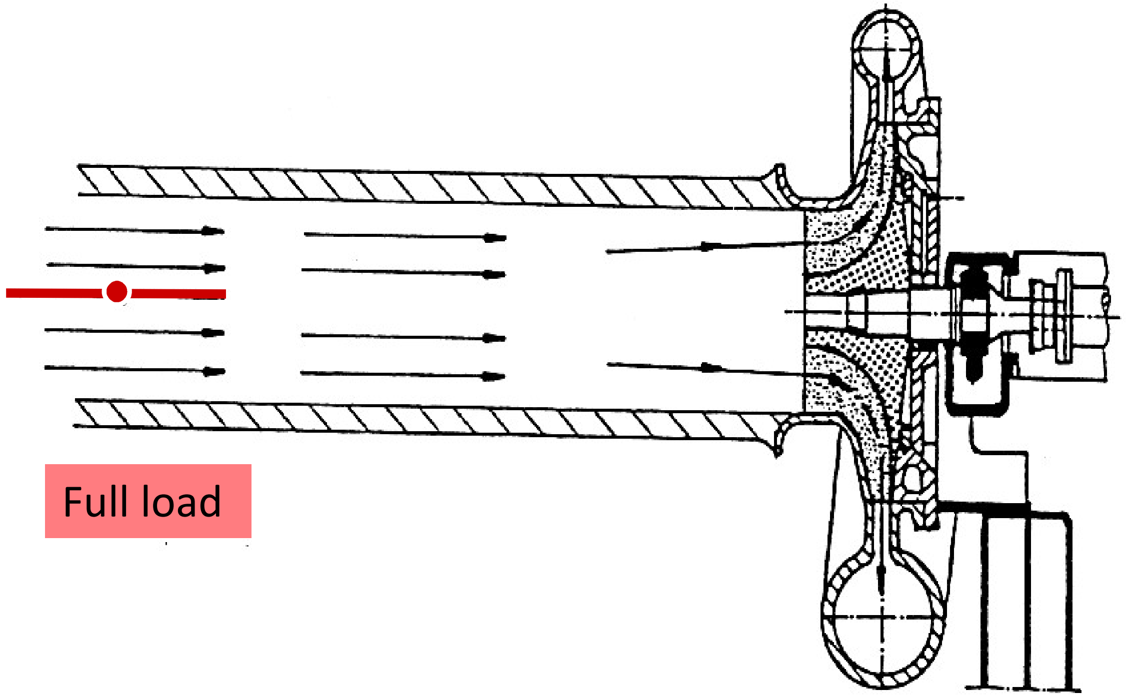
- Smaller size centrifugals now available
  - Over lap in performance with large positive displacement compressors
  - More combined systems with a mix of positive displacement and centrifugal machines.
- Dynamic Control -> Constant Pressure
- Displacement Control -> Pressure Band
- Special Considerations when Controlling Mixed Systems

Turbo compressor: Throttle control





Dynamic Compressors

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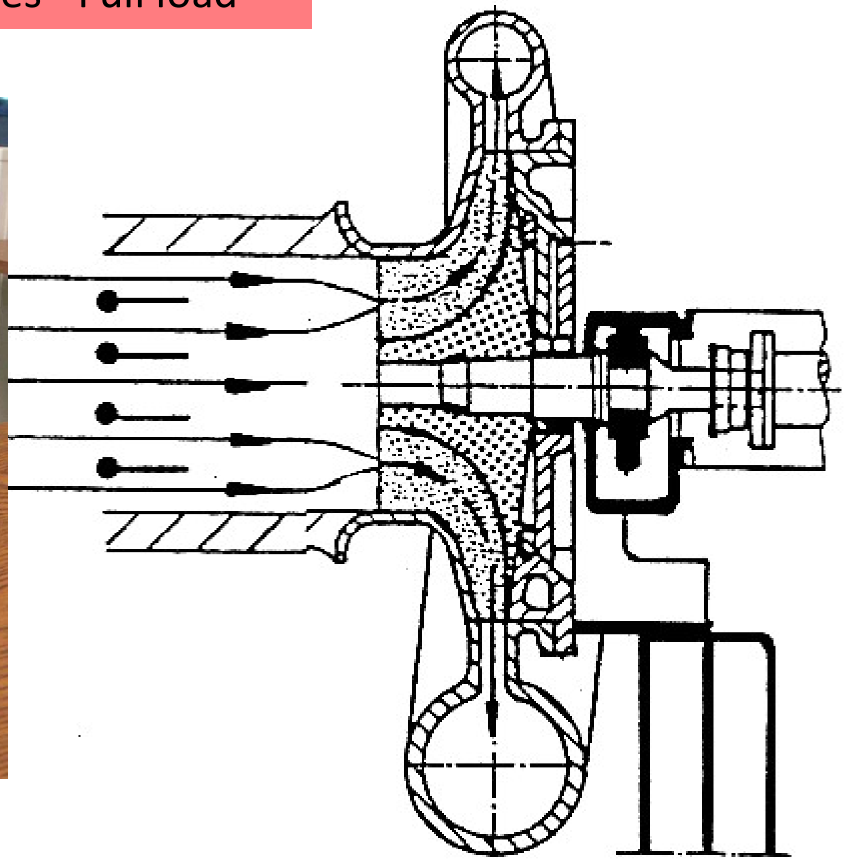
Turbo compressor: Volume control

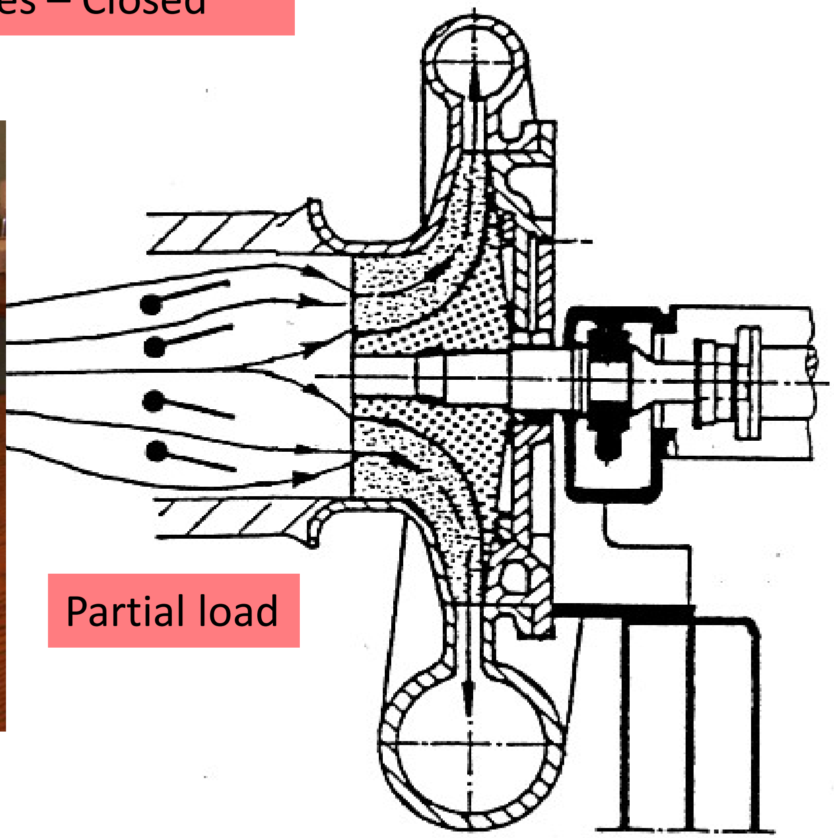
Inlet guide vanes - Full load



Dynamic Compressors

Turbo compressor: Volume control

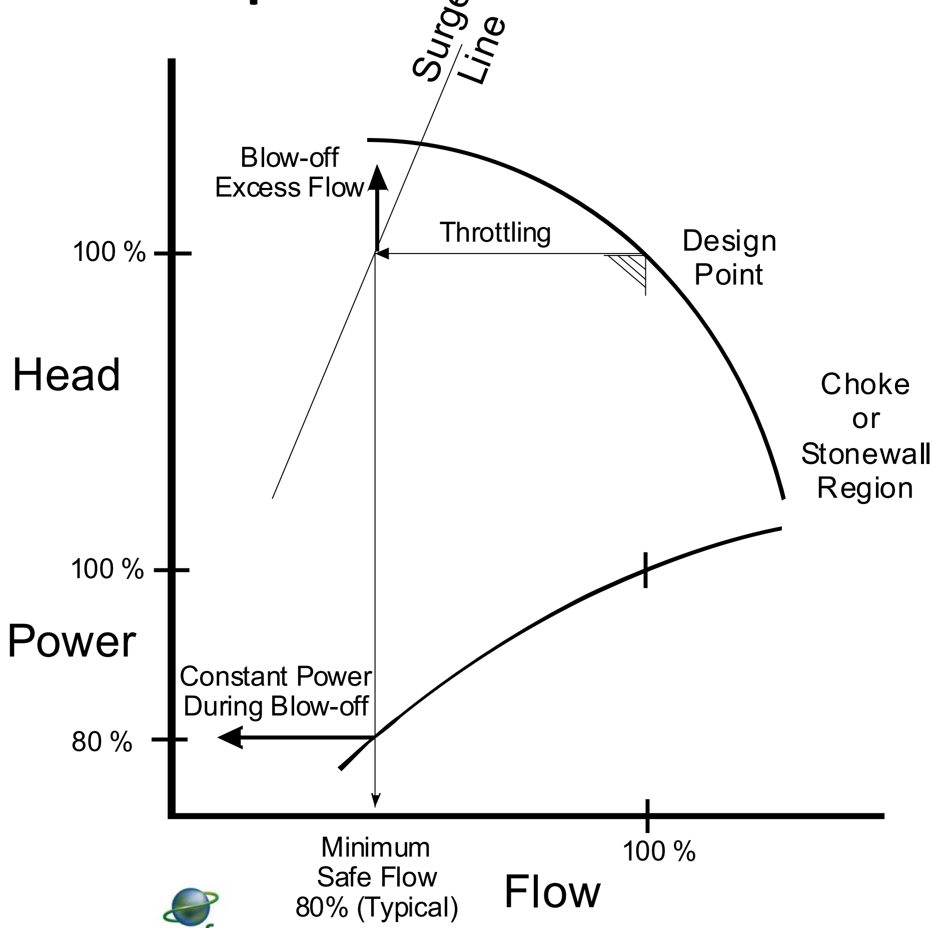
Inlet Guide Vanes – Closed



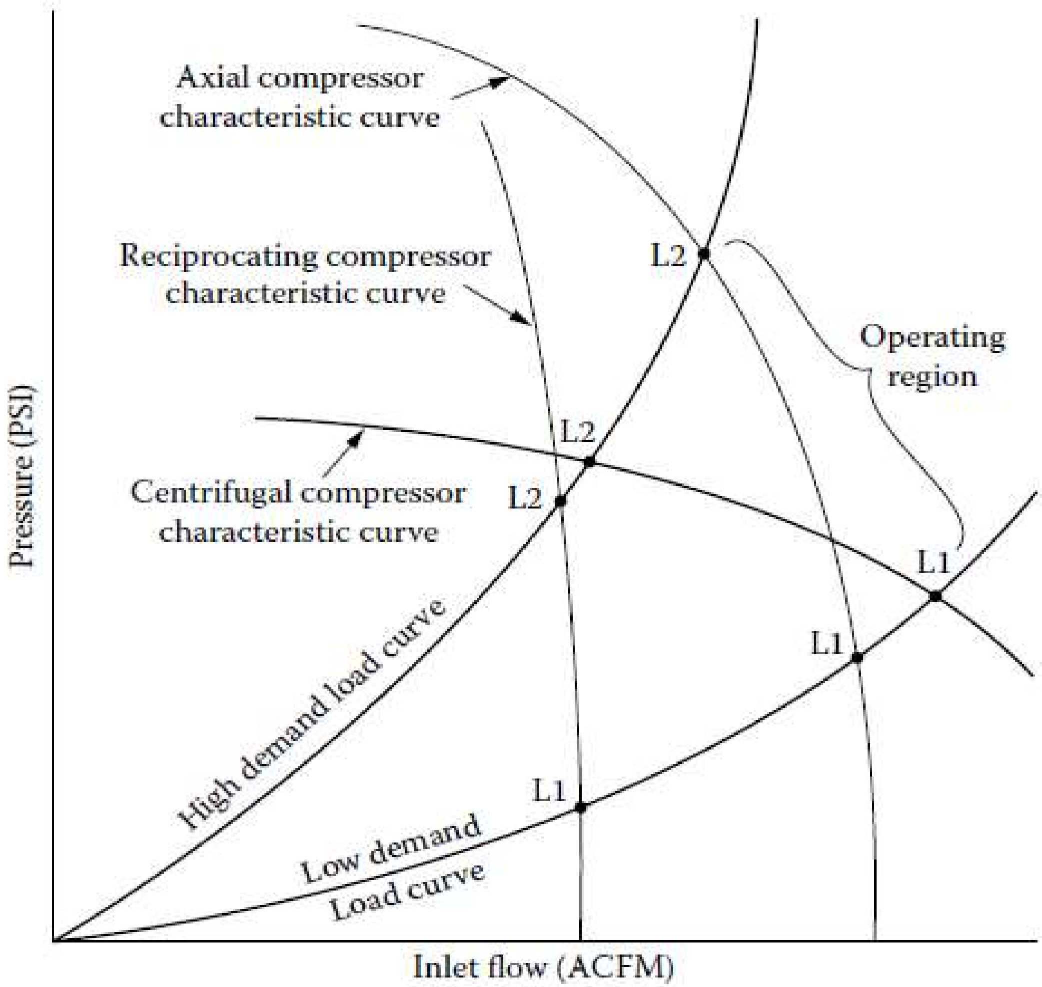
Partial load

Dynamic Compressors

Centrifugal Compressor Performance Curve



Characteristic curves comparison of different compressor types



Key Learning Points

1. 2 categories of industrial air compressors: positive displacement and dynamic.
2. Reciprocating, rotary screw, and rotary vane are positive displacement compressors.
3. Rotary screw compressors are the most common type of industrial air compressor.
4. There are many different types of part load capacity control for rotary screw compressors.
5. Centrifugals are the most common type of dynamic compressor used by industry.
6. Aerodynamic design determines the head -vs- flow performance curve for centrifugals
7. Performing poor routine maintenance for centrifugals can lead to expensive failures
8. Different types of part load capacity control have different part load power characteristics.
9. Operating centrifugal compressors with blow-off control or in the stonewall (or choke) region of the performance range is very inefficient.
10. In systems with rotary screw compressors it is most efficient to have all compressors operate at full load, with only one at part load for trim capacity.
11. When operating multiple centrifugals in a system it is more efficient to have multiple compressors operate at part load within their throttle throttling range as opposed to operating in blow-off.
12. When operating a system using a combination of positive displacement and centrifugal compressors requires special attention to control strategy and the system's pressure profile.

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4. Air Treatment

Quality classification of compressed air

ISO 8573-1 Class	Solid particle content					Moisture content	Oil content
	max. number of particles per m³ sized *d* [µm]				Mass Concentration C_P (mg/m³)	PDP / *(x=liquid water content g/m³)*	mg/m³
	≤ 0,1	0,1< *d* ≤ 0,5	0,5< *d* ≤ 1,0	1,0< *d* ≤ 5,0			
0	as specified by the equipment user or supplier and more stringent than class 1						
1	-	≤ 20 000	≤ 400	≤ 10	-	≤ -70 °C	≤ 0,01
2	-	≤ 400 000	≤ 6 000	≤ 100	-	≤ -40 °C	≤ 0,1
3	-	-	≤ 90 000	≤ 1 000	-	≤ -20 °C	≤ 1,0
4	-	-	-	≤ 10 000	-	≤ +3 °C	≤ 5,0
5	-	-	-	≤ 100 000	-	≤ +7 °C	-
6	-	-	-	-	< 0 C_P ≤ 5	≤ +10 °C	-
7	-	-	-	-	< 5 C_P ≤ 10	*x ≤ 0,5*	-
8	-	-	-	-	-	*0,5 ≤ x ≤ 5,0*	-
9	-	-	-	-	-	*5,0 ≤ x ≤ 10,0*	-

Typical Air Quality Class Recommendations

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Typical Air Quality Classes[4]

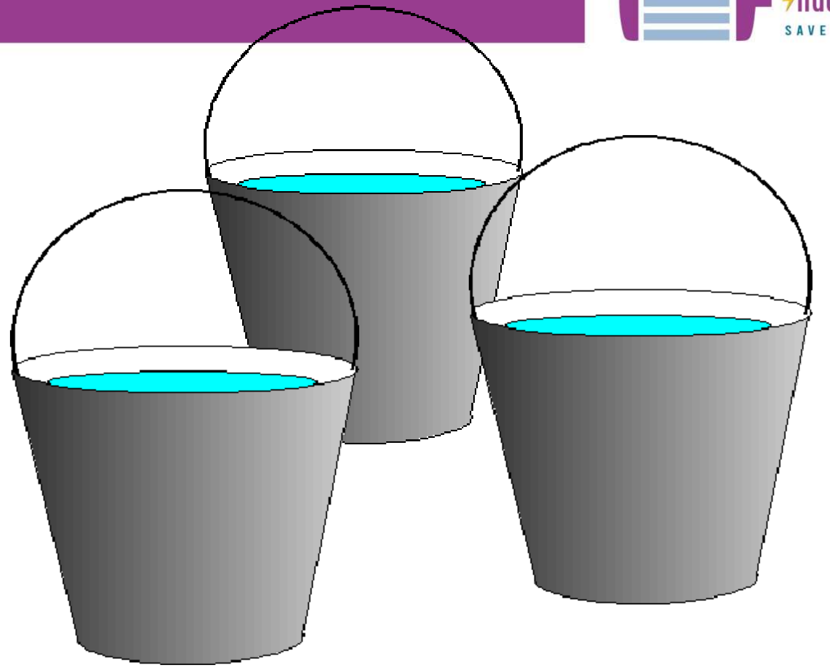
Application	Dirt	Water	Oil	Application	Dirt	Water	Oil
Air agitation	3	5	3	Industrial hand tools	4	5-4	5-4
Air bearing	2	2	3	Handling, food, beverages	2	3	1
Air gauging	2	3	3	Machine tools	4	3	5
Air motors, heavy	4	4-1	5	Mining	4	5	5
Air turbines	2	2	3	Packaging & textile machines	4	3	3
Brick & glass machines	4	4	5	Plant air, general	4	4	5
Cleaning machine parts	4	4	4	Precision pressure regulators	3	2	3
Construction	4	5	5	Process control instruments	2	2	3
Conveying powder products	2	3	2	Rock drills	4	5-4	5
Fluidics, power circuits	4	4	4	Sand blasting	-	5-2	5
Fluidics, sensors	2	2-1	2	Spray painting	3	3-2	3
				Welding machines	4	4	5

Condensate

Impurities in the air

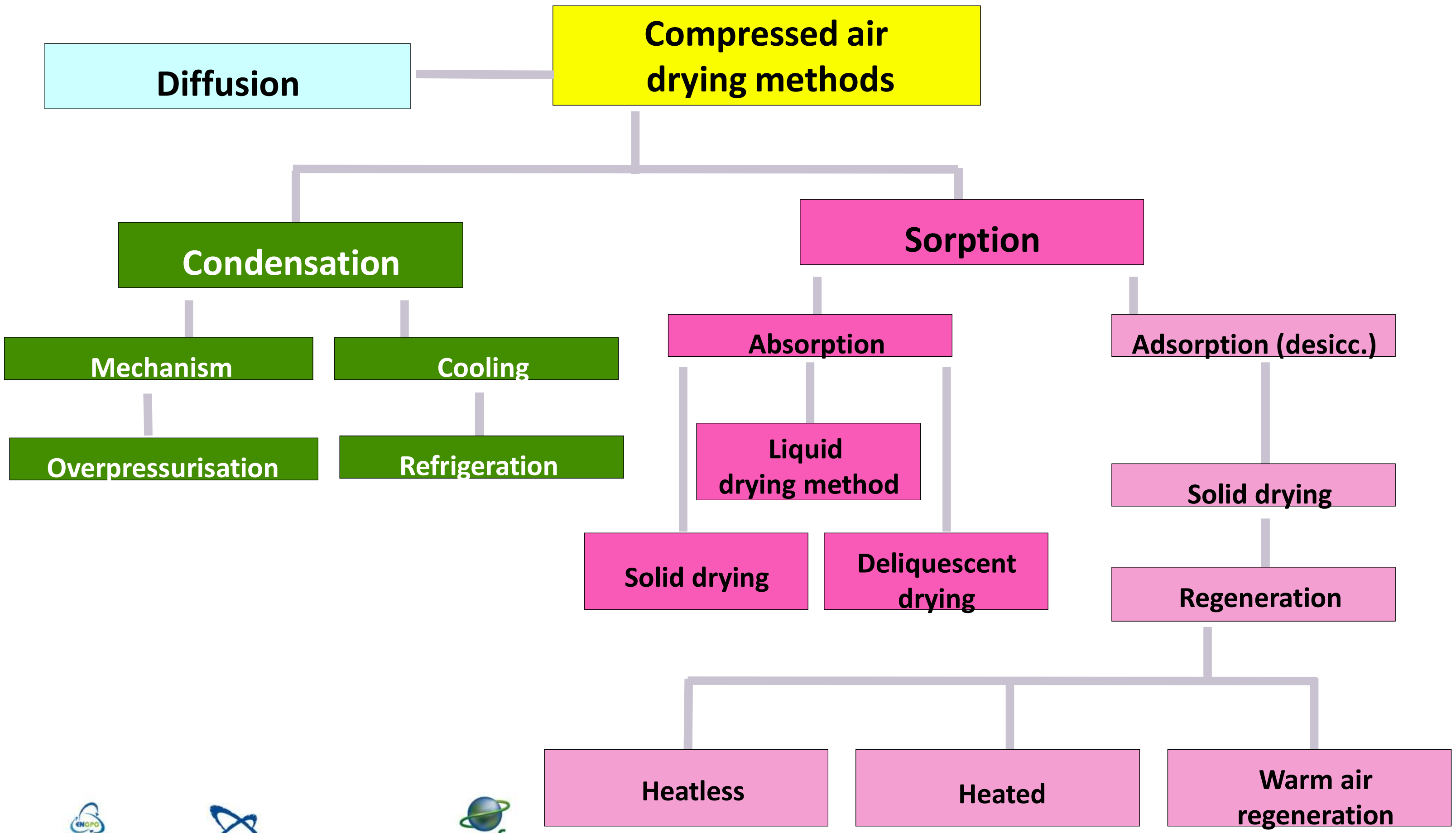
Regardless of which type of construction, all compressors
draw in the impurities in the air and concentrate them many times

Condensate



- Compressor: 5 m^3/min, +20°C, 70 % moisture carry-over, 1 bar(a)
  - +- 30L of water per 8 hours
  - +- 20L accumulates in aftercooler, 7 bar(g), outlet aftercooler temp 30°C

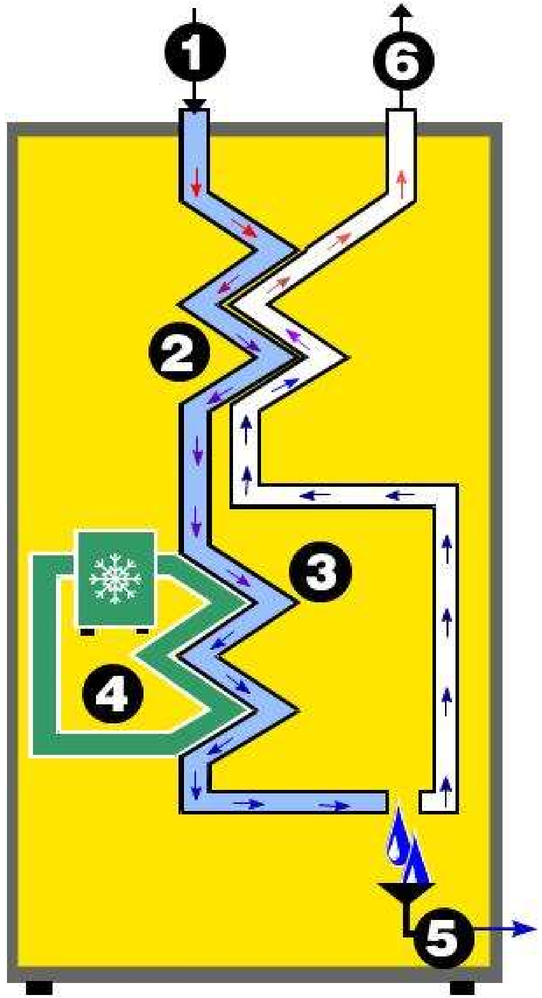
Drying


Compressed air drying methods
Diffusion
Condensation
Mechanism
Overpressurisation
Cooling
Refrigeration
Sorption
Absorption
Liquid drying method
Solid drying
Deliquescent drying
Adsorption (desicc.)
Solid drying
Regeneration
Heatless
Heated
Warm air regeneration

Drying

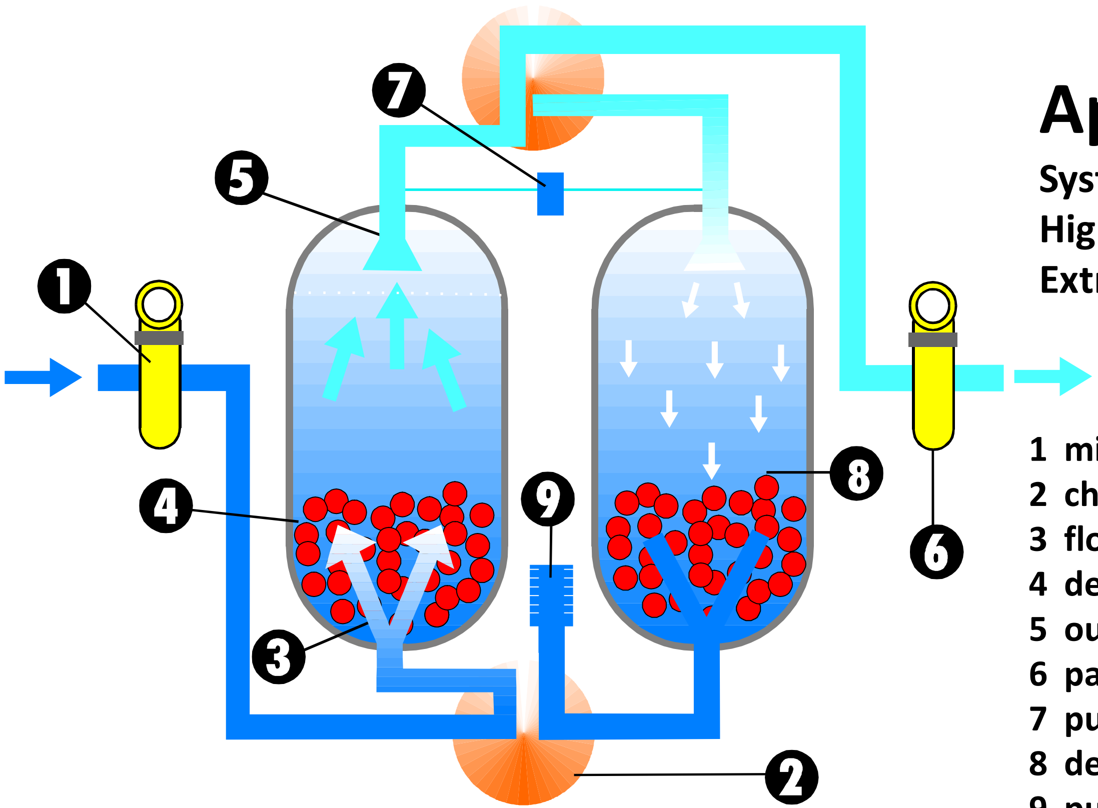
Refrigeration drying

1. Air inlet
2. Air to air heat exchanger
3. Refrigerant to air heat exchanger
4. Refrigerant compressor
5. Condensate separation,
   automatic condensate drain
6. Compressed air outlet



Drying

Desiccant drying - heatless



Application:

Systems subjected to freezing.
High ambient temperatures.
Extreme requirements of air quality.

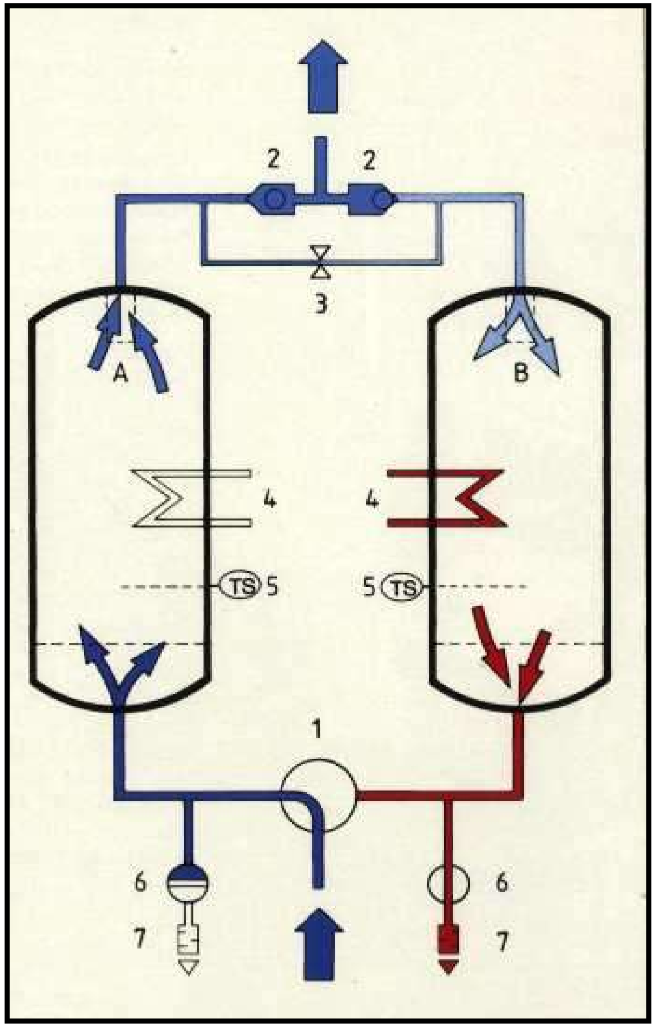
1 microfilter (0.01 µm, 0.01 ppm)
2 changeover valve
3 flow diffuser
4 desiccant bed: moisture adsorption
5 outlet collector
6 particulate filter 1 µm
7 purge (regeneration) air valve
8 desiccant bed: regeneration
9 purge air exhaust silencer

Drying

Desiccant drying -

internally heated

- integrated heating rods
  (desiccant not heated evenly during
  regeneration)
- low purge air requirement (cooling,
  pressure build-up)
- constant dry, oil-free and clean
  compressed air



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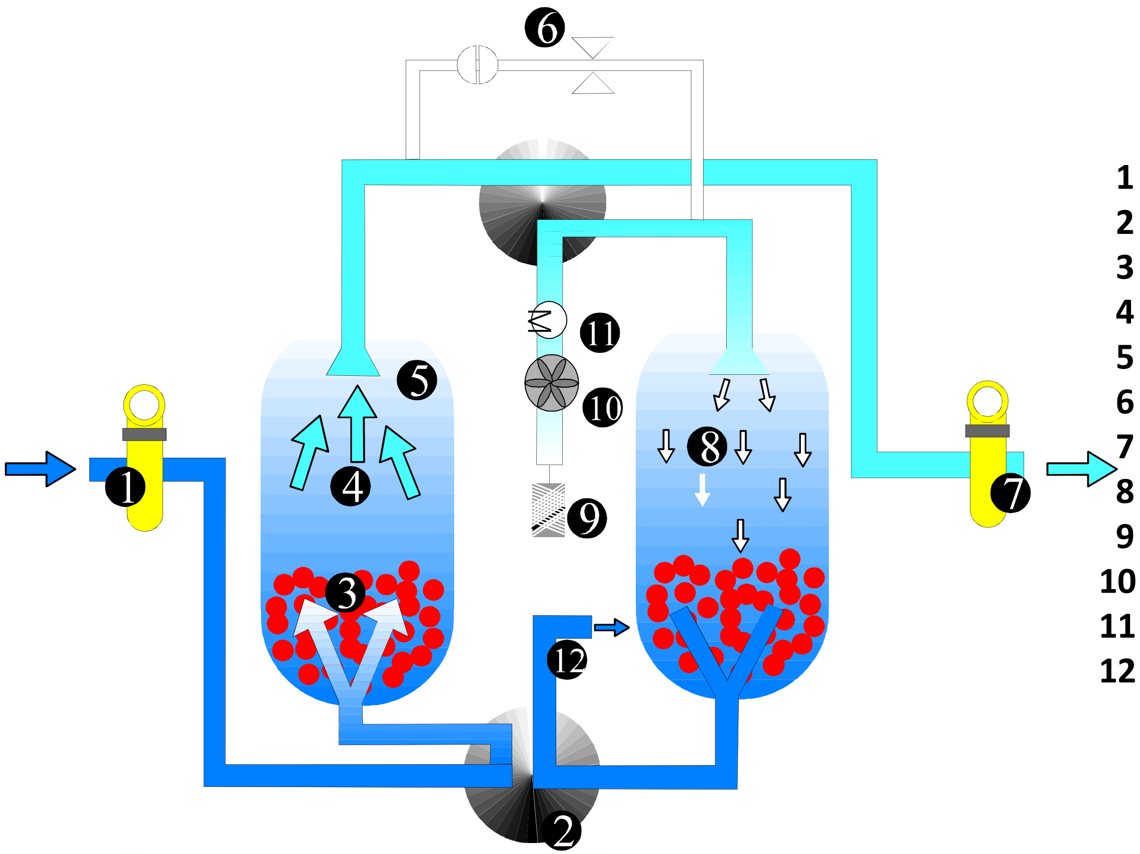
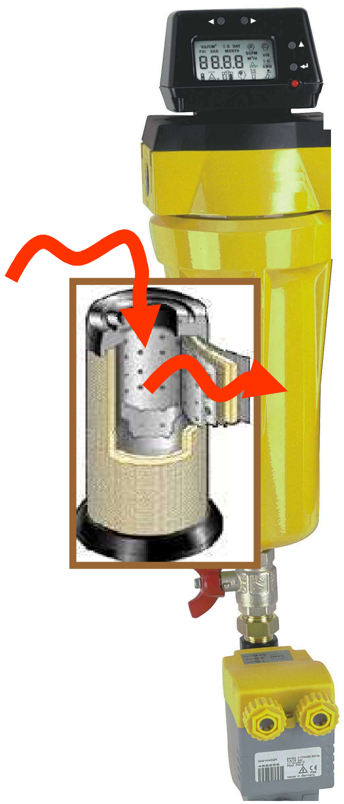
Desiccant drying - externally heated



1 microfilter (0.01 µm, 0.01ppm)
2 changeover valve
3 flow diffuser
4 desiccant bed: adsorption
5 outlet collector
6 regeneration (purge) valve
7 particulate filter
8 desiccant bed: regeneration
9 purge air inlet
10 purge air blower
11 purge air heating
12 purge air outlet

Prefilter



Used as a coarse filter for 100% saturated CA (or for water vapor components in the liquid phase)

- Liquid removal: 99%+ of water
- Maximum liquid loading: 30,000 ppm by weight
- Particulate removal: 10 µm
- Oil carryover: N/A
- Pressure drop: Wet – 0.055 bar

- Downstream of aftercooler
- Remove liquids and only the largest particles
- Usually ahead of a finer filter to reduce loading
- Principle the same as all deep-bed filters

Filtration

Particulate filter

Used as dust filter for dried air

- Liquid removal: 100% of water
- Maximum liquid loading: 2,000 ppm w/w
- Particulate removal: 1 µm
- Oil carryover: 1 ppm
- Pressure drop: Dry – 0.07 bar, Wet – 0.145 bar
- Downstream of dessicant dryer
- Upstream of refrigerated dryer and coalescing filter

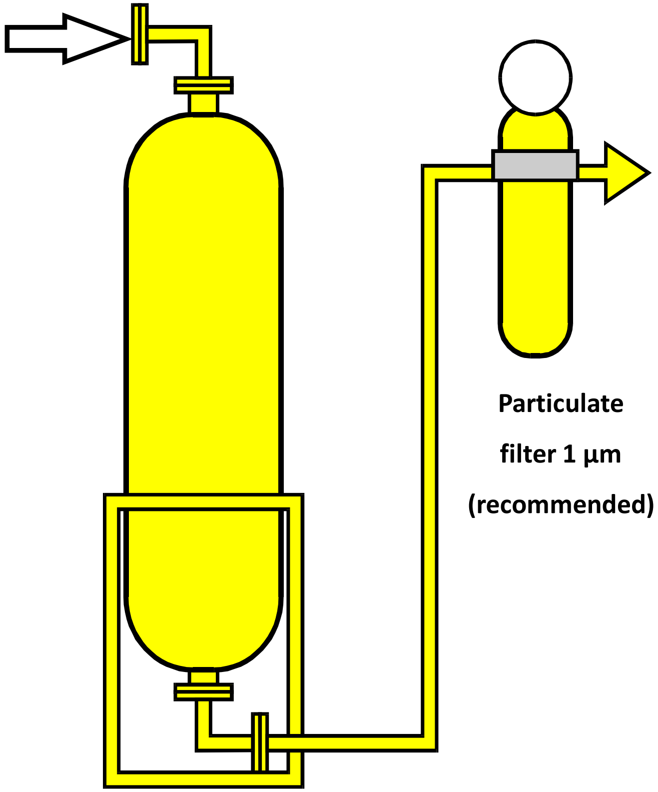
Filtration

Coalescing / Microfilter

- Liquid removal: 99.9% of oil
- Maximum liquid loading: 1,000 ppm by weight
- Particulate removal: 0.01 µm – 0.001 µm
- Oil carryover: 0.008 ppm
- Pressure drop: Dry – 0.07 bar, Wet – 0.2 bar
- Downstream of refrigerated dryer
- Upstream of dessicant dryer or vapour adsorber filter

Filtration

Activated carbon / Vapour adsorber



Quality of inlet air:

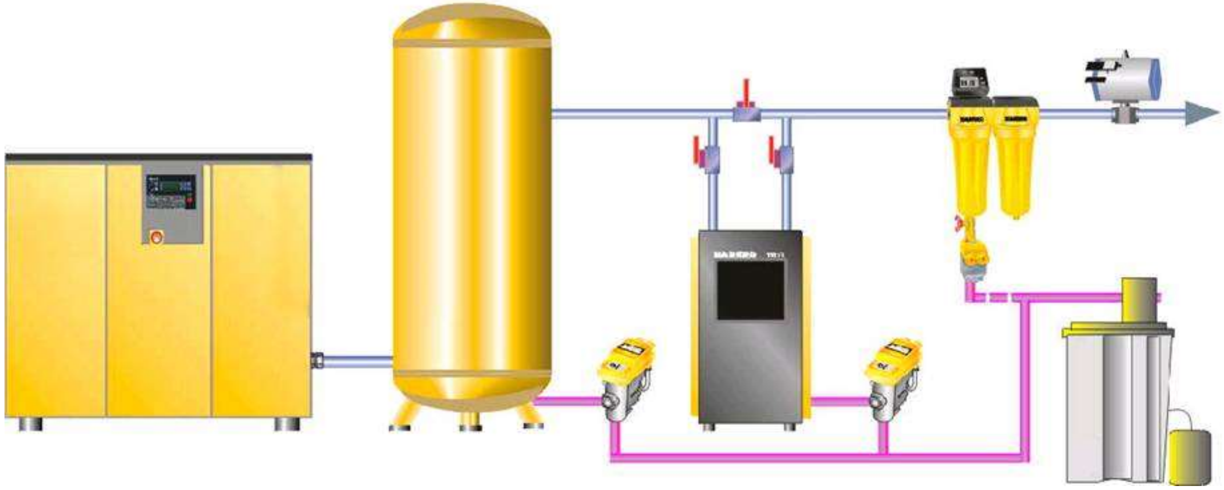
- Liquid removal: 0%
- Maximum liquid loading: 0 ppm
- Particulate removal: 0.01 µm

Quality of outlet air:

- Vapour carryover: 0.003 ppm

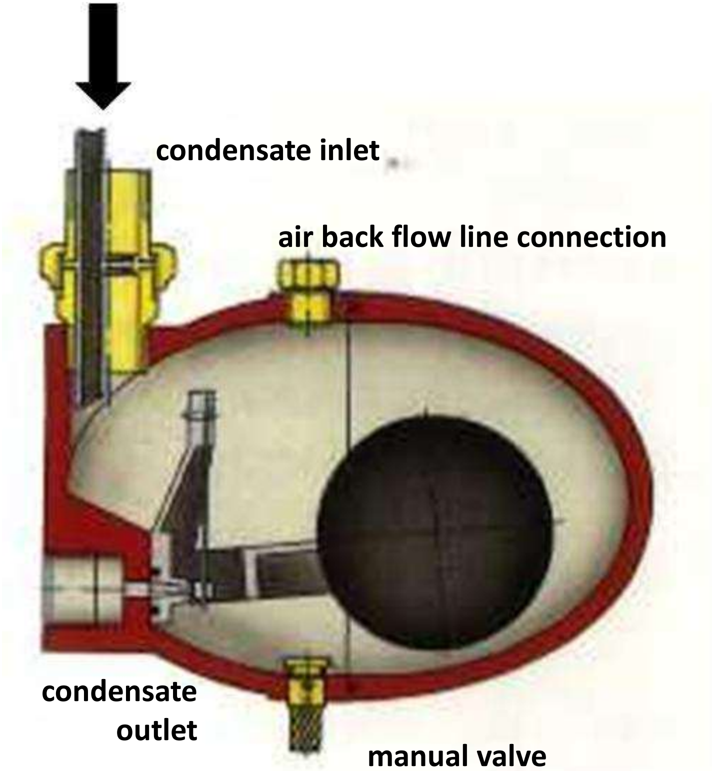
- Pressure drop: Dry – 0.07 bar, Wet – N/A
- Downstream of coalescing filter
- Long contact time of air and activated carbon bed
- Long and reliable life
- Hydro carbon indicator for continuous quality control

Condensate drainage



Reliable drainage must be ensured at all condensate collecting points of the air main. This condensate should be treated prior to disposal

Condensate drains: float type

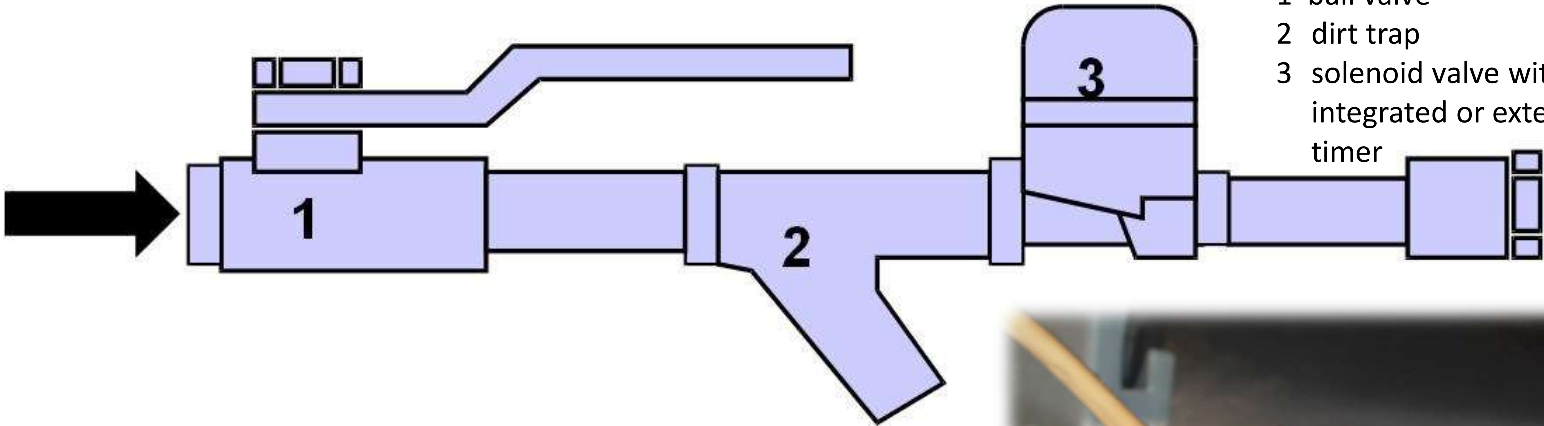


Drainage occurs only when sufficient condensate has collected

No compressed air blowoff

Regular maintenance required

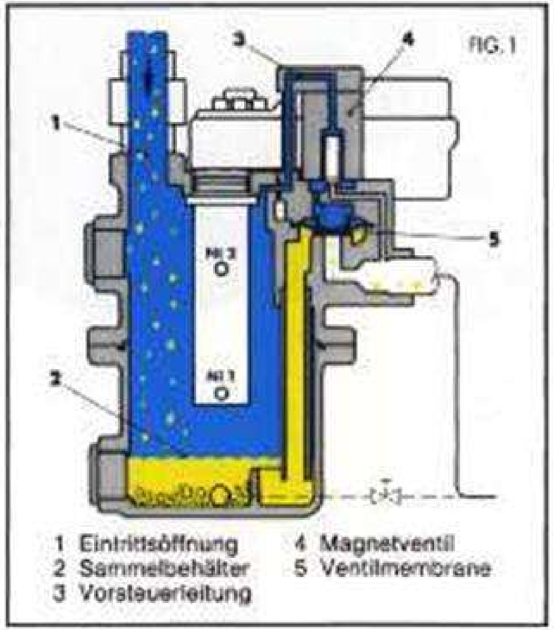
Condensate drains: solenoid valve, timer controlled

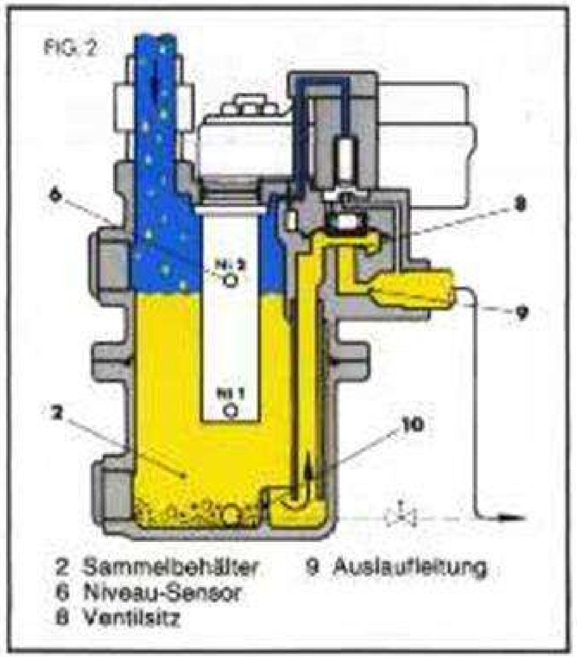


1 ball valve
2 dirt trap
3 solenoid valve with integrated or external timer

- automatic and regular drainage
- interval 1.5 to 30 min
- opening period 0.4 to 10 sec
- condensate can be directed into a disposal canister

Condensate drains: Electronic level-sensing type





- Capacitive level sensing
- Automatic pressure matching
- Self-monitoring
- Volt-free alarm contact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CONDENSATE DRAIN

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5. Demand Side: Eliminate Compressed Air Waste

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INDUSTRIAL MODERNISATION CENTRE
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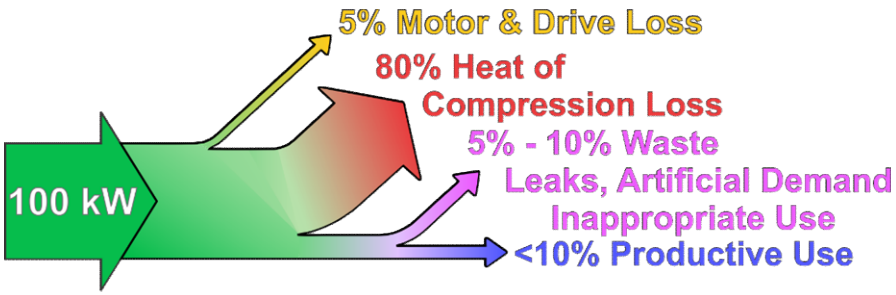
Compressed Air Energy Waste

- Leakage, including open drip legs and condensate drains,
- Operating the system at excessively high pressure, Artificial Demand
- Inappropriate use of compressed air
- Inadequate and / or uncontrolled compressed air energy storage
- Irrecoverable pressure loss in restrictive piping, filters, and other components
- Inefficient compressor control strategy



Leakage Orifice Chart: Loss of flow in m^3/min

Gauge pressure before orifice, bar	Diameter of Orifice, mm (note: calculated flow rate assumes orifice coefficient of 0.61)											
	1	2	3	4	5	6	7	8	9	10	15	20
4	0.03	0.11	0.25	0.45	0.70	1.01	1.38	1.80	2.28	2.82	6.34	11.28
4.5	0.03	0.12	0.28	0.50	0.78	1.12	1.52	1.98	2.51	3.10	6.98	12.40
5	0.03	0.14	0.30	0.54	0.85	1.22	1.66	2.16	2.74	3.38	7.61	13.53
5.5	0.04	0.15	0.33	0.59	0.92	1.32	1.79	2.34	2.97	3.66	8.24	14.65
6	0.04	0.16	0.35	0.63	0.99	1.42	1.93	2.52	3.19	3.94	8.87	15.78
6.5	0.04	0.17	0.38	0.68	1.06	1.52	2.07	2.70	3.42	4.23	9.51	16.90
7	0.05	0.18	0.41	0.72	1.13	1.62	2.21	2.88	3.65	4.51	10.14	18.03
7.5	0.05	0.19	0.43	0.77	1.20	1.72	2.35	3.06	3.88	4.79	10.77	19.15
8	0.05	0.20	0.46	0.81	1.27	1.82	2.48	3.24	4.11	5.07	11.40	20.27
8.5	0.05	0.21	0.48	0.86	1.34	1.93	2.62	3.42	4.33	5.35	12.04	21.40
9	0.06	0.23	0.51	0.90	1.41	2.03	2.76	3.60	4.56	5.63	12.67	22.52
9.5	0.06	0.24	0.53	0.95	1.48	2.13	2.90	3.78	4.79	5.91	13.30	23.65
10	0.06	0.25	0.56	0.99	1.55	2.23	3.03	3.96	5.02	6.19	13.94	24.77

To calculate energy consumption, use typical Specific Power range for various compressors types table:

Volumetric flow rate (free air delivery)	$kW / m^3 / min$
Recip. Single Acting (sgl stage)	7.8 - 8.5
Recip. Single Acting (2 stage)	6.4 - 8.1
Recip. Double Acting (sgl stage)	8.5 - 10.2
Recip. Double Acting (2 stage)	5.3 - 5.7
Lubricated Screw (sgl stage)	6.0 - 7.8
Lubricated Screw (2 stage)	5.7 - 6.7
Lubricant Free Screw (2 stage)	6.4 - 7.8
Centrifugal (3 stage)	5.7 - 7.1

Source: UNIDO, NCPC-SA, Tom Taranto, Wayne Perry

Leakages

Compressed Air Systems: Demand Side

Finding Leaks

- locate source of noise
- soap connections
- ultra-sound device

www.automationdirect.com

Example:

Hole diameter: 3 mm

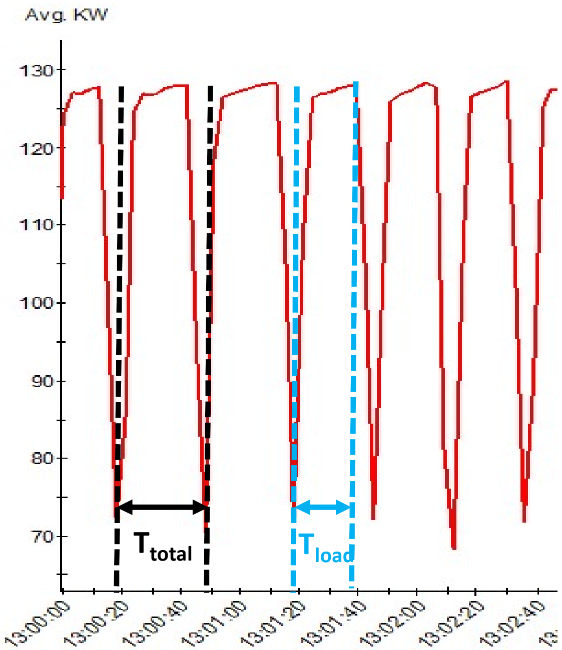
Air loss: 0.35 m^3/min (6 bar gauge)

0.35 m^3/min x 60 min/h x **8,760 h/year** = 183,960 m^3/year

183,960 m^3/year x cost/m^3 = ?

How much is this leak at 7 bar_g?

Measuring Leak Losses by Measuring Load/Unload Time



$$Q_{leaks} = \frac{Q_{gen} \times T_{load}}{T_{load} + T_{unload}}$$

Q_{leaks} = Leak rate (Nm^3/min)
Q_{gen} = Generated flow rate from compressors (m^3/min)
T_{load} = Time that compressor runs on load (minutes)
T_{total} = Time it runs on load, plus the time to unload (minutes)

Example:

Loading time ≈ 18 seconds (0.3min), and total time to load plus unload ≈ 30 seconds (0.5min). Compressor generates $10 m^3$/min flow

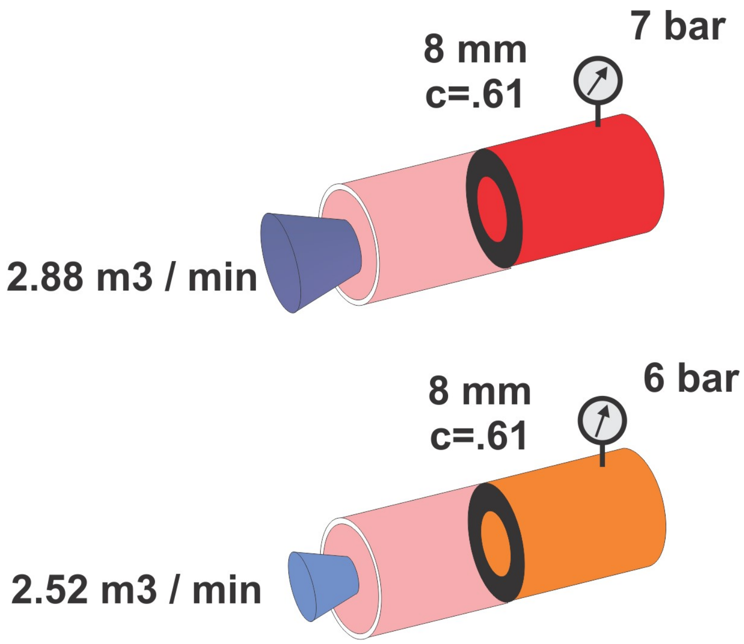
$$Q_{leaks} = \frac{10\frac{m^3}{min} \times 0.3 min}{0.5 min}$$

$$Q_{leaks} = 6\, m^3/min = 60\%$$

Ultrasonic Leak Detection Equipment

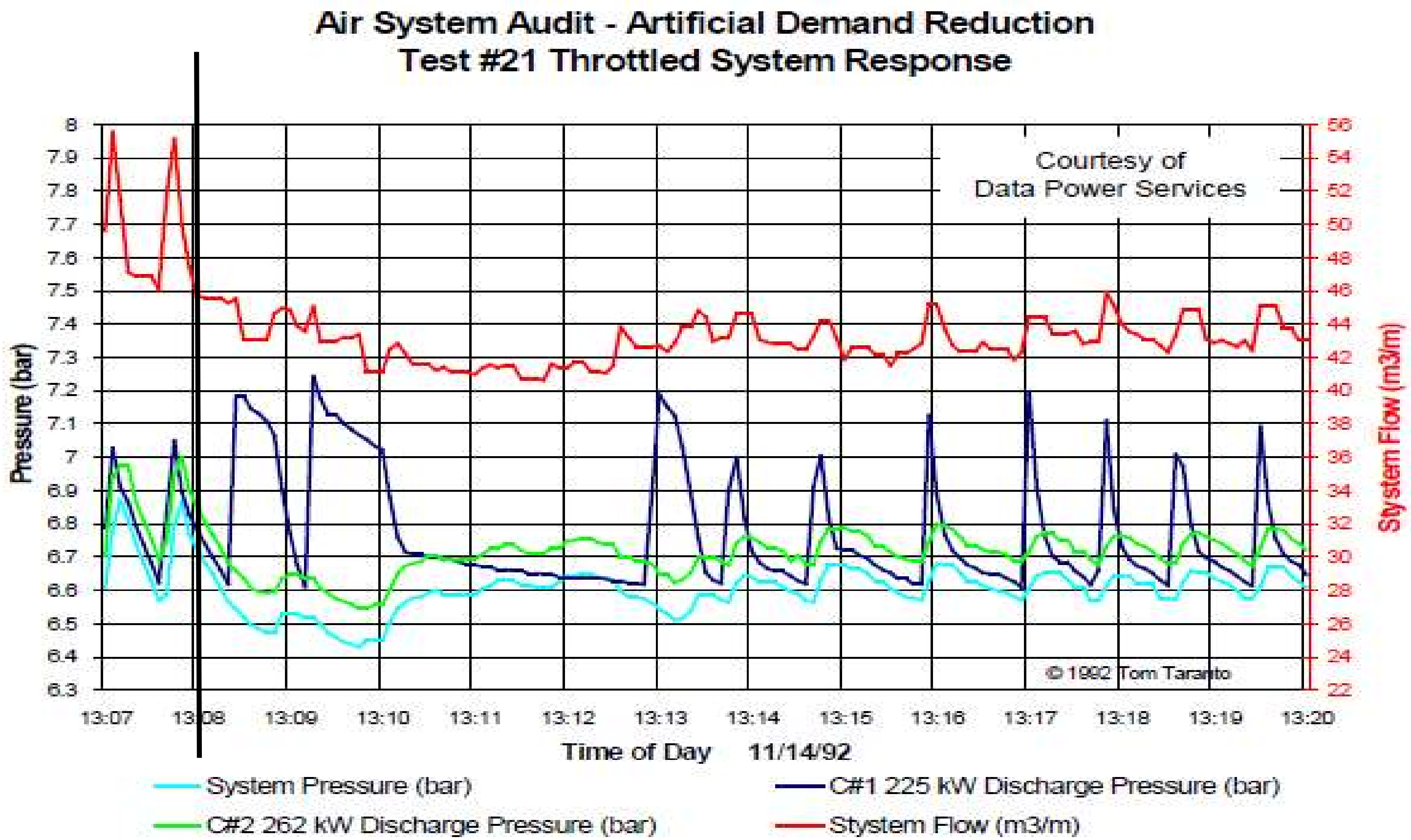
Artificial Demand

- Increasing pressure applied to a hole in the air system, increases the airflow through the air system
- AD is a component of leakage, as well as any **unregulated** air demand
- Leak repair without pressure control is not fully effective and can be consumed by AD



Airflow changes by 6 % to 12% per bar of pressure increase or decrease

Artificial Demand Reduction



Inappropriate Use

The world's most expensive air-conditioner

Fans or blowers could be used instead of sparging

Personnel cooling is always inappropriate (and dangerous)

Inappropriate Use

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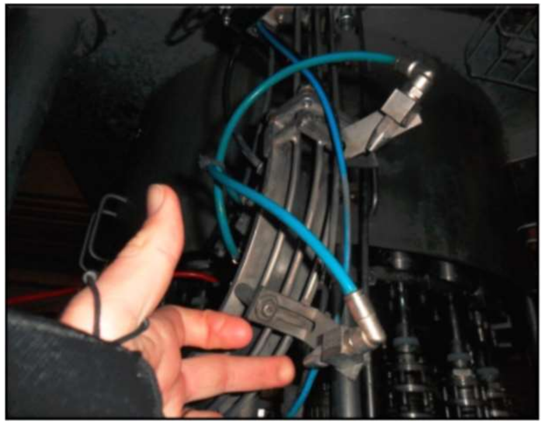
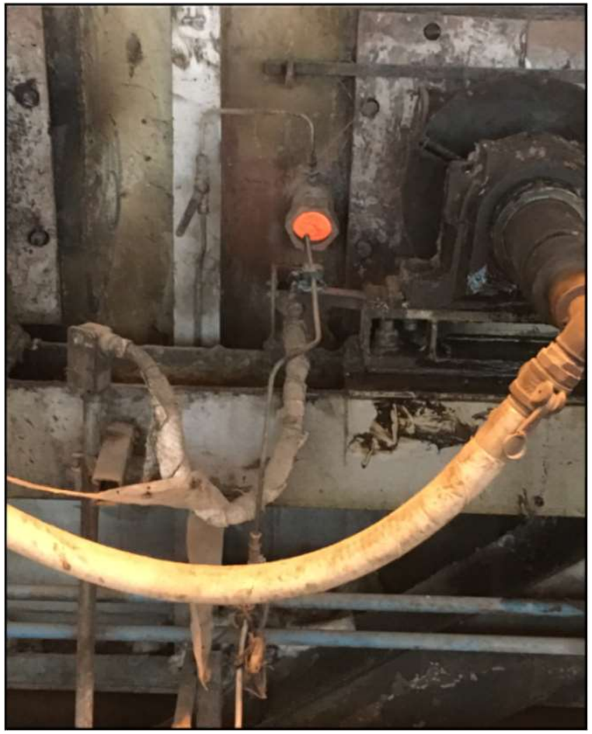


Isolate or interlock during no-production



Camera Cooling

Open blowing at 7.6bar

Tile Cleaning

Inappropriate Use

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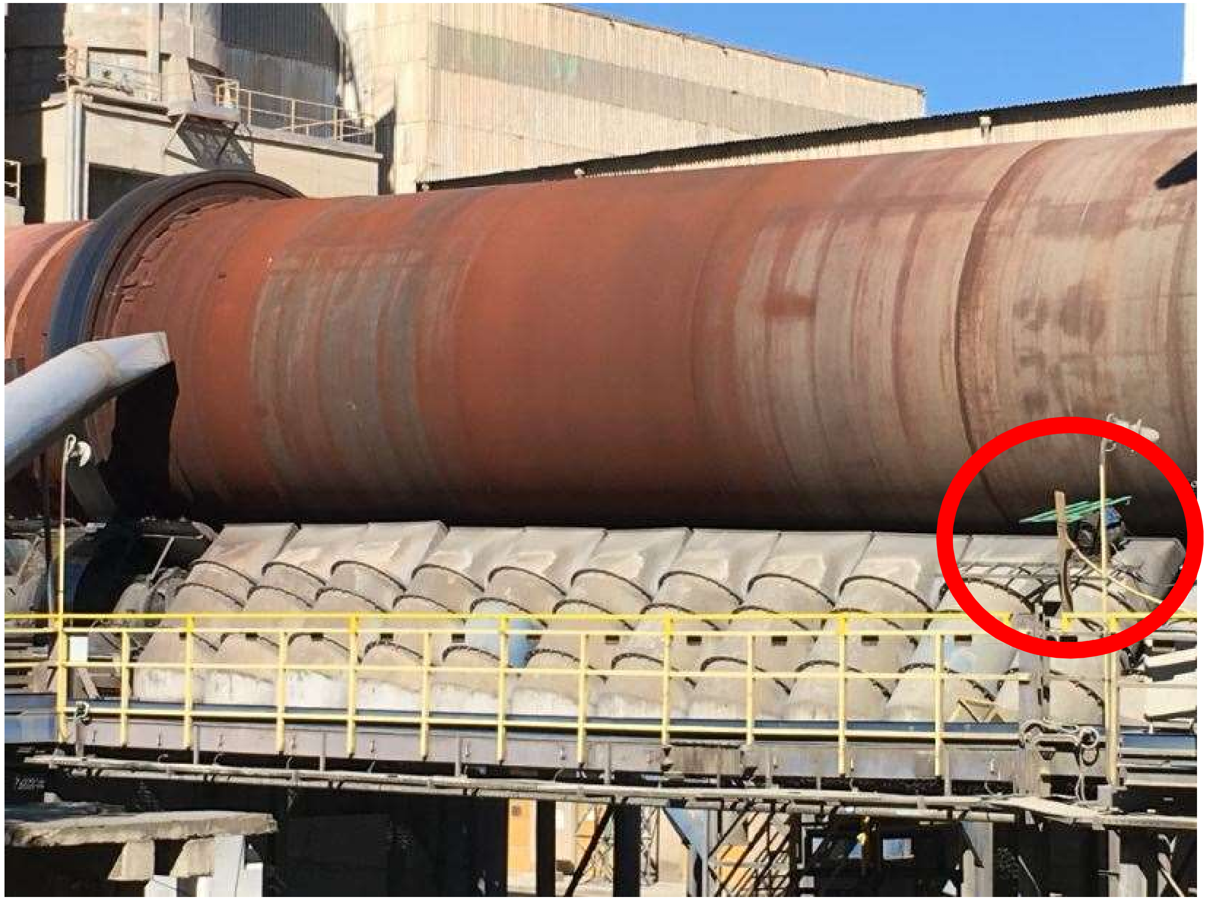

Rotary Kiln cooling

Inappropriate Use

Potentially Inappropriate Uses	Description and Examples	Potential Solutions
Abandoned Equipment	CA continues to be supplied to equipment that remains in place yet does not operate	• Install shut off valves • Remove redundant equipment
Aspirating	Aspirating uses CA to induce the flow of another gas with CA such as flue gas	• Low-pressure Blower
Atomizing	Atomizing uses CA to disperse, or deliver, a liquid to a process as an aerosol	• Low-pressure Blower
Dense phase Transport	Dense phase transport is used to transport solids in a batch format	• Low to High Pressure Blowers
Open blowing	• Blowing using CA applied with an open, unregulated tube, hose, or pipe for cooling • Drying • Clean up	• Brushes • Brooms • Blowers • Electric fans • Mixers • Nozzles

Inappropriate Use

Potentially Inappropriate Use	Description and Examples	Potential Solutions
Unregulated Equipment	End use equipment operating without a regulator at full system pressure	• Install Pressure Regulators
Vacuum generation	CA is sometimes used in conjunction with a venturi to generate a negative pressure vacuum	• Vacuum Pump
Dilute Phase Transport	Transporting solids such as powdery material in a diluted format	
Padding	Padding is using CA to transport liquids and light solids	• Low and Medium Pressure Blowers
Personnel cooling	Personnel cooling using CA can be dangerous from fine particles in the air, or unsecured hoses striking personnel	• Fans
Sparging	Sparging is aerating, agitating, oxygenating, or percolating, liquid with CA	• Low-pressure Blowers Mixers

Key Learning Points

1. Use compressed air only when other alternatives are not available.
2. Compressed air systems should be operated at the lowest practical pressure.
3. Optimize compressor control with a properly implemented control strategy.
4. Eliminating inappropriate use reduces air demand and saves energy.
5. Reducing system pressure eliminates Artificial Demand and saves energy.
6. Reducing leakage loss in the system eliminates waste and saves energy.
7. Minimize irrecoverable pressure loss and reduce compressor discharge pressure to save energy.
8. Greatest energy savings occur when the compressor control strategy optimizes the balance between supply and demand.

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6. Distribution

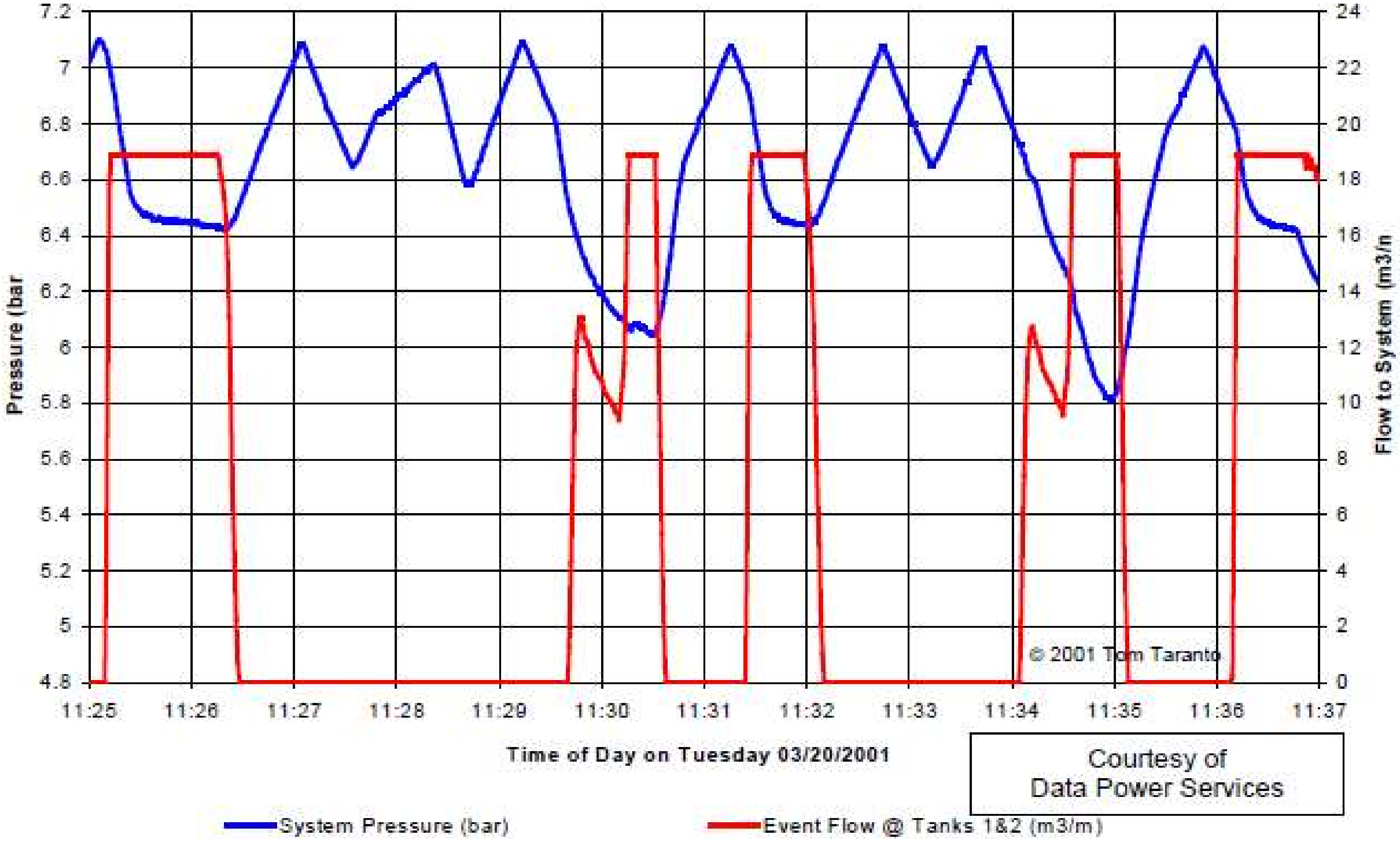
Test Machine Flow Dynamic Demand

What's Wrong With This Picture?

- High Volume Intermittent Demand
  - Consume Large Airflow for Short Periods
  - High Peak Airflow Rate and Low Average Demand
  - Affects the System Pressure Profile
  - Wastes Energy
    - **Initiates Compressor Start-up**
    - **Operational Remedy – Increased Pressure**
    - **Adds to Artificial Demand**
  - Data Logging Airflow & Pressure
    - **Peak Airflow Rate**
    - **Duration of Event & Total Air Consumed**
    - **Dwell Time Between Events – Storage Refill**
    - **Evaluate Control Response & Excess Supply Pressure**

High Volume Intermittent Demand Event - Dynamic Profile

Dense Phase Transport System (Tanks 1 & 2) - Test 2



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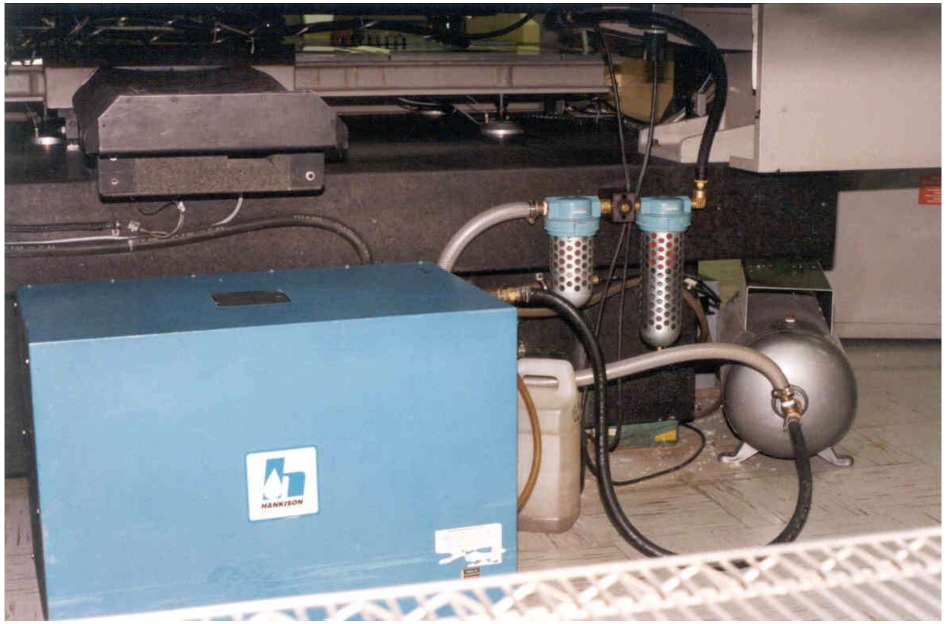
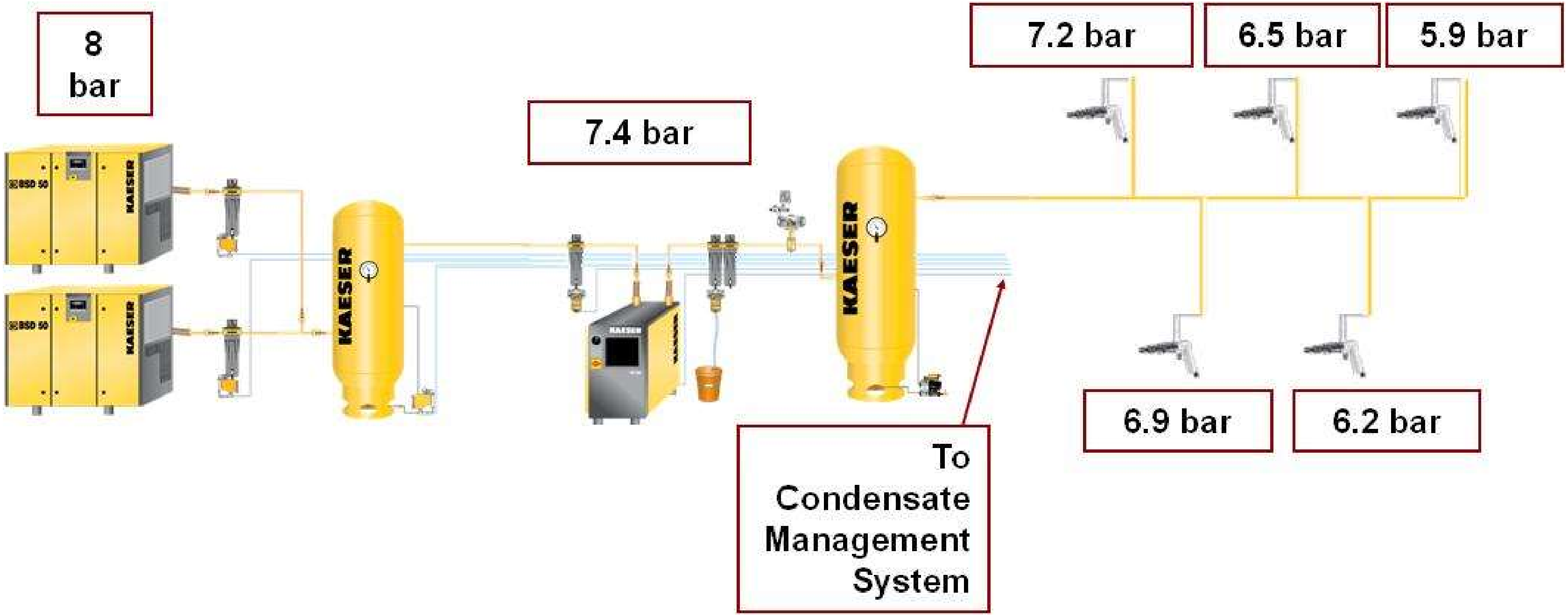


Which Piping Configuration Performs Best?

Pressure Drop in a Dead-End System



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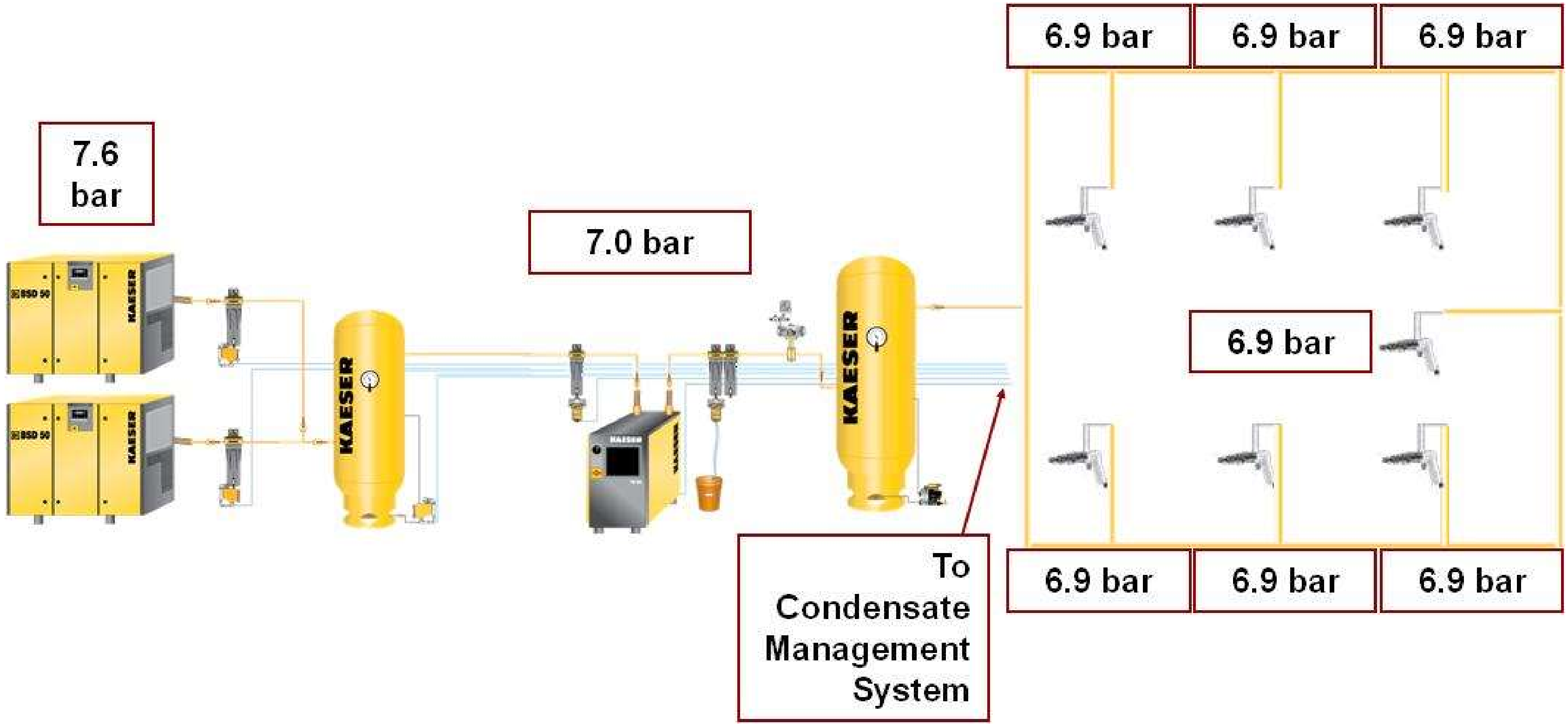
Pressure Drop in a Loop System



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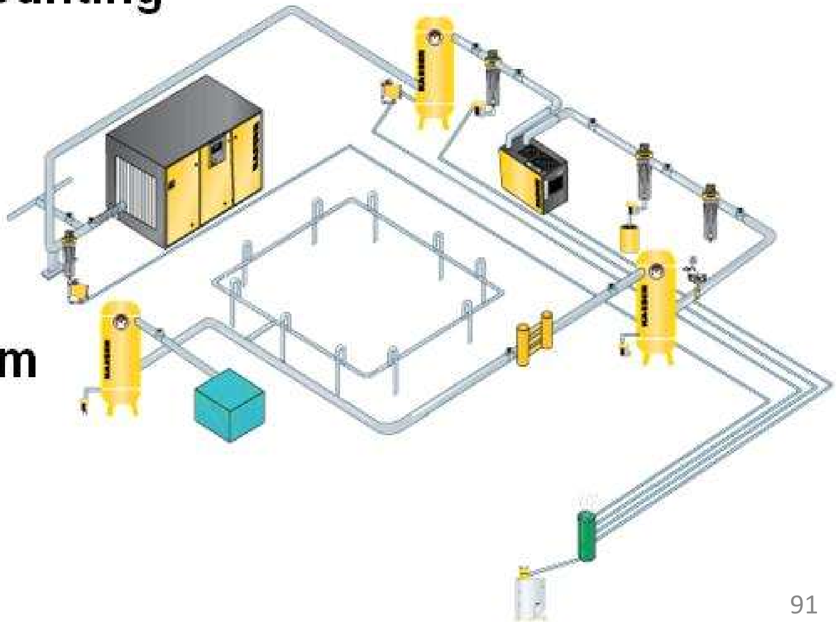
Applying Piping

Rule of thumb:

A well designed piping system will have less than a 0.15 bar pressure drop in the entire system, not counting clean air treatment equipment.



Compressed air velocity should be kept to:

- **5 meters per second in the compressor room**
- **10 meters per second in the main header**
- **15 meters per second in the air drops**

Calculating compressed air air velocity

$$\mathrm{v} = \frac{\mathrm{Q}}{\mathrm{A}}$$

$$v = \frac{Q}{60} \times \frac{4}{\pi d^2} \times \frac{P_{atm}}{(Pat_m + Pga_{uge})}$$

Where:

v = velocity of compressed air [m/s]

Q = flow rate [m^3/min]

A = cross section area of pipe [m^2]

d = inside pipe diameter [mm]

P_{atm} = atmospheric pressure [bar]

P_{gauge} = Gauge pressure [bar]

Calculating compressed air air velocity

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Example

Four compressors deliver a combined 59.5m^3/min compressed air into a 4" common header (inside diameter 105.1mm). The pressure here is measured at 6.7 barg, and the atmospheric pressure at the site is at 1.018 bara. Calculate the pipe velocity, and comment on appropriateness of the pipe diameter.

Calculating compressed air air velocity

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Example

Four compressors deliver a combined 59.5m^3/min compressed air into a 4" common header (inside diameter 105.1mm). The pressure here is measured at 6.7 barg, and the atmospheric pressure at the site is at 1.018 bara. Calculate the pipe velocity, and comment on appropriateness of the pipe diameter.

$$v = \frac{Q}{60} \times \frac{4}{\pi d^2} \times \frac{P_{atm}}{(Pat_m + Pga_{uge})}$$

$$= \frac{59.5 m^3}{min} \times \frac{1 min}{60 sec} \times \frac{4}{\pi \times (0.1051 m)^2} \times \frac{1.018\ bar}{(1.018 bar + \ 6.7 bar)}$$

$$= 15.1 \text{ m/s}$$

In the main header velocity should be less than 10 m/s. At least 5" pipe required

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Key Energy Points

1. Supplying higher end use pressure requiring higher discharge at the compressor(s) increases compressor power (kW) by 6% per bar.
2. Poor piping design with excessive flow restriction can create a perception that the end use air demand requires higher pressure than is actually necessary.
3. Minimize the use of hose for connections. Hose has much smaller ID size (higher pressure drop) than similar diameter pipe.
4. Where hose must be used select the hose size based on the inside diameter and peak airflow rate. Avoid the use of hose, hose barbs and pipe clamps. They are very restrictive and develop leaks.
5. Do not use redundant point of use dryers, filters, etc. as each component represents additional pressure drop.
6. Avoid over filtration, maintain an appropriate compressed air cleanliness class for the application requirements.
7. When components are improperly sized for average airflow rate rather than peak airflow requirements, system is pressure is often increased to accommodate the improperly sized components.
8. Size all connection equipment to the actual dynamic conditions associated with the application. Account for the peak airflow rate that must be supported, do not size equipment based on average airflow rate.

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7. Pressure Profile

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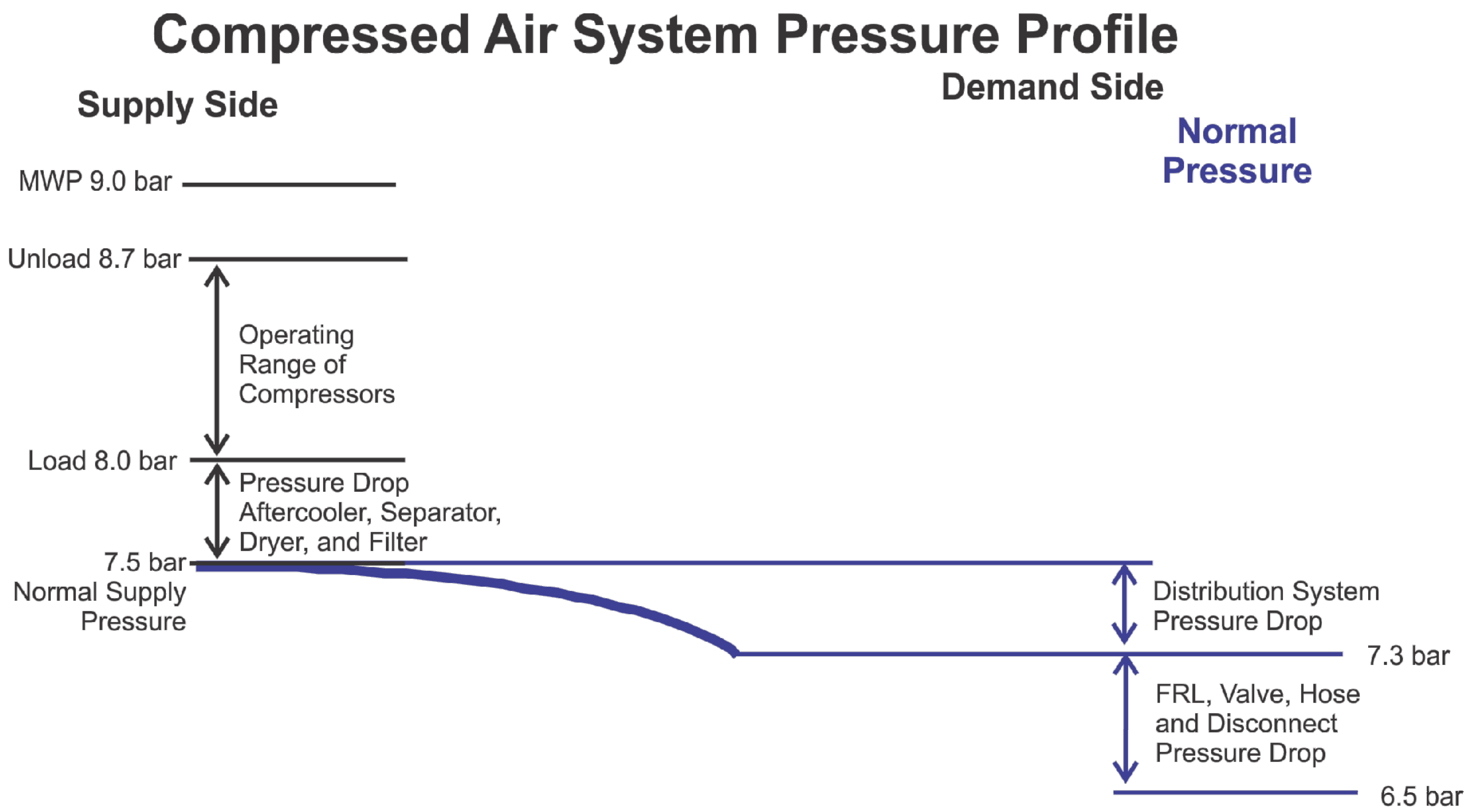
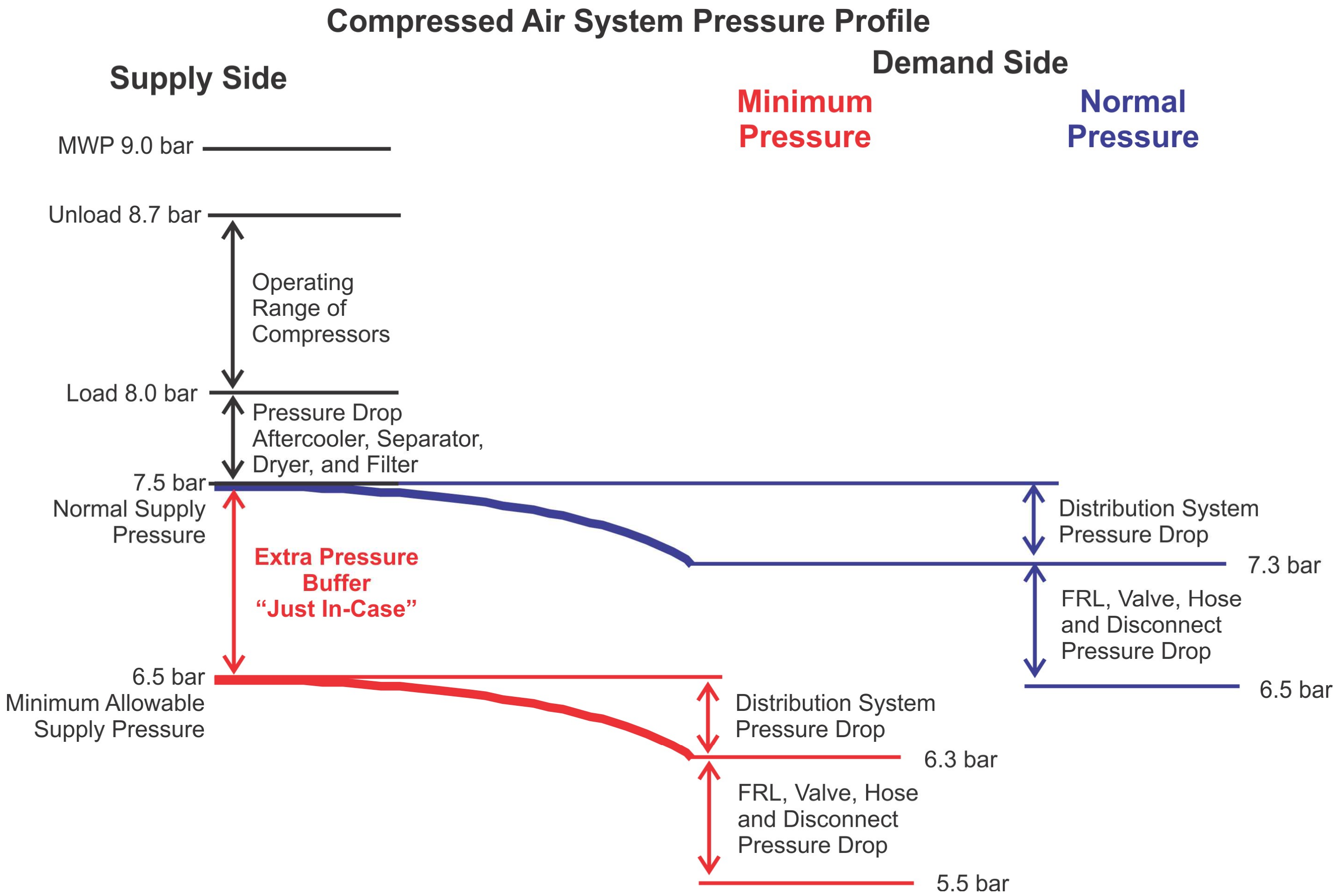
Typical pressure measurement locations

- Compressor maximum working pressure (MWP)
- Compressor control range
- Treatment equipment pressure drop
- Pressure differential reserved for primary storage
- Supply header pressure to the system
- Distribution header pressure in one or more demand side locations
- Point of use connection pressure
- End use pressure

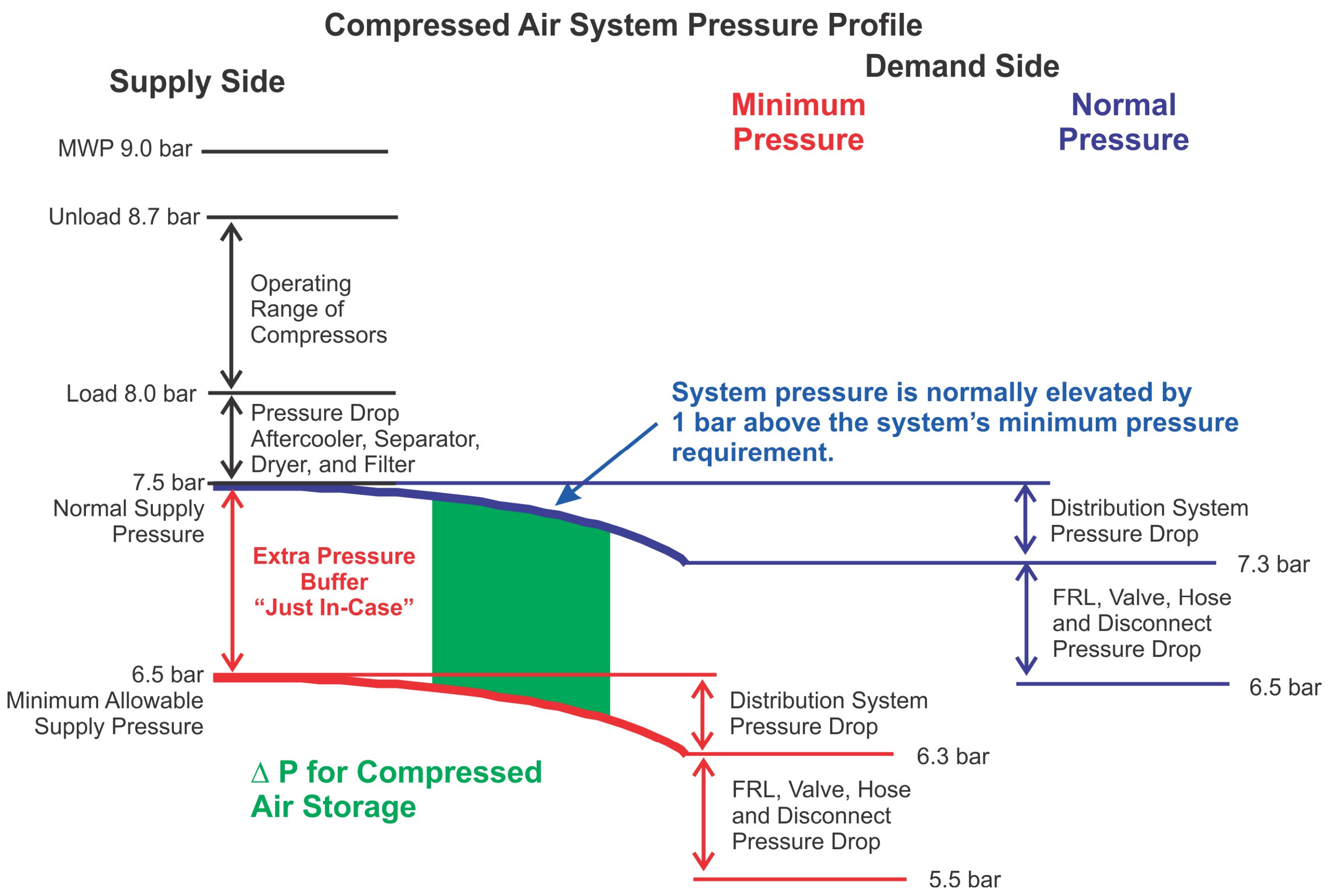
System Pressure Profile



System Pressure Profile



System Pressure Profile



Pressure Profile

Design Criteria

- Operate compressor controls in as narrow a pressure band as possible while allowing:
  - Unneeded compressors to automatically shutdown.
  - All compressors, except one, to operate at full load capacity.
  - Only one compressor to provide trim capacity, selecting the most efficient part load capacity control available.
- Operate compressor discharge pressure at the lowest possible pressure

Pressure Profile

Distribution Pressure Gradient

- Pressure Gradient, the rate of change of pressure with respect to distance in the direction of maximum change.
  - In fluid mechanics the change in pressure P, along the length and distance X of a fluid conduit. It is represented by *d*P / *d*X.
- NOTE 1: The air velocity in a pipeline depends on the magnitude of the gradient and the resistance of the pipeline.
- NOTE 2: With out gradient there is no airflow. In a compressed air system air moves from high-pressure toward low-pressure areas.

System Resistance Creates Pressure

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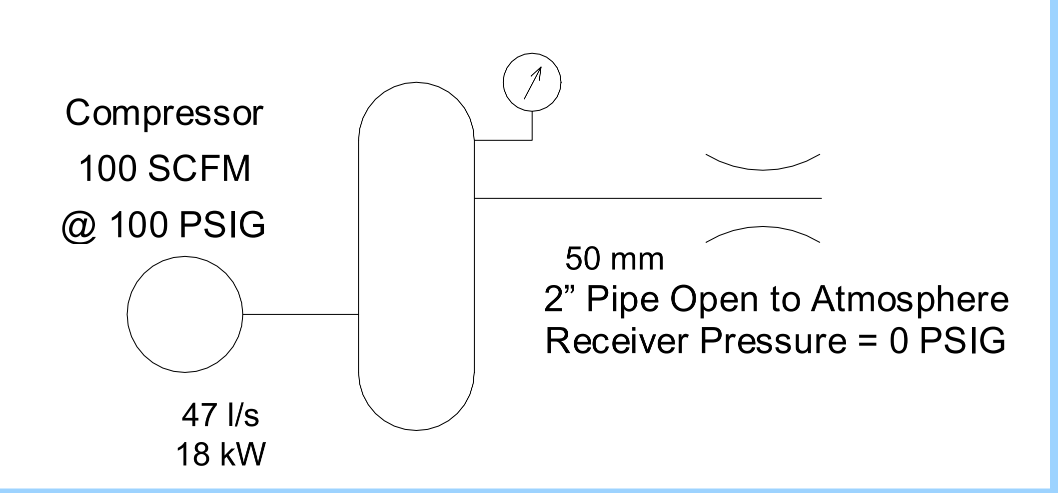
Flow, Pressure & System Resistance

Compressors Pump Flow
Resistance Creates Pressure



System Resistance Creates Pressure

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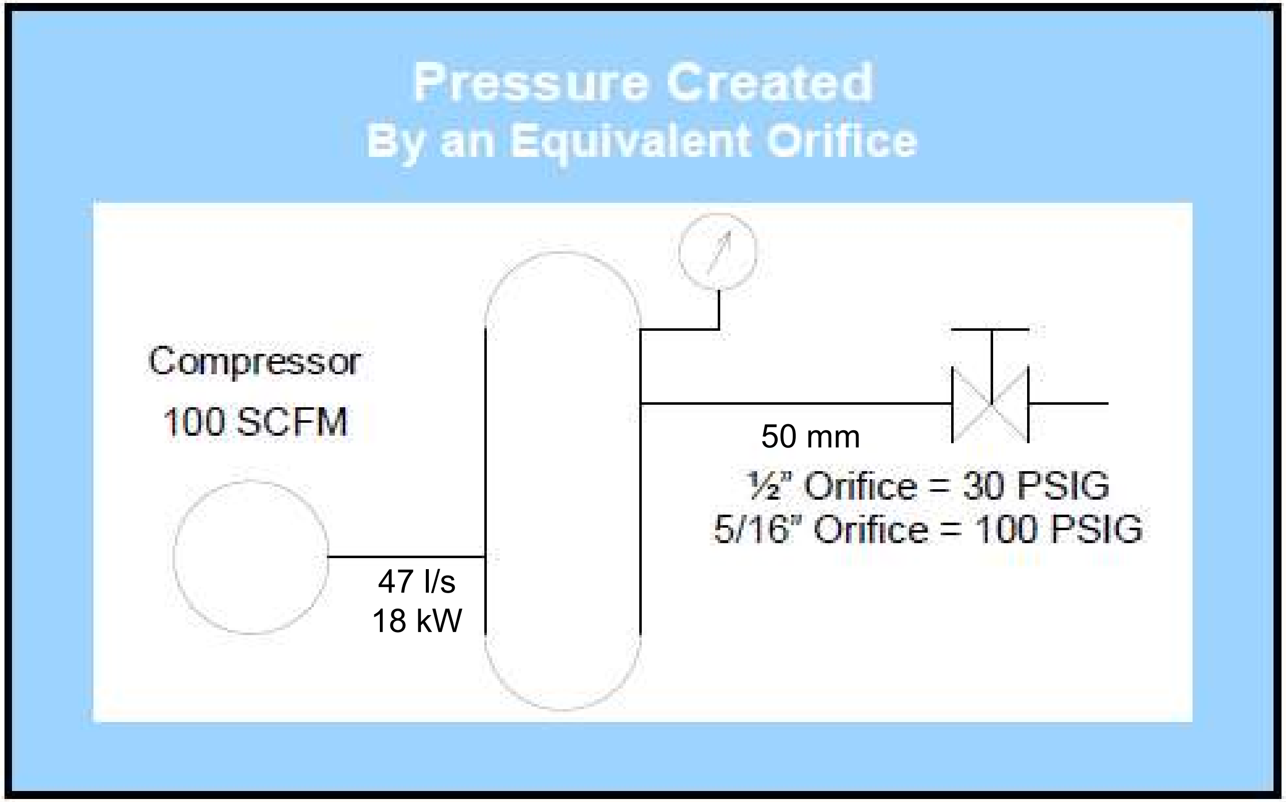
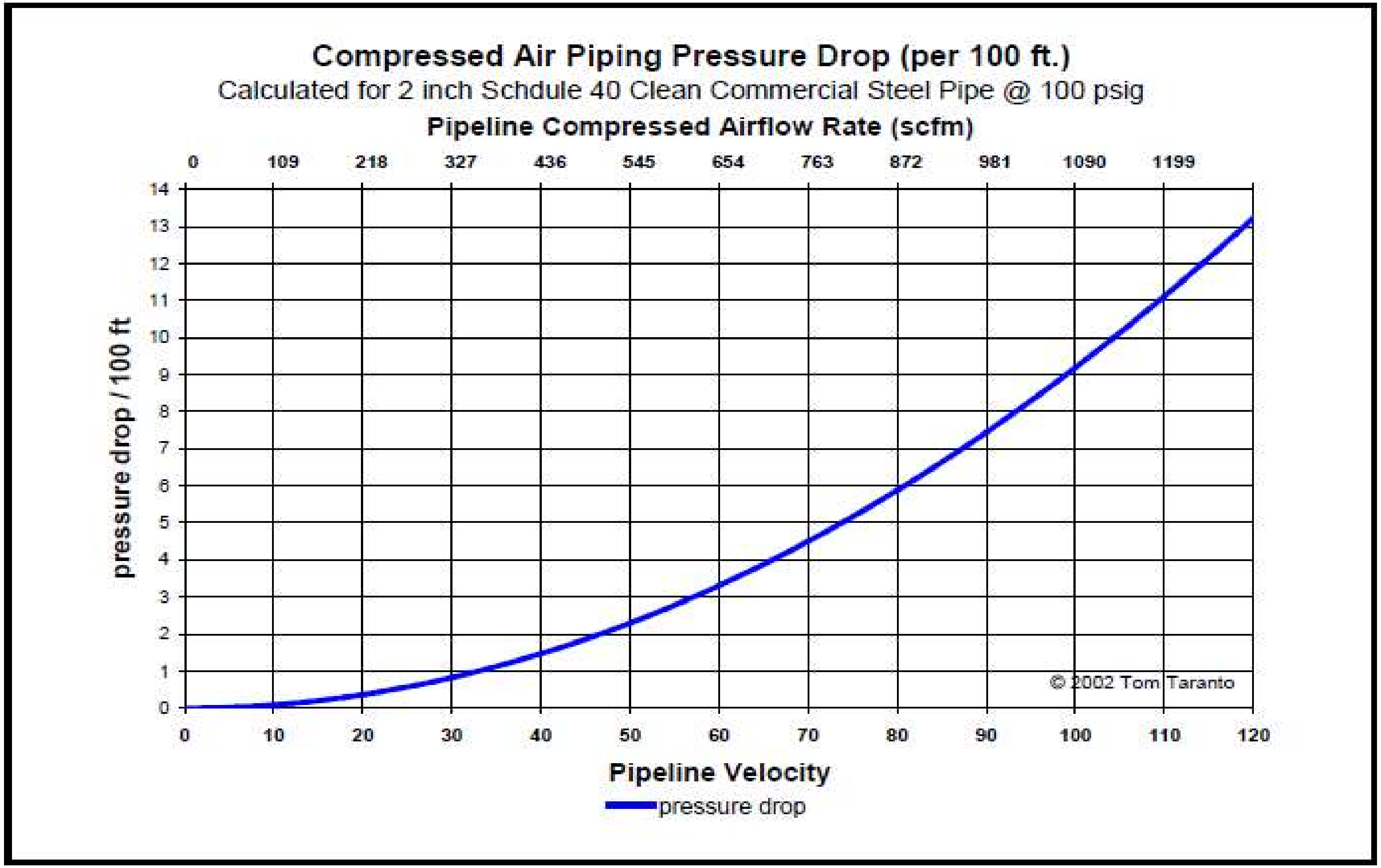


Pressure Loss in Fluid Flow



Key Learning Points

1. Check pressure gradient at peak airflow rate.
2. Normally pressure should track supply at < 0.15 bar pressure differential.
3. High pressure gradient leads to unstable performance.
4. High pressure gradients in distribution piping must be corrected.
5. Compressors create airflow, system resistance creates pressure.
6. Sustained pressure gradient will drive inefficient compressor load cycles.
7. Pressure drop increases as a function of airflow change squared.
8. Mainline distribution headers design velocity should be less than 10 m/s
9. Air compressor capacity controls react to pressure sensed by its control system.
10. As pressure decreases, air delivery will increase until maximum output is produced.
11. As pressure increases compressor air delivery is reduced.
12. Restrictions in the system such as air dryers and filters can impact compressor control.
13. Remote sensing of compressor controls can improve control response. If remote sensing is used, over-pressure protection should sense pressure within the compressor package.

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8. Air Storage and System Energy Balance

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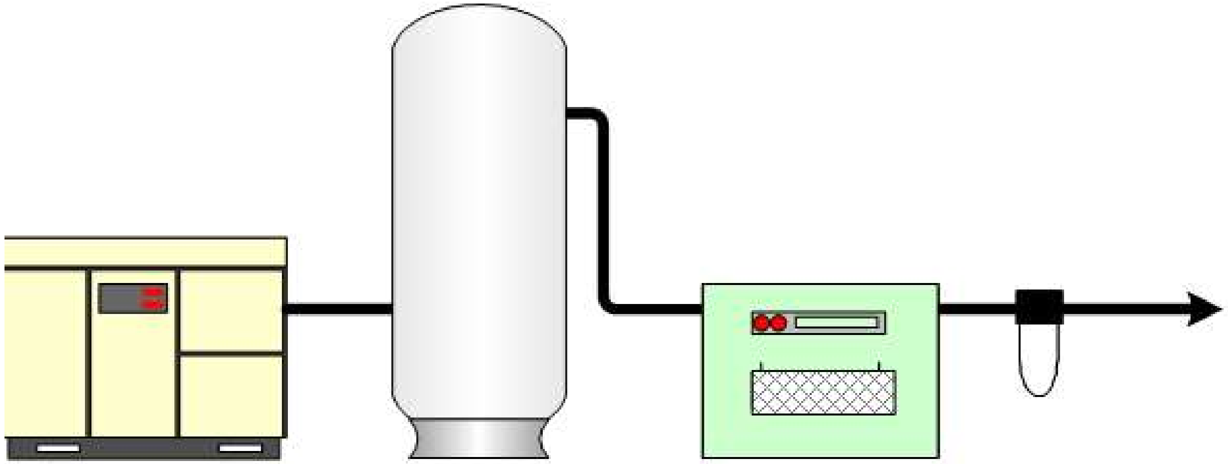
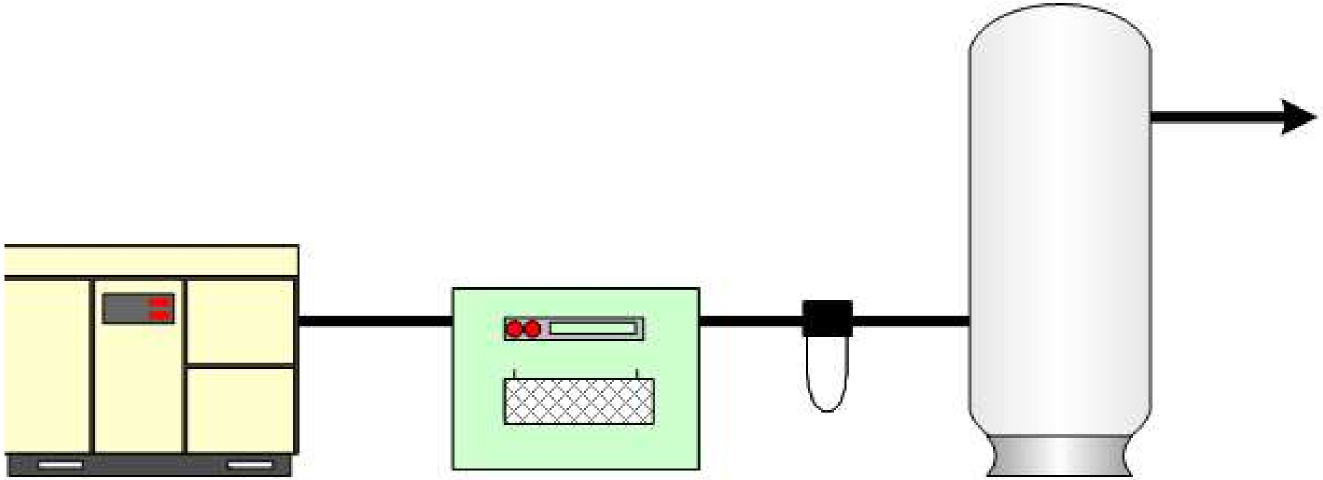
RECEIVER IS LOCATED BEFORE THE AIR DRYER



- Radiant cooling
- Condensate and entrained oil drop out - benefiting the dryer
- BUT, if there is a sudden demand the dryer may be overloaded

Storage

RECEIVER IS LOCATED AFTER THE DRYER



- Receiver no longer benefits the dryer
- Receiver is filled with clean & dry CA
- A sudden demand in excess of the compressor and dryer capacity will be met with dried air
- The dryer will not be overloaded – PDP not affected

Storage

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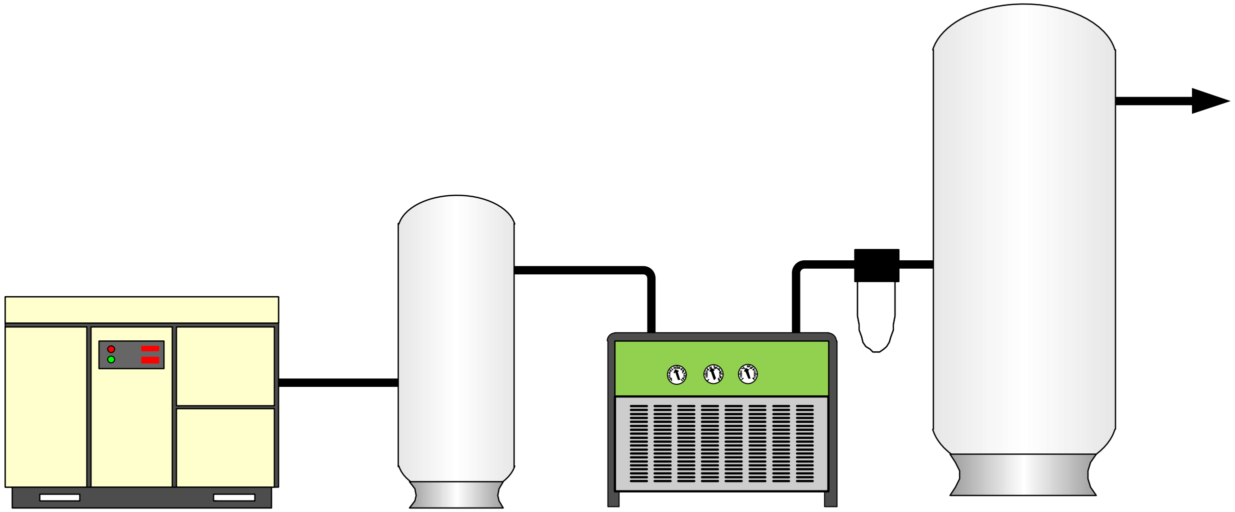
RECEIVER LOCATED BEFORE AND AFTER THE DRYER

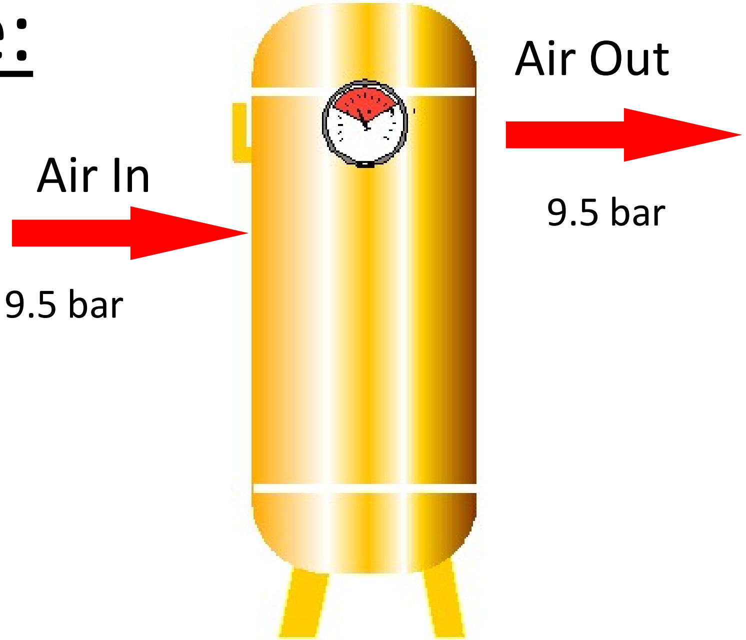


- One "wet" air receiver before the dryer to provide control storage and condensate drop out
- And a second "dry" air receiver to meet sudden demands
- Best practice: Total volume = 1.0 m^3 per m^3/m trim comp output

Uncontrolled Storage:

Without Pressure Differential

- Quiet zone
- Moisture separator
- Protects downstream equipment from oil slugs
- Prevents compressor from excessive cycling

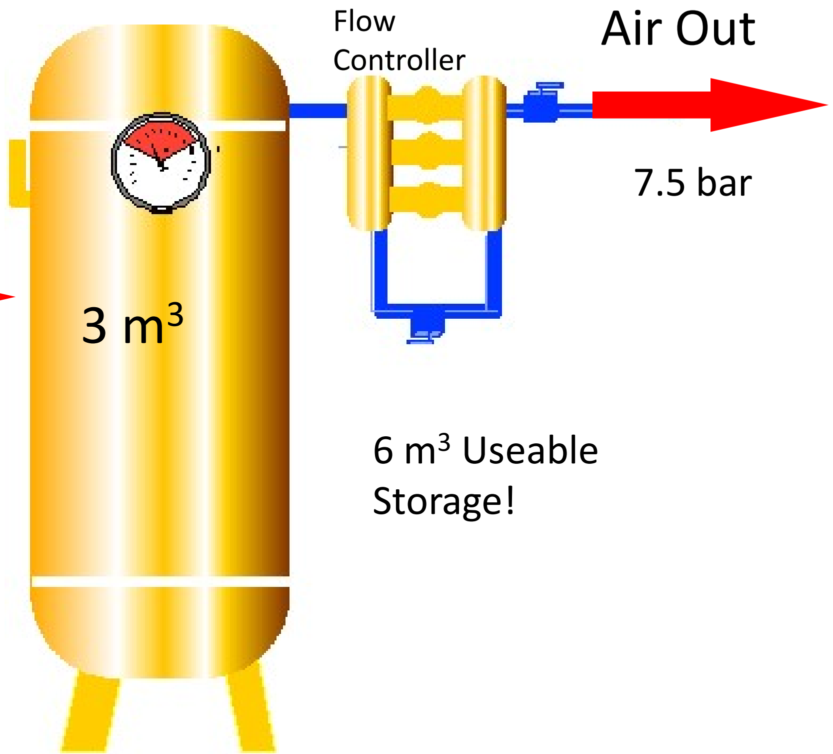


No " Real" Storage

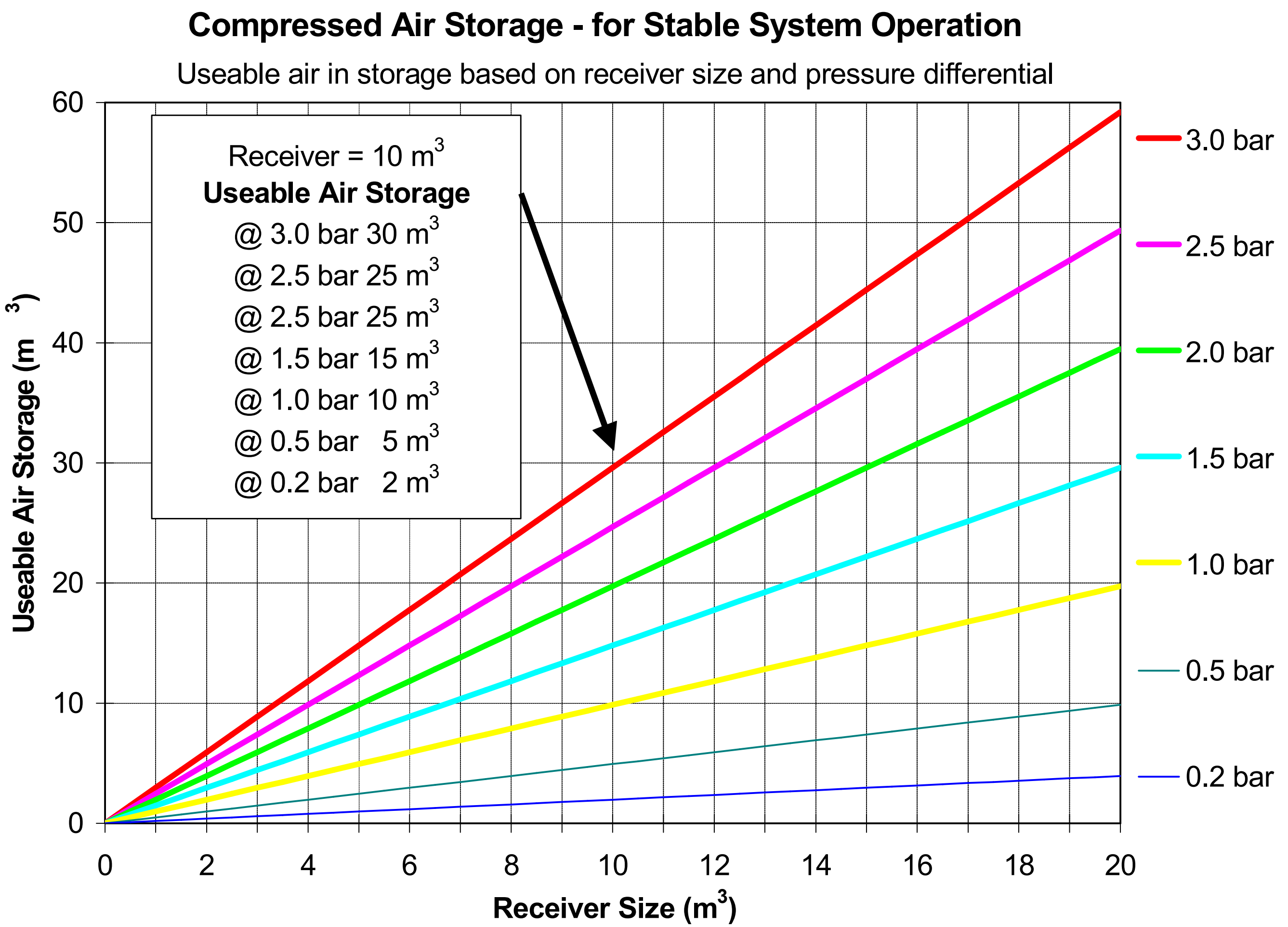
Controlled Storage:

With Pressure Differential

- Quiet zone
- Moisture separator
- Protects downstream equipment from oil slugs
- Prevents compressor from excessive cycling
- PLUS 6 m^3 of useable air in storage!



Pressure Differential Creates Stored Energy!


Compressed Air Storage - for Stable System Operation
Useable air in storage based on receiver size and pressure differential
Receiver = 10 m3
Useable Air Storage
@ 3.0 bar 30 m3
@ 2.5 bar 25 m3
@ 2.5 bar 25 m3
@ 1.5 bar 15 m3
@ 1.0 bar 10 m3
@ 0.5 bar 5 m3
@ 0.2 bar 2 m3
Useable Air Storage (m3)
Receiver Size (m3)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16
18
20
3.0 bar
2.5 bar
2.0 bar
1.5 bar
1.0 bar
0.5 bar
0.2 bar

Tuning Compressor & System Controls

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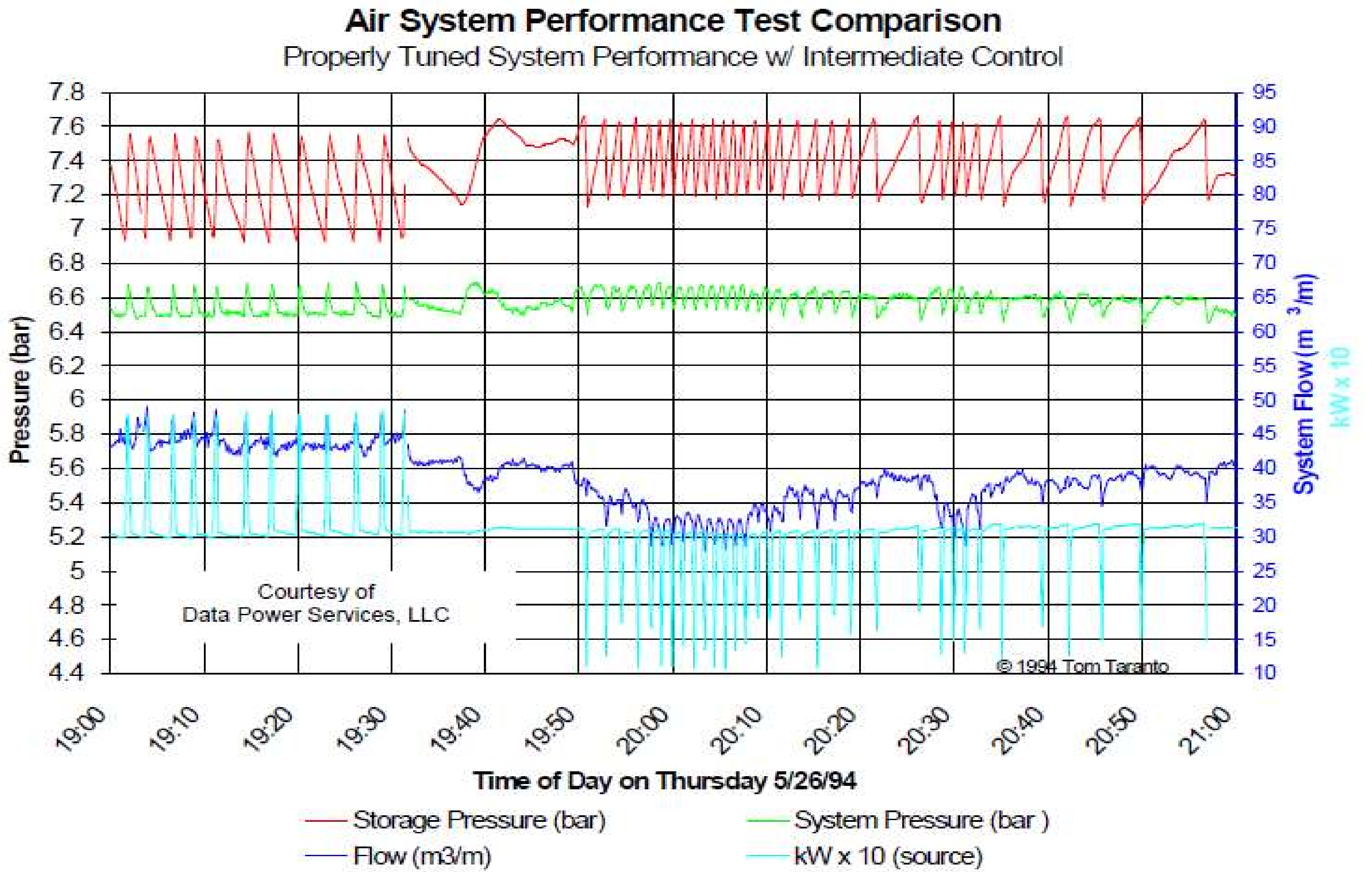

Tuning Compressor & System Controls

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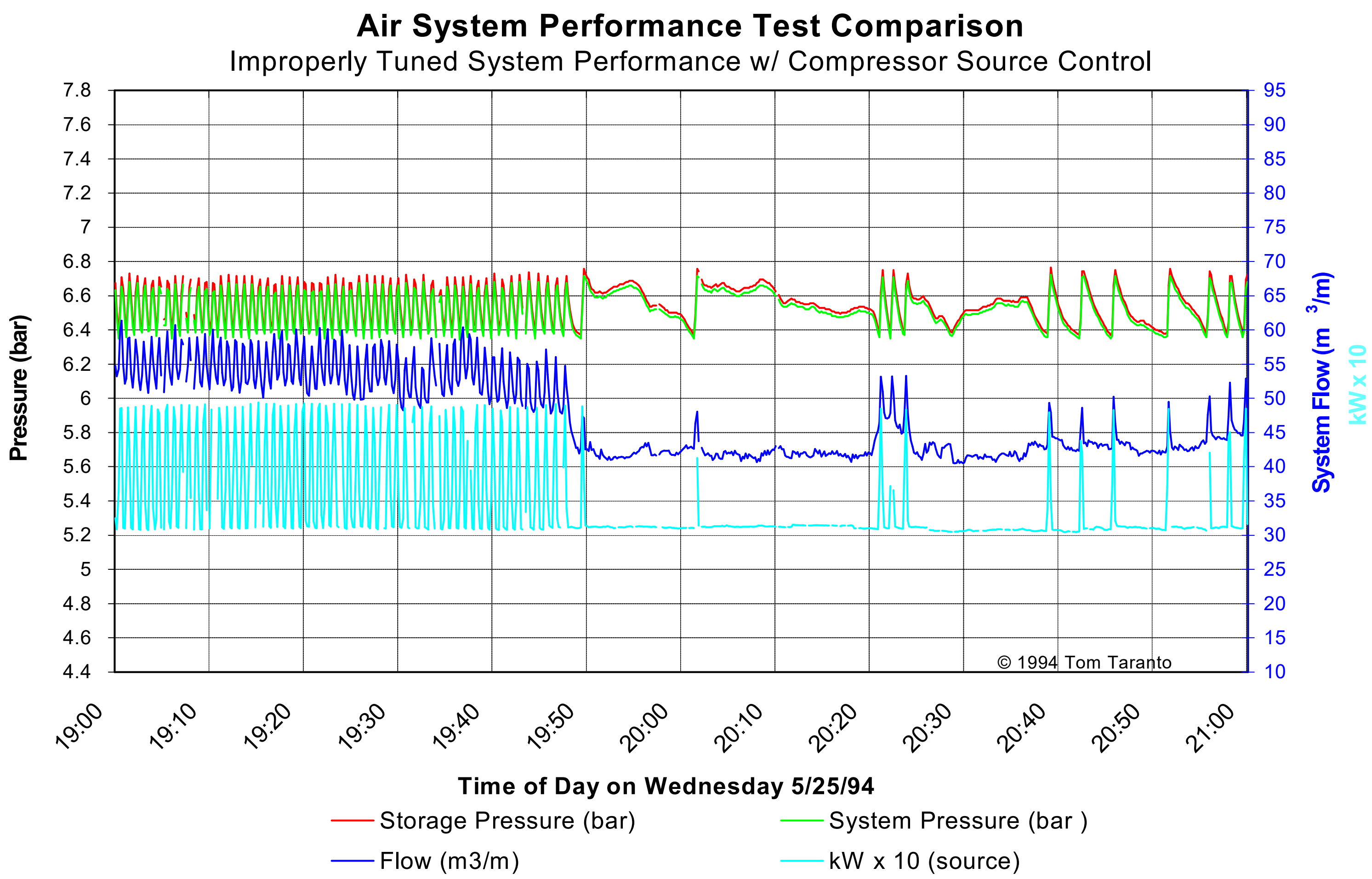
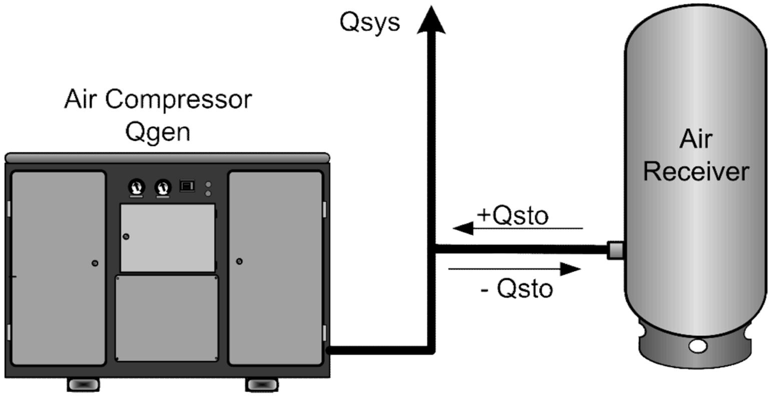


Key Learning Points

1. Stabilize system operating pressure.
2. The amount of energy in storage depends on storage volume and controlled pressure differential.
3. Elevated air pressure increases compressed air demand at leaks and unregulated air demands.
4. Leakage can be reduced by controlling to a lower system pressure.
5. Artificial demand is a component of any unregulated leak or air demand.
6. Target pressure should be the lowest optimal pressure to supply productive air demands.
7. Air storage should be designed to supply surge demands, satisfy events defined in the demand profile, and improve compressor control response.

Compressed Air Storage

- Flow generated by the compressor *Qgen* seldom exactly matches the system air demand Qsys
- To create a supply / demand balance air flows in and out of storage.
- As system pressure increases air enters storage (-Qsto)
- As system pressure decreases air leaves storage (+Qsto)



Storage Capacity Calculation

$$V_a = V_s \times \left(\frac{(P_{\max} - P_{\min})}{P_{amb}} \right)$$

Where:

V_a	=	Useable compressed air storage capacity
V_s	=	Storage Volume = total volume of storage system
P_{max}	=	Maximum storage or receiver pressure (cut-out pressure)
P_{min}	=	Minimum storage or receiver pressure required (cut-in pressure)
P_{amb}	=	Absolute ambient air pressure

Storage Volume Calculation

$$V_s = \frac{T \times C \times P_{amb}}{P_{\max} - P_{\min}}$$

Where:

T	=	Time duration of the event (minutes)
C	=	Air demand of the event
V_s	=	Total volume of storage system
P_{max}	=	Maximum storage or receiver pressure (cut-out pressure)
P_{min}	=	Minimum storage or receiver pressure required (cut-in pressure)
P_{amb}	=	Absolute ambient air pressure

Introducing Time into Air Receiver Storage Calculations

- Adding time to the air storage calculation results in airflow rate Q_{gas} being calculated.
- The flow rate of gas is volume per unit of time.

$$V_{gas} = V_{rec} \times \frac{(P_f - P_i)}{P_{atm}}$$

$$\frac{V_{gas}}{T} = \frac{V_{rec} \times \frac{(P_f - P_i)}{P_{atm}}}{T}$$

$$Q_{gas} = \frac{V_{rec} \times (P_f - P_i)}{T \times P_{atm}}$$

Key Learning Points

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1. System dynamics and the types of compressed air end use applications will determine the nature of the compressed air demand profile.
2. There can be a significant difference between average air demand (what compressors supply) and peak airflow rate driven by real air demand.
3. 4 sources of compressed air: rotating on-line capacity, rotating reserve capacity, storage capacity, and stand-by capacity.
4. The amount of useable energy in storage depends on receiver volume and available pressure differential.
5. The key to consistent, stable, and efficient operation, is maintaining balance between supply and demand.
6. Rotating on-line capacity must be equal to or greater than average air demand.
7. Peak demand is best supplied from storage. However, when air is used from storage there needs to be time and extra compressed air capacity to refill storage before the next event occurs.
8. Compressor controls should shut off compressors that are not needed, operate all compressors at full load, and trim with only 1 compressor operating at part load capacity. (Positive displacement)
9. Select a trim compressor with efficient part load capacity control.
10. There are many different applications for compressed air storage, engineer storage based on system requirements.
11. In many systems the single largest event requiring storage is the unanticipated shutdown of an operating air compressor.

9. Compressed Air System Controls

Match the compressed air supply with system demand

- The objective of any control strategy is also to shut off unneeded compressors or delay bringing on additional compressors until needed.
- All units which are on should be run at full-load, except for one unit for trimming.
- Needed to orchestrate a reduction in the output of the individual compressor(s) during times of lower demand.

Individual Compressor Control Strategies

a. Start/Stop

- Simplest control available to reciprocating or rotary screw.
- Motor is turned on or off in response to the discharge pressure of the machine.
- Typically, using a simple pressure switch.
- Not be used in an applications that has frequent cycling

b. Load/Unload

- Also known as constant speed control
- Allows the motor to run continuously
- An unloaded rotary screw compressor will consume 15-35% of full-load power while delivering no useful work
- Some load/unload control schemes can be inefficient.

Individual Compressor Control Strategies

c. Modulating Controls

- Throttling inlet control
- Applied to centrifugal and rotary screws
  - With displacement: inefficient means of varying output.
  - With centrifugal: More efficient, particularly with IGV's. Limited by surge and choke

d. Multi-step (Part-load) Controls

- Designed to operate in two or more partially-loaded conditions.
- Output pressure can be closely controlled without requiring start/stop or load/unload.
- Reciprocating: two-step (start/stop or load/unload), three- step (0%, 50%, 100%) or five-step (0%, 25%, 50%, 75%, 100%) control.
- Rotary screw: sliding or turn valves. Generally applied in conjunction with modulating inlet valves

e. Variable Frequency Drives

- Cost is no longer a major issue
- VFDs have become more reliable and efficient at full-load.

System Controls

a. Single Master (Sequencing) Controls

- Referred to as single master control units
- Higher efficiency because the control range around the system target pressure is tighter
- Careful matching of system controls and storage capacity

b. Multi-Master (Network) Controls

- Network controls offer the latest in system control
- Individual controllers are linked or networked together, thereby sharing all operating information and status.
- Changing air demand can be met more quickly and accurately
- Tight pressure control range

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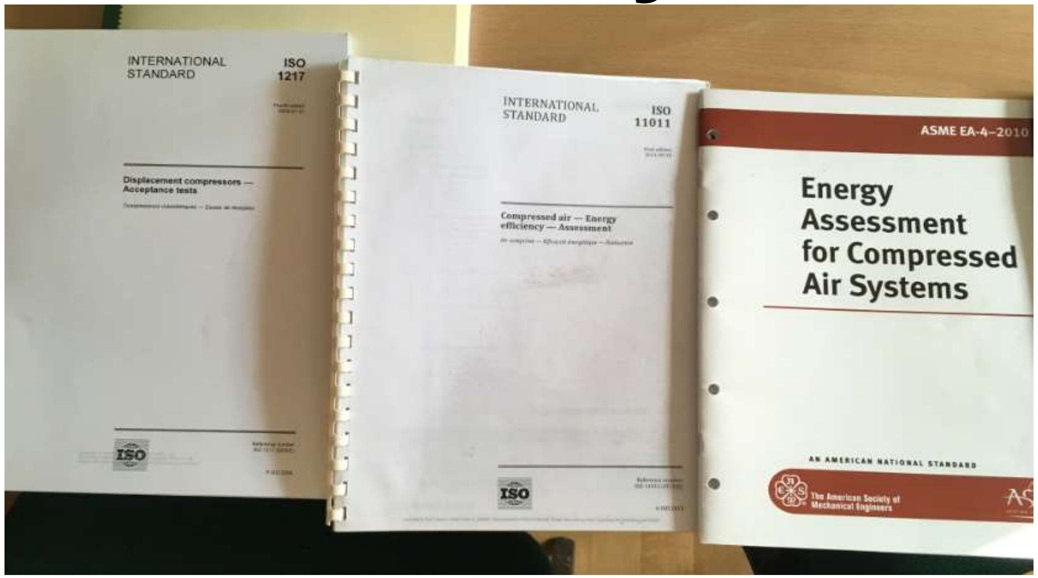
10. Compressed Air System Assessment



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- The information gathered should allow the assessment team to:
  - Understand point of use applications
  - Correct poor performing applications and those that upset system operation
  - Eliminate wasteful practices
  - Create and maintain an energy balance
  - Optimize storage and compressor controls

Power Profile

Energy consumption and baseline operating costs

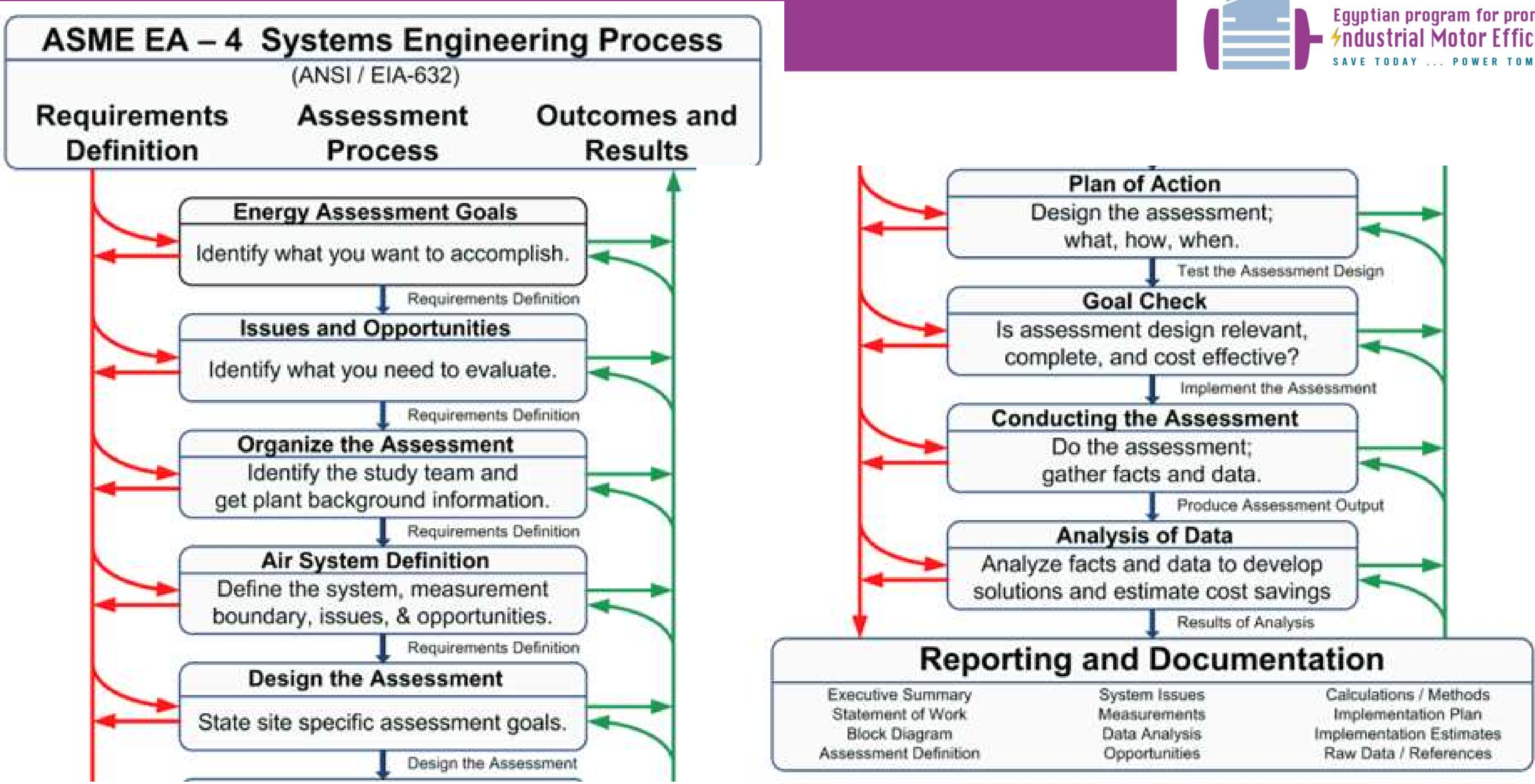
kW is the preferred measurement for power, but amps can also provide valuable information

$$\frac{volts \times amps \times \sqrt{3}\ x\ PF \times hours \times energy\ \text{cost}}{1000} = annual\ energy\ \text{cost}$$

Or, less accurate:

$$\frac{NPKW \times LoadFactor \times hours \times energy\ \text{cost}}{\eta_{motor}} = annual\ energy\ \text{cost}$$

Where: volts = average line to line 3 phase voltage | amps = full load amperage of the motor
√3 = for phase to neutral voltage from line to line voltage
PF= power factor of the motor (0.80 to 0.85 typical @ FL)
hours = annual running hours |energy cost = $ / kWh
NPKW = Nameplate kW rating
Load factor = a ratio of the average actual power to the total package power
η_{motor} = full load motor efficiency


ASME EA – 4 Systems Engineering Process
(ANSI / EIA-632)
Requirements Definition
Assessment Process
Outcomes and Results
Energy Assessment Goals
Identify what you want to accomplish.
Requirements Definition
Issues and Opportunities
Identify what you need to evaluate.
Requirements Definition
Organize the Assessment
Identify the study team and get plant background information.
Requirements Definition
Air System Definition
Define the system, measurement boundary, issues, & opportunities.
Requirements Definition
Design the Assessment
State site specific assessment goals.
Design the Assessment
Plan of Action
Design the assessment; what, how, when.
Test the Assessment Design
Goal Check
Is assessment design relevant, complete, and cost effective?
Implement the Assessment
Conducting the Assessment
Do the assessment; gather facts and data.
Produce Assessment Output
Analysis of Data
Analyze facts and data to develop solutions and estimate cost savings
Results of Analysis
Reporting and Documentation
Executive Summary
Statement of Work
Block Diagram
Assessment Definition
System Issues
Measurements
Data Analysis
Opportunities
Calculations / Methods
Implementation Plan
Implementation Estimates
Raw Data / References

- Common goals in all compressed air system assessments:
  - Baseline airflow and energy use
  - Capture system pressure trends during baseline period
  - Establish pressure profile through system to key applications
  - Characterize system performance and operation of poor performing end use applications that cause productions issues
  - Identify waste and inappropriate use and evaluate alternatives
  - Understand system dynamics and measures to create balance between supply and demand
  - Implement control strategy to maintain balance.

- **Reality is**, the supply of compressed air does not drive system performance or cost. If you never take any air out of a system, performance would be stable and cost would be minimal. The determination of both performance, and cost is how the compressed air gets out of the system, not how it gets in.

- Common Assessment Mistakes
  – An air compressor power study is not an air system assessment
  – An air system assessment designed to prove a point usually will
  – Controlling leaks is not controlling the system
  – Drawing the distribution piping does not define performance.

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11. Data Collection & Analysis

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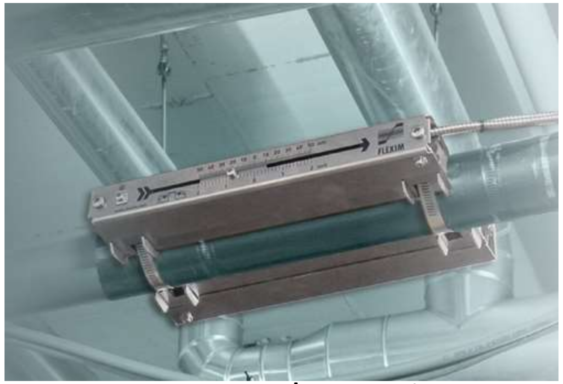
- Informational goals:
  - Demand profile
  - Pressure profile
  - High volume intermittent demand events
  - Perceived high pressure demands
  - Power consumption
  - Production levels

- Developing a Compressed Air System Profile
  - Data Logging, Flow, Power and Pressure

Flow Measurements



Ultrasonic compressed air flow meter

Hot wire anemometer thermal massflow insertion-style meter

Key Learning Points

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1. Training raise awareness of CA cost, opportunities to lower air pressure, and improve system performance.
2. Monitoring CAS performance provides management info to keep the air system operating efficiently, and reliably.
3. In today's highly competitive global economy, timely CAS management information is essential.
4. CA energy is a significant investment including capital, energy, maintenance, and productivity costs.
5. Multiple compressor systems can be very inefficient if not properly controlled.
6. Compressed air demand and pressure profile data can help identify potential areas for improvement.
7. Compressed air system assessment defines performance and current method operating costs
8. Balancing system operation provides stable performance and reduces energy cost.
9. Inappropriate compressed air demands must be identified and replaced with more energy efficient alternatives.
10. Leak management, correctly sized piping, and good PoU piping practice improves air application performance
11. Reducing pressure to the lowest optimum pressure to supply productive air demands, will reduce energy cost.
12. Measurement system accuracy depends on human factors; connections to the system, transducers; wiring, cables, electrical connections; data acquisition hardware and software; along with measurement techniques.
13. Sample rate, data averaging, and data intervals depend on system characteristics.
14. Use appropriate sensors, transducers, and measurement system accuracy.
15. Transducers output various signals in proportion to the physical parameter being measured.
16. Signals must be properly scaled to correctly record the measurement.

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12. Maintenance

- Inadequate maintenance can have an impact on;
  - energy consumption via lower compression efficiency,
  - air leakage,
  - pressure variability,
  - high operating temperatures,
  - poor moisture control, and
  - excessive contamination
- All equipment in the compressed air system should be maintained in accordance with manufacturers' specifications
- Do periodic benchmarking by tracking power, pressure, flow, and temperature

Routine Maintenance for Lubricant Free Rotary Screw Compressor

- Daily
  - Observe the various control panel displays and local gauges
- After Initial 50 Hours of Operation
  - Rid the system of any foreign materials.
  - Change the lubricant filter element.
  - Clean the control line filter element.
  - Check/replace the sump breather filter element.
- Every 3000 Hours of Operation
  - Check/change oil charge, filter element, sump breather filter element, control line filter element, condensate drain valve, shaft coupling element
  - Measure and record vibration signatures

Routine Maintenance for Lubricant Free Rotary Screw Compressor

- Every 15,000 Hours of Operation
  - Operate/test all safety devices.
  - Check/clean heat exchangers, blowdown valve.
  - Check operation of balancing switch/valve assembly.
  - Check/clean water regulating and check valve.
  - Check/clean galvanized interstage pipe work.
  - Check condition of isolation mounts
  - Check/clean strainer and check valve included in oil pump suction line, inside oil sump.
  - Check compressor unit internal clearances.

Routine Maintenance for Centrifugal Air Compressors

- Daily
  - Record air inlet, interstage, discharge pressures and temperatures.
  - Record cooling water inlet and outlet pressures and temperatures.
  - Record lubricant pressure and temperatures, vibration levels.
  - Check air inlet filter differential pressure, proper operation of drain traps.
  - Drain control air filter.
  - Check for leaks, lubricant sump level
  - Check drive motor for smooth operation and record amperes.
- Every 3 months
  - Check lubricant filter differential pressure, lubricant sump venting system.
  - Check operation of capacity control system, surge control system.
  - Check main drive motor amperes, automatic drain traps and strainers.
- Every 6 months
  - Check air inlet filter.
  - Take oil sample for analysis.

Routine Maintenance for Centrifugal Air Compressors

- Annually
  - Inspect intercooler, aftercooler, and lubricant cooler.
  - Inspect main drive motor for loose mounting bolts, frayed or worn electrical cables, accumulated dirt.
  - Inspect main drive coupling for alignment and lubrication.
  - Inspect gearbox
  - Check impeller inlets and diffusers
  - Check control panel for complete and proper operation.
  - Check all control valves for proper operation.
  - Check all safety devices for proper settings and operation.
  - Inspect check valve; replace worn parts.
  - Keep all components/accessories clean.

13. Heat Recovery

- As much as 80-93% of the electrical energy used by an industrial air compressor is converted into heat.
- A properly designed heat recovery unit can recover anywhere from 50-90% of this available thermal energy
- Typical uses: space heating, industrial process heating, water heating, makeup air heating, and boiler makeup water preheating.

Heat Recovery with Air-Cooled Rotary Screw Compressors

- **Heating Air**
  - Ambient atmospheric air is heated by passing it across the system's aftercooler and lubricant cooler
  - Only system modifications needed are the addition of ducting and another fan
  - ± 5.3 kW of energy is available for each m^3/min of capacity (at full-load).
  - Air temperatures of 17-22°C above the cooling air inlet temperature can be obtained.
  - Recovery efficiencies of 80-90% are common.
- **Heating Water**
  - Extract waste heat from the lubricant coolers
  - Can produce non-potable (gray) or potable water
  - Heat exchangers also offer an opportunity to produce a varying ratio of hot air and hot water

Calculating Energy Savings

Energy Savings Calculations
Energy Savings (kWh/year) = 0.8 x Compressor kW x hours of operation **Example:** A 75kW compressors running two shifts, 5 days per week = (0.80) x 75kW x 4160 hours per year ***= 249,600 kWh per year*** *Where 0.80 is the recoverable heat as a percentage of the unit's output* $\text{Cost savings}(\$/\text{y}) = \dfrac{\text{Energy savings in kWh/y} \times \text{kWh/unit of fuel} \times \$/\text{unit of fuel}}{\text{Primary heater efficiency}}$ **Example:** Waste heat will be displacing heat produced by a natural gas forced air system with an efficiency of 85%. Assume the cost for natural gas is \$0.14/m^3, and the energy content of natural gas is 37MJ per m^3. $\text{Cost savings} = \dfrac{249{,}600\ \text{kWh/y} \times \dfrac{\text{m}^3}{37\text{MJ}} \times \dfrac{3.6\text{MJ}}{1\text{kWh}} \times \dfrac{\$0.14}{\text{m}^3}}{85\%}$ $\text{Cost savings} = \$4000 \text{ per year}$ ** Cost of operating an additional fan for duct loading has not been included*

Case Study

Case Study – Steel company in Sadat city, Egypt

- 8 x 56 kW compressors, 2 x 75 kW compressors
- Baseline 3.227 GWh /year, 21.5-million m^3 /year
- Operating pressures between 6.6 and 8.0 bar
- Four wet receiver tanks [3.3 m^3 each] and two dry receiver tanks [5.4m^3 each]

Case Studies

Egyptian program for promoting Industrial Motor Efficiency
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Findings

Leakages

Bearing cooling

Filter bypass open

Case Studies

Recommendation	Baseline before EMO, kWh	Energy Savings, kWh	Energy Savings, EGP	Energy Savings ratio %	Implementation Cost, EGP	Simple Payback, years	Carbon Reduction (kg p.a)[9]
Drain Valves	3,227,133	112,949	77,180	3.5%	10,680	0.14	61,410
Inappropriate use (Bearing cooling)		673,644	455,383	22%	10,000	< month	366,260
Inappropriate use (Air Curtain)		430,992	291,350	14%	6,000	< month	234,330
Inappropriate use (Stands of rod milling)		655,949	443,421	21.3%	9,000	< month	356,639
Pressure drop at peak demand		5,709	3,859	0.18%	0	-	3,104
Pressure across treatment		296,846	200,668	9.2%	55,536	0.276	161,395
TOTALS		2,176,089	1,471,861	67.4%			1,183,138

CONCLUSION

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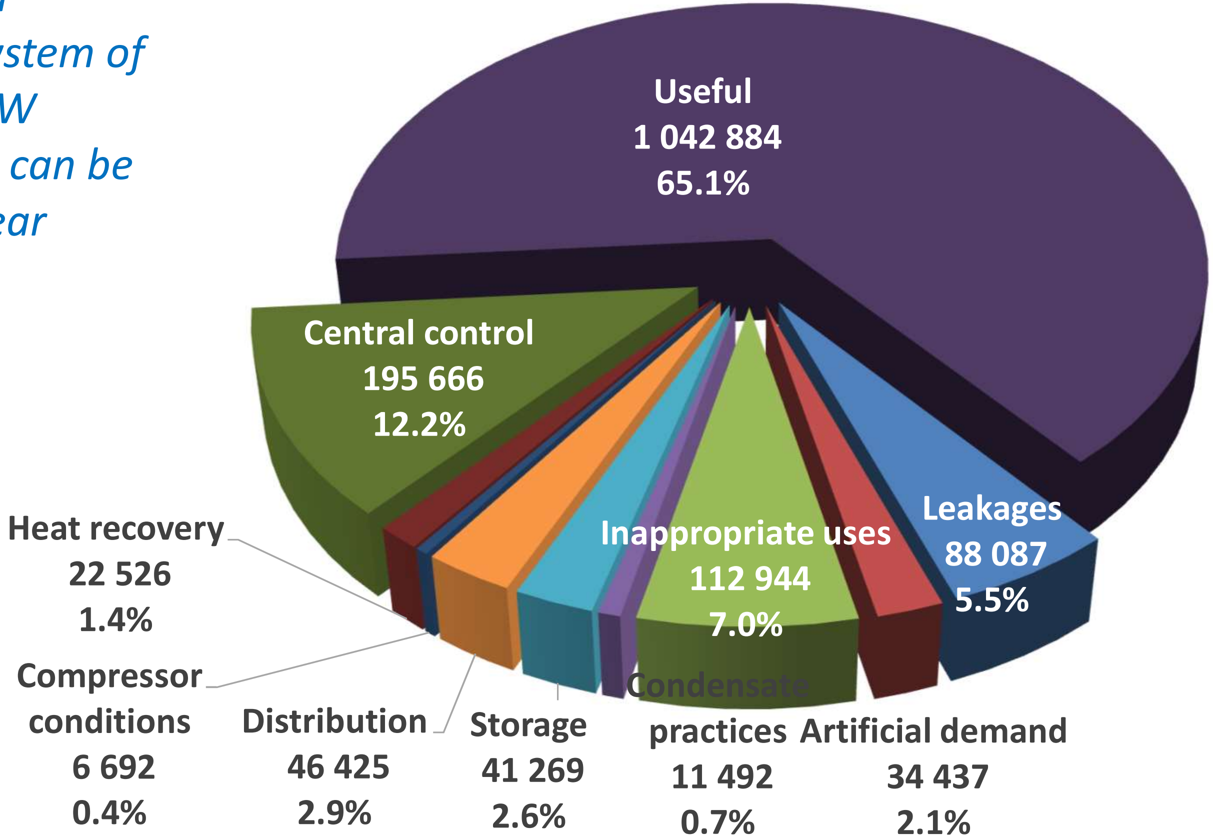
Feasible kWh Saving Opportunities

A study (next slide) shows if you consider an average sized CA system of 1 602 MWh/y (e.g. three x 75 kW comps @ 70% LF), 560 MWh /y can be saved at an ROI of 81.3% per year



Source: Williams, A. "Nine areas of compressed air systems optimization opportunities based on international case studies", 2018

Energy Efficiency Measures:

- Common Measures & Saving Potential

Measure	% systems where it's typically applicable	Typical savings range
Centralised Control Integration on Multiple Compressor Systems	75%	12% - 57%
Engineered controlled storage volume	30%	8% - 28%
Waste Heat Recovery	13%	19% - 65%
Compressor conditions: Improved cooling, drying, filtering	20%	1% - 4%
Distribution network improvement	35%	4% - 18%
Artificial demand	65%	5% - 13%
Inappropriate uses	38%	5% - 32%
Manage air leakages	70%	8% - 25%
Condensate practices	33%	2% - 41%

Source: Williams, A. "Nine areas of compressed air systems optimization opportunities based on international case studies", 2018