MINISTRY OF
INDUSTRY AND TRADE

EU - VIET NAM SUSTAINABLE ENERGY
TRANSITION PROGRAMME (SETP)

Global Gateway
Funded by
the European Union

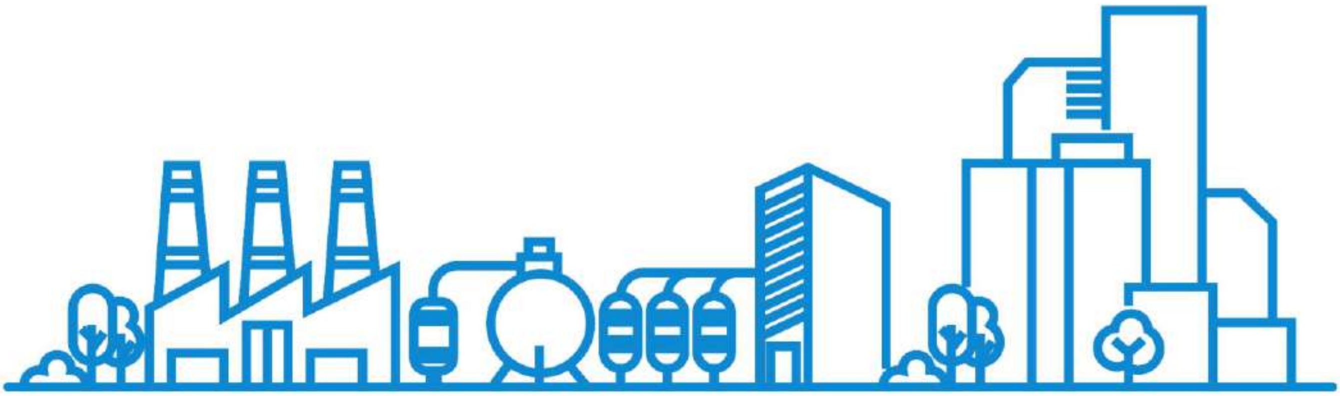
UNIDO
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Project "Accelerating energy efficiency (EE) in large industries through energy management system, system optimisation and the promotion and adoption of EE in SMEs" (IEEP)

EXPERT TRAINING PROGRAMME

COMPRESSED AIR SYSTEM OPTIMISATION (MODULE 2)

Ha Noi, 19 - 22/11/2024



AGENDA

Expert Training on Compressed Air System Optimisation
19-22 November 2024

At Adonis Hotel - 55 Quang Trung Street, Hai Ba Trung District, Ha Noi
And HOST plants in Nam Dinh province

Day 1: 19 November 2024

(Classroom Training at Adonis Hotel, 55 Quang Trung, Hai Ba Trung District, Hanoi)

Time	Contents	Speakers
8.00-8.30	Registration and welcome	
8.30-8.40	Opening speech	Representative of Department of Energy Efficiency & Sustainable Development, Ministry of Industry & Trade Representative of European Union Delegation
8.40-9.00	Introduction	International Expert
9.00-10.00	Review of basics	International Expert
10.00-10.15	**Tea-break**	
10.15-12.00	Carrying out a compressed air survey	International Expert
12.00-13.15	**Lunch at the hotel**	
13.15-15.00	Learning to use the equipment	Equipment supplier / class / International Expert
15.00-15.15	**Tea-break**	
15.15-16.45	Learning to use the equipment / Overview of useful calculations	Equipment supplier / class / International Expert

Day 2: 20 November 2024

(Onsite Training at HOST plants in Nam Dinh province)

Time	Contents	Speakers
6.45-7.00 7.00-9.00	Trainees gathering at the Adonis hotel Moving to the HOST plants by cars	All the class
9.00-9.10	Coming to the HOST plants Introduction	All the class
9.10-9.20	Welcome speech	Enterprise representative
9.20-9.45	Safety instruction	International Expert
9.45-10.00	**Tea break**	
10.00-11.45	Measurement and data collection (5-6 people per group max)	All the class
12.00-13.30	**Lunch near the HOST plants**	
13.30-16.30	Measurement and data collection Leak detection in factory areas	All the class
17.00 – 18.00	Check-in at the hotel in Nam Dinh	

Day 3: 21 November 2024

(Onsite Training at HOST plants in Nam Dinh province)

Time	Contents	Speakers
7.45-8.00	Trainees gathering at the hotel lobby and moving to the HOST plants by cars	All the class
8.30-8.40	Coming to the HOST plants, Safety instruction	International Expert
8.40-11.45	De-install loggers, retrieve data	All the class, International Expert
11.45-13.30	**Lunch near the HOST plants**	
13.30-15.00	Review logged data / Analysis - Group discussion	All the class, International Expert
15.00-15.30	Tea break	
15.30-16.00	Provisional/overview (pending analysis) Finding presentation to enterprise's representative	Enterprise representative, All the class, International Expert
16h-19h	Coming back to Ha Noi	

Day 4: 22 November 2024

(Classroom Training at Adonis Hotel, 55 Quang Trung, Hai Ba Trung District, Hanoi)

Time	Contents	Speakers
8.00-8.30	Registration and welcome	All the class
8.30-9.30	Analysis / Report writing Questions and Answers about the on-site training	International Expert
9.30-10.00	Analysis / Report writing Questions and Answers about the on-site training	International Expert
10.00-10.15	**Tea-break**	
10.15-11.00	Report writing Questions and Answers about the on-site training	International Expert
11.00-11.30	Next steps (candidate plant assessments and webinars	International Expert
11.30-12.00	- Reviews on the training - Closing remarks	UNIDO Project Office
12.00-13.00	**Lunch at the hotel**	All the class

MINISTRY OF INDUSTRY AND TRADE
EU - VIET NAM SUSTAINABLE ENERGY TRANSITION PROGRAMME (SETP)
Accelerating energy efficiency (EE) in large industries through energy management system, System optimisation and the promotion and adoption of EE in SMEs -(IEEP project)
Global Gateway Funded by the European Union
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Compressed Air Systems

Ian Moore CEng FIMechE
UNIDO Compressed Air System Expert

Part 1 – Compressed air basics

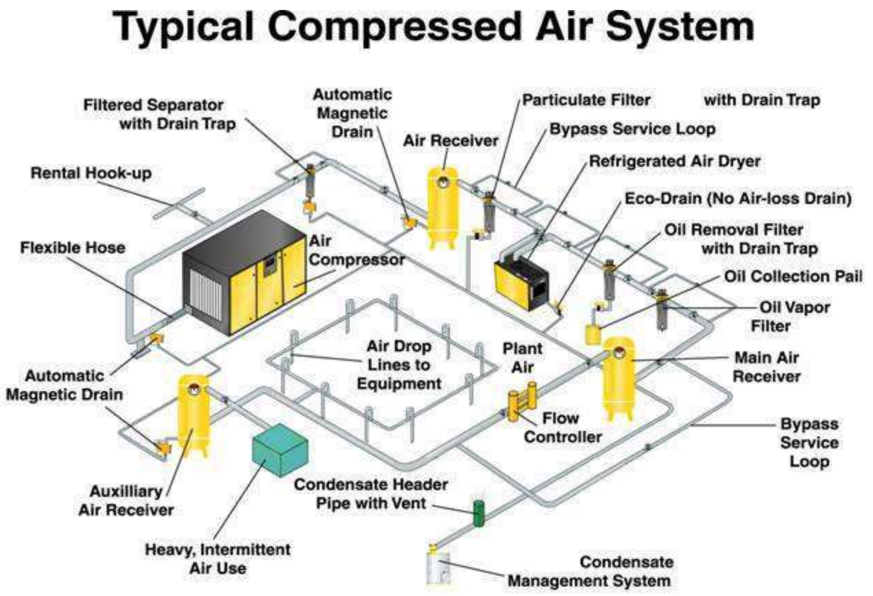
Course Agenda

- Introduction
- Review of basics
- Carrying out a compressed air survey
- Survey case study
- Overview of useful calculations
- Practical survey on user site
- Review and analysis of data from site

Compressed Air - The Facts

- 10% of industrial electricity is typically used to produce compressed air
- In Vietnam this equates to around VND31,836,105,000,000
- On average 30% can be saved some at little or no cost this equates to 1,228,864Tonnes CO_2
- Compressed Air is NOT free - it's an expensive resource - don't waste it

Compressed Air Systems



Common problems in practice

The symptoms

- High running cost
- High pressure drops
- Wet air
- High purge or drain losses
- Poor reliability

The causes

- Incorrect sizing
  - Compressors
  - Dryers
  - Filters
  - Receivers
  - Pipework
- Poor control
- Inadequate cooling
- Poor maintenance

What constitutes a best practice system?

- Compressors well matched to the demand and well controlled
- Compressors efficient and well maintained
- Treatment to the minimum required standard
- Dryers running efficiently
- Condensate collected and treated correctly
- Piping correctly sized in all areas
- Operating pressure minimum required
- Pressure drop <0.5 bar in compressor house
- Pressure drop <0.2 bar in system
- Leakage <10% of mean demand
- Air on only when required

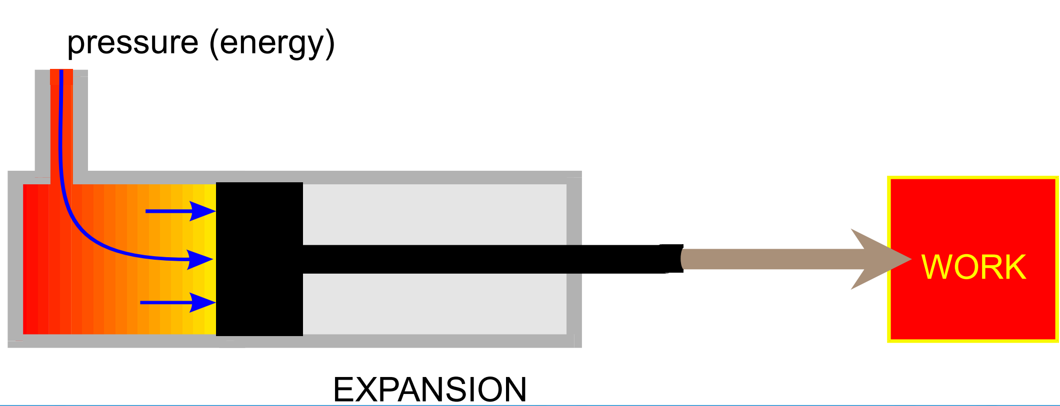
Review of compressed air basics

- ✓ Understanding compressed air
- ✓ Compressors
- ✓ Treatment & condensate
- ✓ Compressed air installations
  - Compressor houses
  - Receivers
  - Distribution
- ✓ Optimisation opportunities

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.

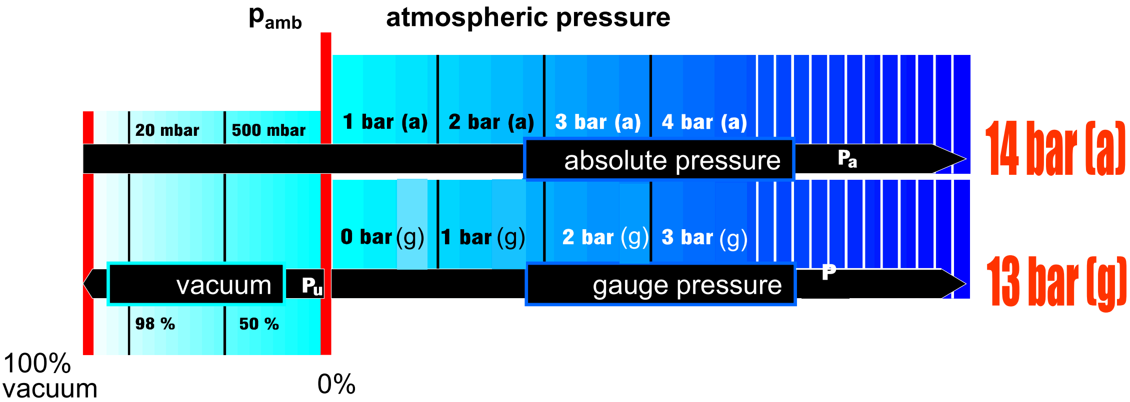


Absolute pressure ...

... is the pressure measured from absolute zero. It is used for all theoretical calculations and is required in vacuum and blower applications.

Gauge pressure ...

... is the practical reference pressure and is based on atmospheric pressure.



Definition of pressures

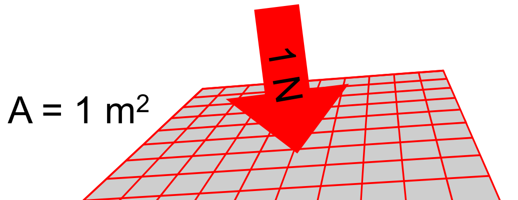
Generally:

$$\text{Pressure (p)} = \frac{\text{Force (F)}}{\text{Area (A)}}$$

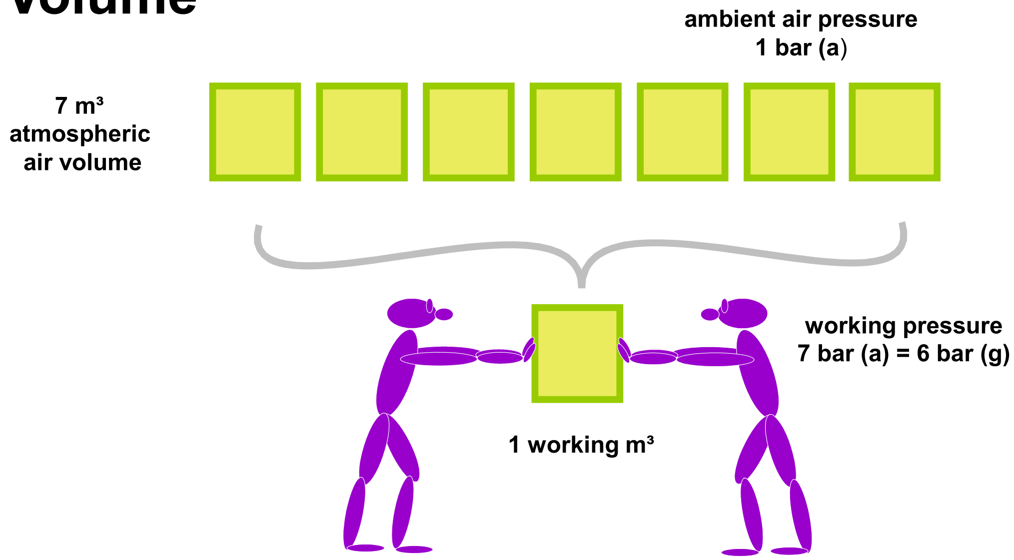
Dimensions:

$$1 \text{ Pascal (Pa)} = \frac{1 \text{ Newton (N)}}{1 \text{ m}^2 \text{ (A)}}$$

Equivalents		
10^5 Pa	=	1 bar
1 MPa	=	10 bar
1 hPa	=	0.001 bar
Gauge pressure 1 bar	=	14.5 psi(g)
1 bar	=	10197 mmWC
1 bar	=	750.062 Torr



Volume



Gas equation

Gas law relating to a closed system:

$$\frac{p_0 \times V_0}{T_0} = \frac{p_1 \times V_1}{T_1} = R = \text{constant}$$

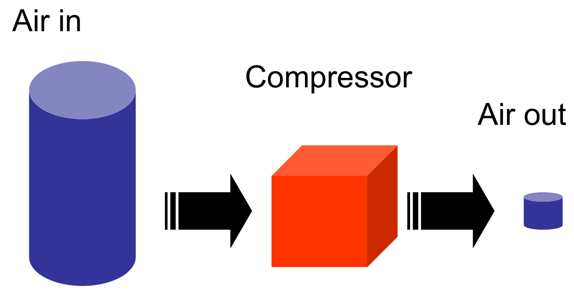
p	=	pressure (bar (absolute))
V	=	volume (m^3)
T	=	temperature (K)
R	=	special gas constants

e.g. $R = 28.96 \frac{bar \cdot m^3}{K} = 289.6 \frac{J}{kg \cdot K}$

for dry air

Compressed air – The basics

- Compressors are rated at their inlet conditions
  - 500 cfm = 500 cfm at compressor inlet
  - 250 m³/hr = 250 m³/hr at compressor inlet



Ambient air
Pressure: 1000 mbarA
Volume: $8m^3$
Mass: 10 Kg

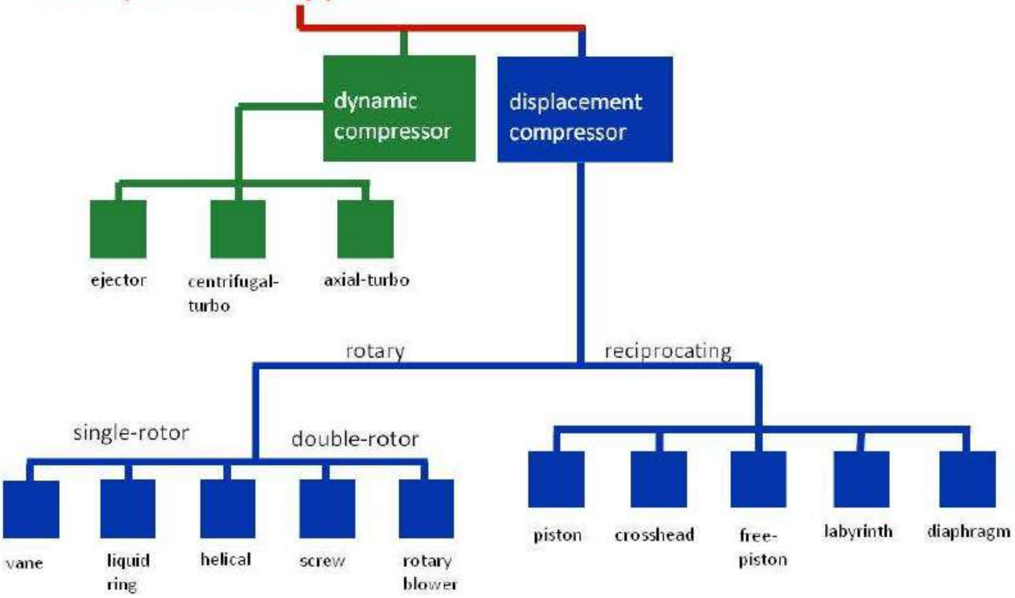
Compressed air
Pressure: 7 barg (8 barA)
Volume: $1m^3$
Mass: 10 Kg

Definition of volumes

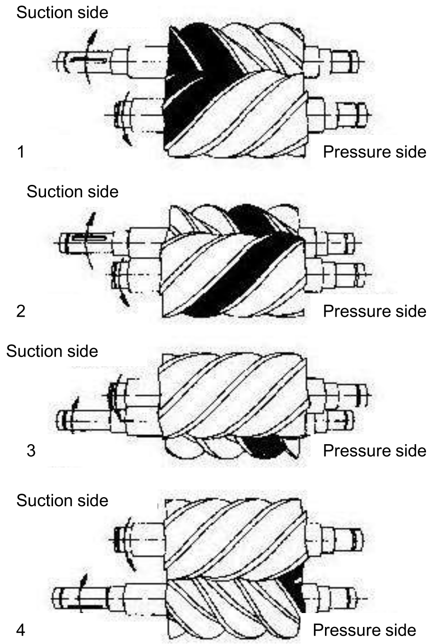
	Temperature	Pressure	Relative humidity	Density
Volume according to DIN 1343 - **Normal**	0°C = 273.15K	1.01325 bar	0%	1.294 kg/m^3
Volume according to DIN/ISO 2533 - **Standard**	15°C = 288.15K	1.01325 bar	0%	1.225 kg/m^3
Volume related to atmosphere (normal state)	atmospheric temperature	atmospheric pressure	atmospheric humidity	variable
Volume related to operating state	working temperature	working pressure	variable	variable

Compressors

Compressor types

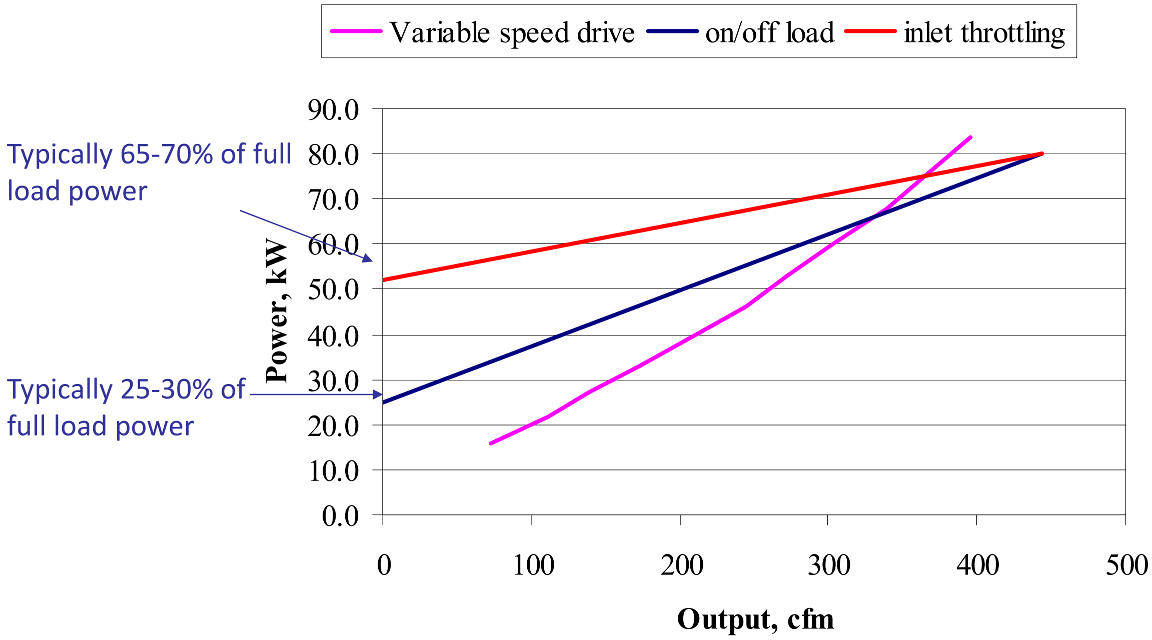


The screw compressor

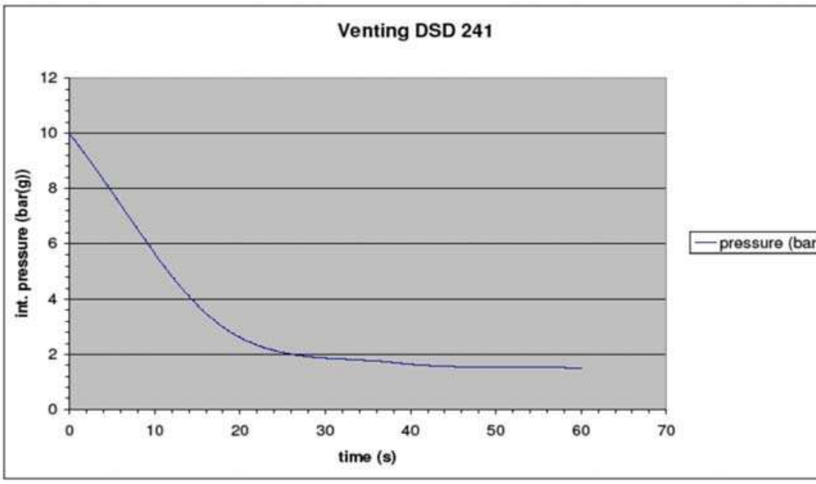


Oil injected – single stage
Oil free – two stage

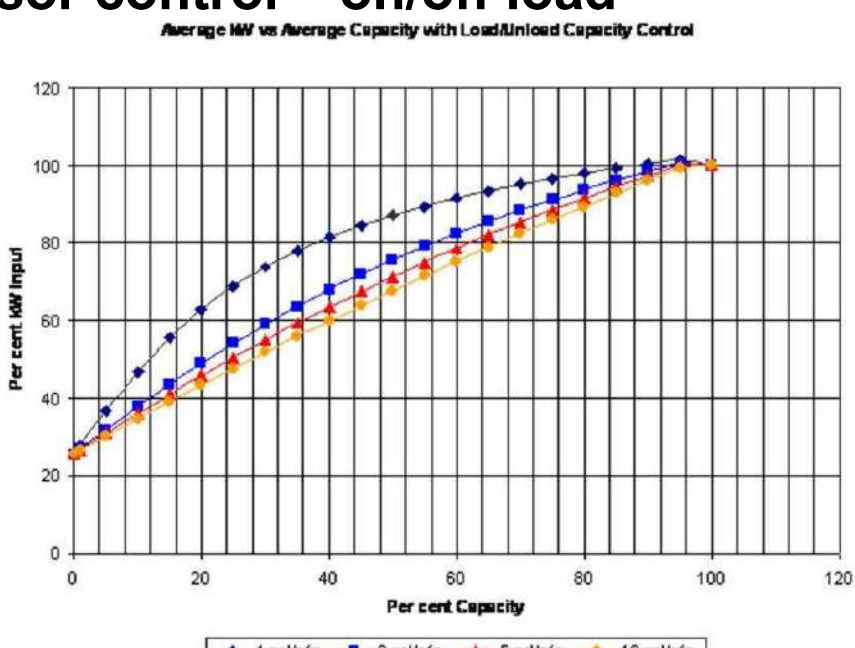
Compressor control – positive displacement



Unloading Power Time

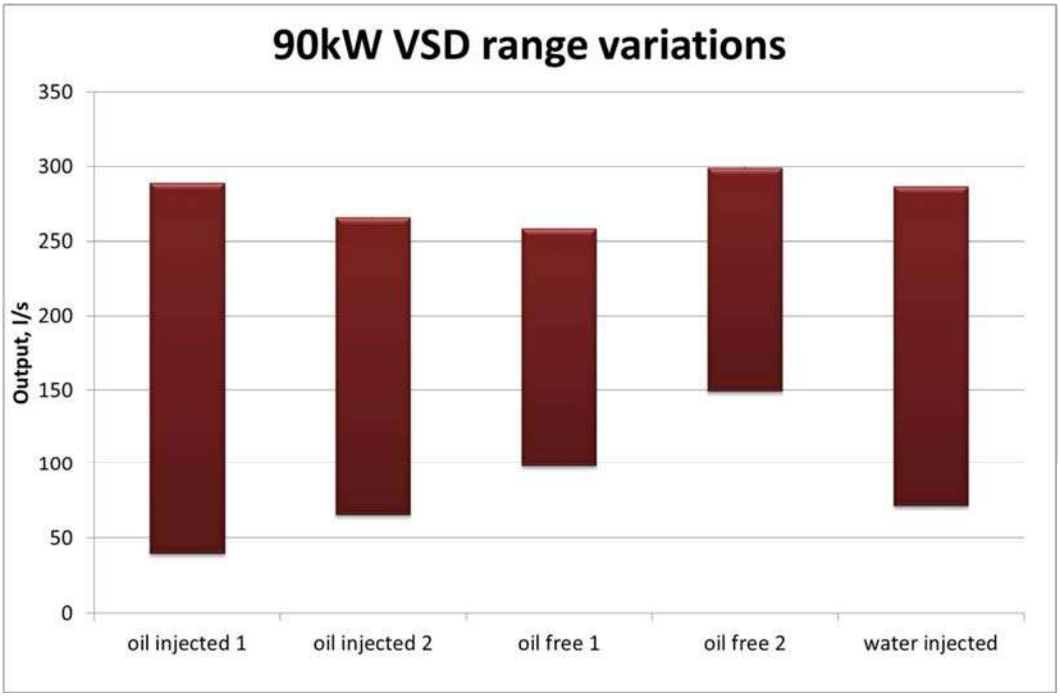


Compressor control – on/off load

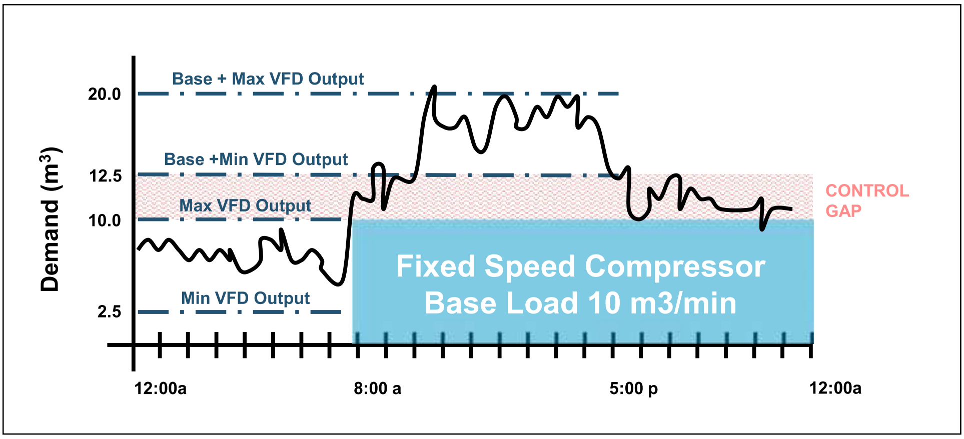


VSD compressors

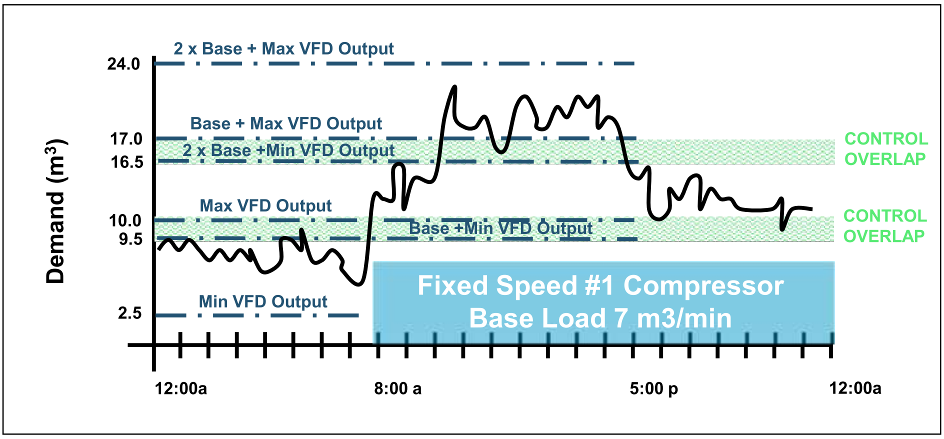
- ✓ Size compressor to cover demand range
- ✓ Avoid control gaps
- ✓ Maximise running at mid range speeds
- ✓ Remember not all VSDs offer the same performance range



Variable Speed Control
“Control Gap”



Variable Speed Control
Eliminating “Control Gap”

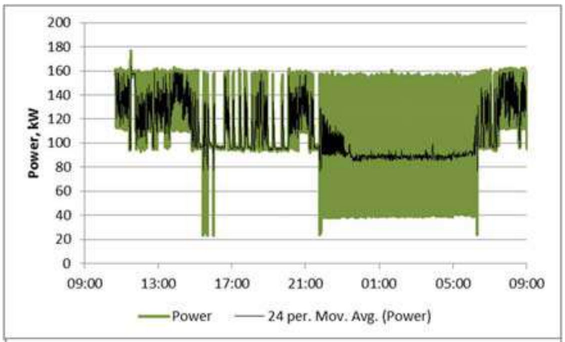


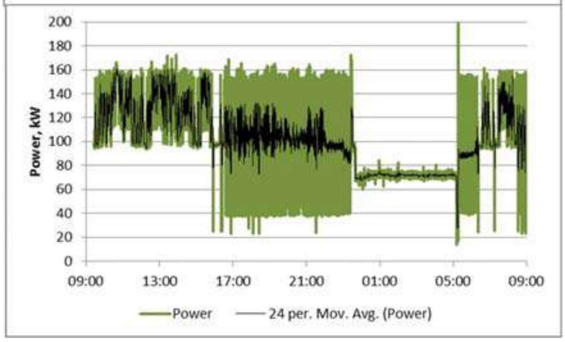
VSD misapplication

Graph 1 – VSD and on/off cycling together

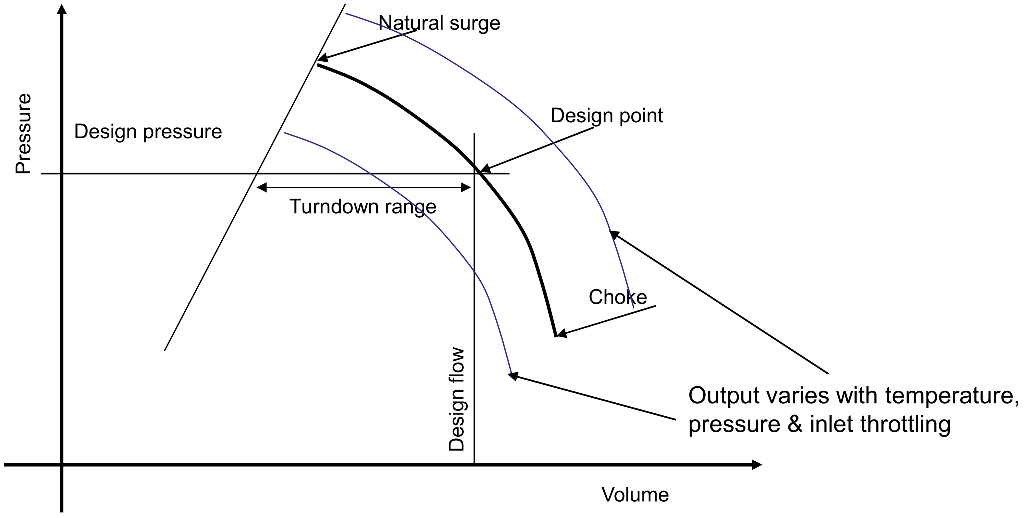
Graph 2 – VSD alone

Change in control setting reduces night load by 20 kW





Centrifugal Compressor control range



Efficiency - comparison of specific power consumption

$$\text{Specific power consumption*} = \frac{\text{power* in kW}}{\text{Effective FAD in } m^3 / \text{min}}$$

$$P_{spec} = \frac{P^*}{\dot{V}}$$

* depending on reference point:
- compressor shaft power
- motor output power
- electric power input

Maintenance

What causes loss of compressor efficiency?

- ✓ Internal leakage paths
- ✓ Poor cooling
- ✓ High internal friction
- ✓ Internal pressure losses
- ✓ Poor lubrication
- ✓ Poor or lack of maintenance

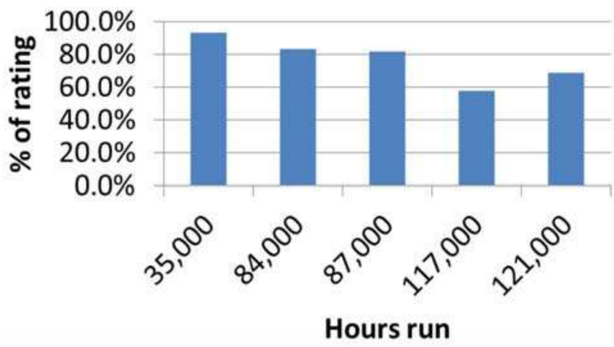
Other vital signs of efficient running

- ✓ Total hours run
- ✓ Oil leaks and air leaks from within package
- ✓ Bearing noise when running off loaded
- ✓ Separator pressure drop (oil injected)
- ✓ Intercooler pressure and temperatures
- ✓ Temperature balance all heads (recips)
- ✓ Unloading system working correctly

Running parameters

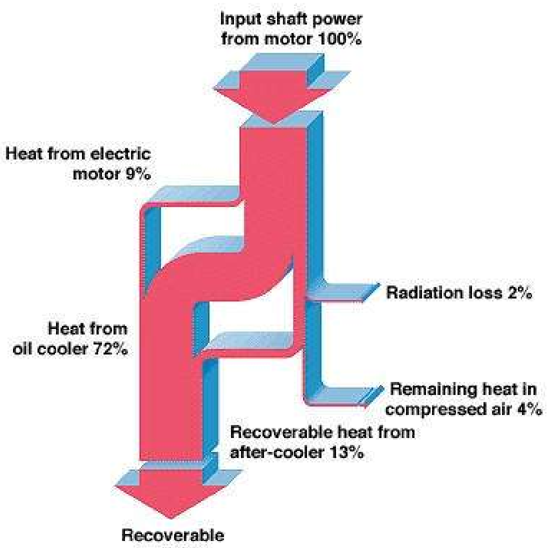
- ✓ Intercooler pressure (2-2.4 barg)
- ✓ Stage temperatures – ideally balanced
- ✓ Discharge air temperatures
  - Air cooled – 10 degrees above ambient
  - Water cooled – 5 degrees above water on temp
- ✓ Inlet temperature – As close to ambient as possible
- ✓ Inlet filter pressure drop <45mbar
- ✓ Oil separator pressure drop <0.2 bar

The effect of time and maintenance



Compressor	Pressure barg	Temp °C	Hours run	Output Nm3/min	Rated Nm3/min	Result as % rated	SPC (kW/Nm3/min)
1	5.7	46.2	84,000	16.6	20	83.0%	7.15
2	5.7	65.0	117,000	11.5	20	57.5%	9.55
3	3.87	46.2	87,000	61.4	75	81.8%	6.01
4	3.8	45.8	121,000	51.4	75	68.5%	9.70
5	3.8	50.0	35,000	70.0	75	93.3%	5.29

Heat recovery



On average 85% of input energy can be recovered for heating applications.

The possibility for heat recovery depends on:

- Heating demand of the factory
- Matching of compressor
- operation and heat demand
- Proximity of compressor station to
- heating distribution lines/consumers
- Temperatures

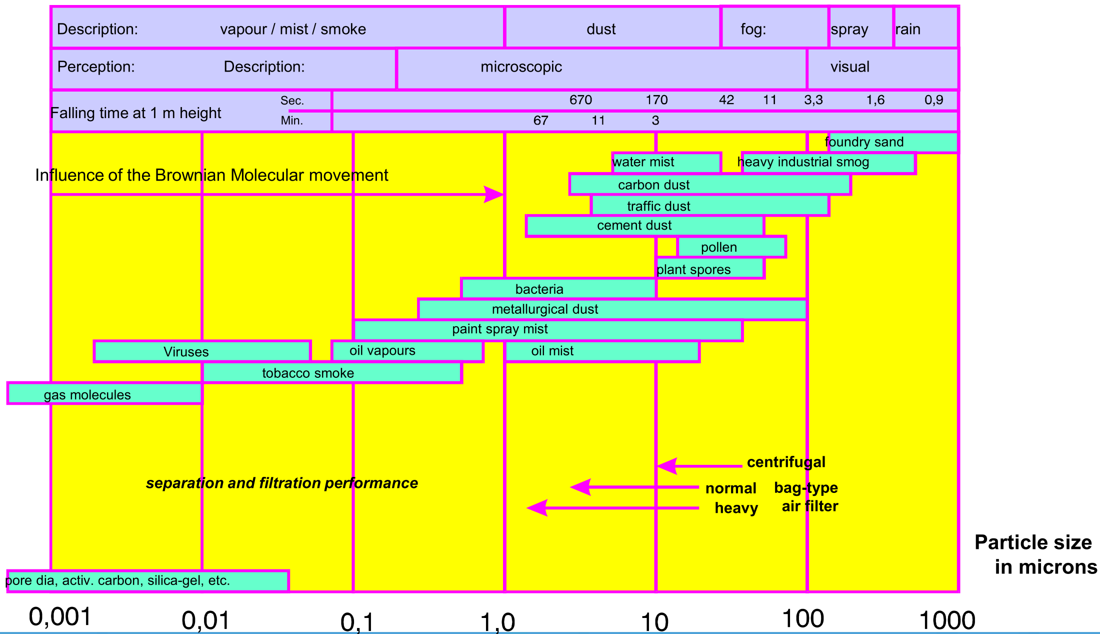
Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Treatment and condensate

Compressed Air Treatment

- Treatment is essential to reduce water, dust and oil in the delivered air
- Treat the main supply of air to minimum quality then upgrade at point of use where required
- Use ISO8573.1 air quality specification

How large are the impurities in the air?



The effect of untreated air

Corrosion in pipework

Abrasive condensate sludge

Damaged tools

Compressed air quality classes ISO8573.1:2010

Technology: **Filtration** → Particulate; **Drying** → Dewpoint; **Filtration** → Oil carry over

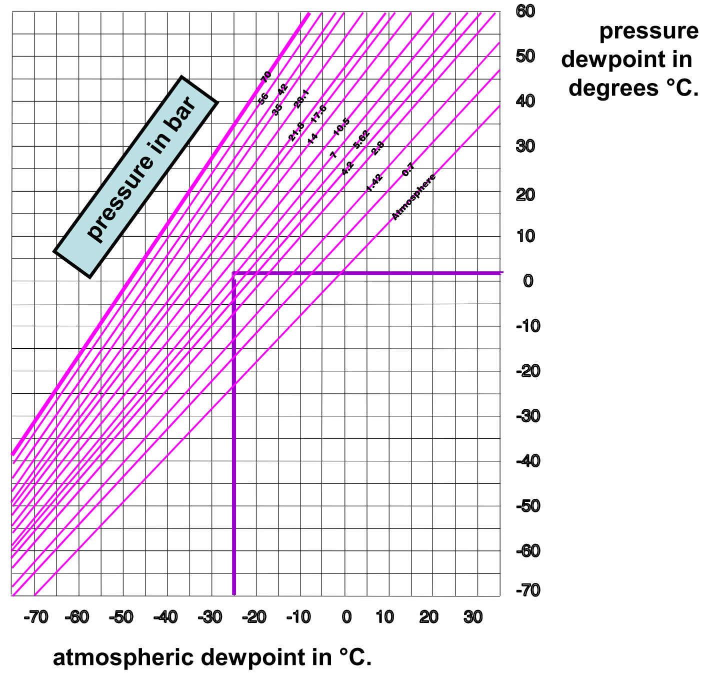
Summary of ISO8573.1-2010						
Class	Particulate - Maximum number of particles per m³				Dewpoint	Oil carry over
	Particle size					
	≤0.1	0.1<d≤0.5µm	0.5<d≤1.0µm	1.0<d≤5.0µm	°C	Mg/m³
0	As specified by the equipment user or supplier and more stringent than class 1					
1	Not specified	20,000	400	10	≤-70	≤0.01
2	Not specified	400,000	6,000	100	≤-40	≤0.1
3	Not specified	Not specified	90,000	1,000	≤-20	≤1
4	Not specified	Not specified	Not specified	10,000	≤+3	≤5
5	Not specified	Not specified	Not specified	100,000	≤+7	
6	≤5 Mg/m³				≤+10	
7	5>Cp≤10 Mg/m³				Cw≤0.5g/m³	
8					0.5<Cw≤5	
9					5<Cw≤0.5	
X	Cp>10				Cw>10	>5

Water Content of Ambient Air

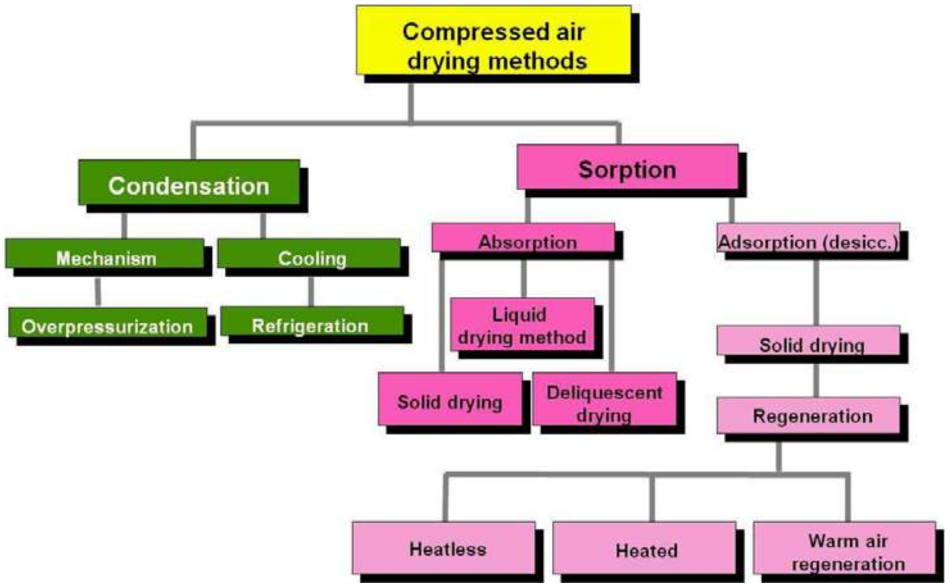
Dewpoint	g/m³	Dewpoint	g/m³
+100	588.208	+6	7.246
+90	417.935	+4	6.359
+80	290.017	+2	5.570
+70	196.213	+0	4.868
+60	129.020	-10	2.156
+50	82.257	-20	0.88
+40	50.672	-30	0.33
+30	30.078	-40	0.117
+20	17.148	-50	0.038
+10	9.356	-60	0.011
+8	8.342	-70	0.0033

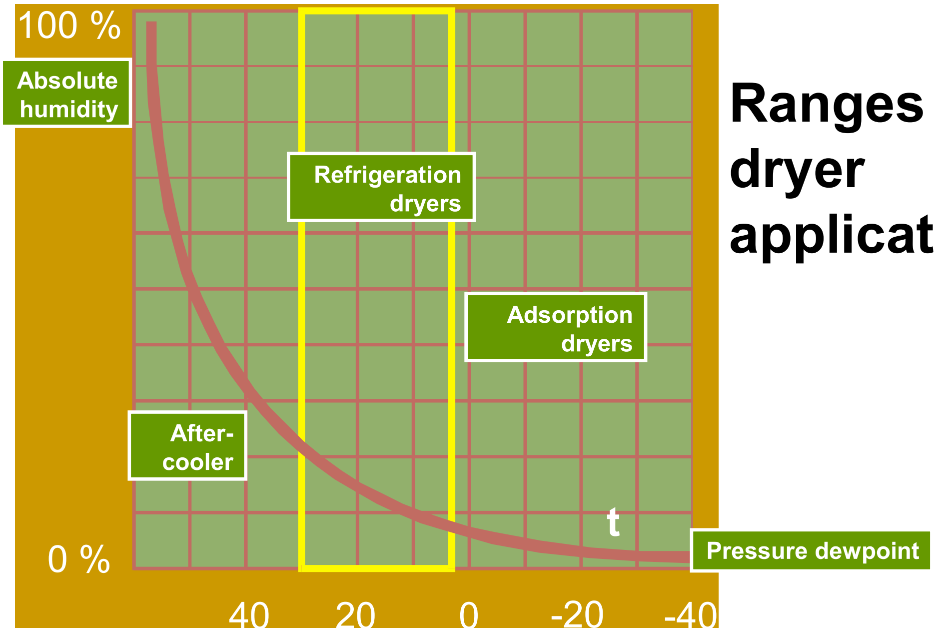
Pressure dewpoint - atmospheric dewpoint

Example:
Pressure dewpoint: 2-3 °C.
Working pressure: 7 bar
Atmospheric dewpoint: - 25 °C.



Compressed Air Drying





Ranges of dryer application

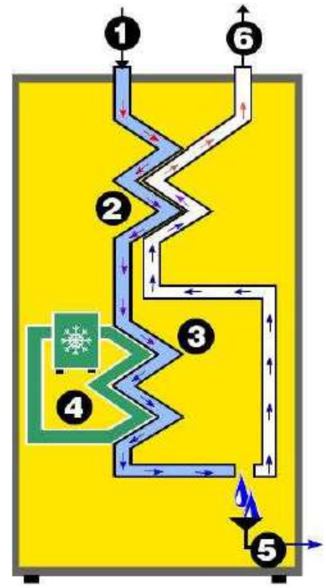
Additional Cost of Treatment

Pressure dewpoint, C	Dryer type	Filtration	Additional cost
+3	Refrigerant	General purpose	3%
-20	Waste heat regenerated	None	<1%
-40	Air regenerated	Pre & After	10-15%
-40	Heat regenerated	Pre & After	5-12%
-70	Air regenerated	Pre & After	15-21%

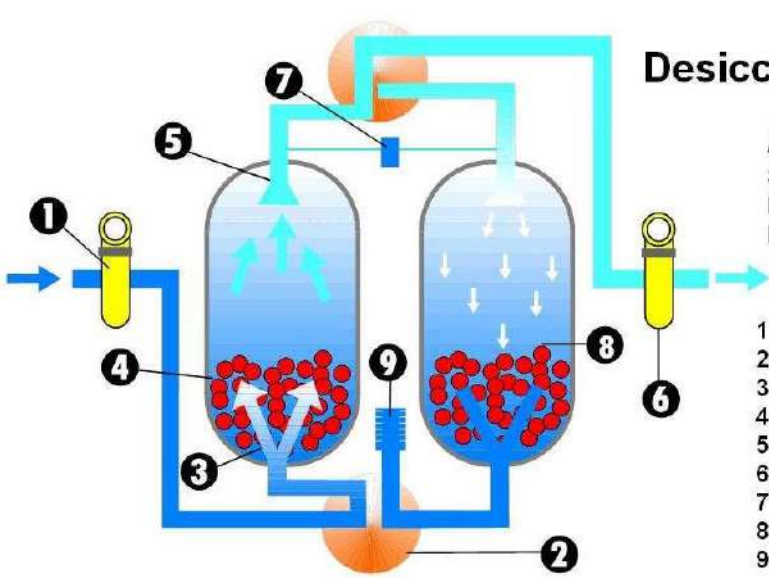
Incorrect sizing can significantly increase costs

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



Desiccant dryers



Desiccant drying - heatless

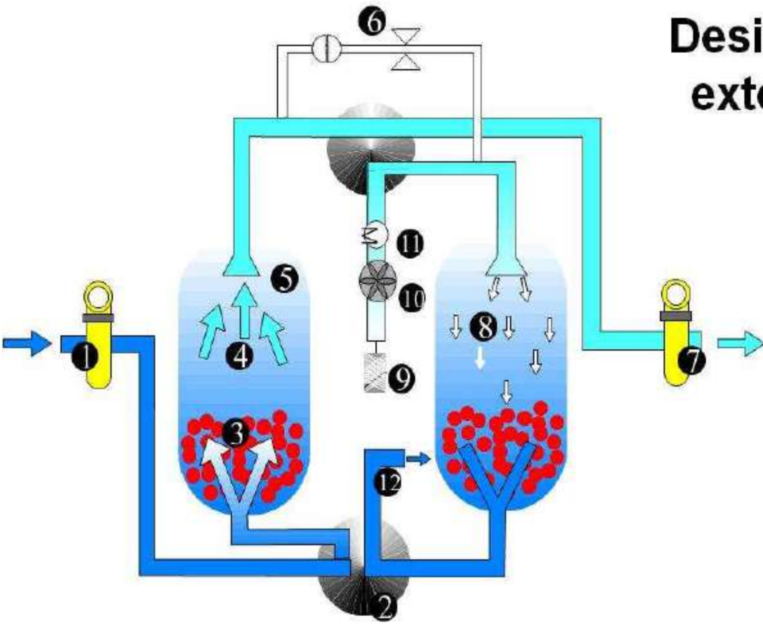
Application:

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

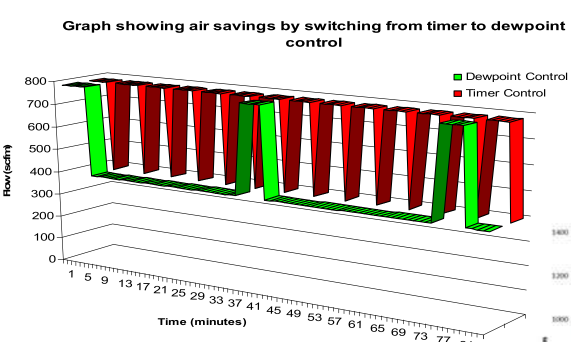
Compressed Air Systems

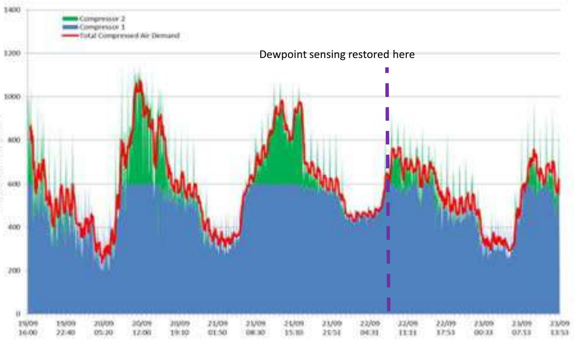
Desiccant drying - externally heated



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

Air dryers with dewpoint sensing control





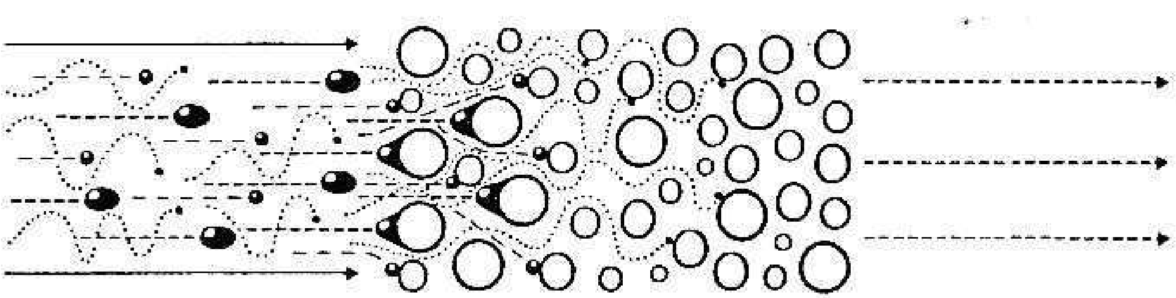
- Savings up to 70%
- Systems can often be retrofitted to existing dryers

Compressed Air Filters

Applying Filters

- Sized for demand side air quality and air flow
- Under-sized filters:
  1) High pressure drop
  2) Reduced air quality
  3) Possible filter damage
- Grossly over-sized: May reduced air quality

How does the microfilter work?



- - - - - - - - - Direct interception

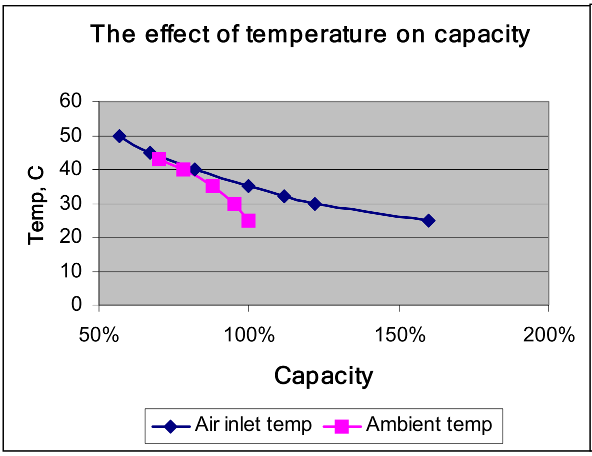
— — — — — — — — Impact

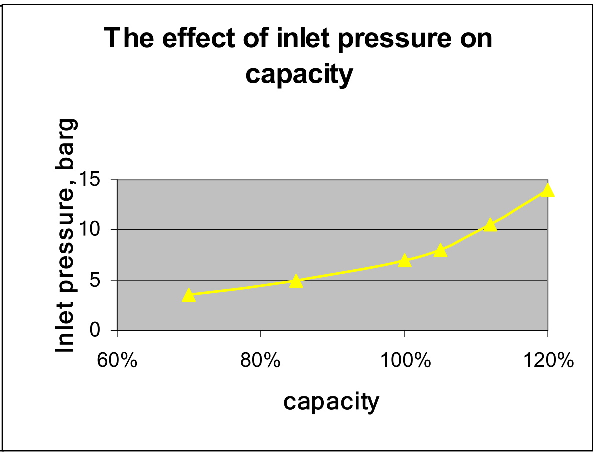
. . . . Diffusion /Coalescence

The effect of operating conditions

- Dryer capacities normally based on 7 barg 35C inlet temperature
- Low pressure or high temperature reduces capacity and can affect performance
- Filters are tested at specified inlet conditions (7 barg 20C inlet, 20C ambient)
- Manufacturers claims for ISO classification are based on specified conditions
- Change in conditions/performance may affect performance and ISO classification

The effect of conditions on capacity

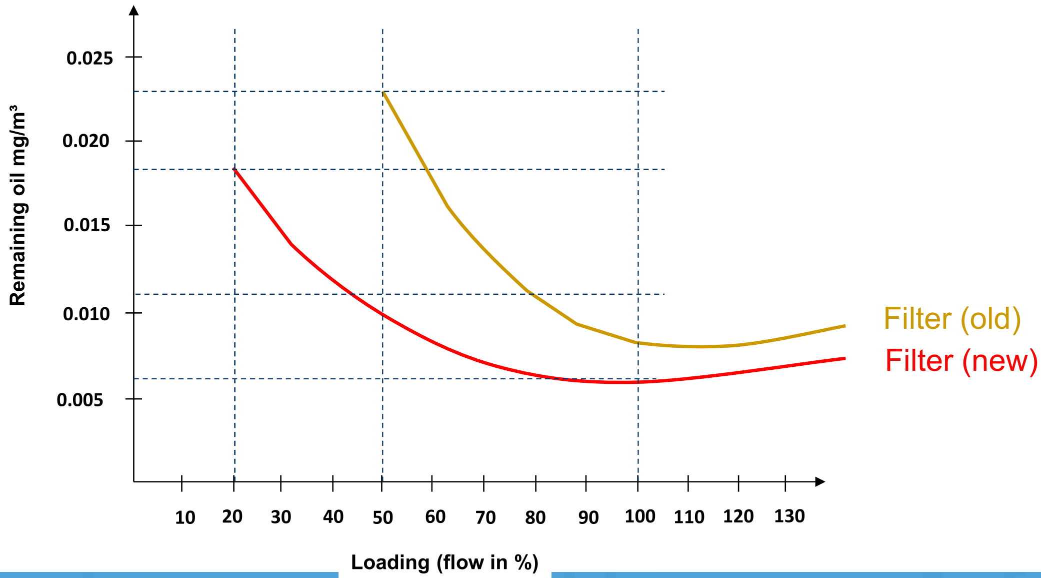




- **Multiply factors where several conditions vary**
- **Eg 100 cfm dryer at 7 barg, 35C, 25C ambient = 70 cfm at 6 barg, 40C inlet, 30C ambient**

Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Coalescing filter behaviour in the partial load range



Condensate drainage

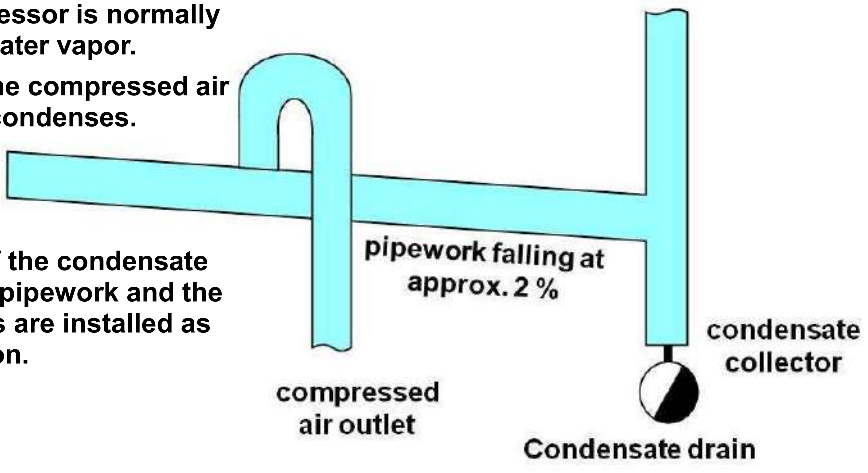
Reliable drainage must be ensured at all condensate collecting points of the air main

Condensate separation

The compressed air discharged from the aftercooler of a compressor is normally 100% saturated with water vapor.

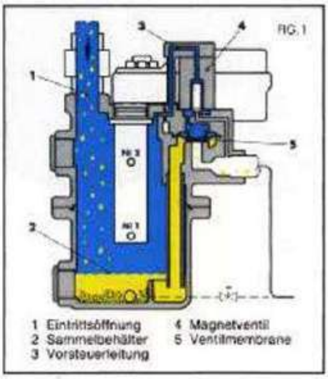
If the temperature of the compressed air falls, the water vapor condenses.

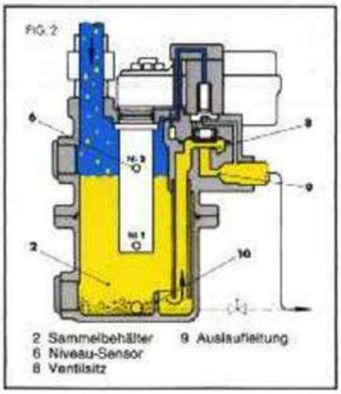
A coarse separation of the condensate can be achieved if the pipework and the compressed air outlets are installed as shown in the illustration.



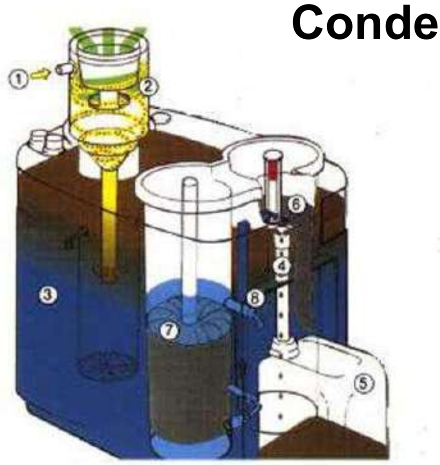
Condensate drains: Electronic level-sensing type

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





Condensate: Oil-Water separator



1 condensate inlet
2 expansion chamber
3 separating tank: gravitational separation
4 oil overflow drain
5 oil collector tank
6 prefilter: retention of solids
7 adsorption filter: retention of oil particles
8 water drain (clean water)

Used to separate condensate components

Compressed air installations

Receivers

<u>Purposes:</u>

- **Reduce compressor cycling**
- **Store air for periods of high demand**
- **Facilitate air/liquid separation**
- **Prevent oil and water migration downstream**
- **Dampen pulsations from piston compressors**

<u>Locations:</u>

- **After compressor and before dryer ("wet tank")**
- **After all air treatment ("dry tank")**
- **At points of use with high volume intermittent demand**
- **<u>Not</u> in the path of cooler exhaust**

Air Storage
Controlled and Uncontrolled

✓ Controlled Storage

- pressure / flow controls separate the demand side of the system from the supply side.
- pressure in the distribution system is maintained at a low pressure in order to minimize artificial demand
- provide a stable pressure regardless of air use or compressor control response.

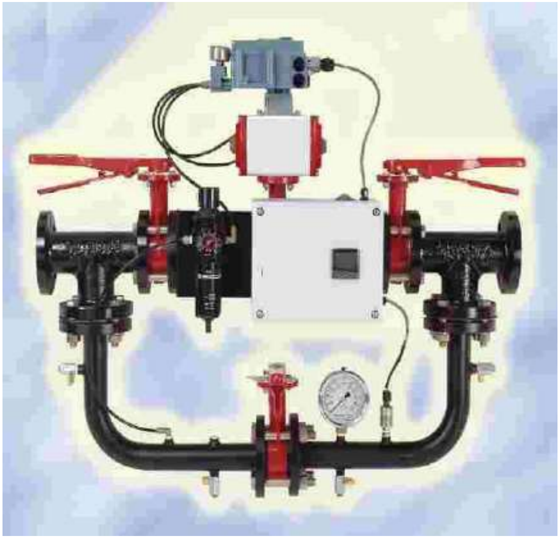
Air Storage
Controlled and Uncontrolled

✓ Uncontrolled Storage

- pressure throughout the plant rises and falls over the full control range of the compressors.
- plant air pressure can fall significantly below the lowest desired pressure because the compressor controls cannot react to changes in demand as quickly as they occur.
- artificial demand is introduced whenever the demand side pressure is above the lowest optimum pressure for the system.

Flow controllers

- Used to separate supply from demand
- Allows system pressure to be maintained at a very steady level – set to minimum
- Reduces/removes artificial demand



Air Storage & System Energy Balance – Key Points

1. Consistent, Stable, & Efficient Operation – Balance Supply & Demand.
2. System dynamics determine the nature of the compressed air demand profile.
3. Average air demand (compressors) – Peaks & valleys in demand (system).
4. Sources of supply – rotating capacity – rotating reserve – energy storage & stand-by compressors.
5. Rotating online capacity must be greater than average air demand.
6. Peak demand from storage – don't forget that refill of storage is an air demand.

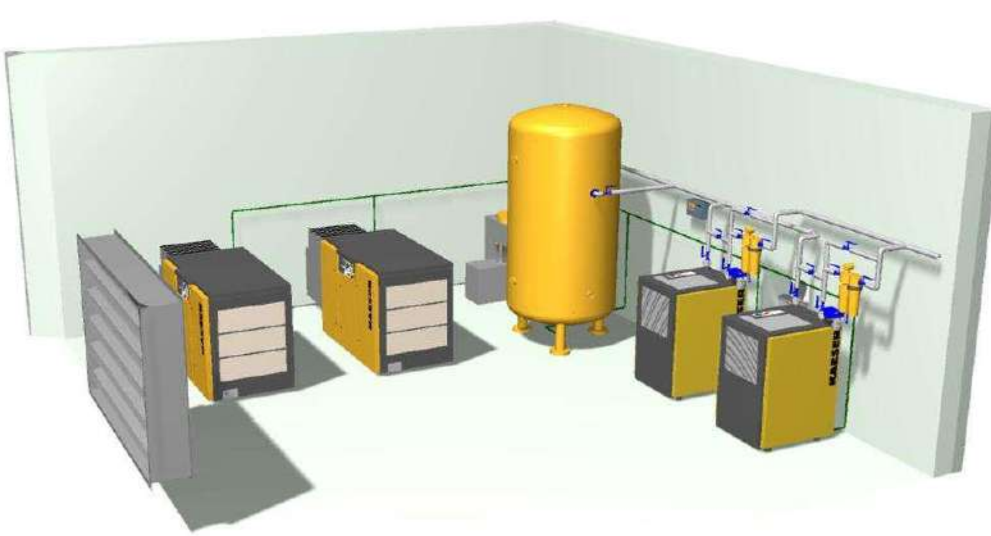
Air Storage & System Energy Balance – Key Points

7. Control Strategy – turn off unneeded compressors – run compressors at full load
8. Pick one machine for trim capacity (efficient at part load operating point).
9. Engineer storage to system applications avoid using rules of thumb.
10. Energy available from storage depends on volume and available pressure differential.
11. The unanticipated shutdown of an operating air compressor is often the largest event that will occur in a system.

Compressor Installation

- Compressor location affects performance
- Air quality and compressor reliability are directly impacted by the environment
- Avoid high dirt/dust areas
- Avoid areas with fumes that may react with or degrade compressor fluid or filters
- Allow space around the compressor for service access
- Maintain adequate lighting for service

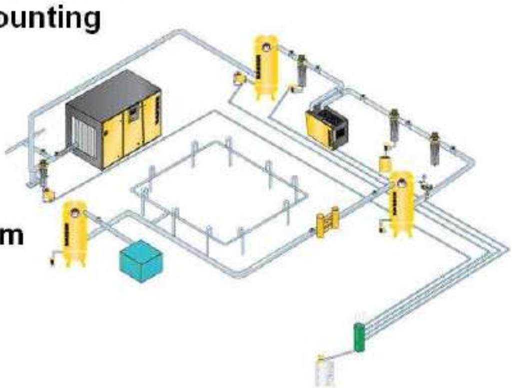
Ventilation Example



Compressed Air Distribution

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
- 6 meters per second in the main header
- 15 meters per second in the air drops

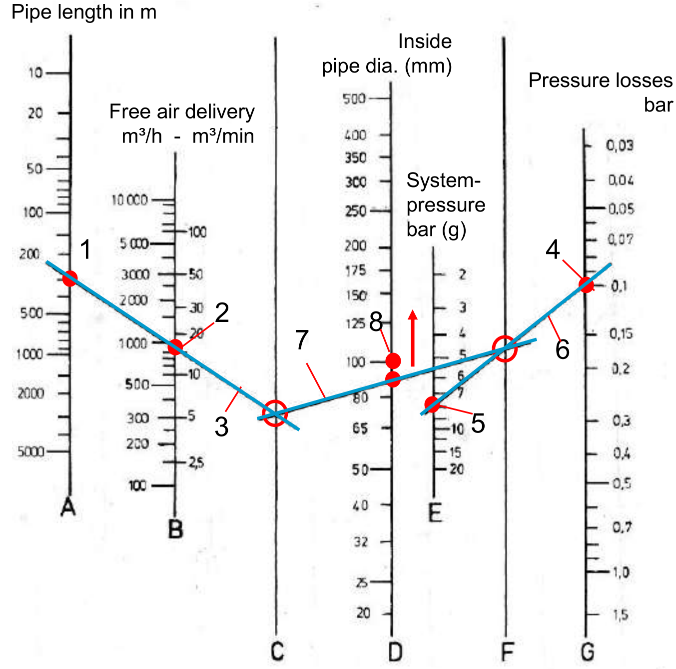
Compressed Air Distribution

Minimum diameters of pipes

FAD m^3/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	

Straight-line graph

for determining inside pipe diameter (steps 1 to 8)



Compressed Air Distribution

Applying Piping

Piping Key Points

<u>Choice of Material</u>

- **Ambient conditions**
- **Compressed air quality requirement**
- **Electrostatic charge**
- **Applicable regulations**
- **Costs**
- **Anticipated operational life**

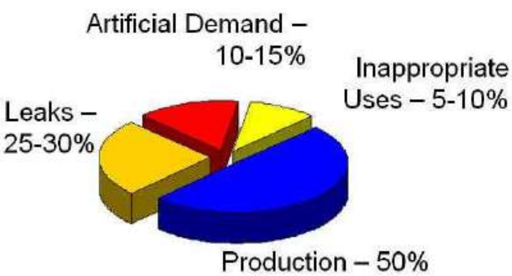
Optimisation opportunities

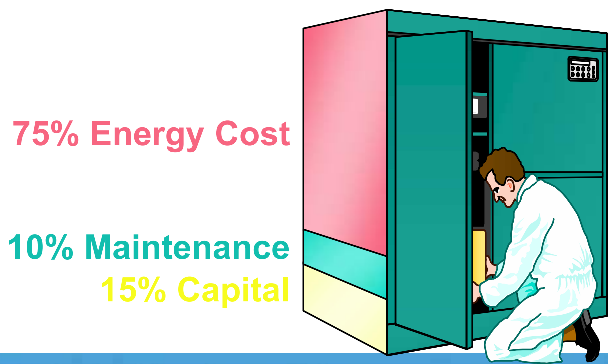
Optimizing compressed air systems includes:

- Evaluating energy requirements in factory.
- Matching system supply to these requirements
- Eliminating or reconfiguring inefficient uses and practices (sparging, open blowing, etc)
- Changing out or supplementing existing equipment to better match work requirements and increase operating efficiency

Optimisation and Waste Minimisation

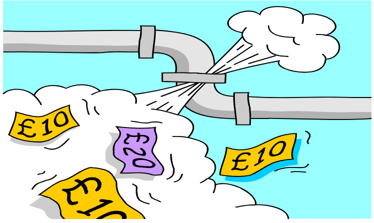
- Typically 10% of industrial electricity is used to produce compressed air
- Average saving = 30%
- 75% of lifetime cost of a compressor is energy usage
- Leaks, artificial demand and inappropriate uses can use as much as 50% of the air supply.
- Compressed air driven equipment costs around 10 times more to run than electric drive.





Main causes of waste

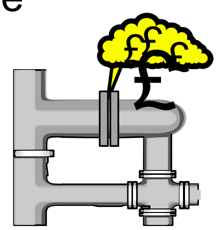
- ✓ Inefficient Generation & Treatment
  - Poor compressor control
  - Poor efficiency
  - Incorrect sizing
- ✓ Pressure drops in treatment and distribution systems
- ✓ Leaks
- ✓ Misuse of air - cooling, product ejection & ventilation
- ✓ Waste heat not recovered



Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Compressed air leaks

- Carry out a no load leak test
- Should not be more than 10% of the mean production demand in a normal factory
- Can be up to 20% for large sites, over 80% measured on occasion
- Leaks come back but seldom in the same place
- Regular ongoing leakage campaigns must be conducted



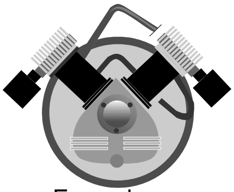
Measuring leakage losses

by exhausting an air receiver

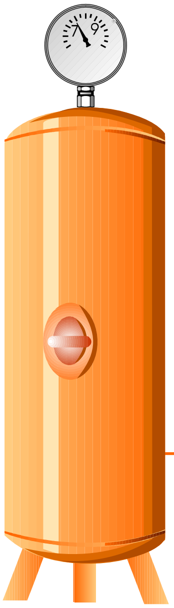
$$V_L = \frac{V_R \times (p_I - p_F)}{T}$$

V_L = Leakage volume
V_R = Receiver volume
p_I = Initial receiver pressure
p_F = Final receiver pressure
T = Measuring period

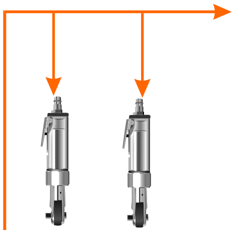
Feed pipe shut off



Example:
V_R = 500 l
p_I = 9 bar (g)
p_F = 7 bar (g)
T = 3 min



Leakage volume (tools not in use!)

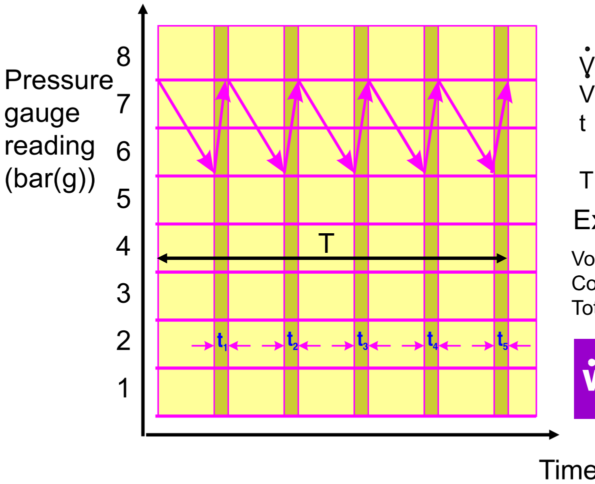


Leakage losses in the compressed air system: 333 l/min

$$V_L = \frac{500\ l \times (9 - 7)}{3\ min} = 333\ l/min$$

Measuring leak losses

by measuring loaded time of the compressor with end users shut off



$\dot{V}_L$ = Leakage volume in m^3/min

V_C = Compressor volumetric flow rate in m^3/min

t = Time units during which the compressor ran on load

T = Total time of the measurement procedure

Example:

Volumetric compressor flow rate	$\dot{V}$ =	3 m^3/min
Compressor time on load	$t = t_1+t_2+t_3+t_4+t_5$ =	120 sec
Total measurement time	T =	600 sec

$$\dot{V}_L = \frac{\dot{V}_C \times t}{T} \qquad \frac{3 \times 120}{600} = 0.6\ m^3/min = 20\%$$

Leakage losses

Hole diameter	Air consumption at 6 bar (g) m^3/min	Loss kW
1 mm	0.065	0.3
2 mm	0.240	1.7
4 mm	0.980	6.5
6 mm	2.120	12.0

At VND3000/kWh, a 4mm leak costs over VND170,820,000/year in power plus additional service on the compressed air equipment.

Leak Detection

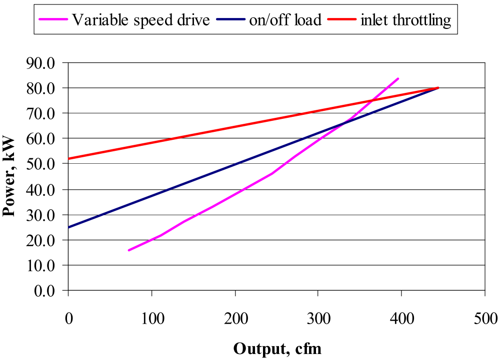
Many leaks can be heard, felt or seen.

Other techniques:

- ✓ **Using soapy water:**
  - **Tried and trusted, time consuming but sometimes the only way**
  - **Only suitable for small leaks**
- ✓ **Ultrasound**
  - **Very effective even in high background noise areas**

Control of compressors

- ✓ Only minimum required compressors should be on line
- ✓ How do your compressors control? – on/off, modulate, blow off
- ✓ Understand how they will interact with each other
- ✓ Consider a group control system
  - Minimise pressure band
- ✓ Auto shut down should be working to minimise long periods of no load running
- ✓ Can a variable speed drive machine be used?

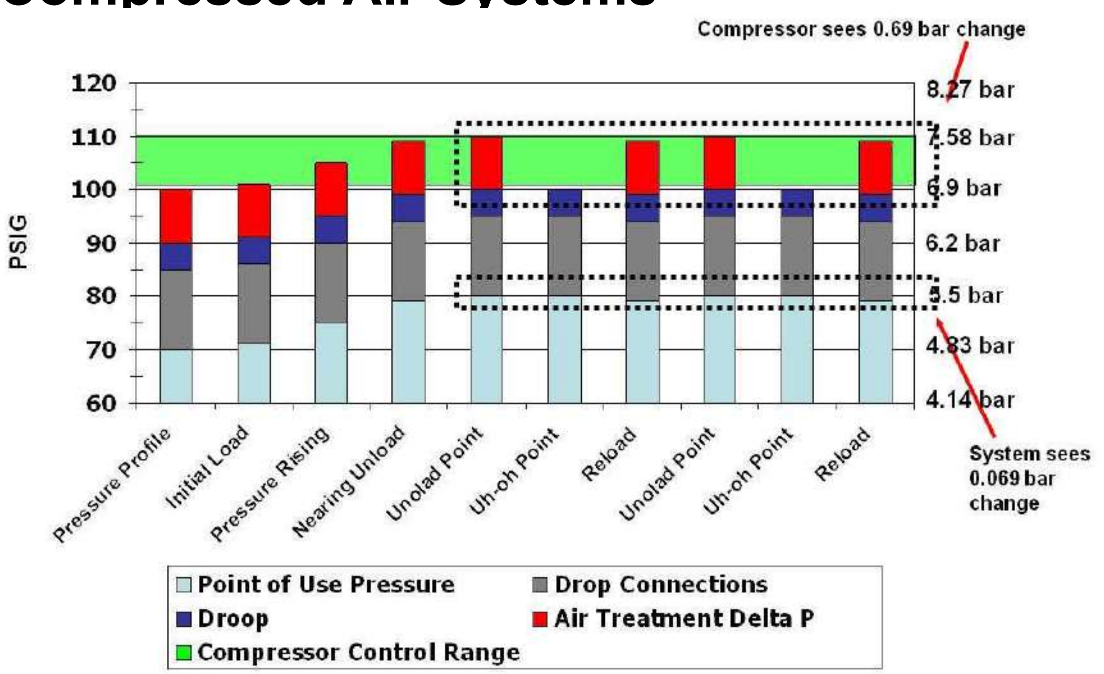


Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

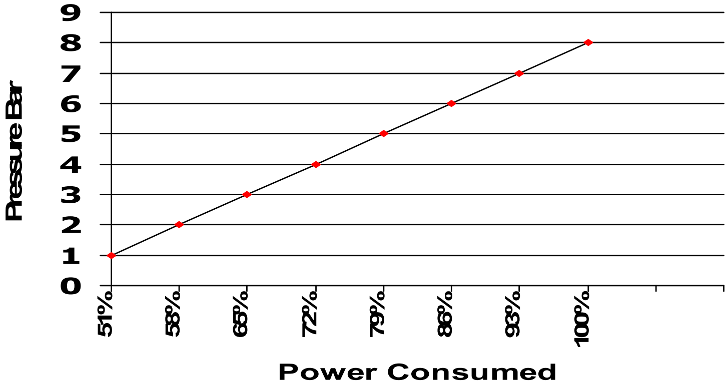
Pressure Profile
Key Point – Control Signals

1. Air compressor capacity controls react to pressure sensed by its control system.
2. As pressure decreases compressor air delivery will increase until its maximum output is being produced (VSD compressor).
3. As pressure increases compressor air delivery is reduced (VSD compressor).
4. Restrictions in the system such as air dryers and filters can impact compressor control.
5. Remote sensing or external sequencing of compressor controls can improve control response.
6. Over pressure protection should sense pressure within the compressor package.

Compressed Air Systems



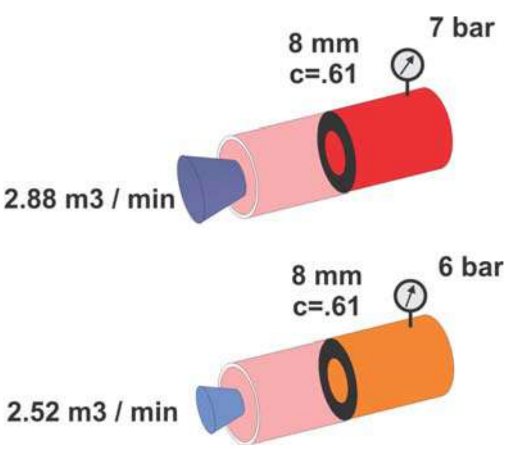
Reducing pressure - Reducing cost



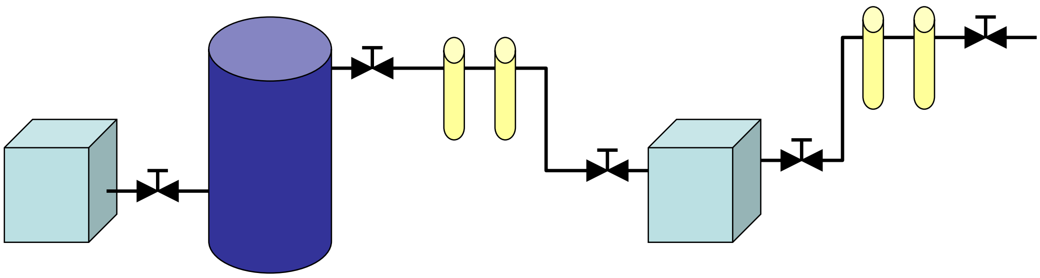
1 bar = reduction of 6-7% of full load power
1 bar = reduction of around 15% in artificial demand and other unregulated usage

Artificial demand

- ✓ Increasing pressure applied to a hole in the air system, increases the airflow through the air system.
- ✓ Leaks and unregulated air demands all have a potential component of artificial demand.
- ✓ Leak repair without pressure control is not fully effective.



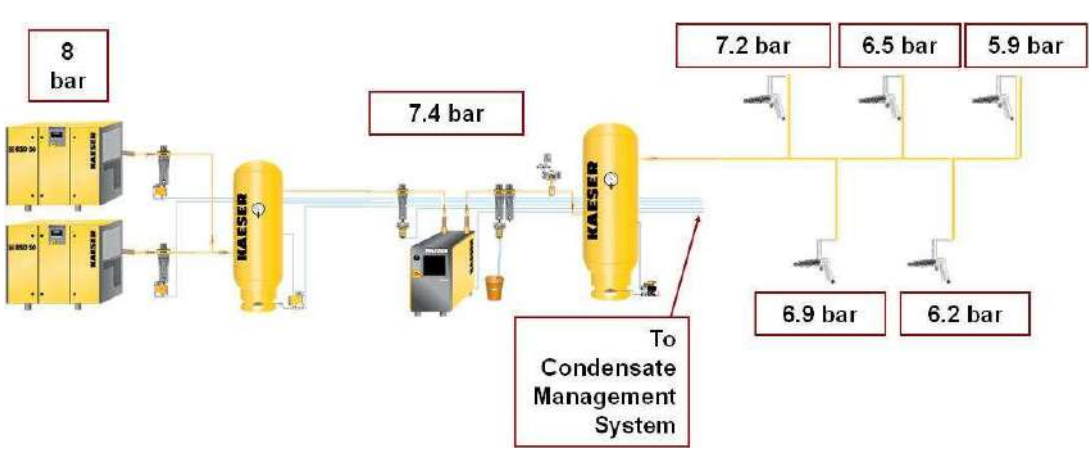
Pressure Drops in a Compressor House



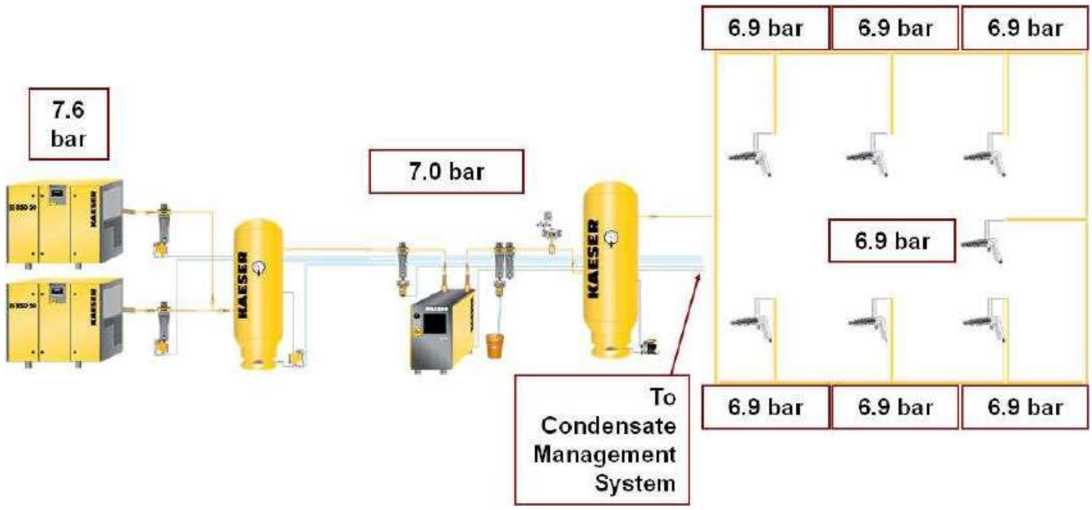
Undersized pipework
Restrictive valves
Dryer

Water separator
Prefilter
Afterfilters

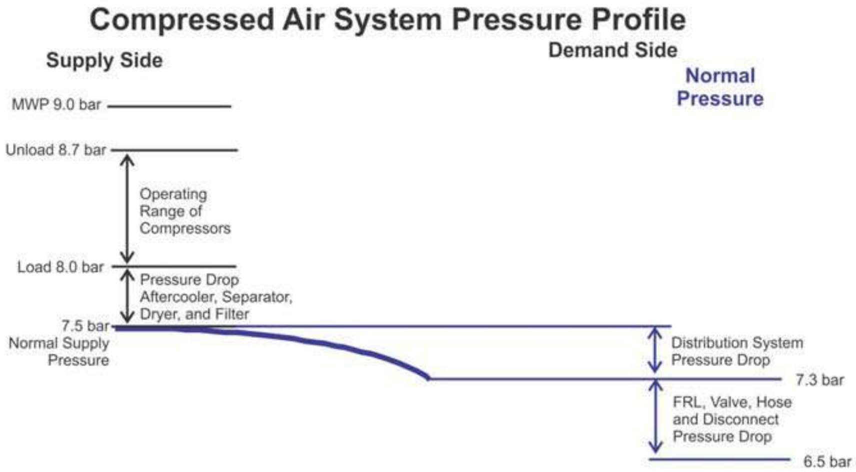
Pressure Drop in a Dead-End System



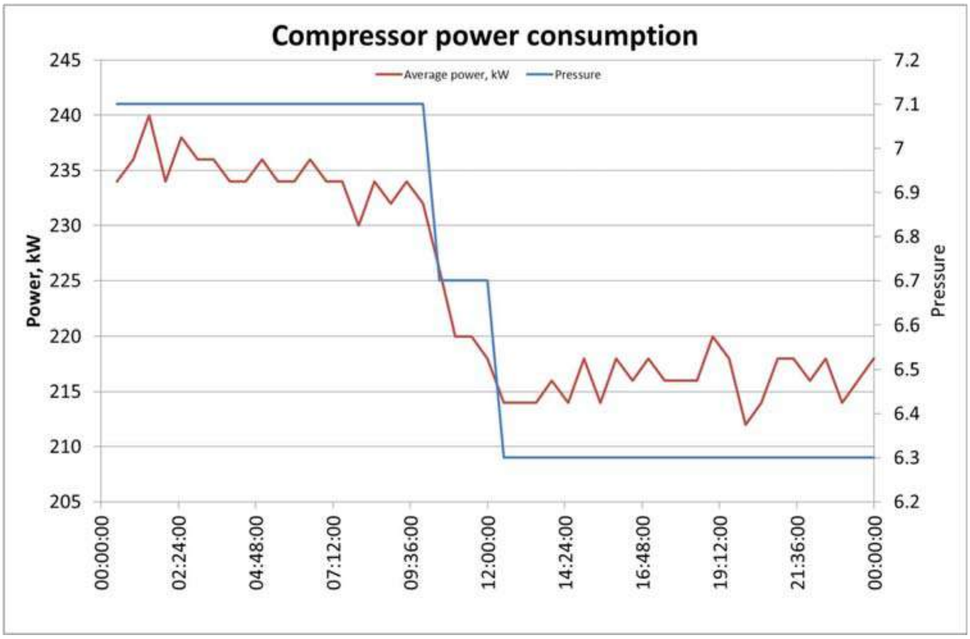
Pressure Drop in a Ring System



System Pressure Profile



Reducing pressure



Misuses of compressed air

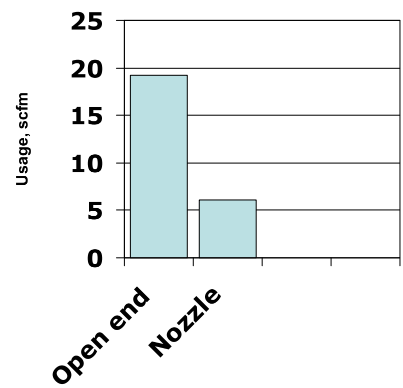
- ✓ Cleaning
- ✓ Component ejection
- ✓ Ventilation - cooling of people & products
- ✓ Agitation of paint or cleaning baths
- ✓ Moving product around bends or on conveyors
- ✓ Keeping product in line
- ✓ Using air at higher pressures than necessary
- ✓ Vacuum generation on large scale

Blowing

- Use air intensifying jets can save around 40% of the air at lower pressure
  - Quieter can overcome area noise issues
- Use air knives at reduced pressure
- Use fans
- Use low pressure blow guns
  - Safer and quieter

Air efficient nozzles

Copper pipe	19.2 scfm
Air efficient nozzle	<u>6.1 scfm</u>
Reduction	13.1 scfm



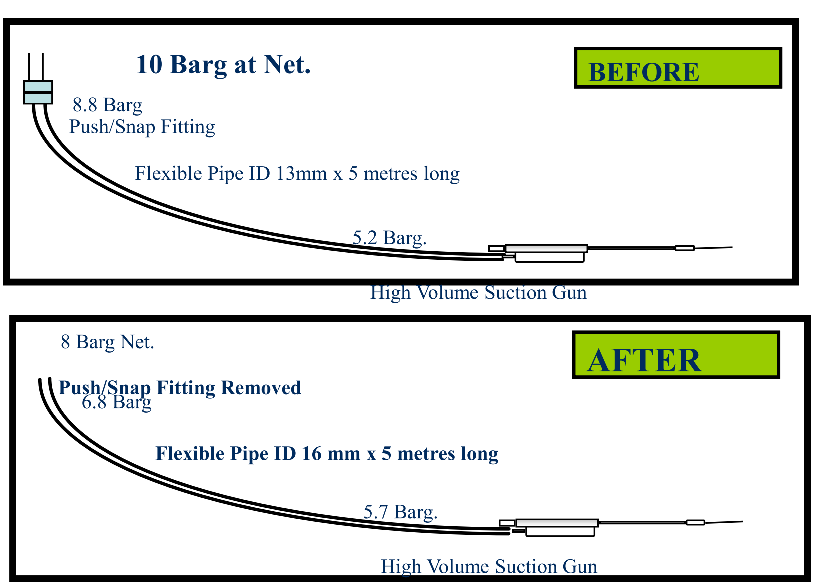
Specific energy = 0.122 kW/cfm
Energy saved = 1.6 kW/nozzle
Saving/nozzle = VND9,600,000per year
(based on 2000 hours/year)

Cost VND350,000-700,000 per nozzle
Payback < 2 months

Vacuum generation

- ✓ Use of air to create vacuum for processes:
  - Rule of thumb this should not exceed 10% of the mean air demand
  - Create local vacuum systems a vacuum pump typically uses 8% of a compressor motor input power
- ✓ Use efficient vacuum ejectors and shut off when not required
  - Multi stage
  - Check valves

Pressure reduction at the end user



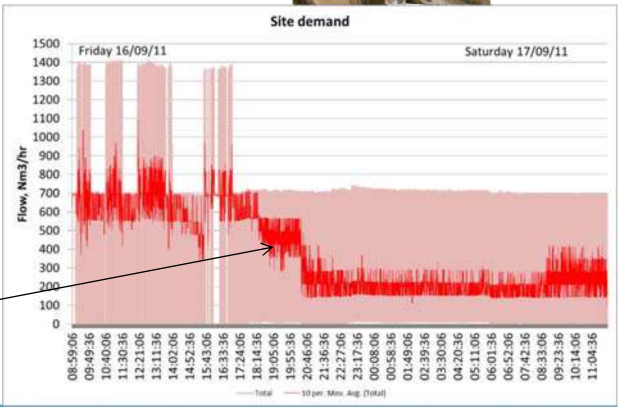
Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Machine isolation

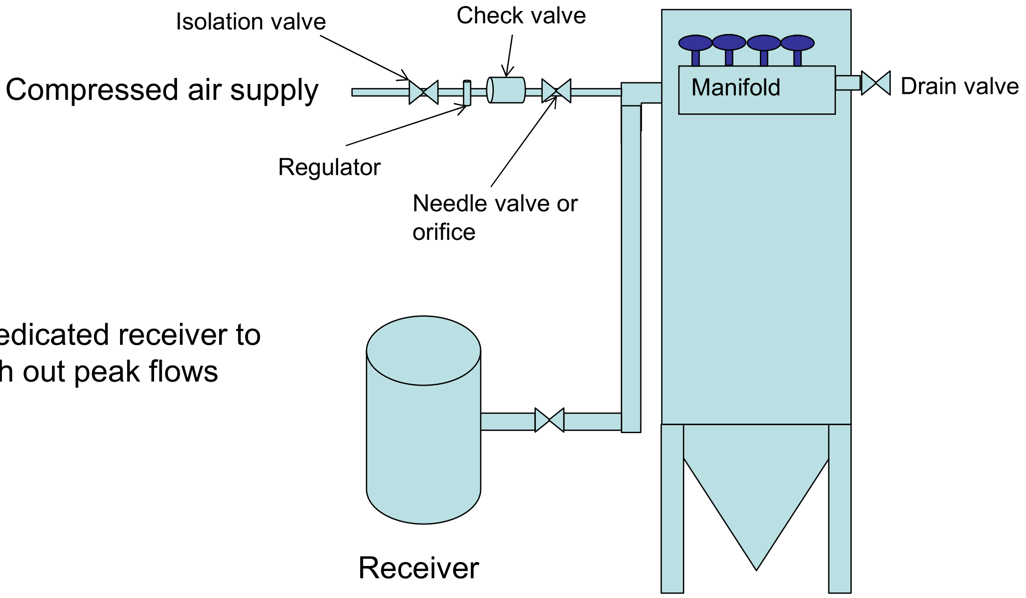
A machine operates 8 hours a day with the air on 24 hours for users elsewhere on site
Air consumption in use: 20 scfm
Air consumption when stopped: 8 scfm
Power consumed when stopped: 0.976 kW

Annual cost = 0.976*16*3000*365
= VND17,099,520 per year

Typical cost of ½" solenoid valve d1,700,000



Dust Extraction plants



Use dedicated receiver to smooth out peak flows

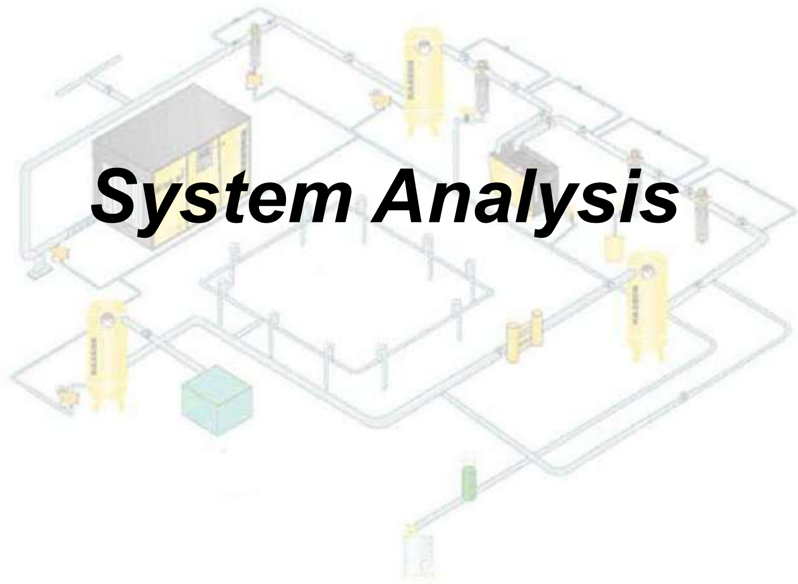
Review of compressed air basics

- ✓ Understanding compressed air
- ✓ Compressors
- ✓ Treatment & condensate
- ✓ Compressed air installations
  - Compressor houses
  - Receivers
  - Distribution
- ✓ Optimisation opportunities

NEXT SESSION – CARRYING OUT SURVEYS

Compressed Air Systems

System Analysis



Session 2

- The systems approach
- Calculating running costs
- Carrying our a survey
- Pressure profiling
- Demand profiling
- Assessing results
- Reporting and reviewing vendor bids

8. Compressed Air System Assessment

- The Systems Approach
  - A comprehensive system assessment examines the entire compressed air system, including:
    - Generation
    - Treatment
    - Storage
    - Distribution
    - Use and waste of compressed air

8. Compressed Air System Assessment

- The systems approach evaluates overall system performance rather than individual component efficiency.

- The system boundary includes energy input to the compressed air supply and treatment through the production equipment and work performed as a result of the energy input.

8. Compressed Air System Assessment

- 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

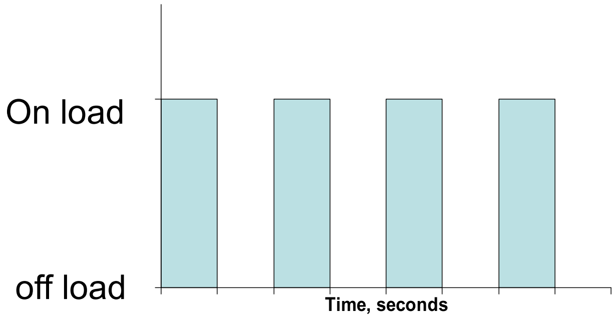
8. Compressed Air System Assessment

- 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.

No meters – How do you analyse a system?

- Use what you have
  - Hours run meters
  - Stopwatch
  - Installed gauges
  - Manufacturers data

No meters? - Calculating the demand



Average load = Time on load / Total cycle time

Repeat during non production time to estimate leakage
Isolate areas to split up base demand

May not allow you to size a new compressor but will help you understand the system

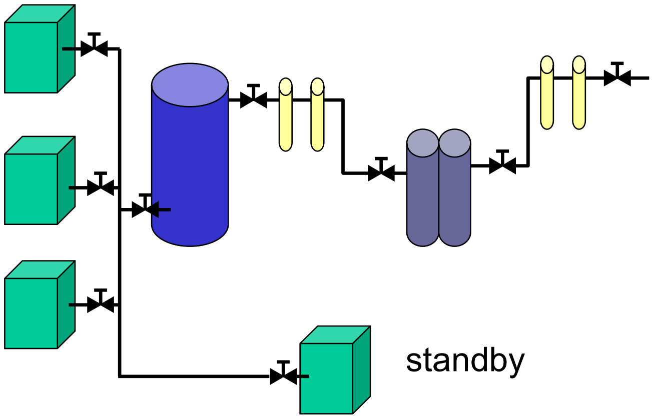
Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Calculating the demand

450 cfm, 75 kW base load

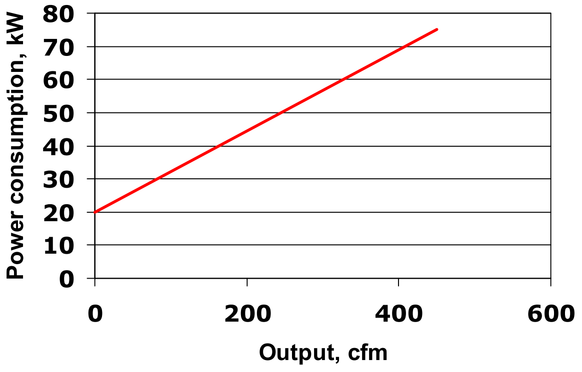
450 cfm, 75 kW base load

450 cfm, 75 kW on/off load



Calculating running costs

Typical screw compressor control characteristic



Full load = 75 kW, 450 cfm

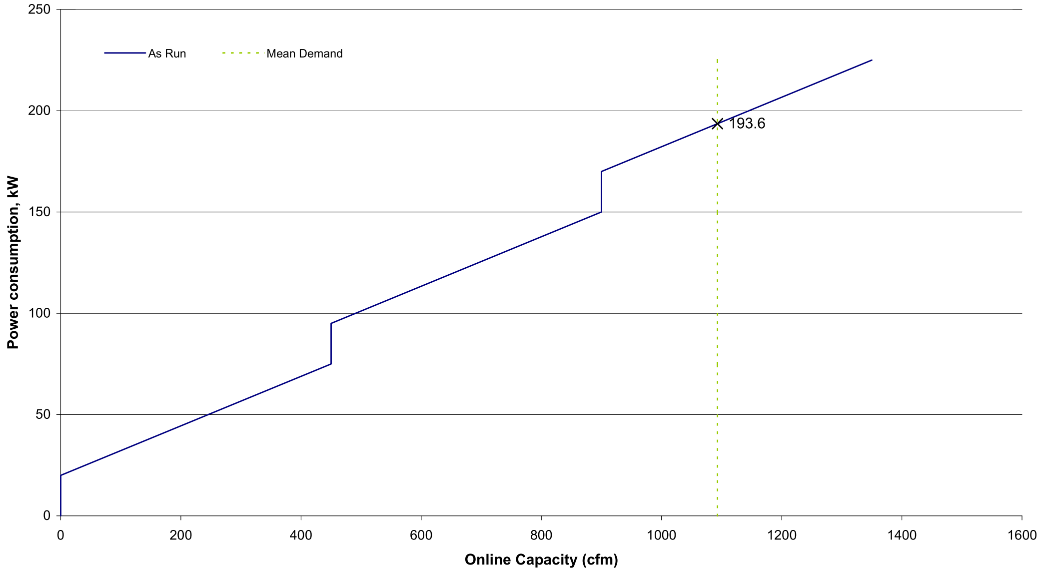
No load = 20 kW =26.66% of full load but 0 cfm

Timing calculation

Average time on load = 30 seconds
Average time off load = 40 seconds
Average loading = 30/70 = 43%

Demand = 450+450+(450*43%)
= 1094 cfm

Calculating generating costs



Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Demand Vs power consumption

3 off 75kW compressors

2 base load = 900 cfm, 150 kW
1 on/off load = 193 cfm, 43.6 kW

Output	450 cfm
Full load Power	75 kW
No load power	20 kW

Power = full load power + no load power
= 75*0.43 + 20*0.57
= 32.1 +11.4
= **43.6 kW**

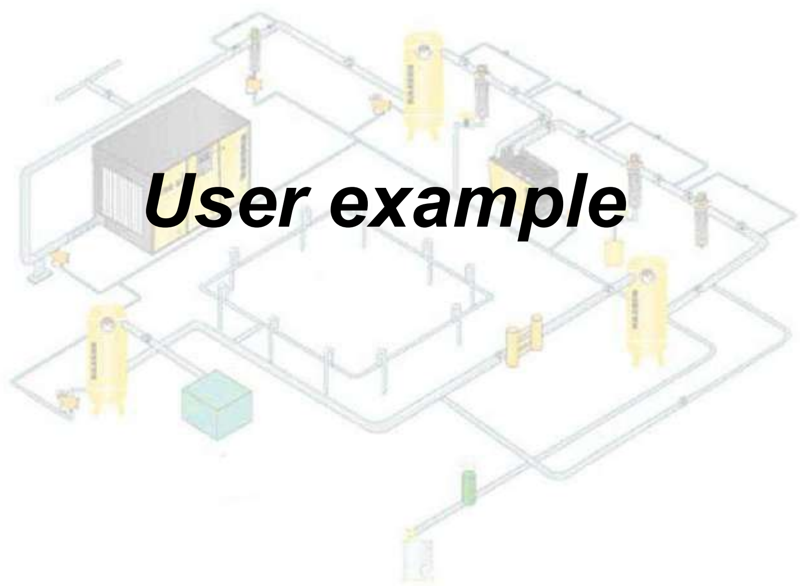
Total power consumption 193.6 kW

Total annual running cost

Production hours = 80 hours/week, 52 weeks/year

@ VND3000/kWh
Production cost = 193.6*80*52*3000 = VND2,416,128,000

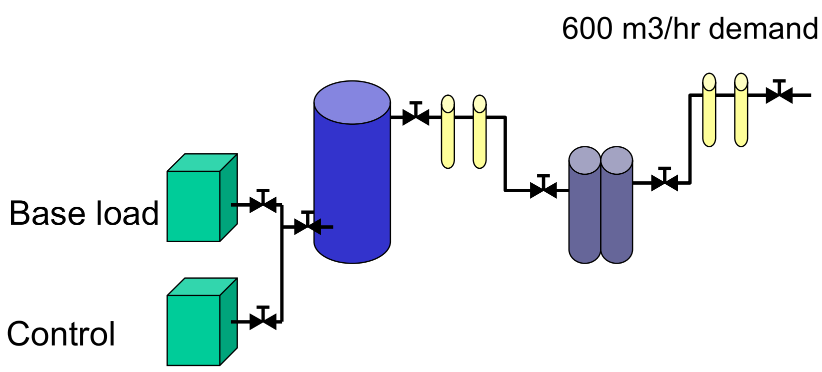
Compressed Air Systems



User example

Calculating the demand

Compressors:
400 m3/hr
50 kW on load
20% no load power



16 hours a day
5 days a week
50 weeks a year
Electricity cost – 3000d/kWh

What is the annual operating cost?

Total annual running cost

Hours = 16 x 5 x 50 = 4000 hours/year

Base load = 400m3/hr so, 50 kW x 4000hrs = 200,000kWh
= 200,000kWh x 3000 = **VND600,000,000**

Control = (600-400)/400 = 50% load, 50% no load
Full load = 50kW x 4000hrs x 50% = 100,000kWh
No load = 10kW x 4000hrs x 50% = 20,000kWh

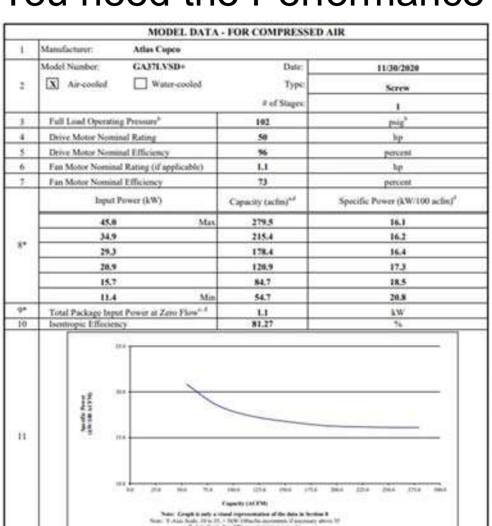
Total control = (100,000 x 3000) + (20,000 x 3000)
300,000,000 + 600,000 = **VND360,000,000**

Total compressor house = 600,000,000+ 360,000,000 = **VND960,000,000**

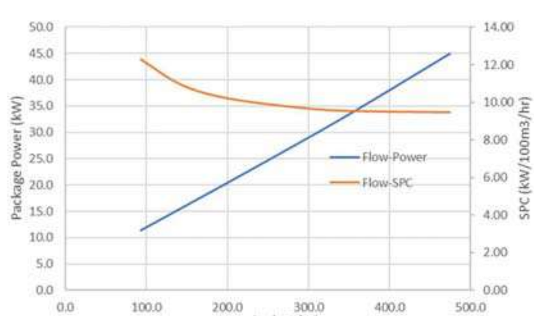
MINISTRY OF INDUSTRY AND TRADE · Global Gateway · UNIDO

What about VSD Machines?

You need the Performance Data – See CAGI datasheets



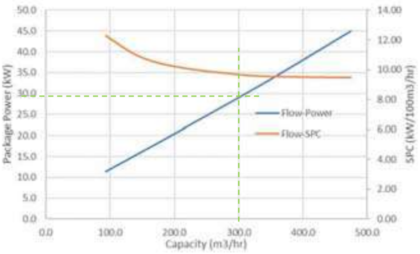
MODEL DATA - FOR COMPRESSED AIR			
1	Manufacturer: Atlas Copco		
2	Model Number: GA37LVSD+ [X] Air-cooled [ ] Water-cooled	Date:	11/30/2020
		Type:	Screw
		# of Stages:	1
3	Full Load Operating Pressure	102	psig
4	Drive Motor Nominal Rating	50	hp
5	Drive Motor Nominal Efficiency	96	percent
6	Fan Motor Nominal Rating (if applicable)	1.1	hp
7	Fan Motor Nominal Efficiency	73	percent
8*	Input Power (kW)	Capacity (acfm)	Specific Power (kW/100 acfm)
	45.0 Max	279.5	16.1
	34.9	215.4	16.2
	29.3	178.4	16.4
	20.9	120.9	17.3
	15.7	84.7	18.5
	11.4 Min	54.7	20.8
9*	Total Package Input Power at Zero Flow	1.1	kW
10	Isentropic Efficiency	81.27	%
11			



Can select power manually from data or use linear interpolation in excel (can provide template for modification)

What about VSD Machines?

Demand is 600m3/hr using 2 equally sized machines



Each machine delivers 600/2 = 300m3/hr

Power required at 300m3/hr = ~29kW

Total Power = 2 x 29kW = 58kW

58kW x 4,000hrs = 232,000kWh

276,000kWh x 3,000VND = **696,000,000VND**

Compressed Air Systems

Where do you start?

- Ask questions
- Take notes
- Walk around
- Take notes
- Take pictures

Compressed air audits – Initial Questions

- How many hours each week is the system pressurised?
- What is the minimum pressure allowed in the plant?
- What air quality is needed?
- What is the base demand?

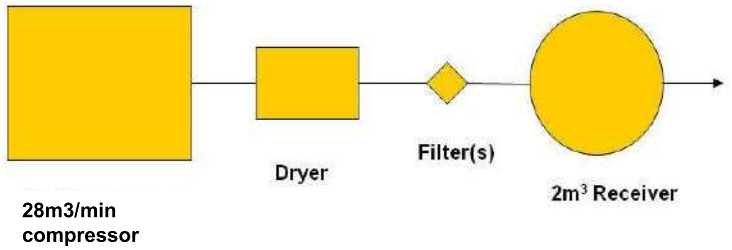
What to look out for in the compressor room

- Type, make, capacity, hours run and control of each compressor
- Type make and configuration of treatment package
- Room ventilation, inlets in or outside
- Is waste heat recovered?
- Generation pressure & pressure drop over treatment system
- Is there a group controller?
- What is running and estimated demand?
- Are the feeding mains OK are there any other bottlenecks?
- Are there electronic zero loss condensate traps?

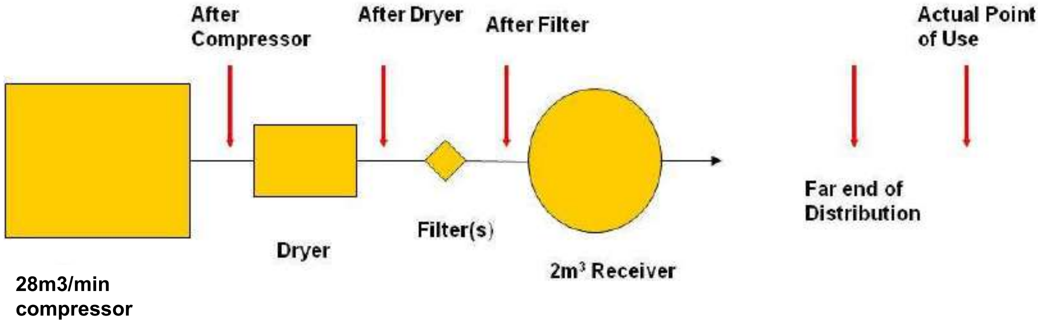
What to look out for in the factory

- Air leaks
- Main uses of air such as tools, painting, instrumentation or process
- Misuses such as open ended lances, full pressure blow guns, product ejection and vacuum venturis
- End of line pressure
- Ring or spur mains?

Start with a block diagram



Identify possible measurement points



Compressed Air Systems

Remote pressure monitor.

Pipe rope instead of pipe dope.

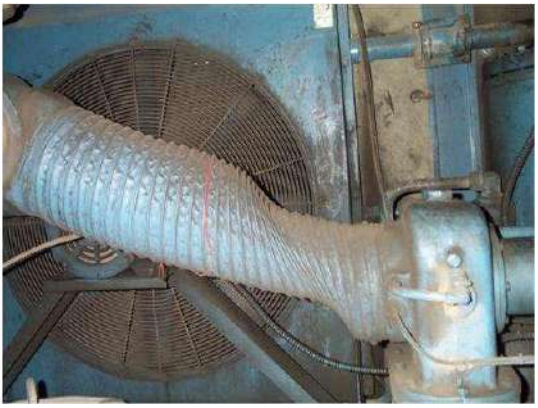
If you see something unusual, ask about it.

Compressed Air Systems

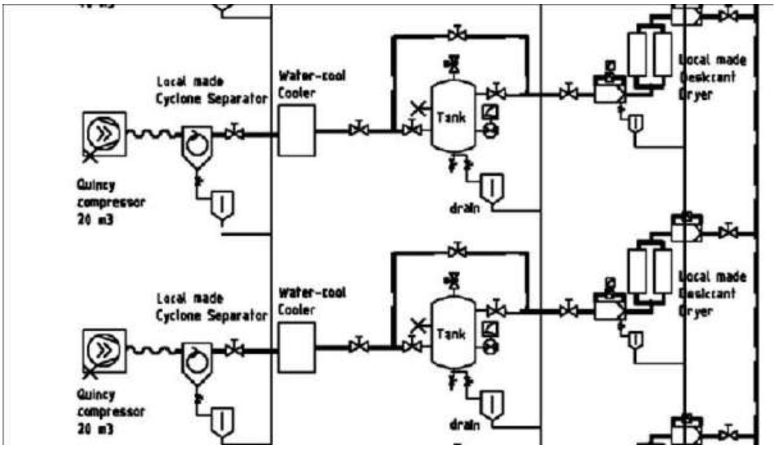
Note bad connection practices. Take pictures.

Compressed Air Systems

If a gauge reading does not look right, find out why. Instead of inlet valve modulation, you may find inlet hose modulation.



Use drawings to check installation



1) Compressor
2) Liquid separator
3) Trim cooler
4) Receiver w/drain
5) Pre-filter w/drain
6) Desiccant dryer
7) Post-filter

- The walk-through is complete.
- Interviews have been conducted.
- Notes taken.
- Pictures taken.
- Drawings corrected.
- What next?

- **Sit down and think!**
- **Work from the point of use back to the compressor.**
- **Determine the true demand requirements.**
- **Develop information goals needed to analyze the system.**
- **Develop a measurement plan required to acquire that information.**

9. Data Collection & Analysis

- Collect demand data to establish the dynamics of the system.
- Identify events and their impact on the system.
- Identify cycle times and duration of these events.
- Identify periods of system draw-down.

9. Data Collection & Analysis

- What is worse than having no information about system performance?
- **Having bad information about system performance.**

- Many factors impact the accuracy of measured performance data.

  - Sample Rate
  - Data Interval
  - Accuracy
  - Repeatability
  - Electrical signals
  - Interference and errors
  - Equipment set –up
  - Scaling of engineering units

9. Data Collection & Analysis

Hourly Trend Data – Hourly trend data can be used to develop the profile of compressor power, or flow data to calculate operating cost. Trend data will not, however, define dynamic performance.

	Method #1	**Method #2**
Sample Rate	T = 5 minutes	T = 1 second
Samples to Average	n = 12 samples	n = 3600 samples
Data Interval	60 minutes (1 hour)	3600 seconds (1 hour)

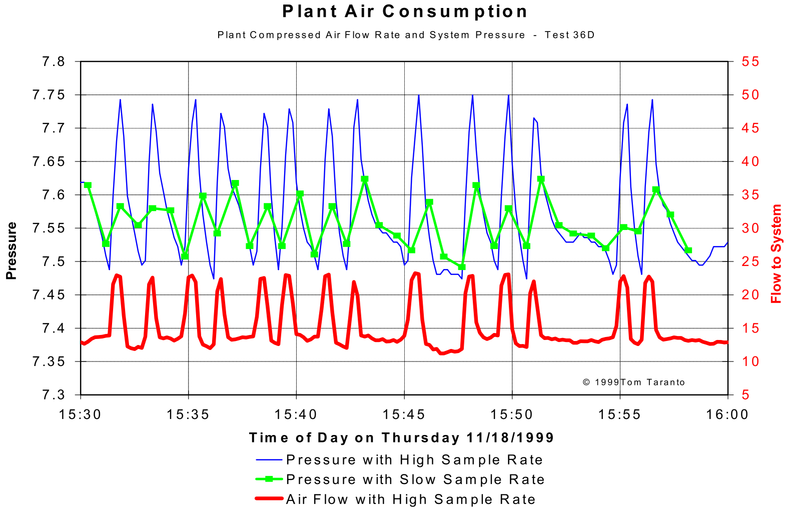
9. Data Collection & Analysis

<u>Dynamic Response</u> – When system events are of short duration, the data interval must decrease to properly characterize performance.

	High Rate	Slow Rate
Sample Rate	1 sample per 1 second	1 sample per 3 seconds
Data Averaging	10 samples	15 samples
Data Interval	10 seconds	45 seconds

9. Data Collection & Analysis

Data shown for the high sample rate is reading pressure once per second and averaging 10 samples. The low sample rate is reading pressure every 3 seconds and averaging 15 samples.



9. Data Collection & Analysis

- Key Points
  - 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.
  - Sample rate, data averaging, and data intervals depend on system characteristics.
  - Use appropriate sensors, transducers, and measurement system accuracy.
  - Transducers output various signals in proportion to the physical parameter being measured.
  - Signals must be properly scaled to correctly record the measurement.

8. Compressed Air System Assessment

- Analysis of Data –
  - Is it reasonable and correct?
  - Consistent with established assessment goals?
  - Create various profiles
  - Estimate energy savings
  - Suggest multiple measures to improve reliability and produce sustainable savings

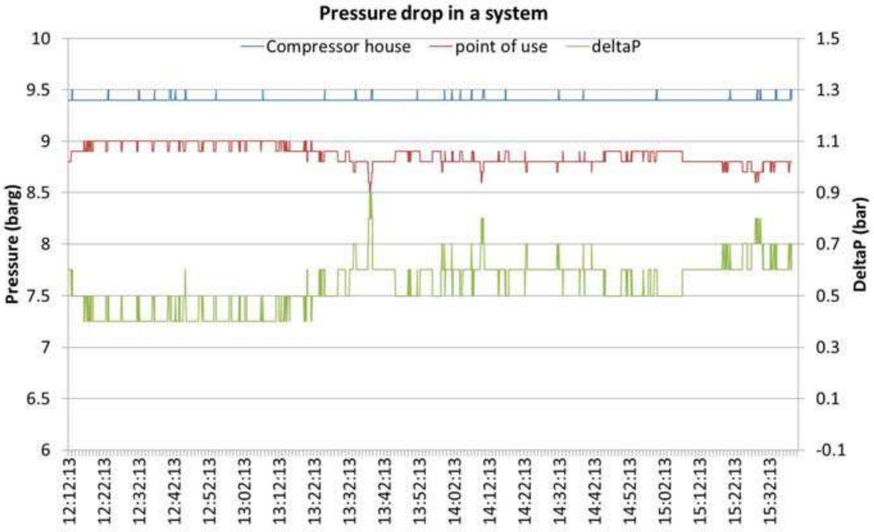
Compressed Air Systems

– **<u>Pressure profile</u>**
– **Demand profile**
– **High volume intermittent demand events**
– **Perceived high pressure demands**
– **Power consumption**
– **Production levels**

Typical pressure measurement locations

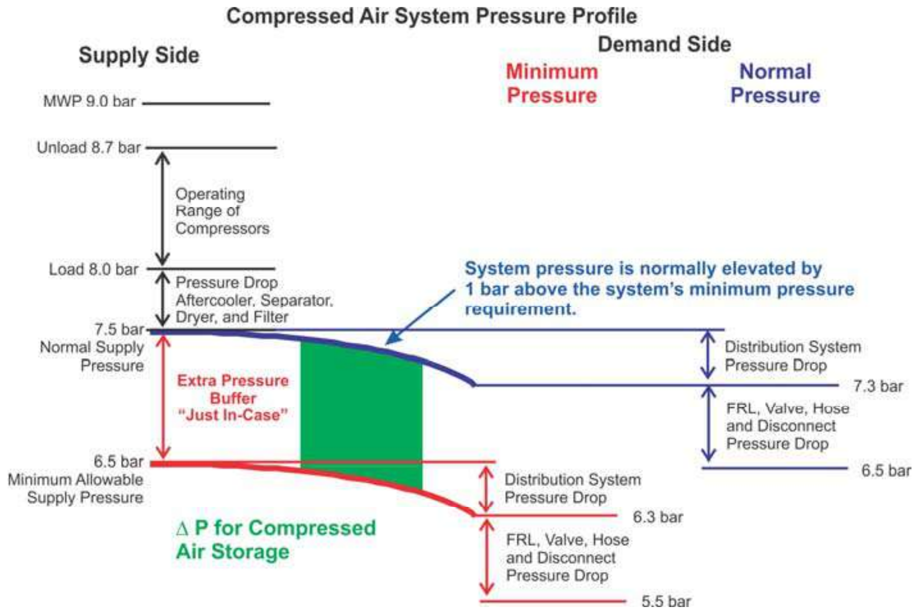
- Compressor maximum working pressure (MWP)
- Compressor control range
- Treatment equipment pressure drop
- Pressure differential reserved for primary storage
- Supply header pressure to the system
- Distribution header pressure in one or more demand side locations
- Point of use connection pressure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

System pressure drop



- High differential pressure
- Undersized mains

System Pressure Profile



Compressed Air Systems

- Pressure profile
- <u>Demand profile</u>
- High volume intermittent demand events
- Perceived high pressure demands
- Power consumption
- Production levels

Compressed Air Systems

What do you measure to determine a demand profile?

- Flow in the pipe
- Inlet vacuum on modulating machines
- Load cycles on load/unload machines
- Airend speed on variable speed machines
- Inlet air flow
- Power

9. Data Collection & Analysis

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

Compressed Air Systems

What do you measure to determine a demand profile?

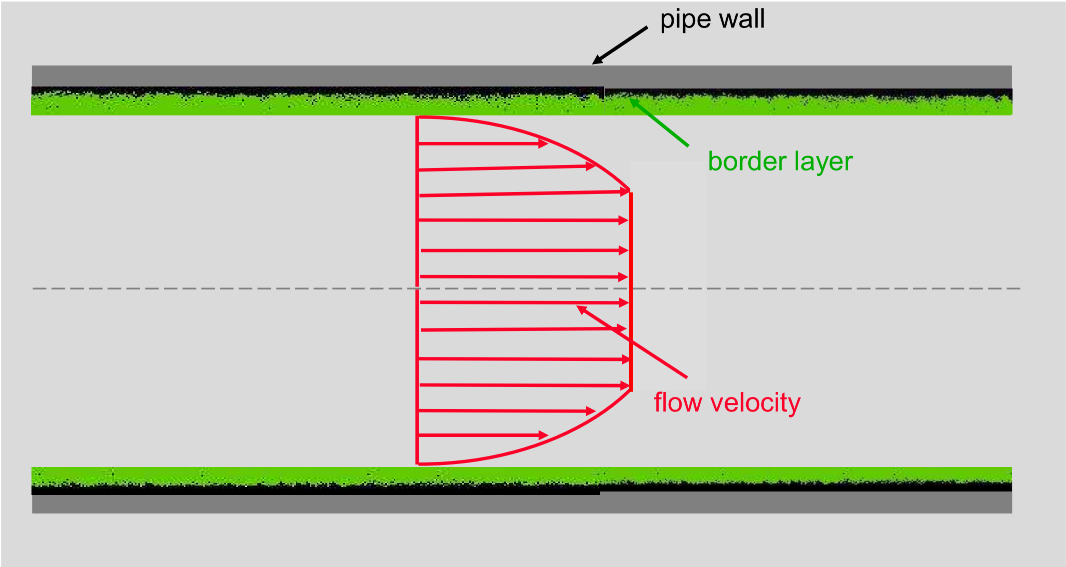
- **Flow in the pipe**

Flowmetering

- Important to measure pressure
- Demand or flow?
- Flowmeters don't always give a correct compressor capacity

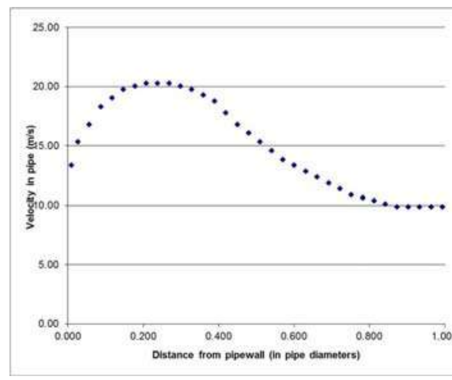
MINISTRY OF INDUSTRY AND TRADE · Global Gateway · Funded by the European Union · UNIDO

Flow profile

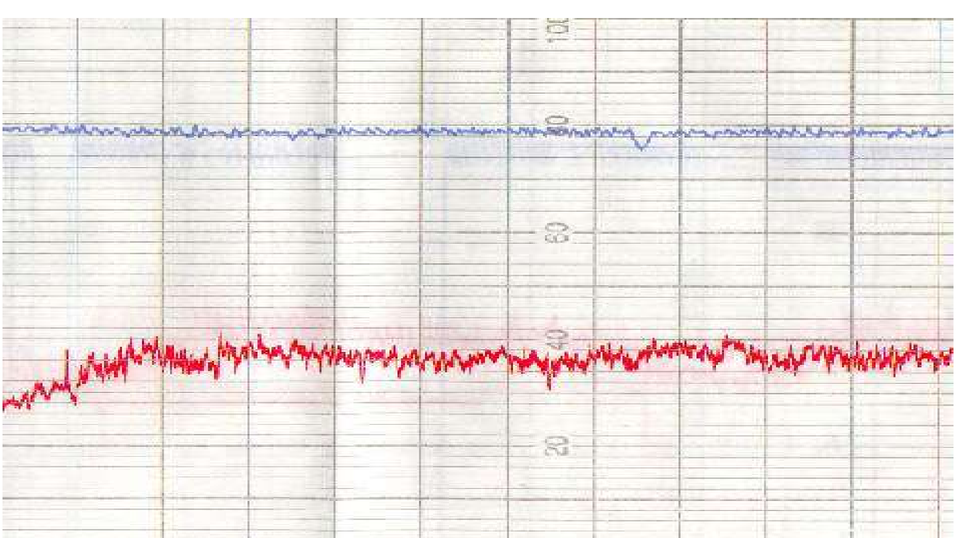


Flowmetering

- ✓ Installation dependent
- ✓ Flow profile variations affect accuracy
- ✓ Poor position = poor accuracy



Flowmetering – demand or flow?



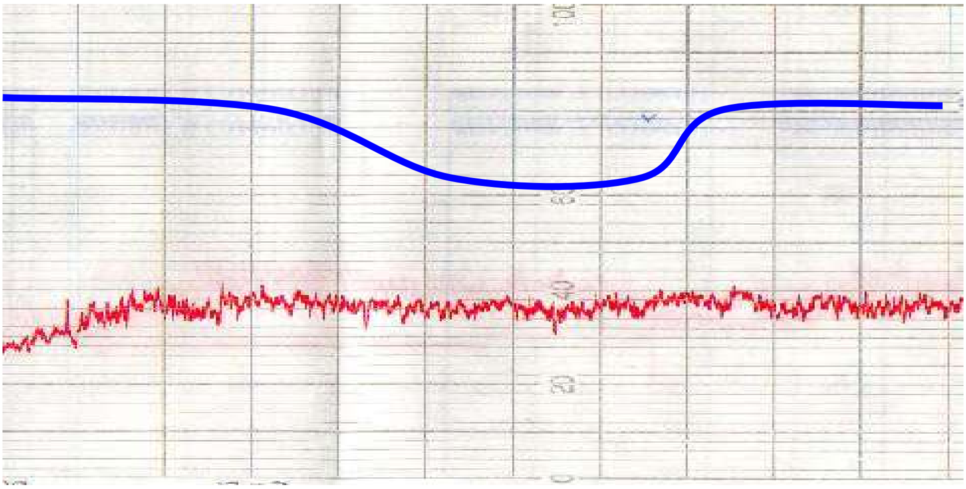
Pressure

Flow

Pressure held well therefore measured flow = demand

Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Flowmetering – demand or flow?



Pressure

Flow

Pressure drops

Flow stays steady – compressors running flat out

Measured flow is less than site demand

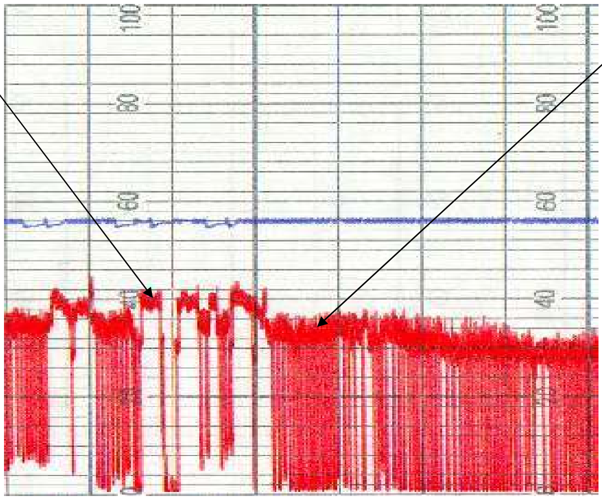
Flowmetering – compressor capacity

Compressor fully loaded for longer periods flowmeter reads over 40

Compressor cycling on and off load flowmeter reads up to 36

Pressure

Flow



Receiver damping flow changes

Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Metering – inlet conditions & flowreadings

- Flow meter readings normally given at set conditions eg scfm, Nm^3/hr:
  - Standard – 1013 mbarA, 15C, 0%RH
  - Normal – 1013 mbarA, 0C, 0%RH
- Compressor outputs usually free air delivered at 1000 mbarA, 20C, 0%RH for screw compressors, different for centrifugal
- Corrections required between the two sets of data (can be over 15% difference)

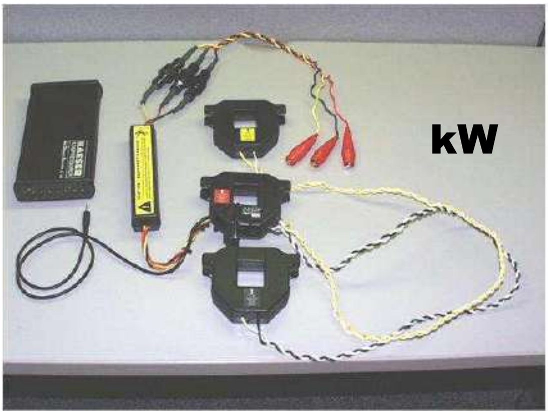
The effect of inlet conditions

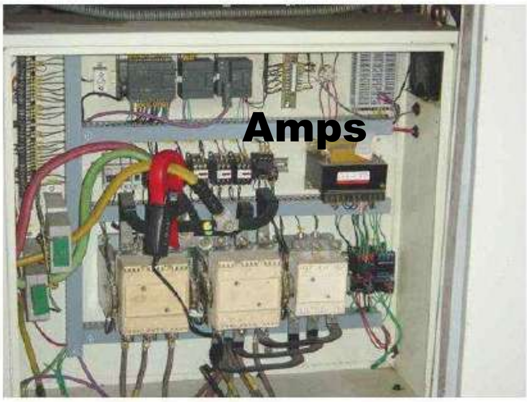
Inlet conditions	FAD	Nm^3/hr	Scfm	Comments
1000 mbarA, 20C, 60%RH	1000 m^3/hr 589 cfm	915 Nm^3/hr 91.5%	568 scfm 96.4%	Cool Vietnam
980 mbarA, 35C, 70%RH	**1000** m^3/hr 589 cfm	**845** Nm^3/hr **84.5%**	525 scfm 89.1%	Warm Vietnam
780 mbarA, 35C, 80%RH	1000 m^3/hr 589 cfm	670 Nm^3/hr 67%	416 scfm 70.6%	Mexico City

A 1000 m^3/hr compressor will only deliver 845 Nm^3/hr at certain conditions
You need to know the inlet conditions to know if the compressor is performing correctly

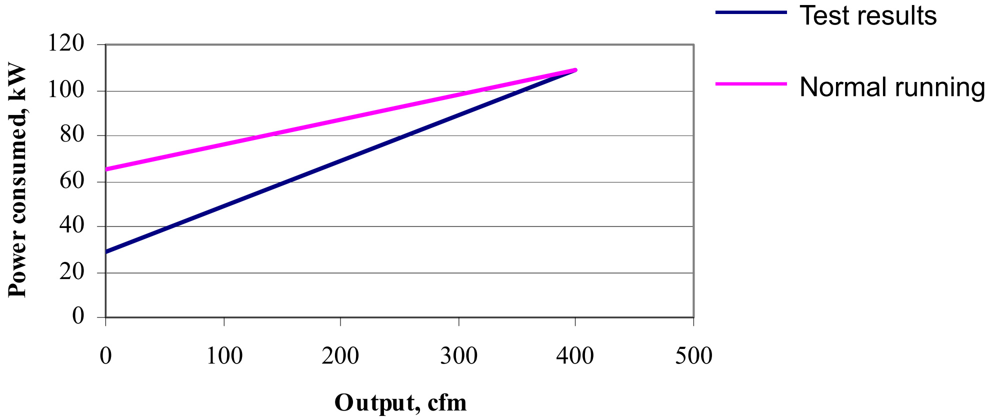
Power metering

- kW is the preferred measurement for power
- Amps can provide valuable information but power factor can be very low when off load (0.3-0.5)





Rapid cycling – The effect on power metering

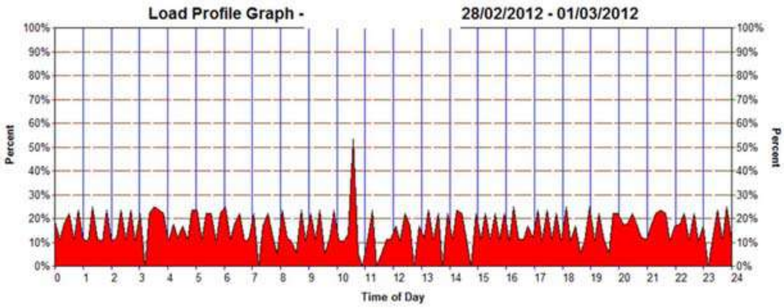


- 80 kW = 255 cfm - high base demand?
- 80 kW = 140 cfm – low base demand
- Power monitoring results can be inaccurate for flowmetering

Compressed Air Systems

What do you measure to determine a demand profile?

- Load cycles on load/unload machines

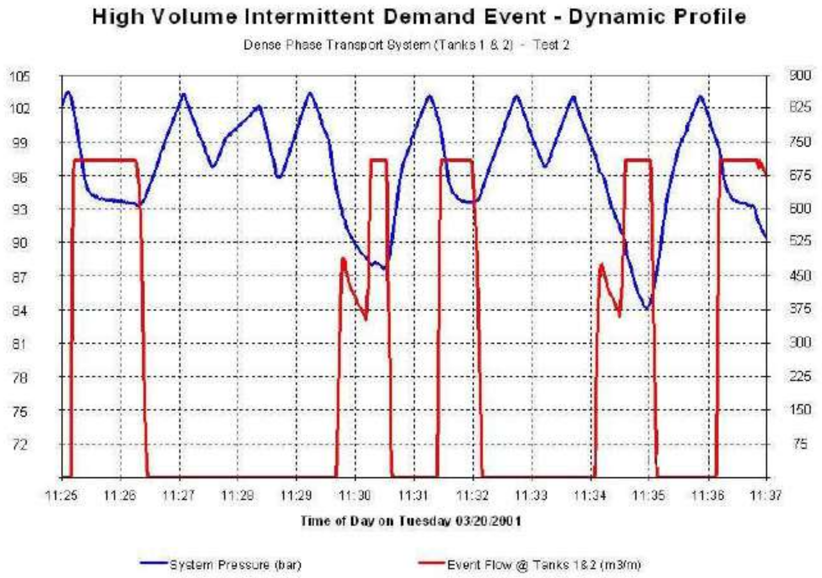


Compressed Air Systems

High Volume Intermittent Demand Events:

- Define short-lived peak airflow rate, valley pressure, and rate of system pressure decay. Gather information necessary to calculate compressed air storage solutions.
- Measure the duration of demand events and total air consumed.
- Measure the delay time between demand events and the ability to refill storage during the available delay time.
- Evaluate compressor control response and determine if compressors are running unnecessarily.
- Consider that excessive system pressure may currently be an operational solution to inadequate air storage.

Compressed Air Systems

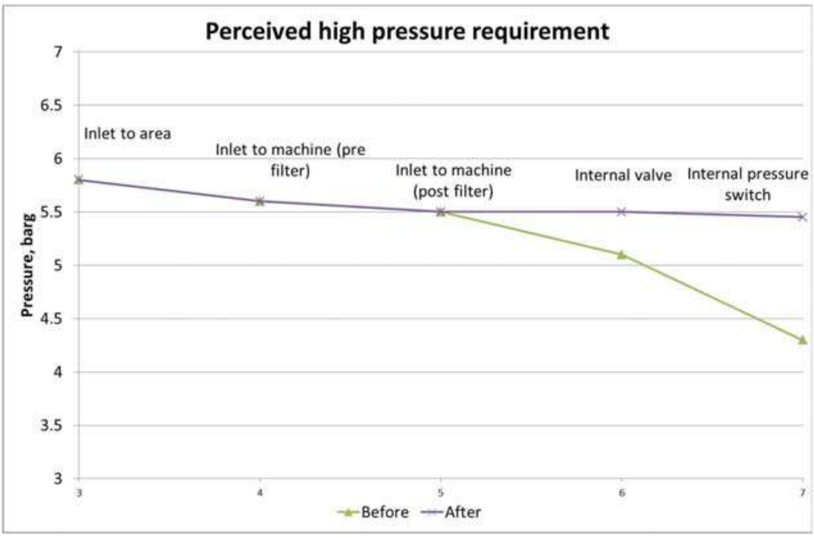


Compressed Air Systems

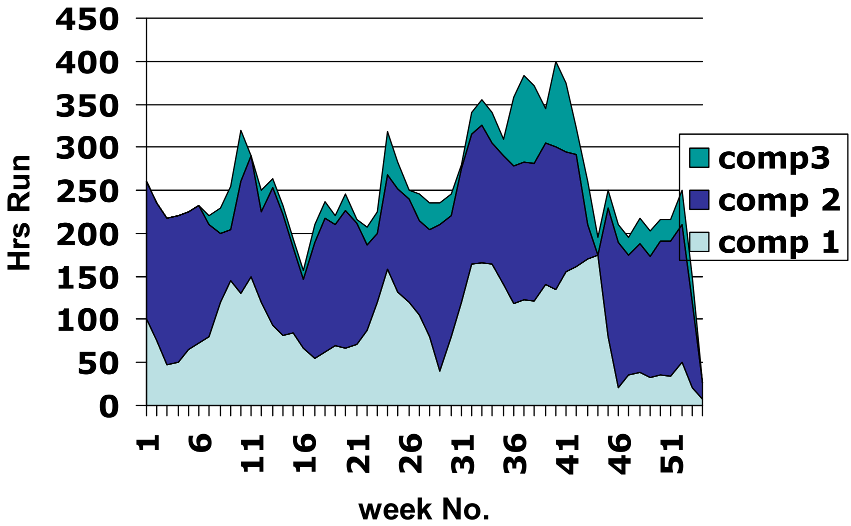
Are poor point of use connection practices causing the system to run at higher than required pressures?

Perceived high pressure demands

Upgrading internal lines prevented pressure increase across the site



Analysis of hours run



Even the most basic data can give useful results

Productivity monitoring

- Calculate air used per unit of product
  - Cfm per tonne
  - Cfm per car
  - Cfm per daily rate of production
- Set limits and rectify
- Compressor stations
  - Use total power input versus air demand - ideal for an energy management system
  - Put in acceptable limits for base use and normal production
  - Rectify when limits exceeded

Benchmarking

- Compare your air consumption per unit of production with:
  - Other group plants
    - Eg: an aluminium products plant in UK taking twice the air per tonne as a sister plant in France
  - Other similar plants
    - Eg: European car plants taking three times the air per unit as Japanese plants

Analysing air saving projects

- Determine the demand or pressure reduction
- Recalculate running costs based on new data
- Consider the effect of projects together
  - Two projects may each save d150,000,000 per year alone but the two together will not save d300,000,000
- Are there any other benefits eg increased production, reduced maintenance?
- A small demand reduction can make big savings if it means a compressor can be shut down.

8. Compressed Air System Assessment

- Reporting and documentation
  - Executive summary
  - Detailed report
  - Appendices
  - Attachments
  - Data files

8. Compressed Air System Assessment

- 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.

Analysing Vendors Proposals for new compressors and plant

- Check each proposal conforms to specification
  - Do the proposals offer sufficient capacity to meet peak demands?
  - Are the air quality and pressure requirements met?
  - Are all items included?
  - Is all the requested information included?
  - Is installation quoted as per spec?
  - Etc
- If not request more information from vendor

Making comparisons – initial impressions

Actual example:
3 Vendors - 3 compressors plus dryers, filters etc:

Capital cost:

- 1 VND4,158,509,991
- 2 VND4,828,180,599
- 3 VND4,305,850,966

Maintenance:

- 1 VND285,609,642 pa
- 2 VND337,019,378 pa
- 3 VND346,091,684 pa

Initial impressions:

- No.1 VND670,000,000 less than No.2, No.1 same ball park as No.3
- No.1 maintenance VND50,400,000 pa less than others
- No.1 definite top contender

Making comparisons – life cycle costs

Annual running cost:

1	2	3
VND1,763,723,543	VND1,525,155,489	VND1,682,812,012

Life cycle costs	1	2	3
3yr cost	6,147,999,555	5,586,524,601	6,086,711,088
5 yr cost	10,246,665,925	9,310,874,335	10,144,518,480
10 yr cost	20,493,331,850	18,621,748,670	20,289,036,960

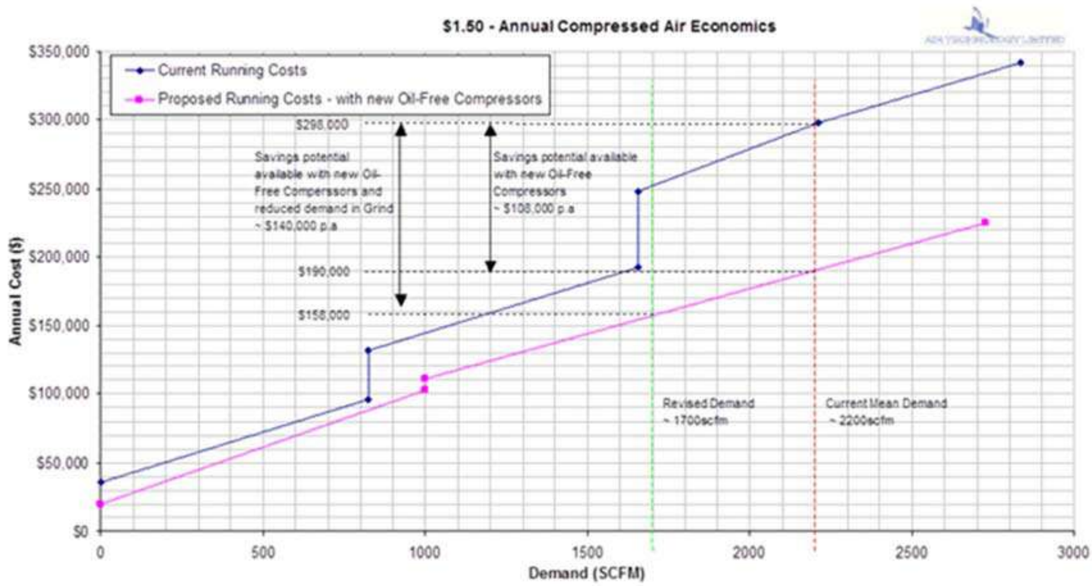
Over lifetime:

- No.2 VND561,474,954 cheaper than No.1 over 3 years
- No.2 VND1,871,583,180 cheaper than No.1 over 10 years
- No.2 VND1,667,288,290 cheaper than No.3 over 10 years

- Over 5-10 years No.2 is the definite winner

Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

New compressor analysis



Session 2 - review

- The systems approach
- Calculating running costs
- Carrying our a survey
- Pressure profiling
- Demand profiling
- Assessing results
- Reporting and reviewing vendor bids

Next sessions

- Example survey case study
- Use of spreadsheets
- Useful calculations
- Carry out a survey on site
- Review of data and report writing

Spreadsheets and Tools

- ✓ Some useful calculation tools
- ✓ Understand them before using
- ✓ Check results make sense
- ✓ Use at your own risk

Generating costs

- ✓ Calculate running costs at different demands and pressures
- ✓ Check costs with different compressors
- ✓ Use to build up annual profile using different demands
- ✓ Use to calculate savings

Leak detection

- ✓ Reporting tool for leaks surveys
- ✓ Use to assess leakage rates
- ✓ Identify leaks by area
- ✓ Rank leaks according to size
- ✓ Combine with photos for full leak report

Video Photos Excel

Air Density & Inlet Condition Conversion

- ✓ Estimate Air density at inlet conditions
- ✓ Estimate condensate created
- ✓ Convert between different inlet conditions

Inlet Density

CO_2 conversion

- ✓ Use to convert from cost to kWh and CO_2
- ✓ Useful for building summary tables

Receiver and line pressure drop

- ✓ Use to calculate and check pressure drop in a line
  - Based on steel lines
- ✓ Use to calculate receiver sizing

Linear Interpolation in Excel

- ✓ Very useful to find intermediate values from curves
- ✓ Can be used in modelling very effectively

Pipeline pressure drop

$$\Delta P = 450 \times \frac{Qc^{1.85} \times l}{d^5 \times p}$$

Δp	=	Pressure drop (bar)
Qc	=	Air flow (litres/sec)
d	=	Internal pipe diameter(mm)
l	=	Length of pipe (m)
p	=	Compressor inlet pressure (bara)

Receiver sizing to stop rapid cycling

$$V = \frac{0.25 \times Qc \times P1 \times T0}{F_{max} \times (Pu - PL) \times T1}$$

V	=	Total volume of storage system (litres)
Qc	=	Compressor FAD (litres/sec)
P1	=	Compressor inlet pressure (bara)
T0	=	Air temperature in receiver (K)
T1	=	Compressor inlet temperature (K)
P_u	=	Compressor unload pressure (barg)
P_L	=	Compressor loading pressure (barg)
Fmax	=	Maximum loading frequency (1/minimum cycle time(secs))

Receiver sizing to cope with peak events

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

Where:

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

Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Current- cfm conversion

- ✓ Use to convert current data to flow and power
  - On/off load spreadsheet
  - VSD spreadsheet
- ✓ Assume or measure voltage and power factor

Measured Volts - Amps calculation for annual energy cost.

Where: *volts = average line to line 3 phase voltage*
amps = full load amperage of the motor
1.732 = square root of 3 for phase to neutral voltage from line to line voltage
pf = power factor of the motor (0.80 to 0.85 typical)
hours = annual running hours
energy cost = $ / kWh
mtr eff = full load motor efficiency

Other useful sources of tools and information

- ✓ Experts training manual
- ✓ Compressed air challenge
- ✓ ATL Spreadsheets
- ✓ WebPlotDigitizer
- ✓ Engineering Toolbox
- ✓ Equipment manufacturers websites
  - CAGI data sheets
- ✓ Almig Calculation Tools

ian.moore@airtechnology.co.uk for advice – I can help sometimes!

DISCLAIMER

This document was developed within the framework of the project “Accelerating energy efficiency in large industries through energy management systems, system optimization and the promotion and adoption of energy efficiency in small and medium-sized enterprises (IEEP)”, funded by the European Union (EU), managed by the Ministry of Industry and Trade (MOIT), and implemented by the United Nations Industrial Development Organization (UNIDO). The content of this document is the sole responsibility of the Project and does not necessarily reflect the views of any individual or organization.