
# Compressed Air Engineering

## Basic principles and tips

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## Basic principles


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# Foreword

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Dear reader,

Over two thousand years ago, Socrates, the famous Greek philosopher, succinctly declared: “There is only one good, knowledge, and one evil, ignorance.” These ancient words of wisdom from one of the founding fathers of Western civilisation apply today more than ever, since nothing seems more permanent than change. The ever-increasing scope and speed of change brought about by technological evolution and economic globalisation demand new answers and new strategies.

Now more than ever, challenges should be seen as chances to achieve even greater success in the future – and should therefore be adopted and utilised to their full potential. Our increasingly networked and complex world is transforming knowledge into the most valuable raw material of the future; its exponential growth means that only those with a strong commitment to education and continuous further training will reap the rewards.

In the world of compressed air engineering, merely possessing the knowledge of how to manufacture powerful compressors, and install and operate them correctly, is no longer enough.

Those who wish to take full advantage of what a modern compressed air supply has to offer as an energy source, i.e. to use it as efficiently as possible, must consider the compressed air system as a whole. Moreover, they need a detailed understanding of the numerous interrelations and influences that occur within the system, as well as how to integrate it into the associated operating environment.

KAESER KOMPRESSOREN is therefore dedicated to the further training of its customers and achieves this in a number of different ways. For example, qualified technical experts with extensive practical experience travel around the world every year, stopping on every continent, to speak at conferences, information events and seminars about efficient compressed air generation and usage. This is in addition to the many technical publications issued across a broad range of media.

In this brochure you will find a summary of our extensive expert knowledge. In addition to an in-depth yet highly readable introduction to the field of compressed air technology, you will find a series of practical tips for system operators and compressed air users. You will recognise a common theme throughout: that often even small modifications to the compressed air system result in tangible improvements in the efficiency and availability of this key energy source.

Chapter 1

# Basic principles of compressed air generation

It's the same with compressed air as it is with many other things in life: a small cause can have a large effect – both in a positive and negative sense. Upon closer inspection, things are often different from how they first appear. In unfavourable conditions compressed air can be expensive, but in the right circumstances it is very economical. In this first chapter, we will explain the terms used in compressed air engineering and the things you should watch out for in connection with them.

**1. Flow rate**
The flow rate, or delivery volume, of a compressor is the actual, non-compressed volume of the compressed air that the compressor delivers into the network. The correct way of measuring this flow rate is specified in the standard **ISO 1217, Annexe C**. To measure the delivery volume of the compressor system, proceed as per **Fig. 1**: the temperature, atmospheric pressure and humidity must first be measured at the air inlet for the overall system. Then, the working pressure (set to the maximum value if possible), temperature and volume of the compressed air at the outlet of the compressor package are measured under constant operating conditions. Finally, the volume $V_2$ measured at the compressed air outlet is calculated in accordance with intake conditions using the following equation **(see formula)**.

$$V1 = \frac{V_2 \times P_2 \times T_1}{[p_1 - (p_V \times H_{rel})] \times T_2}$$

The result is the delivery volume of the compressor package. This figure should not be confused with the flow rate of the airend (airend delivery volume).

***Please note:***
**ISO 1217 alone describes the airend delivery volume only.**

**2. Motor shaft power**
Motor shaft power is the power that the compressor drive motor delivers mechanically to the motor shaft. The optimal value for motor shaft power is the point at which optimum utilisation of the electrical efficiency rating is achieved and the cos φ power factor is reached without the motor becoming overloaded. This figure lies within the range of the rated motor power, which is indicated on the electric motor nameplate.
***Caution!* Should the motor shaft power deviate too far from the rated motor power, the compressor will run inefficiently and/or will be subject to increased wear.**

**3. Electrical power consumption**
The electrical power consumption is the power that the compressor drive motor draws from the mains when the motor shaft is subject to a defined mechanical load (motor shaft power). It exceeds the motor shaft power by the value of the electrical and mechanical motor losses from bearings, ventilation, etc. The electrical power consumption at the nominal point can be calculated using the formula:

$$P = U_n \times I_n \times \sqrt{3} \times \cos \varphi_n$$

$U_n$, $I_n$, and **cos** $\varphi_n$ are indicated on the electric motor nameplate.

**4. Specific package input power**
The relationship between the electrical power consumed and the compressed air volume delivered at the corresponding working pressure is known as specific package input power **(Fig. 2)**. The electrical power consumption of a compressor is the sum of the electrical power consumed by all of the drives in a compressor, e.g. drive motor, fan motor, oil pump motor, standstill heater, etc.
If the specific package input power is required for a cost efficiency calculation, it should relate to the overall compressor package and the maximum working pressure.
The total electrical power consumption at maximum pressure is then divided by the package's flow rate at maximum pressure:

$$P_{spec} = \frac{\text{Electrical power consumption}}{\text{Flow rate}}$$

**5. IE – The new formula for energy-saving drives**
In 1997, the USA introduced the Energy Policy Act (EPACT) for classification of energy efficiency in three-phase asynchronous motors. Later, Europe also introduced an efficiency classification of its own. The international IEC standard for electric motors has been in place since 2010. Classifications and legal requirements have resulted in significantly improved energy efficiency for premium-class electric motors. More efficient motors provide significant advantages:

***a) Lower operating temperatures***
Internal efficiency losses caused by heat and friction can be as high as 20% of power consumption in smaller motors and 4 to 5% in motors above 160 kW. IE3/IE4 motors operate with significantly less heat generation and, as a result, lower losses **(Fig. 3)**:
If a conventional motor at normal load experiences an operating temperature increase of around 80 K with a temperature reserve of 20 K compared with insulation class F, for an IE3 motor under the same conditions the temperature increase will only be around 65 K and the temperature reserve 40 K.

***b) Longer service life***
Lower operating temperatures mean less thermal load on the motor, bear-

ings and terminal box. This results in the further advantage of a longer service life.

***c) 6% more compressed air for less energy***

Lower heat losses lead to increased cost efficiency. Therefore, with precise matching of the compressors to more efficient motors, KAESER is able to achieve up to a 6% increase in flow rate and a 5% improvement in specific package input power. This means improved performance, shorter compressor running times and less energy consumed per cubic metre of compressed air generated.

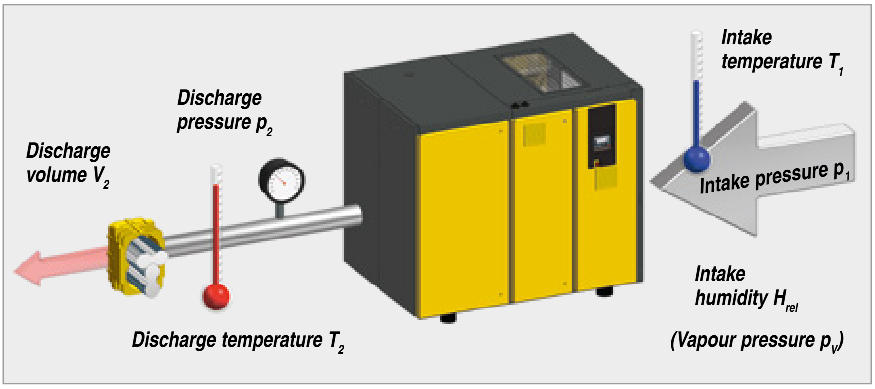



*Fig. 1: Flow rate measurement in accordance with ISO 1217, Annexe C*

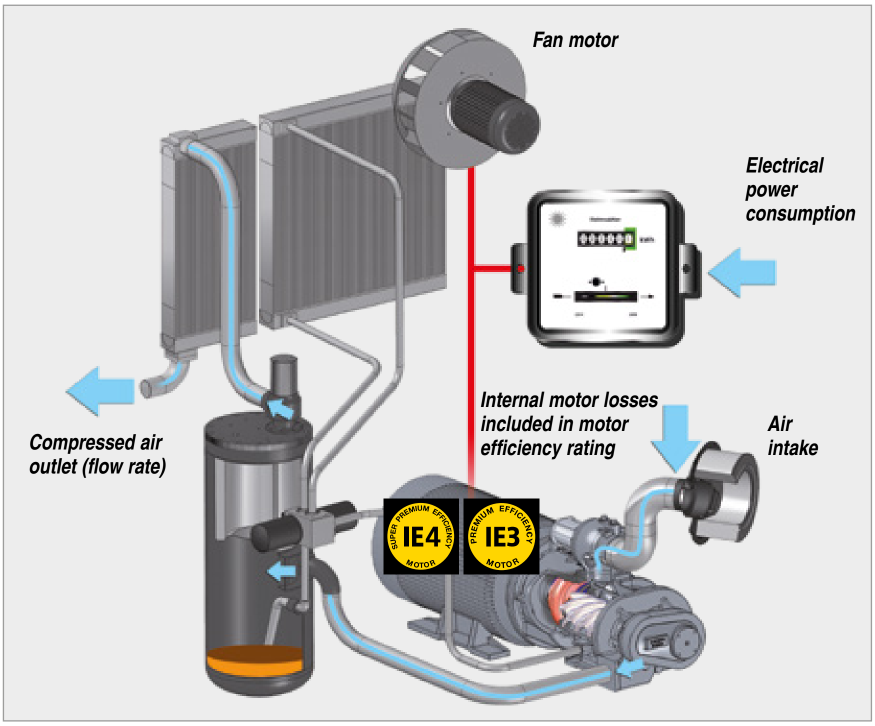



*Fig. 2: Basic design of a rotary screw compressor, determining specific package input power*

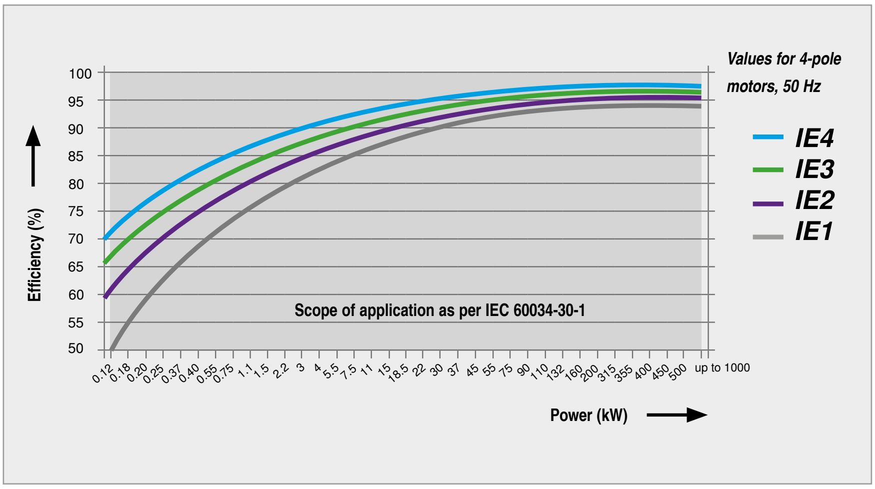



*Fig. 3: The IEC standard – Efficiency classification for electric motors.*
*In the EU, three-phase motors in the power class 0.75 to 1000 kW with relative duty cycles of 80% and up must comply with energy efficiency class IE3 since July 2021; from July 2023, 75 to 200 kW must comply with energy efficiency class IE4. The next efficiency class, IE5, has not yet been defined in detail and is intended for a future edition of this standard.*

Chapter 2

# Efficient compressed air treatment

So, which compressor system provides the best way of generating oil-free compressed air? Leaving aside the claims of individual manufacturers, there is no doubt that premium-quality, oil-free compressed air can be achieved with both oil-free compression (dry-running) and oil- or fluid-cooled compressors. Therefore, the deciding factor when selecting a system should be cost efficiency.

**1. What is "oil-free" compressed air?**
According to ISO 8573-1, compressed air can be described as oil-free if its oil content (including oil vapour) is less than 0.01 mg/m³, which is approximately four-hundredths of the amount found in normal atmospheric air.
This amount is so minute as to be barely measurable. But what about the quality of the compressor intake air?
This, of course, depends heavily on local ambient conditions. Even in zones with normal levels of contamination, the hydrocarbons present in the air from industry and traffic emissions can be between 4 and 14 mg/m³.
In industrial areas, where oil is used as a lubricating, cooling and processing medium, the mineral oil content can be far in excess of 10 mg/m³.
Other contaminants such as hydrocarbons, sulphur dioxide, soot, metals and dust are also present.

**2. Why treat compressed air?**
Every compressor works like a giant vacuum cleaner, drawing in contaminated air, concentrating the contamination by compression and, if no treatment measures are taken, passing it on into the compressed air network.

**a) "Oil-free" compressors**
This especially applies to so-called "dry-running", or "oil-free", compressors. Because of the contamination mentioned previously, it is impossible to produce oil-free compressed air with a compressor equipped only with a three-micron dust filter. Other than these dust filters, so-called "oil-free" compressors possess no further treatment components.

**b) Fluid- / oil-cooled compressors**
By contrast, in fluid-cooled compressors, aggressive elements are neutralised and solid particles partially flushed out of the compressed air by the cooling fluid (oil).

**3. No defined compressed air quality without treatment**
Despite the higher degree of compressed air purity achieved, this also applies to oil-free compressors: It's a no-go without compressed air treatment. Under normal intake conditions and with the associated air contaminant levels, neither dry-compression nor oil-cooled compressors alone can achieve defined oil-free compressed air quality in accordance with ISO 8573-1. As for how efficient compressed air generation is, it depends on the pressure and flow rate range, as well as on the type of compressor required. Sufficient drying is the cornerstone for all application-oriented compressed air treatment. Energy-saving refrigeration drying is usually the most efficient way of achieving this **(also see chapter 3, page 10).**

**4. Treatment with the KAESER Pure Air System**
Modern fluid- or oil-cooled rotary screw compressors are up to 10% more efficient than dry-compression models. The Pure Air System, developed by KAESER for fluid- or oil-cooled rotary screw compressors and dry-compression compressors, enables further cost savings of up to 30%.
The residual oil content achieved by this system is less than 0.003 mg/m³, far below the limit stipulated for Quality Class 1 (with regard to residual oil content) in the ISO standard. The system includes all of the treatment components needed for achieving the required compressed air quality. Depending on the application, either refrigeration or desiccant dryers are used (see chapter 3, page 11), together with various filter combinations. Compressed air quality ranging from simply dry to particle-free, technically oil-free and sterile are achieved reliably and economically in accordance with the quality classes set out in the ISO standard – see diagram on the following two pages.

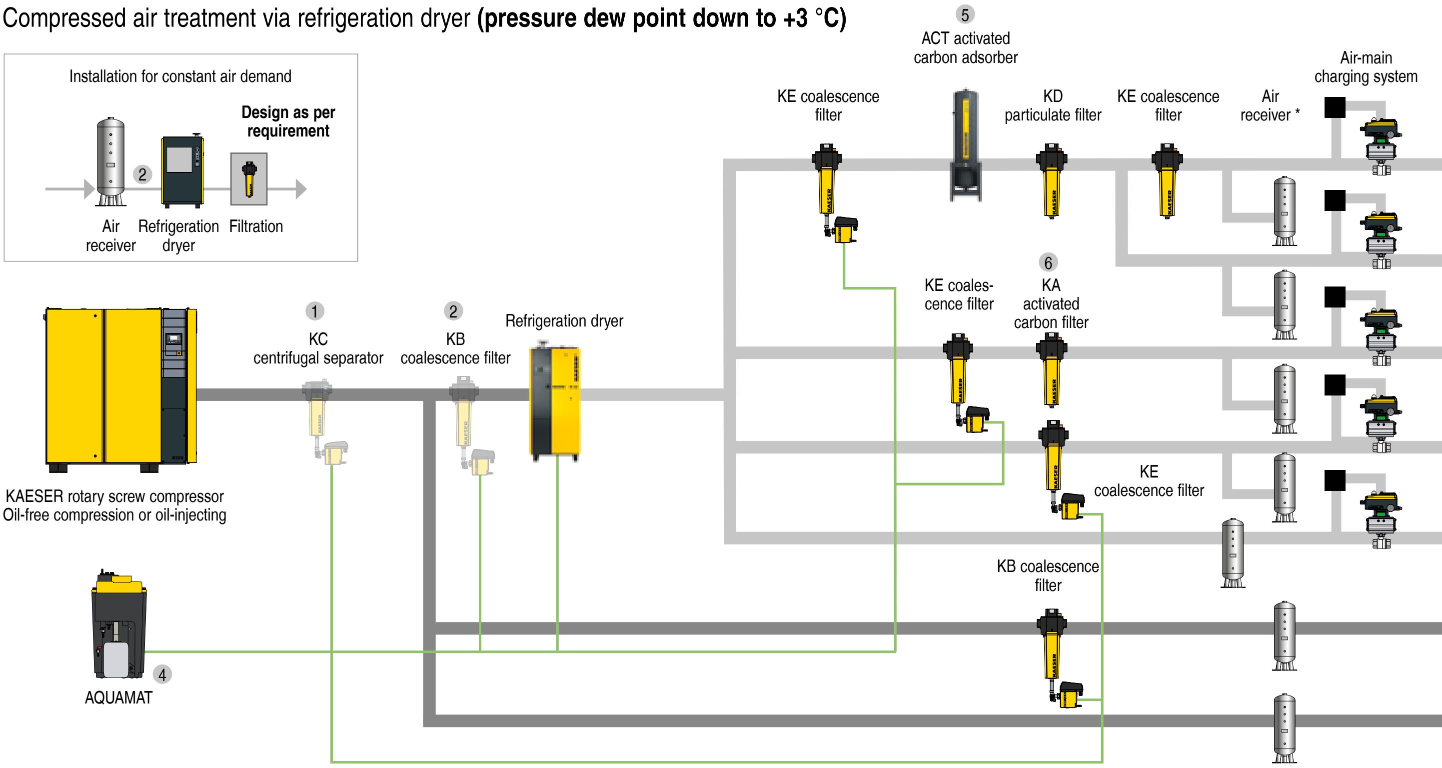

*Fig. 1: Compressed air refrigeration dryers in a compressed air station*


*Fig. 2: Installation example for compressed air treatment with refrigeration dryer, coalescence filter and activated carbon filter plus air-main charging system*

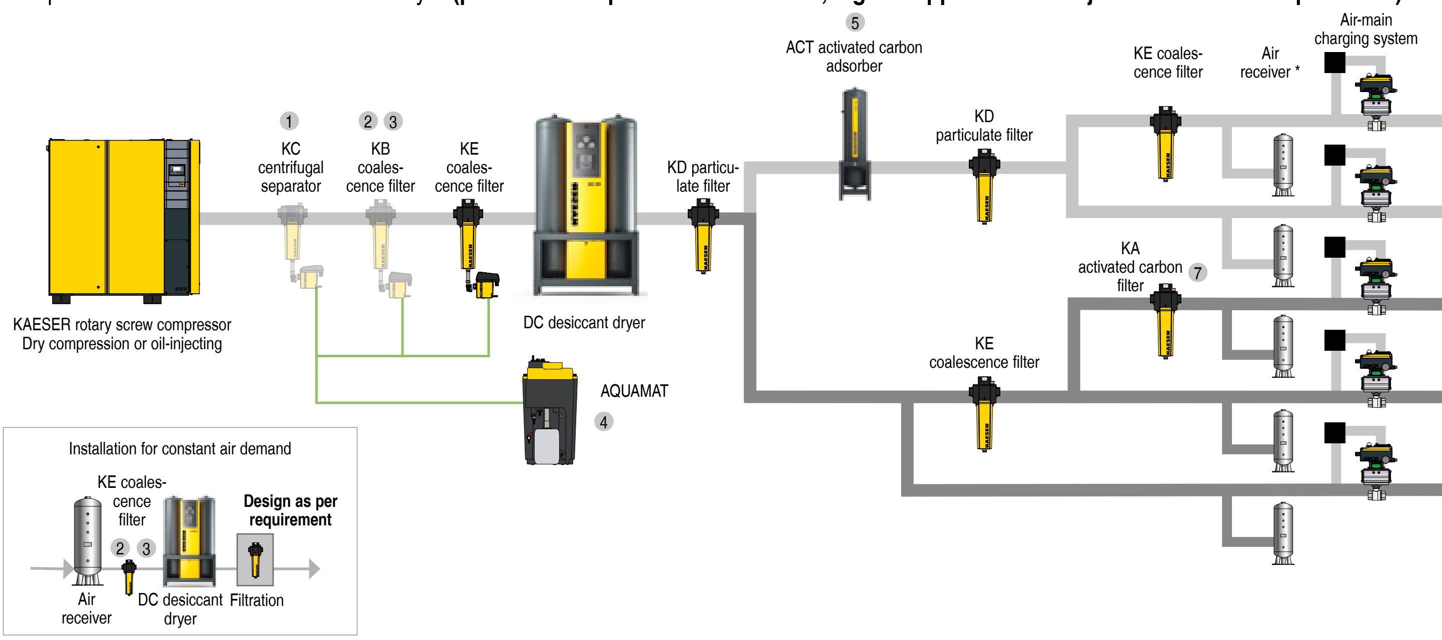
# Efficient compressed air treatment

From the diagram below, the correct combination of treatment devices for the relevant application can be determined at a glance. Select the desired grade of treatment according to your specific requirement/application. Application examples: Selection of compressed air treatment classes as per ISO 8573-1 (2010)

Compressed air treatment via refrigeration dryer **(pressure dew point down to +3 °C)**




Compressed air treatment via desiccant dryer **(pressure dew point down to -70 °C, e.g. for applications subject to sub-zero temperatures)**




1. No KC required in compressors with integrated centrifugal separator.
2. KB filter stage installed upstream for third-party compressors or contaminated / heavily corroded pipework.
3. KB filter stage installed upstream for critical applications requiring compressed air with a high purity level.
4. With oil-free compression rotary screw compressors, condensate must be disposed of at the user-end.
5. Service life approx. 12,000 h
6. Service life approx. 500 h
7. Service life approx. 1,000 h

## Achievable compressed air purity class

| Particulates | Water | Oil | Sector/Application |
|---|---|---|---|
| 1 | 4 | 1 | Pure air and clean-room technology, dairies, breweries, food production |
| 2 | 4 | 1 | Especially clean conveying air, chemical plants |
| 1 | 4 | 1 | Weaving machines, photo labs, pharmaceuticals industry |
| 1 | 4 | 2 | Paint spraying, powder coating, packing, control and instrument air |
| 4 | 4 | 3 | General works air, high-grade sandblasting |
| 4 | 7-X | 3 | Shot-blasting |
| 4-6 | 7-X | 3-4 | Conveying air for wastewater systems |

## Achievable compressed air purity class

| Particulates | Water | Oil | Sector/Application |
|---|---|---|---|
| 1 | 1-3 | 1 | Pure air and clean-room technology, pharmaceuticals industry, food production |
| 2 | 1-3 | 1 | Paint spraying installations |
| 1 | 1-3 | 1 | Process air, pharmaceuticals industry |
| 1 | 1-3 | 2 | Photo labs |
| 2 | 1-3 | 2 | Especially dry conveying air, paint spraying, fine pressure controllers |

* Where there are high demands on compressed air quality, the air receiver should always be installed in a branch line downstream from the treatment to prevent the entrainment of deposits.

**Compressed air quality classes as per ISO 8573-1 (2010):**

### Particulates

| Class | Max. particle count per m³ of particle size d in µm *) | | |
|---|---|---|---|
| | 0.1 < d ≤ 0.5 | 0.5 < d ≤ 1.0 | 1.0 < d ≤ 5.0 |
| 0 | Consult KAESER, e.g. regarding pure air and clean-room technology | | |
| 1 | ≤ 20,000 | ≤ 400 | ≤ 10 |
| 2 | ≤ 400,000 | ≤ 6,000 | ≤ 100 |
| 3 | Not defined | ≤ 90,000 | ≤ 1,000 |
| 4 | Not defined | Not defined | ≤ 10,000 |
| 5 | Not defined | Not defined | ≤ 100,000 |
| **Class** | **Particle concentration $C_p$ in mg/m³ *)** | | |
| 6 | $0 < C_p \leq 5$ | | |
| 7 | $5 < C_p \leq 10$ | | |
| X | $C_p > 10$ | | |

### Water

| Class | Pressure dew point, in °C |
|---|---|
| 0 | Consult KAESER, e.g. regarding pure air and clean-room technology |
| 1 | ≤ -70 °C |
| 2 | ≤ -40 °C |
| 3 | ≤ -20 °C |
| 4 | ≤ +3 °C |
| 5 | ≤ +7 °C |
| 6 | ≤ +10 °C |
| **Class** | **Concentration of liquid water $C_w$ in g/m³ *)** |
| 7 | $C_w \leq 0.5$ |
| 8 | $0.5 < C_w \leq 5$ |
| 9 | $5 < C_w \leq 10$ |
| X | $C_w > 10$ |

### Oil

| Class | Total oil concentration (fluid, aerosol + gaseous) [mg/m³] *) |
|---|---|
| 0 | Consult KAESER, e.g. regarding pure air and clean-room technology |
| 1 | ≤ 0.01 |
| 2 | ≤ 0.1 |
| 3 | ≤ 1.0 |
| 4 | ≤ 5.0 |
| X | > 5.0 |

*) At reference conditions 20 °C, 1 bar(a), 0% humidity.

Chapter 3

# Why is it necessary to dry compressed air?

The problem is in the air – quite literally: When atmospheric air cools down, as is the case following compression in a compressor, water vapour forms as condensate. Under reference conditions of +20 °C ambient temperature, 70% relative humidity and 1 bar(a), a compressor with a flow rate of 5 m³/min will "produce" approximately 30 litres of condensate in an eight-hour shift. This condensate has to be removed from the compressed air system in order to prevent damage and avoid costly production downtime. Cost-effective and environmentally friendly compressed air drying is therefore a key element in application-oriented compressed air treatment.

**1. A practical example**

If a fluid-cooled rotary screw compressor draws in 10 m³ of air per minute at +20 °C, atmospheric pressure and a relative humidity of 60%, this air will contain approximately 100 g of water vapour. If this air is then compressed to an absolute pressure of 10 bar at a compression ratio of 1:10, this is referred to as 1 working cubic metre per minute. At a temperature of +80 °C after compression, the air is capable of absorbing 290 g of water per cubic metre. Since only approx. 100 g is present, the air is very dry, with a relative humidity of around 35%, meaning no condensate forms. The compressor aftercooler then reduces the temperature of the compressed air from 80 to approx. +30 °C.

At this temperature, a cubic metre of air can absorb only around 30 g of water. As a result, a water excess of approx. 70 g/min occurs, which condenses and is then separated. This means that approximately 35 litres of condensate accumulate during an eight-hour work shift.

A further 11.5 litres accumulate each day when using a downstream refrigeration dryer. In these dryers, the compressed air is initially cooled down to +3 °C and then reheated to ambient temperature. This leads to a moisture undersaturation of approximately 20% and therefore to relatively dry, better-quality compressed air **(Fig. 1)**.

**2. Causes of humidity**

To a greater or lesser extent, our ambient air always contains a certain concentration of moisture.

The amount of humidity depends on the respective temperature. For example, air saturated to 100% with water vapour at a temperature of +25 °C holds almost 23 g of water per cubic metre.

**3. Condensate formation**

Condensate forms when the volume of the air and the air temperature are reduced at the same time. This in turn reduces the capacity of the air to absorb water. This is precisely what happens after compression in the airend and aftercooler of a compressor.

**4. Important terms – A brief explanation:**

***a) Absolute humidity***

Absolute humidity is the water vapour content of the air in g/m³.

***b) Relative humidity (Hrel)***

Relative humidity is the degree of saturation, i.e. the ratio of the current water vapour content to the respective saturation point of the air (100% $H_{rel}$). This depends on the temperature; warm air can absorb more water vapour than cold air can.

***c) Atmospheric dew point***

The atmospheric dew point is the temperature at which the air reaches 100% humidity saturation ($H_{rel}$) at atmospheric pressure (ambient conditions).

***d) Pressure dew point***

The pressure dew point is the temperature at which the compressed air reaches its humidity saturation point (100% $H_{rel}$) under its absolute pressure. This means, in the above case, that air subjected to a pressure of 10 bar(a) with a pressure dew point of +3 °C has an absolute humidity of 6 g per working cubic metre. If one of these cubic metres were expanded from 10 bar(a) to atmospheric pressure, then its volume would multiply tenfold. The water vapour component of 6 g would remain unchanged, but it would now be distributed over ten times the volume.


*Fig. 1: Condensate occurs as a result of compressed air generation, storage and treatment (figures relate to 10 m³/min, 10 bar(a), 8 h, 60% Hrel and +20 °C)*

This means that every cubic metre of expanded air would now contain only 0.6 g of water vapour. This corresponds to an atmospheric dew point of -24 °C.

**5. Efficient and environmentally friendly compressed air drying with refrigeration or desiccant dryer?**

New environmental legislation concerning refrigerants cannot change the fact that desiccant dryers do not provide an alternative to refrigeration dryers, either from an economical or an environmental point of view. Refrigeration dryers consume only 3% of the energy that the compressor requires to generate compressed air; desiccant dryers, on the other hand, require 10 to 25% or more. For this reason, refrigeration dryers should be used wherever possible.

The use of a desiccant dryer only makes sense when an extremely dry compressed air quality with pressure dew points down to -20, -40 or -70 °C is required **(Fig. 2)**. Over the course of a working day, compressed air systems often experience considerable fluctuations in air demand. The same thing also occurs over the course of a year due to heavy fluctuations in temperature.

| Drying process | Pressure dew point °C | Typical specific package input power kW / (m³/min)**) |
|---|---|---|
| Refrigeration dryer | +3 | 0.1 |
| **HYBRITEC** | **+3 / -40*)<br>-40** | **0.2<br>0.3** |
| **Heat regenerative desiccant dryer** | **-40** | **0.5 – 0.6** |
| Heatless regenerative desiccant dryer | -20<br>-70 | 1.4 – 1.6 |

***Fig. 2: Depending on the required pressure dew point, different drying processes are available***

*) PDP -40 °C for one third of operating time
**) As per ISO 7153 Option A

For this reason, compressed air dryers should be designed to handle the least favourable operating conditions that may arise: lowest pressure, maximum compressed air consumption, maximum ambient and compressed air inlet temperatures.

The preferred solution to this used to be continuous dryer operation, which – especially in partial load operation – led to considerable energy wastage. On the other hand, modern refrigeration dryers with efficient cycling control ensure consistently high compressed air quality whilst adapting their energy consumption in accordance with changing operating conditions **(Fig. 3)**. Consequently, they are able to achieve average annual energy savings of more than 50%.

It is particularly important to use energy-efficient technology to reach pressure dew points in the minus range, since the desiccant dryers required to achieve this level have a very high energy requirement. However, using a cost-effective and energy-efficient combined process, such as with the HYBRITEC system, it is possible to reduce energy consumption significantly. This system consists of both a refrigeration dryer and a desiccant dryer. Firstly, the refrigeration dryer brings the inflowing compressed air down efficiently and cost-effectively to a pressure dew point of +3 °C . Having now been pre-dried, the air passes into the desiccant dryer, which subsequently requires considerably less energy to dry the air further to a pressure dew point of -40 °C **(Fig. 4)**.

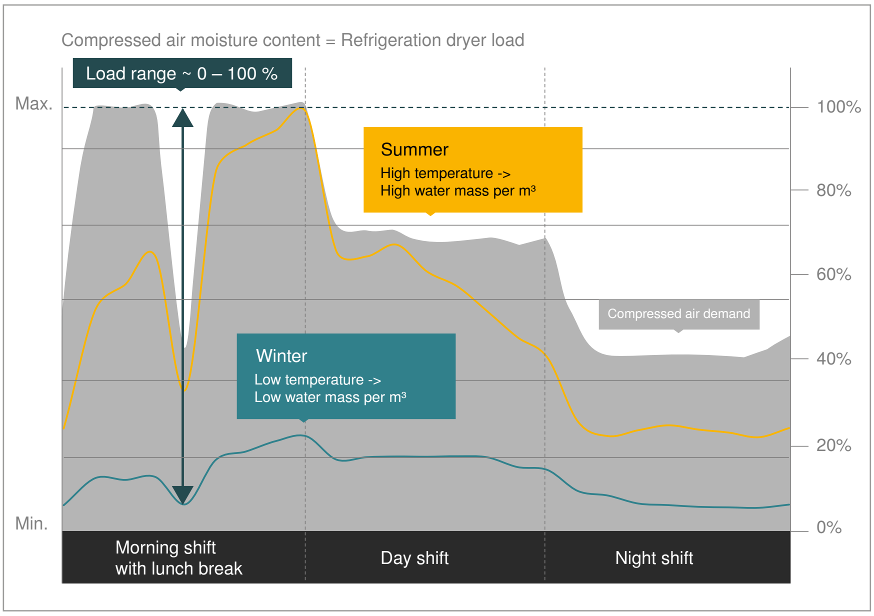



***Fig. 3: Energy-saving potential of refrigeration dryers with cycling control***


***Fig. 4: Hybritec system***

Chapter 4

# Automatic condensate drainage

Condensate is an unavoidable by-product of compressed air production. A 30 kW compressor with a flow rate of 5 m³/min produces around 20 litres of condensate per shift under average operating conditions. This must be removed from the compressed air system in order to prevent malfunctions and corrosion. In this chapter, you will discover how to drain condensate correctly and save significant costs at the same time.

**1. Condensate drainage**

Condensate, containing a variety of contaminants, collects at certain points in every compressed air system **(Fig. 1)**. Dependable condensate drainage is therefore essential, as it has significant influence on compressed air quality, operational reliability and system efficiency.

***a) Condensate collection and drainage points***

Initially, mechanical elements of the compressed air system serve to collect and drain the condensate. 70 to 80% of all condensate accumulates at these points – provided the compressors are fitted with effective after-cooling.

**Centrifugal separator:**

This is a mechanical separator which separates condensate from the air by means of centrifugal force **(Fig. 2a)**.
In order to ensure optimum performance, each compressed air generator must be equipped with its own dedicated centrifugal separator. On larger systems, a separation system is often integrated into the compressor **(Fig. 2b)**; however, due to the structural proportions, there are significant differences in separation rate depending on the technical solution.

**Intercooler:**

On two-stage compressors equipped with intercoolers, condensate also collects at the separator for the intercoolers.

**Air receiver:**

In addition to its main function as a storage or buffer tank, the air receiver separates condensate from the air via gravity **(Fig. 1)** when installed in the "wet" section of the pipework. If sufficiently dimensioned (compressor output per min. : 3 = minimum air receiver size in m³), an air receiver is equally effective as a centrifugal separator.
In contrast to the centrifugal separator, however, the air receiver can be used in the main compressed air collector pipe for the compressor station, provided the air inlet is at the bottom and the outlet at the top. Moreover, due to its large heat dissipation surface area, the air receiver provides additional compressed air cooling, thereby further enhancing condensate separation.


*Fig. 1: Condensate collects at certain points in every compressed air system*

*Fig. 2a: Centrifugal separator with condensate drain*

*Fig. 2b: Integrated centrifugal separator with condensate drain*

**Water trap in the compressed air line:**

To avoid undefined condensate flow, the compressed air line should be

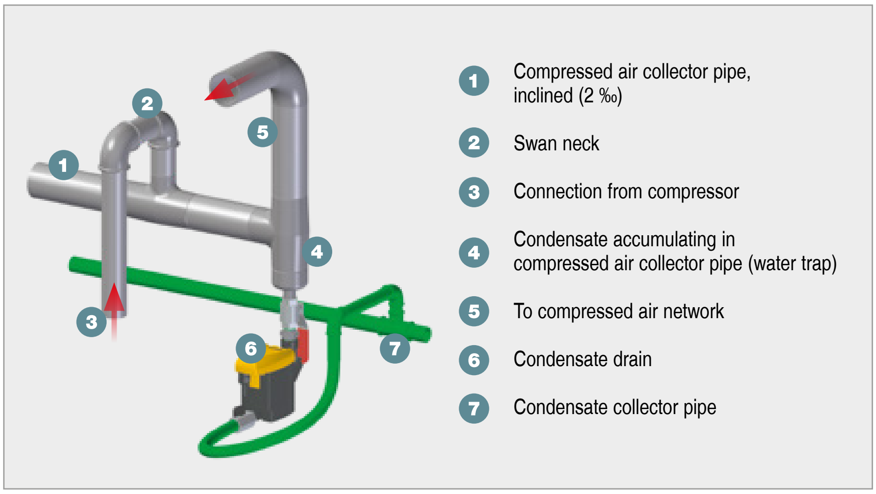



*Fig. 3: Water trap with condensate drain in the humid area of a compressed air system*

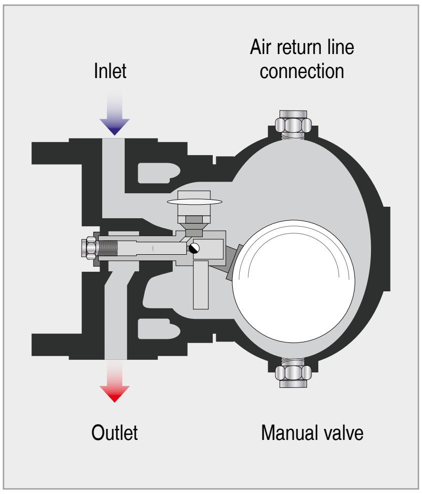



*Fig. 4: Float drain for compressed air condensate*

designed so that all inlet and outlet points in the humid area are connected from above or from the side. Defined condensate outlets leading downwards – so-called water traps – convey condensate away from the main line. When designed correctly and with an airflow velocity of 2 to 3 m/s, a water trap **(Fig. 3)** in the humid area of the compressed air system separates condensate as effectively as an air receiver **(Fig. 1)**.

***b) Compressed air dryers***

In addition to those already mentioned, there are further condensate collection and drainage points on compressed air dryers.

**Refrigeration dryers:**

Further condensate is separated in a refrigeration dryer due to the drying effect of cooling the compressed air.

**Desiccant dryers:**

Cooling in the compressed air line causes condensate to accumulate at the desiccant dryer's prefilter.
In the desiccant dryer itself, water exists only in the form of vapour due to the prevailing partial pressure conditions.

***c) Decentralised separators***

If no central drying system exists, large quantities of condensate collect at water separators installed just upstream of the compressed air consumers. However, this solution is exceptionally maintenance-intensive.

## 2. Drainage systems

At present, three systems are mainly used:

***a) Float drains***

Float drains are one of the oldest drainage systems to be found; they replaced manual drainage, which was both uneconomical and highly unreliable. However, even condensate drainage using the float principle **(Fig. 4)** is both maintenance-intensive and highly susceptible to malfunction due to contaminants in the compressed air.

***b) Solenoid valve***

Time-controlled solenoid valves are more reliable than float drains, but must be checked regularly for contamination. Incorrectly adjusted valve opening times can cause compressed air losses and increased energy consumption.

***c) Condensate drains with level-sensing control***

Nowadays, drains equipped with intelligent level-sensing control are predominantly used **(Fig. 5)**. These have the advantage that the float, which is highly susceptible to malfunction, is replaced by an electronic sensor. This eliminates faults caused by contamination or mechanical wear. Furthermore, compressed air losses are prevented by automatically controlled valve opening times. Additional benefits include automatic self-monitoring and the ability to transmit signals to a master control system.

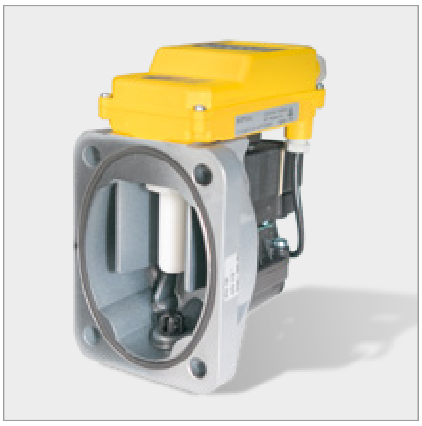


*Fig. 5: Condensate drain with electronic level-sensing control (ECO-DRAIN)*

***d) Correct installation***

A short length of pipe equipped with a ball valve should be fitted between the condensate separation system and the condensate drain **(Figs 2a, 2b and 3)**. This allows the drain to be isolated during maintenance work and the compressed air system can remain in operation.

Chapter 5

# Reliable and economical condensate treatment

The condensate that inevitably occurs during compressed air generation by no means consists only of condensed water vapour. Every compressor works like an oversized vacuum cleaner: it draws in contaminants along with the ambient air and passes them on to the condensate in concentrated form via the as yet untreated compressed air.

**1. Why treat condensate?**
Compressed air users who dispose of condensate by simply pouring it down the drain are risking heavy fines. The reason? Because the condensate accumulating during compressed air generation is a highly volatile mixture. In addition to dust particles, condensate contains hydrocarbons, sulphur dioxide, copper, lead, iron and a number of other substances caused by environmental pollution. In Germany, regulations concerning the disposal of condensate from compressed air systems are set out in the Water Management Act. This stipulates that water contaminated with harmful substances must be treated in accordance with "generally recognised engineering regulations" (§ 62 WMA). This affects all types of condensate – including condensate from oil-free compressors.
Legal limits are in place for all harmful substances and pH values. These vary according to federal state and the industry involved. The maximum permissible limit for hydrocarbons, for example, is 20 mg/l, whilst the pH limit for disposable condensate ranges from 6 to 9.


*Fig. 1: All condensate collection points in a compressed air system must be fitted with reliable drainage. The best results are achieved with an electronically controlled condensate drain.*

**2. Condensate composition (Fig. 2)**
***a) Dispersion***
Condensate can consist of various compositions. Generally, dispersions occur in fluid-cooled rotary screw compressors using synthetic coolants, such as Kaeser "Sigma Fluid S460".
This type of condensate normally has a pH value between 6 and 9, and can be regarded as pH-neutral. With this condensate, contaminants drawn in from the atmospheric air are captured in a floating layer of oil that is easily separated from the water.

***b) Emulsion***
The visible sign of an emulsion is a milky fluid which does not separate into two phases, even after several days. This condensate composition occurs frequently in reciprocating, rotary screw and rotary vane compressors operated with conventional oils. Here, harmful substances are also bound to the oil components. Because of its thick, stable mixture, oil, water and contaminants such as dust and heavy metals cannot be separated by gravity.
If the oils contain ester compounds, the condensate can be aggressive and must be neutralised. Such condensate can only be treated using emulsion-splitting systems.


*Fig. 2: Every compressor draws in water vapour and contaminants along with atmospheric air. The condensate resulting from compression (Fig. 2 (1)) must be free from oil and other harmful substances (Fig. 2 (2)) before it can be disposed of as normal wastewater (Fig. 2 (3)).*


*Fig. 3: Condensate separation system for compressed air using the gravity principle (functional diagram)*

**3. External disposal**

Of course, it is possible to arrange for the condensate to be collected and disposed of by a specialist. However, the cost of this service can be up to €500 per m³, and even higher, depending on the composition. In view of the amount of condensate accumulating, treatment is the more economical approach. It has the advantage that only about 1% of the original volume remains to be disposed of in accordance with environmental regulations.

**4. Treatment processes**

***a) For dispersions***

A triple-chamber separator comprising two pre-separation chambers and an activated carbon filter chamber usually suffices to treat this kind of condensate **(Figs 3 and 4)**. Actual separation takes place via force of gravity. The oil layer floating on the surface of the liquid in the separating chamber is skimmed off into a collector tank and disposed of as waste oil. The remaining water is then filtered in two stages and can be disposed of via the sewer system. This procedure saves up to 95% of the cost of disposal via a specialist company.

Such separators are available with capacities capable of handling compressor flow rates up to 100 m³/min.


*Fig. 4: KAESER AQUAMAT condensate separation system*

If necessary, multiple devices can be connected in parallel.

***b) For emulsions***

Generally, two types of separator are used for the treatment of stable emulsions:

Membrane separating systems work according to the principle of ultrafiltration, using the so-called “cross-flow” process. Here, prefiltered condensate flows across the membranes. Part of the liquid permeates the membranes and exits the separator as clean water that can be disposed of as normal wastewater.

The second type of device uses a powdered splitting agent. This encapsulates oil particles, forming easily filtered macro-flocs which are reliably retained by filters of a defined pore size. The drained water can be disposed of as normal wastewater.

Chapter 6

# Efficient compressor control

Only by correctly matching compressor flow rate to fluctuating compressed air demand can energy-intensive and costly partial load phases be virtually eliminated. The right compressor controller plays a key role in ensuring optimum energy efficiency.

Compressors operating at less than 50% load should set off loud alarm bells with regard to energy wastage. Many users are not even aware of this, because their compressors feature an indicator showing operating hours only and not hours under full load. Well-matched control systems can help by increasing utilisation to over 90% and achieving energy savings of up to 20% and more.

**1. Internal control**

***a) Full load / idle control***

Most compressors are fitted with three-phase asynchronous drive motors. The permissible starting frequency of these motors decreases the higher the power, meaning they are not capable of the starting frequency required in order to switch compressors with lower switching differentials on and off in accordance with actual compressed air demand. The switching cycles for these compressors therefore only relieve the pressure-bearing areas of the system.

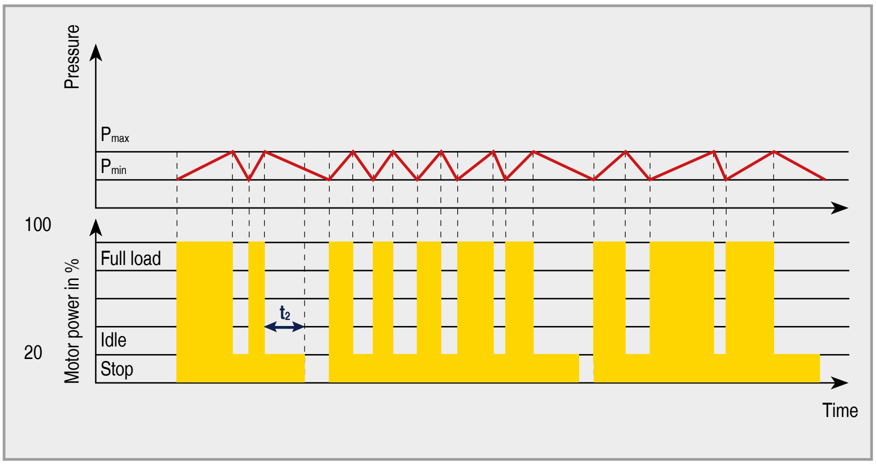



*Fig. 1: Full load / idle cycling control with fixed idling periods, so-called Dual Control*

The motor continues to run for a period **(Fig. 1)**; the power required for this period must be regarded as a loss. The energy requirement of a compressor during the idle phase is still 20% of the power required for full load.
Modern, computer-optimised control systems such as Quadro control with automatic optimal operating mode selection **(Fig. 3)**, Dynamic control with drive motor temperature-dependent idling **(Fig. 4)** and Vario control with variably calculated idling periods **(Fig. 5)** help to keep costly idling to a minimum and ensure maximum motor protection.
Proportional controllers using intake-side throttling are not recommended, since the compressor still requires 85% of the energy it would need to provide 100% flow output in order to deliver just 50% of capacity.

***b) Frequency converter***

The efficiency of compressors which are speed-controlled by a frequency converter **(Fig. 6)** is inconsistent over their control range. In the range between 30 and 100% for example, efficiency is reduced from 96% to 88% for a 90 kW motor. Added to this are the frequency converter losses and the non-linear power characteristics of the compressors. FC-controlled compressors should be operated in the 40-80% control range, which is where they deliver optimum cost efficiency.
The components should be designed for 100% load. If FC-systems are deployed incorrectly, they can end up consuming a lot of energy without the operator being aware of the fact. Frequency control is not a universal remedy for energy-saving compressor operation.

*Fig. 2: Modern control systems can provide energy savings of up to 20%.*

## 2. Classification of compressed air demand

Generally, compressors can be classified by function into base load, medium load, peak load or standby units.

### *a) Base load demand*

Base load air demand is the volume of compressed air constantly required by a production facility.

### *b) Peak load demand*

Peak load demand is the volume of compressed air required at certain peak load times. It varies in volume due to the differing demand from various consumers.

In order to fulfil this diverse range of load demands in the best way possible, the compressors need to be operated with individual controllers.

These internal controllers must be capable of maintaining compressor operation, and therefore a continued supply of compressed air, in the event of a malfunction in the master control system.

## 3. Master controller

Modern master controllers equipped with web-based software are not only capable of coordinating compressor operation within a compressed air station in order to ensure optimum energy efficiency, but are also able to record performance data and document compressed air supply efficiency. Furthermore, by transferring process data to the manufacturer, they can serve as the basis for modern system management including monitoring, analysis and preventative maintenance.

### *a) System splitting*

Splitting is the division of compressors of equal or differing capacities and types of control according to the base load and peak load compressed air demand of an operation **(Fig. 7)**.

### *b) Master controller duties*

Coordinating compressor operation is a demanding and comprehensive task. Modern master controllers must not only be able to activate compressors of differing make and size simultaneously; they must also be capable of monitoring the system from a maintenance point of view, balancing compressor operating

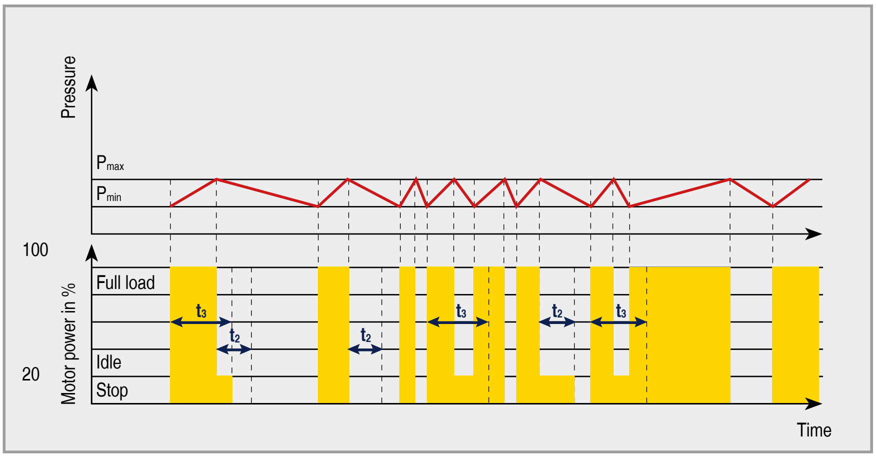



*Fig. 3: Full load / idle cycling control with automatic selection of optimum operating mode, so-called Quadro Control*

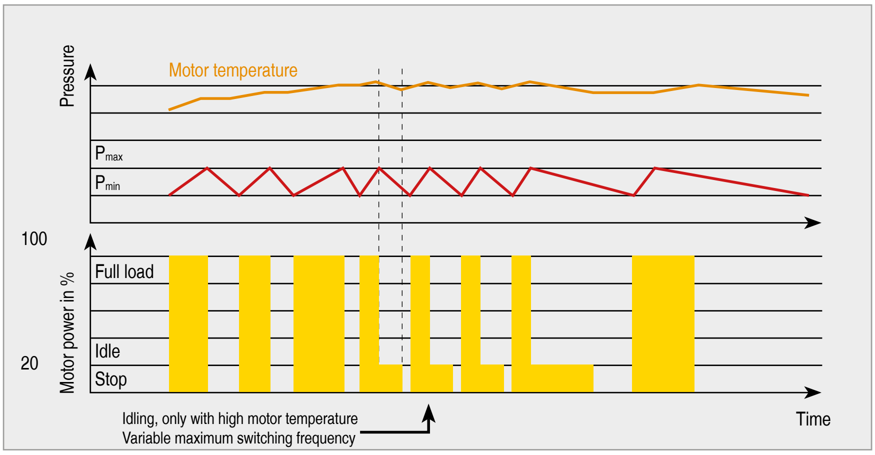



*Fig. 4: Dynamic Control, based on Dual Control, with idling periods dependent upon the temperature of the drive motor*

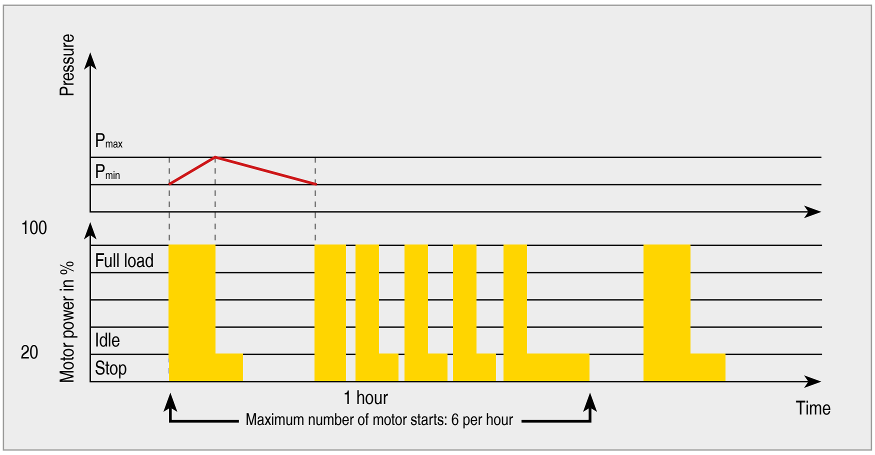



*Fig. 5: Vario Control with variably calculated idling periods*

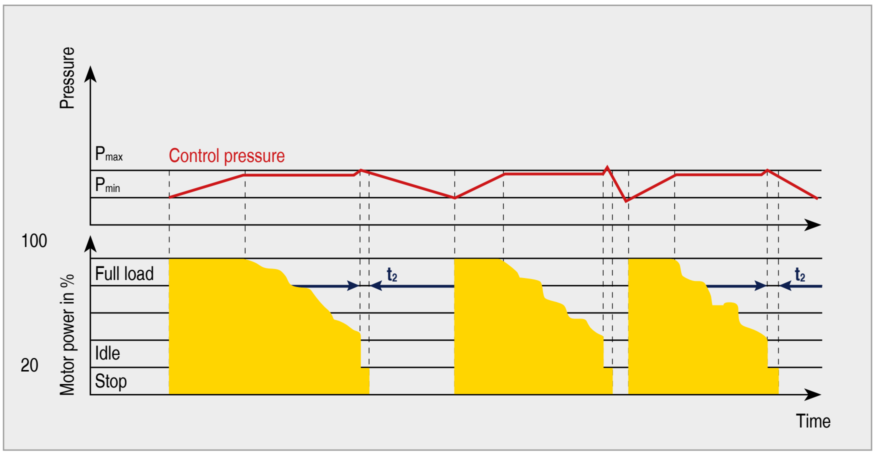



*Fig. 6: Continuous flow rate control via motor speed (with frequency converter)*

Chapter 6

# Efficient compressor control

hours and recording faults in order to reduce servicing costs and increase operational reliability.

***c) Correct grading***

In order for a master controller to operate efficiently – i.e. for it to save energy – the compressors must be perfectly graded.

The sum of the flow rates of the peak load machines must therefore be larger than that of the next base load machine to cut in. If a speed-controlled peak load machine is used, the control range must be greater than the delivery volume of the next compressor to cut in. Otherwise, the cost efficiency of the compressed air supply cannot be guaranteed.

***d) Safe data transfer***

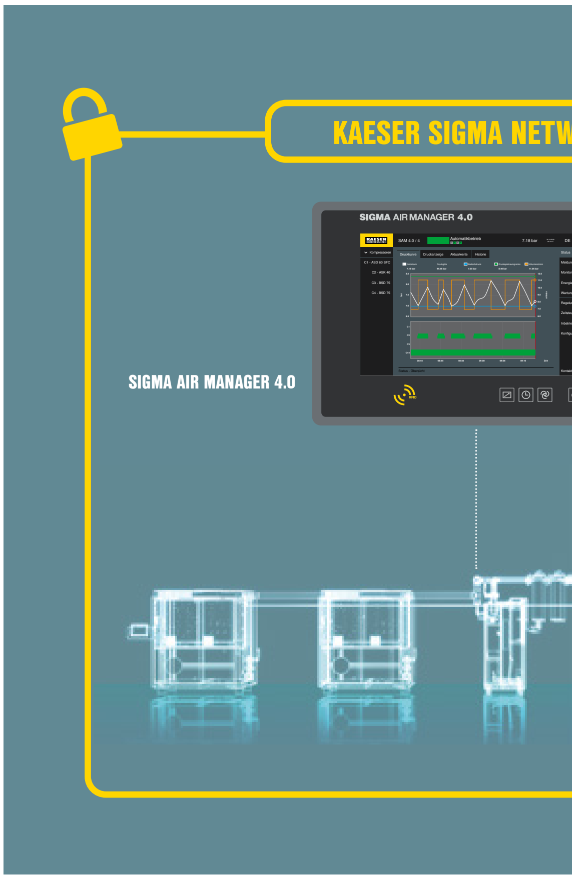
Another important prerequisite for perfect function and efficiency of a master controller is the safe transfer of data.

It must be ensured that messages are transferred not only between the individual compressors, but also between the compressors and the master control system. In addition, the signal paths must be monitored so that faults, such as an interrupted connecting cable, are recognised immediately.

The most common transfer methods are:

1. Floating relay contacts
2. Analogue signals 4-20 mA
3. Electronic interfaces, such as Profibus DP, Modbus or Ethernet.

Industrial Ethernet offers the most advanced data transfer technology. This system can quickly transfer large volumes of data over long distances. In combination with state-of-the-art data transfer technology, the option exists of connection to and visualisation on standardised computers and monitoring systems. This means that master controllers do not have to be located in the compressed air station itself **(Fig. 8)**.



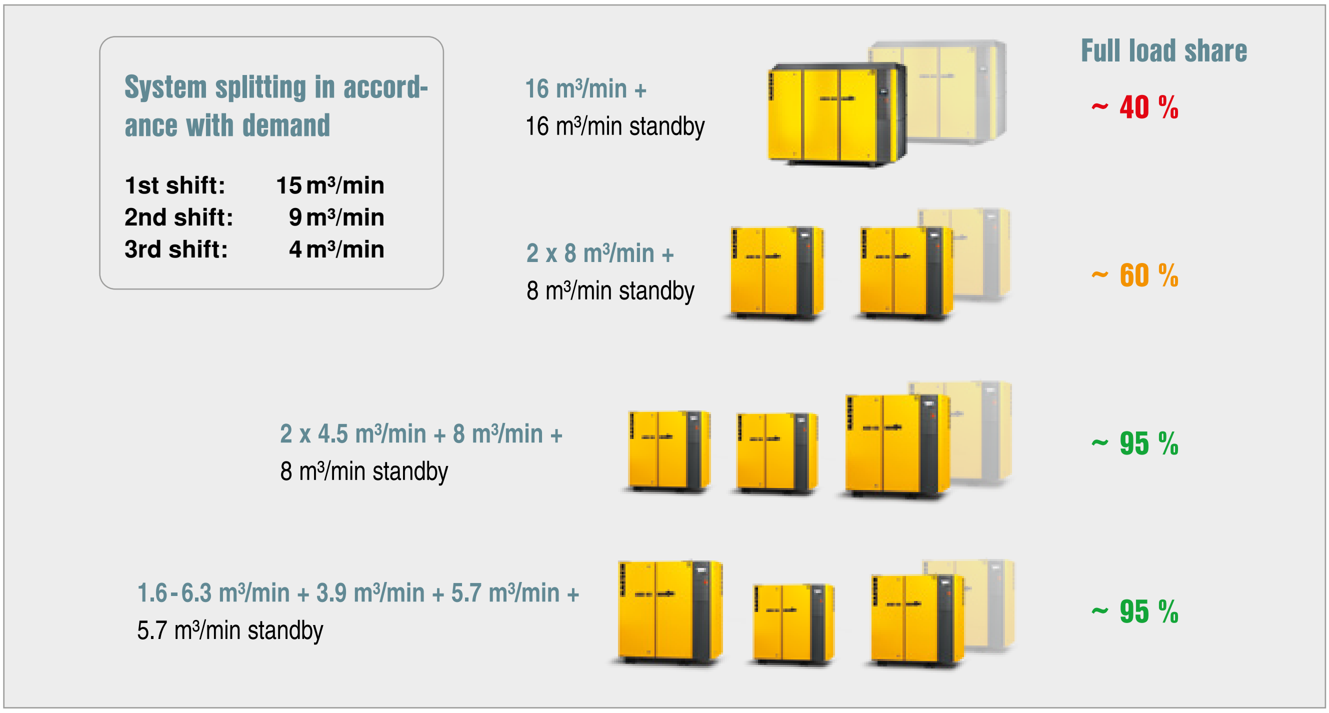
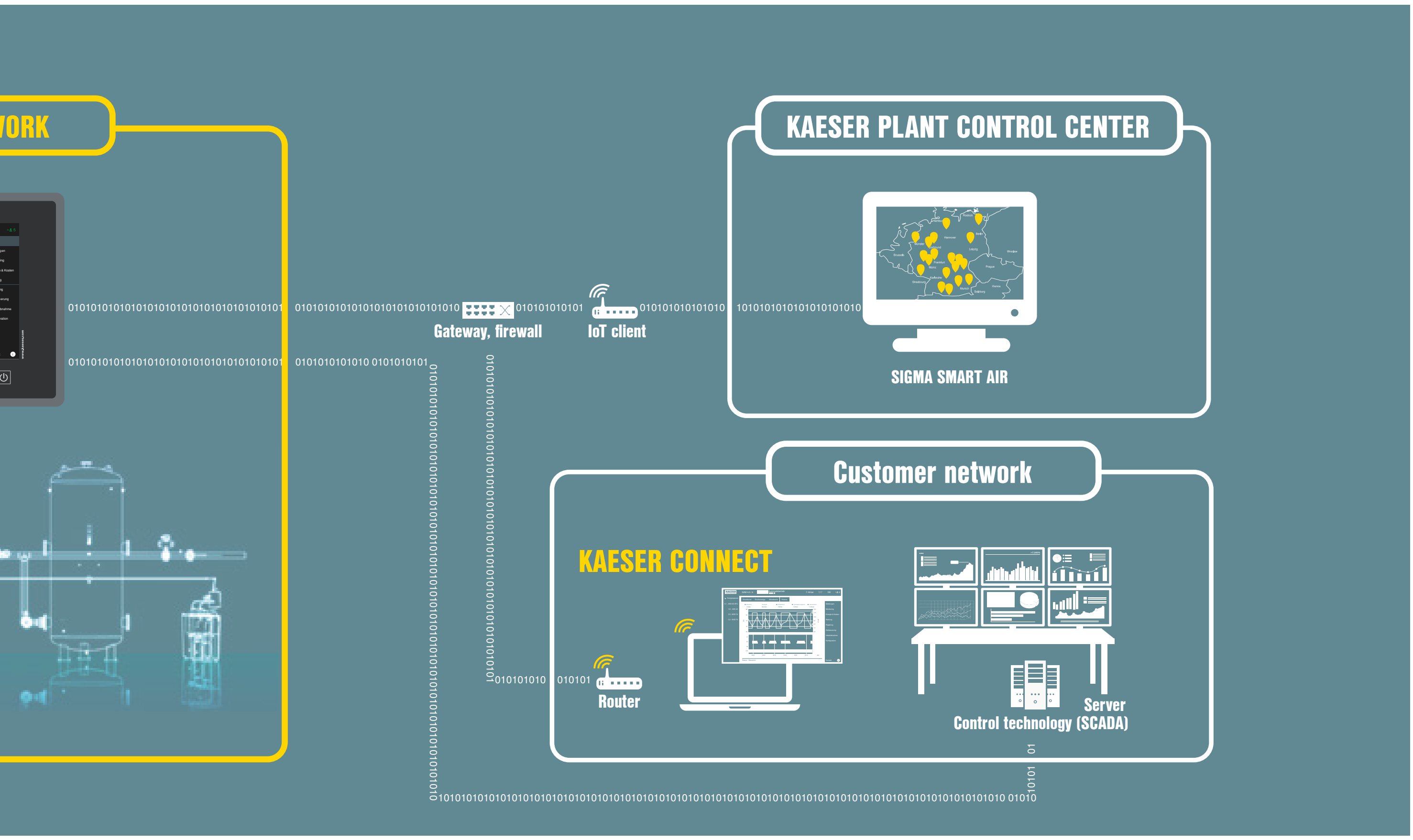



*Fig. 7: Demand-dependent load splitting across compressors of different power ratings*

*Fig. 8: The wide range of connection options for a master controller contributes to energy-efficient operation of a compressed air station*



Chapter 7

# Optimal, demand-oriented compressor coordination

Compressed air systems typically comprise multiple compressors of similar or differing sizes. As effective control is essential to ensure efficient system operation, a master controller is needed to coordinate the operation of individual machines: compressed air generation is optimally matched to suit actual compressed air demand and maximum efficiency is ensured at all times.

Within the scope of control technology, the systems generally referred to as compressor controllers should be considered as regulating systems. These are divided into four groups:

**1. Cascade control**

The classic method of controlling a group of compressors is cascade control. Each individual compressor is assigned lower and upper switching points. If multiple compressors are coordinated, this strategy results in a cascaded, or stepped, control system. When air demand is low, only one compressor is switched on and pressure fluctuates in the upper range between this compressor's minimum ($p_{min}$) and maximum pressure ($p_{max}$) setpoints; pressure falls when air demand is higher and multiple compressors cut in **(Fig. 1, column 1)**. This results in a relatively unfavourable constellation with maximum pressure in the system, increasing the significance of leaks and the consequent energy losses; on the other hand, when air demand is high, pressure falls and the pressure reserve in the system is reduced. Depending on whether conventional membrane pressure switches, contact pressure gauges or electronic pressure sensors are used as measurement sensors, the control system pressure spread will be very broad due to the individual allocation of the compressors to a certain pressure range. The more compressors used, the larger the pressure ranges overall. This leads to ineffective control with leakages, energy losses and the increased pressures already mentioned. Cascade control systems should therefore be replaced by other control methods when used in combination with more than two compressors.

**2. Pressure band control**

In contrast to cascade control, pressure band control **(Fig. 1, column 2)** enables coordination of multiple compressors within a single defined pressure range. This allows the pressure range within which the compressed air station is controlled to be kept relatively narrow.

***2. a) Simple pressure band control***

Simple versions of pressure band control are, however, not able to coordinate operation of compressors of differing sizes; they therefore do not meet the requirements to cover peak load demand in compressed air networks that need to accommodate continuously fluctuating demand conditions. This method was therefore replaced by a system which aims to control the appropriate compressors, and therefore cover peak load demand, based on periods of pressure fall and rise. These control characteristics, however, require a relatively broad pressure band spread **(Fig. 2)**. Moreover, similar to with cascade control, the reactions of the compressors and the compressed air network are not taken into consideration, which results in a shortfall of the minimum possible pressure point. It is therefore necessary to maintain a safety distance between the required minimum pressure and the lowest switching pressure of the control system.

***2. b) Setpoint pressure-oriented pressure band control***

Setpoint pressure-oriented pressure band control introduced a significant improvement **(Fig. 1, column 3)**. This method strives to maintain a certain average pressure setpoint within defined pressure limits, whilst at the same time monitoring the pressure curve within narrower limits and thereby controlling compressors of different

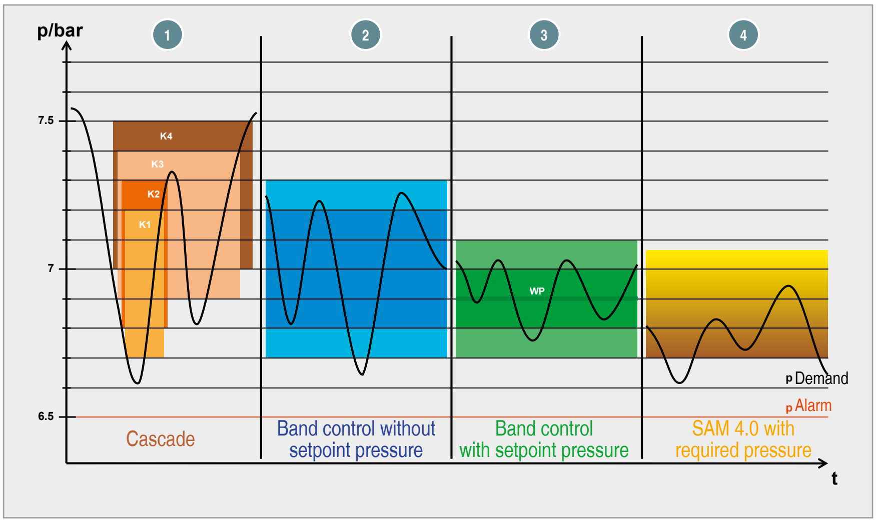



*Fig. 1: Different variants of master compressor control*

sizes in accordance with compressed air demand. The key advantage of this control variant is that it allows the average working pressure of the compressed air system to be significantly reduced and therefore helps to achieve considerable energy and cost savings.

**3. Required pressure control**

Required pressure control **(Fig. 1, column 4)** currently offers the optimum control method. With this variant, no fixed pressure limits or switching points are specified, but rather the lowest possible working pressure that must not be fallen short of at the pressure sensor measuring point. By observing and recording the compressed air demand curve and the switching operations carried out, events in the compressed air system are analysed and the principle influences on the behaviour of the station and its components are learned. Taking into consideration all possible losses due to pressure increase, start-up times, reaction times and idling periods **(Fig. 3)**, the simulation-based optimisation process in the SIGMA AIR MANAGER 4.0 master controller predictively selects the most efficient switching operations in real time. These are determined with the objective of achieving lowest possible compressed air generation costs – whilst maintaining the specified required pressure **(Fig. 4)**.

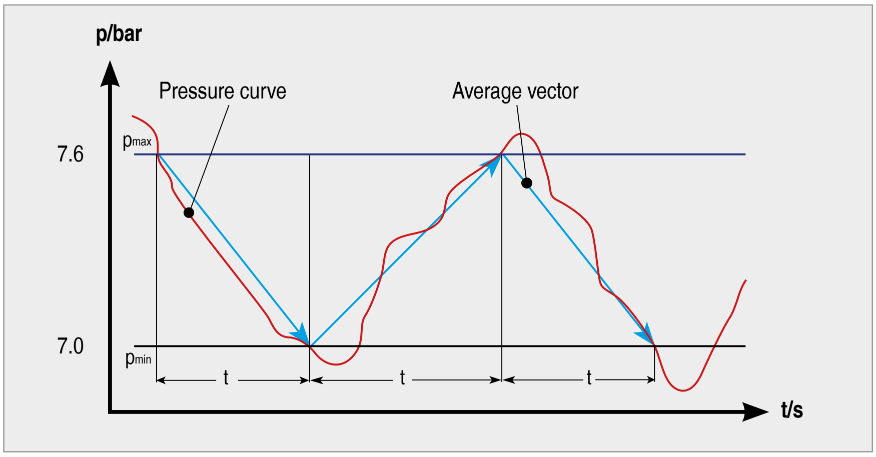



*Fig. 2: Simple pressure band control with evaluation of average pressure-time curve and broad pressure band spread*

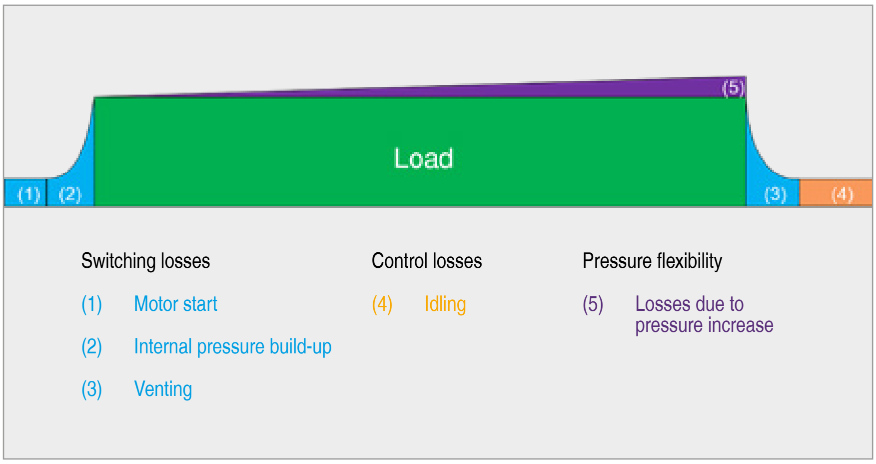



*Fig. 3: Switching cycle of a rotary screw compressor*

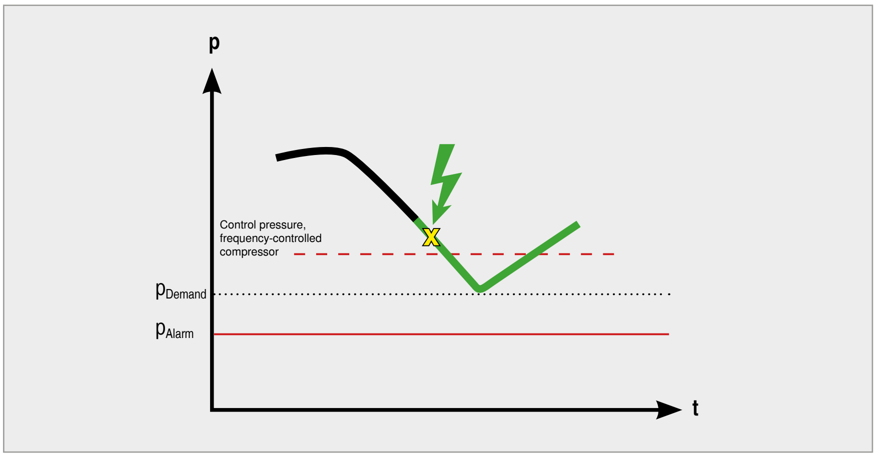



*Fig. 4: By cutting in at the correct time, the system prevents a shortfall of the preset minimum required pressure*

Chapter 8

# Saving energy with heat recovery

In view of ever-increasing energy prices, efficient use of energy is not only important for the environment, but is also increasingly becoming an economic necessity. Compressor manufacturers offer various solutions in this regard, such as heat recovery with rotary screw compressors.

### 1. Compressors primarily generate heat

Amazingly, 100% of the electrical energy supplied to a compressor is converted into heat. The act of compression charges the air in the compressor with potential energy **(Fig. 1)**. This energy can be harnessed by expanding the air back to atmospheric pressure, cooling it and thereby extracting the heat.

### 2. Heat recovery options

Compressed air users interested in further increasing the efficiency of their supply can choose between different variants of heat recovery:

#### *a) Air heating*

The simplest method of recovering the heat generated in an air- or oil/fluid-cooled rotary screw compressor is by directly using the heat from the compressor system's heated cooling air; the heated air is ducted away to be used for space heating in warehouses and workshops.
The hot air can also be used for other applications, such as drying processes, heat curtains and the preheating of combustion air. When no heating is required, the exhaust air is discharged outside the building via a flap or louvre. The louvre can be thermostatically controlled to provide bursts of hot air and thereby maintain a constant temperature. This variant allows 96% of the electrical energy consumed by a rotary screw compressor to be reused. It is well worth it too; even small systems, such as a 7.5 kW compressor, can easily generate enough recyclable heat energy to warm a typical family home.

#### *b) Hot water heating*

Hot water for a variety of purposes can be recovered from both air-cooled and water-cooled rotary screw compressors by means of a heat exchanger installed in the fluid circuit. Plate-type, or fail-safe, heat exchangers are used – or heat transfer may take place via an intermediate circuit, depending on whether the water is required for heating, laundry, showering, or production and cleaning purposes **(Fig. 3)**. Water temperatures of up to +70 °C can be achieved with these types of heat exchanger. Experience shows that for compressor packages upwards of 7.5 kW drive power, the additional costs of these heat recovery systems are amortised within two years. Correct planning is, of course, a prerequisite for this **(Fig. 2)**.

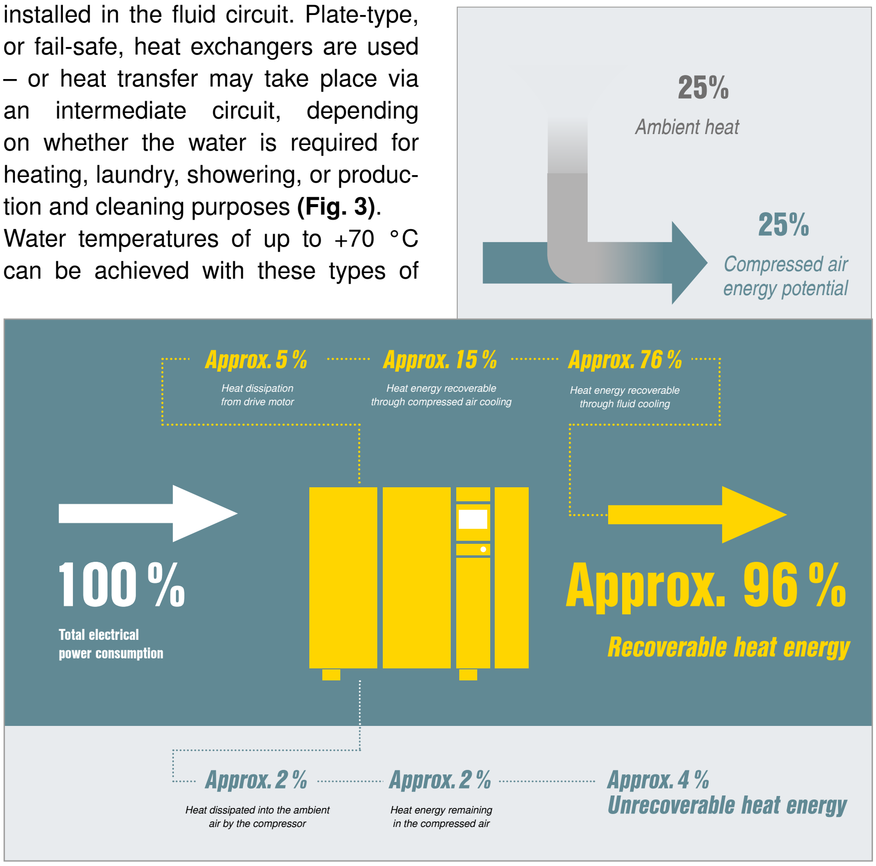



*Fig. 1: Heat-flow diagram*

### 3. Ensuring reliability

Normally, the compressor's primary cooling system should never be used both for cooling and as a heat recovery system. The reason for this is that if the heat recovery system fails, then compressor cooling and therefore

*Fig. 2: Correct connection of compressors to a heat recovery system*

compressed air generation is at risk. Taking this into consideration, an additional heat exchanger is installed in the compressor system specifically for heat recovery purposes. Compressor reliability is therefore safeguarded in the event of a fault; if heat is not dissipated via the heat recovery system's fluid/water heat exchanger, the compressor can revert to its primary air or water cooling system and so continue operating, thereby ensuring the compressed air supply.

**4. Up to 96% reusable heat energy**

The largest proportion of the energy supplied to a compressor with oil- or fluid-cooling and recoverable as heat – around 76% – is to be found in the compressor cooling medium; approx. 15% is contained in the compressed air itself and up to 5% is lost as heat through the electric drive motor. On a fully enclosed fluid-/oil-cooled rotary screw compressor, with targeted cooling even the losses from the electric motor can be recovered as heat energy. This brings the total proportion of supplied energy available to be reused as heat up to 96%. Of the remaining energy, 2% is lost through thermal radiation and 2% remains in the compressed air **(Fig. 1)**.

**5. Conclusion**

Recovering the heat of compression for a useful purpose is an intelligent way of improving the economics of compressed air generation and benefiting the environment at the same time; relatively little effort is involved. The investment is quickly recovered – depending on local circumstances, the purposes for which the heat is to be used and the method of recovery selected **(Fig. 4)**.

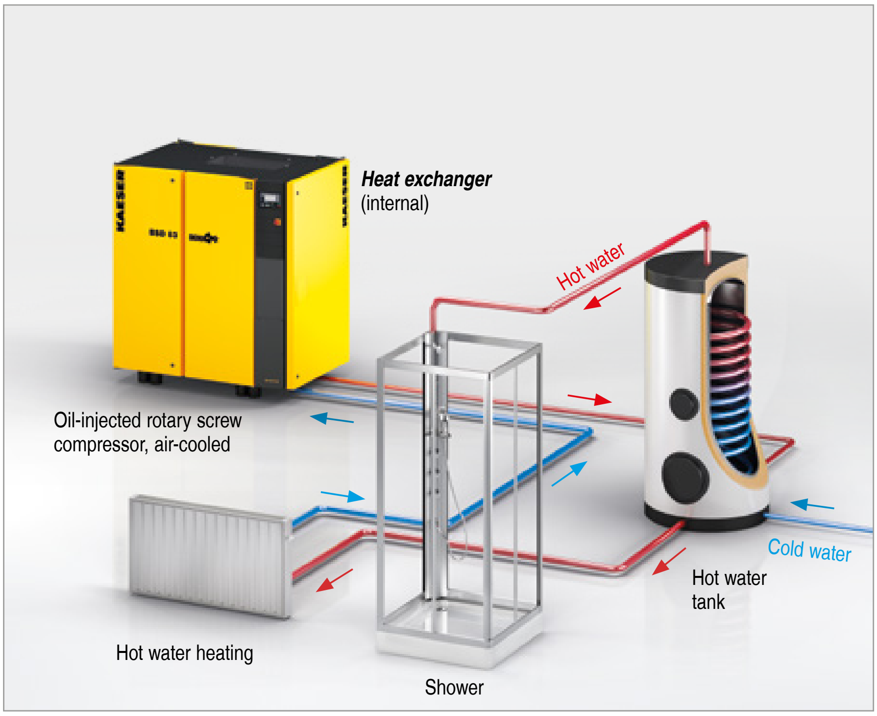



*Fig. 3: Heat recovery diagram for hot water usage*

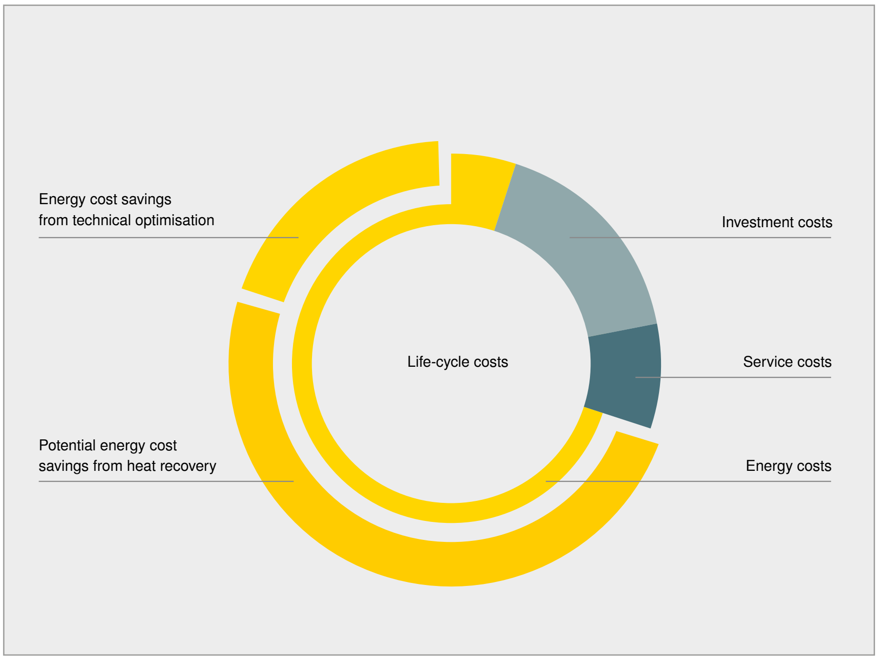



*Fig. 4: Heat recovery offers significant additional energy cost savings potential*

Chapter 9

# Planning a new compressed air network

Compressed air is an efficient source of energy, provided that its generation, treatment and distribution components are perfectly matched to one another. Moreover, in addition to the correct system design and equipment, appropriate dimensioning and installation of the compressed air network are also essential.

### 1. Economical compressed air generation

When the cost of energy, cooling medium, maintenance, and equipment depreciation has been taken into account, the cost of each cubic metre of compressed air generated is between 0.5 and 3 cents, depending on compressor size, utilisation, maintenance condition and model. Many operators place great importance on particularly efficient compressed air generation. This is the reason for the success of fluid-/oil-cooled rotary screw compressors: they can reduce compressed air generation costs by as much as 20%.

### 2. Influence of treatment on a compressed air network

Rather less consideration is given to treating the compressed air to suit the application. This is regrettable, since only correctly treated compressed air can reduce the maintenance costs for consumers and piping. Where pipework needs to transport humidity-laden, as-yet-undried compressed air, it is imperative that corrosion-resistant materials be used. Care must also be taken to ensure that inadequate pipework does not negatively affect the compressed air quality achieved by the treatment system.

#### *a) Refrigeration dryers reduce maintenance requirement*

Refrigeration drying provides compressed air treatment sufficient to meet 80% of all applications. Refrigeration dryers often eliminate the pressure losses associated with in-line filters in the piping network and consume only approx. 3% of the energy that the compressor would otherwise use to make up for these pressure losses. In addition, the costs saved on maintenance and repair of compressed air consumers and pipework can amount to ten times the average cost of refrigeration drying.

#### *b) Space-saving combined systems*

For smaller or decentralised applications, space-saving combined systems comprising a rotary screw compressor, refrigeration dryer and air receiver **(Fig. 1)** are available.

### 3. Planning and installing a compressed air network

Firstly, it must be decided whether it should be designed as a centralised or a decentralised system. A centralised supply is usually suited to smaller and mid-sized operations, since many of the problems that occur in larger centralised systems do not generally arise, e.g. high installation costs, risk of inadequately insulated outdoor piping freezing during winter, and increased pressure drop caused by longer pipe lengths.

#### *a) Correctly dimensioning the network*

A calculation is always required to correctly dimension the piping network.
This calculation should be based on a maximum pressure drop of 0.1 bar between the compressor and the compressed air consumers, plus the standard treatment system (refrigeration drying) and the switching differential of the compressors.
The following individual pressure losses should be taken into account **(Fig. 2)**:

| | |
|---|---|
| Main line (1) | 0.03 bar |
| Distribution line (2) | 0.03 bar |
| Connecting line (3) | 0.04 bar |
| Dryer (4) | 0.20 bar |
| Maintenance unit and hose (5) | 0.50 bar |
| **Total max.** | **0.80 bar** |

The importance of calculating pressure drop in the individual piping sections becomes apparent when they are itemised in this way. Shaped components and shut-off units should also be taken into consideration. Therefore, it is not enough simply to enter the number of metres of straight piping into a calculation formula or table; the actual technical flow length of the piping must be determined. During the initial system-planning phase, however, there is usually no overview of all shaped components and shut-off units available. For this reason, the technical flow length of the piping is calculated by multiplying the number of metres of straight piping by a factor of 1.6. The piping diameter can then easily be determined by referring to tried and tested formulae **(Fig. 3)** or design diagrams.
**A design can also be created via the KAESER Toolbox (https://www.kaeser.com/int-en/services/know-how/calculator)**


*Fig. 1: Modern AIRCENTER compact compressed air station for space-saving compressed air generation, treatment and storage*

#### *b) Installing energy-saving piping*

In order to save energy, the piping system should be laid out as straight as possible. Bends, such as when going around supporting pillars, can be avoided by arranging the piping in a straight line beside the obstruction.

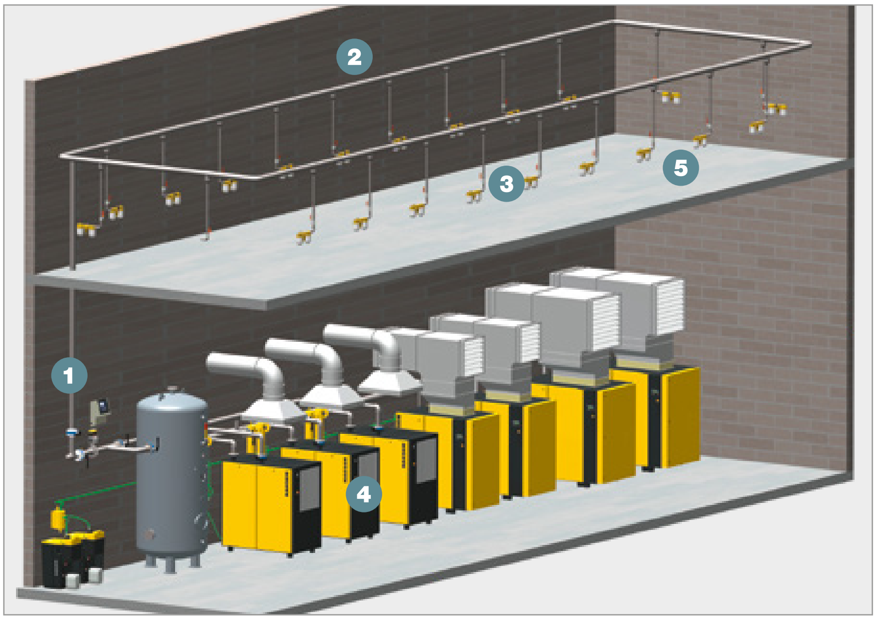



*Fig. 2: Main elements of a compressed air distribution system: Main line (1), distribution line (2), connecting line (3), dryer (4), maintenance unit/hose (5)*

Sharp 90° corners cause high pressure drops and should be replaced with large-radius 90° elbows. Instead of the commonly used water shut-off valves, ball or butterfly valves with full through-flow bores should be used.
In humid pipe sections, i.e. only in the compressor room in the case of modern compressed air stations, pipe connections to and from the main line should

*Approximation formula:*

$$d_i = \sqrt[5]{\frac{1.6 \times 10^3 \times V^{1.85} \times L}{\Delta p \times p_s}}$$

| | |
|---|---|
| *di* | *= Inner diameter of piping (m)* |
| *ps* | *= System pressure (absolute in Pa)* |
| *L* | *= Nominal length (m)* |
| *V* | *= Flow rate ($m^3$/s)* |
| *Δp* | *= Pressure loss (Pa)* |

*Fig. 3: Approximation formula for determining pipe diameters*

be made from above or at least from the side. The main line should have a gradient of 2 in 1000. The possibility of connecting a condensate drain should be provided at the lowest point in this line. In dry sections, the pipes can be placed horizontally with branch lines connected directly downwards.

***c) Which piping material is the best?***

No specific recommendation can be made with regard to material properties. However, due to the high thermal loads associated with compressors, metal piping should always be used. The procurement price alone provides little help in making a decision, since galvanised steel, copper and plastic pipes all cost around the same when material and installation costs are added. Stainless steel piping is approx. 20% more expensive. However, more efficient production methods have caused prices to drop recently.
Most manufacturers offer reference tables in which the optimal conditions for each piping material are given. It is advisable to study these tables before making a decision, taking into account the loads expected during future normal operation and then to create specifications for the pipework accordingly. This is the only way to ensure a truly effective selection.

***d) Important – correct pipe joining***

Traditionally, pipes are joined either through welding, gluing or screw connections with adhesive. Even if this makes it difficult to separate them again, one can be sure that such connections reduce possible leakages to a minimum. Nowadays, press connections on copper, stainless steel and carbon steel pipes are also widespread. The material used for the sealing O-ring depends on the flow medium and operating conditions. The quality of the connection is essentially determined by the pressing tool; auxiliary materials are not necessary when creating press connections.

Chapter 10

# Refurbishing a compressed air network

Year in, year out, thousands of euros are wasted due to ageing and/or poorly maintained piping networks which increase the energy requirement of the compressed air system. Resolving these deficiencies requires considerable thought and involves a lot of hard work. Here are some useful tips for correct refurbishment of a compressed air piping network.

**1. The basic requirement: Dry compressed air**

When planning a new compressed air network, many errors leading to problems in the future can be avoided. Refurbishment of an existing network is rarely straightforward and, above all, is pointless if the air being fed into it contains moisture. Before beginning a refurbishment, the first essential action is to ensure a centralised dryer unit.

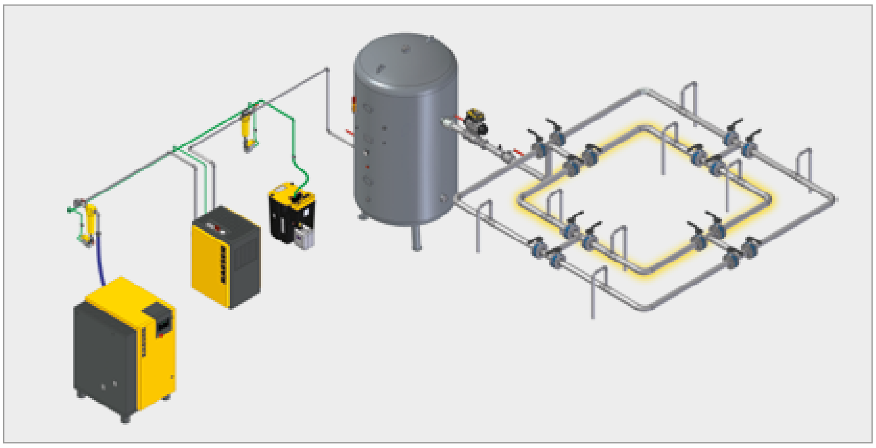


*Fig. 1: Refurbishment of a compressed air line via installation of a second ring line*

**2. What if there is an excessive pressure drop in the network?**

If the pressure drop in the piping network is excessive, even after a suitable treatment system has been installed, then the cause is down to deposits in the pipes. Contaminants entering the pipework with the compressed air form these deposits and reduce the flow cross section down to a minimum.

***a) Replace or blow out***

If the deposits are firmly encrusted, there may be no alternative but to replace the affected sections of pipe. However, it is possible to blow out the pipes if the flow cross section is only slightly narrowed by deposits, followed by thorough drying before bringing them back into service.

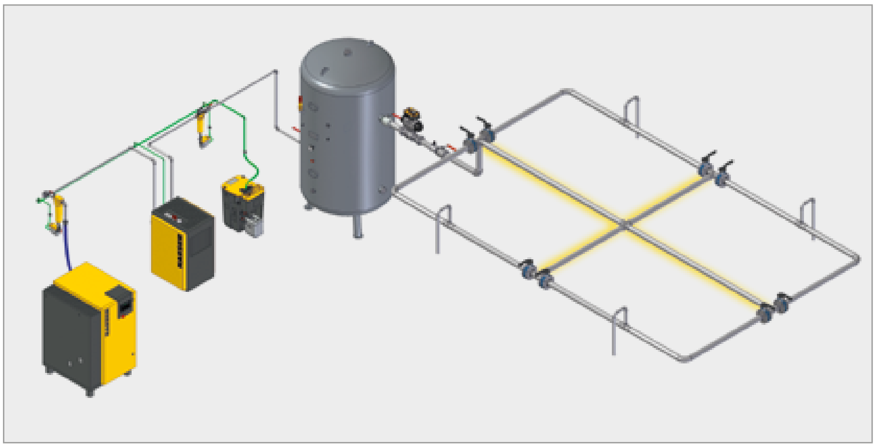


*Fig. 2: Expansion of pipework capacity using cross-connection lines*

***b) Installing supplementary lines***

A good way of increasing the flow cross section of a branch line is to install a parallel line connected to it. A supplementary ring line can also be installed if the inner diameter of the original ring has become too narrow **(Fig. 1)**. If correctly dimensioned, a double branch line or double ring system not only relieves the pressure drop problem, but also increases the reliability of the compressed air distribution network in general.

A further possibility for refurbishing ring lines is to expand the system by using cross-connection lines **(Fig. 2)**.

**3. Tracing and resolving leaks**

Of course, refurbishment only produces the best possible results if the leaks in the compressed air network have also been resolved as far as possible.

***a) Determining total leakage volumes***

Before searching for individual leaks in the network, the scope of the overall leakages should first be determined. This is achieved relatively simply: all compressed air consumers are switched off and then the cut-in times of the compressor measured over a specific period **(Fig. 3)**. The results are then used to determine the leakage volume as per the following formula:

$$VL = \frac{VC \times \sum t_x}{T}$$

**Key:**

**VL** = Leakage volume (m³/min)
**VC** = Flow rate of the compressor (m³/min)
**∑ tx** = t1 + t2 + t3 + t4 + t5 Time the compressor was run under load (min)
**T** = Total time (min)

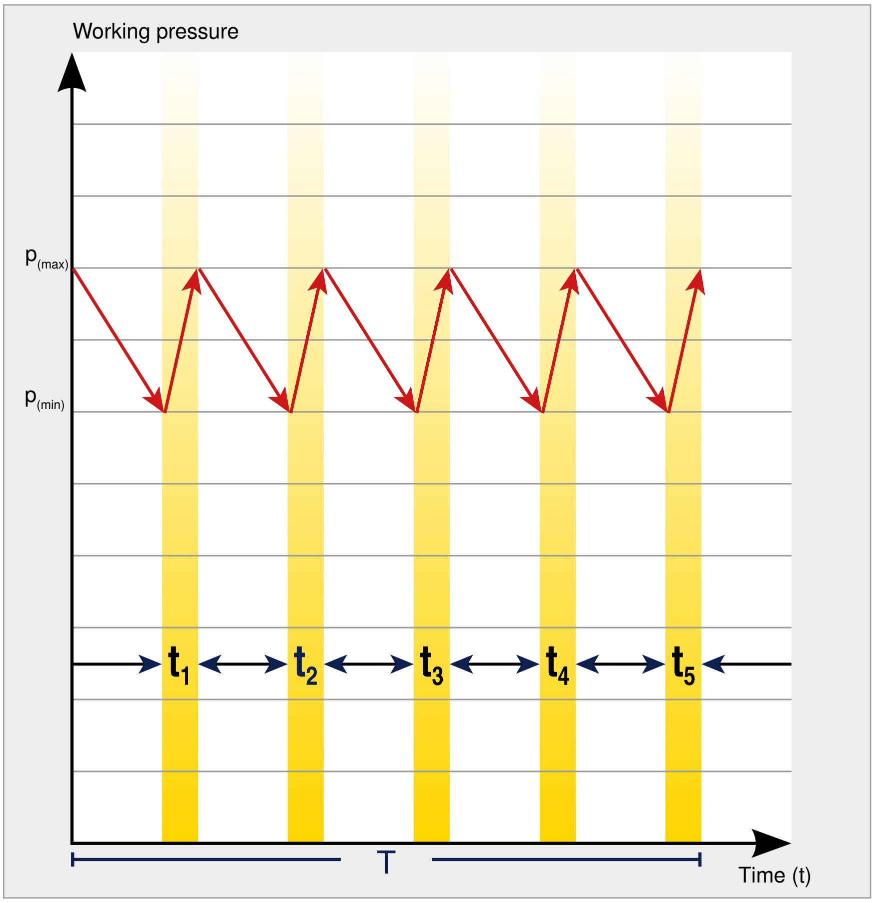



*Fig. 3: Determining leakages by measuring compressor cut-in times with all consumers switched off*

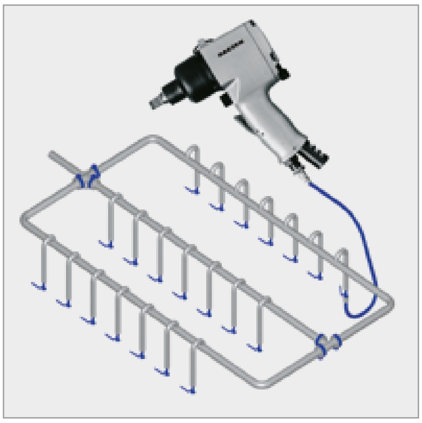


*Fig. 4: Leakage measurement of compressed air consumers + piping network*

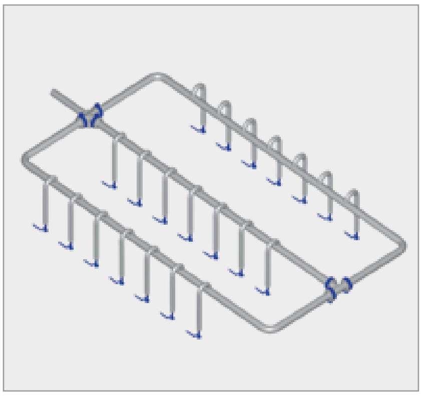


*Fig. 5: Leakage measurement of piping network*

***b) Determining consumer leakages***

In order to determine leakage losses in decentralised compressed air consumers, all pneumatic tools, machines and equipment should first be connected and the sum of all leakages measured **(Fig. 4)**. Then, the shut-off valves upstream of the consumer connections are closed and the leakages in the piping network measured again **(Fig. 5)**. The difference between total and network leakages are the losses from the compressed air consumers and their fittings.

**4. Where do most leakages occur?**

Experience shows us that around 70% of leakages occur in the last few metres of the compressed air network, i.e. at the discharge points. These leaks can usually be pinpointed with the help of soap suds or special sprays. The main pipework is only a source of significant leakage if an originally humid network equipped with old hemp seals is operated with dry compressed air and these seals consequently dry out after a period of time. To determine the precise location of leaks in the main piping network, the aid of ultrasonic equipment is recommended. When the last leak has been located and resolved, and the cross section of the pipeline is sufficient for the current air demand, then the old air network has (again) become an efficient compressed air distribution system.

Chapter 11

# Air Demand Analysis (ADA): Determining the current situation

Modern compressed air stations are usually highly complex systems. They can only be operated at maximum cost efficiency if this is properly taken into account during all stages of system planning, expansion and refurbishment. KAESER has developed a comprehensive service concept to aid these processes. It combines familiar elements such as compressed air components, customer consultation and advice with new advances in the information technology available for compressed air engineering.

The spectrum of compressed air applications is extremely broad, from A for automotive manufacturing to Z for zinc coating. However, a common prerequisite for the efficient use of compressed air is a dependable generation and treatment system that can deliver compressed air cost-effectively at precisely defined volumes and quality.

**1. Consultation influences cost efficiency**

A compressed air system only meets these requirements if it suits the application for which it is intended and matches the installation and ambient conditions under which it operates. In other words, the compressors, treatment equipment and pipework must be correctly dimensioned and there must be an efficient controller, suitable ventilation and appropriate condensate treatment; additionally, if possible, there should be a means of recovering and reusing exhaust heat from the compressors. All of these aspects are covered by the “KAESER Energy Saving System” (KESS). It comprises compressed air demand analysis, planning **(Fig. 1)**, implementation, training and customer service.

The decisive factors are the quality of the consultation and the selection of the correct technology, since the greatest potential for cost savings with any compressed air system lies in efficient energy consumption and maintenance requirement, rather than in the initial purchase price.

**2. Air Demand Analysis**

Detailed investigation into the user’s current and possible future compressed air demand forms the basis of every KESS analysis. This process, conducted by KAESER in the form of an ADA (Air Demand Analysis), takes into account different framework conditions depending on the user’s requirements.

***a) Designing a new compressed air supply***

When planning a new compressed air station, the future operator is first provided with a special design questionnaire **(Fig. 2)**. An experienced KAESER consultant then uses the information provided to determine what equipment would be required in order to meet the expected compressed air demand of the application in question. The questions cover every possible aspect of an efficient and environmentally friendly compressed air supply.

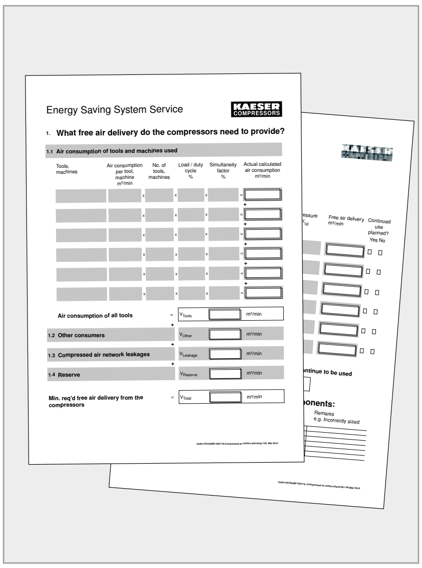



*Fig. 2: “Compressed air station” questionnaire for the collection of information regarding new and existing systems (see Annexe, page 56 f.)*

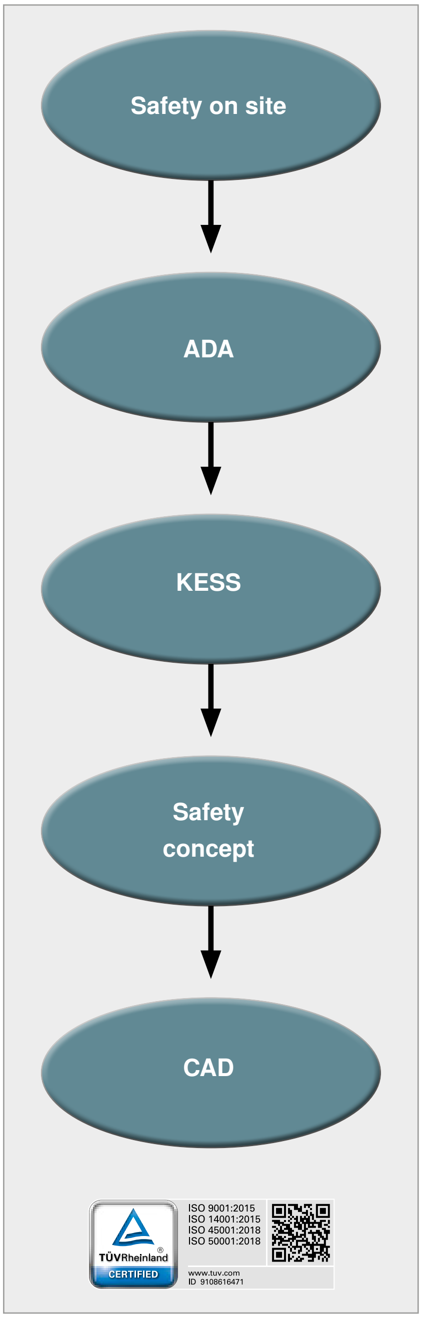



*Fig. 1: KAESER Kompressoren compressed air system analysis*

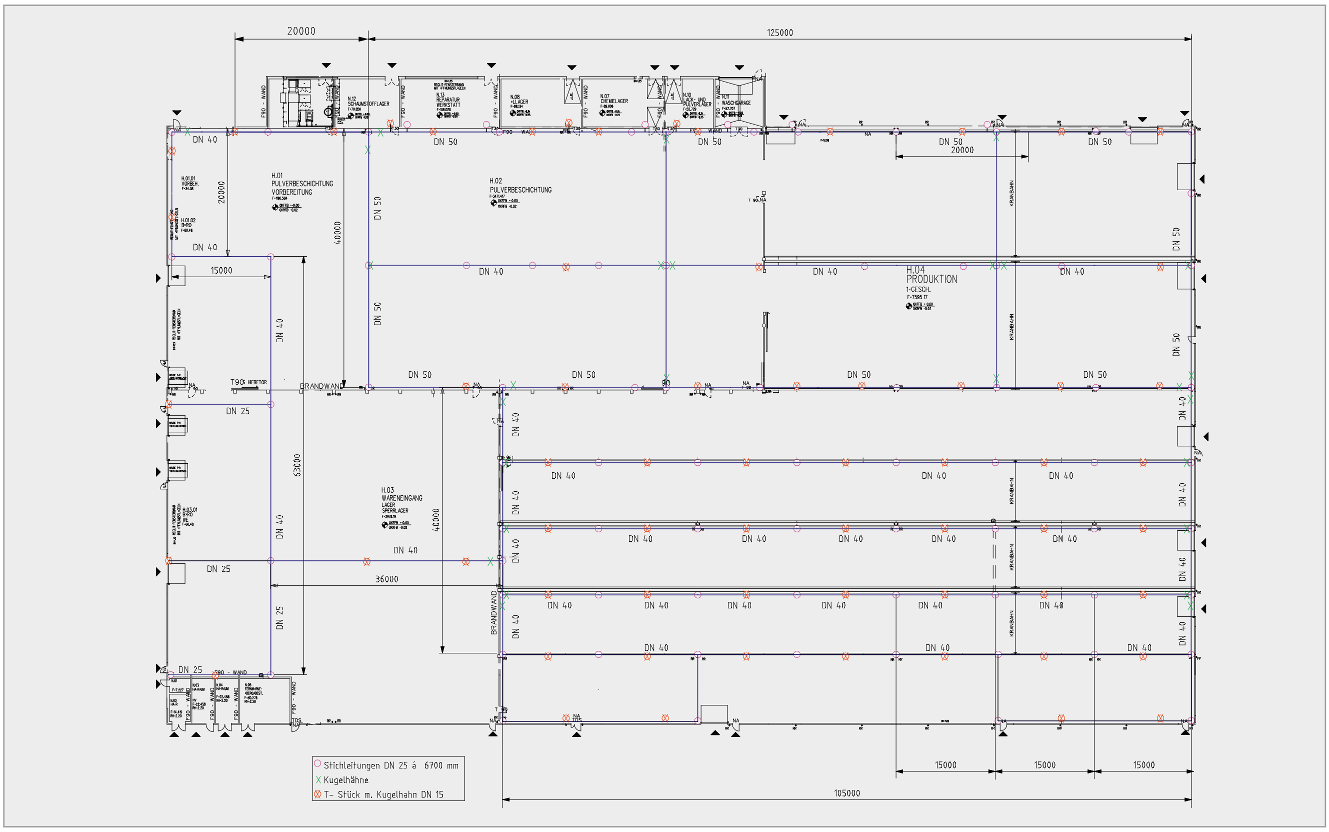



*Fig. 3: Floor plan of a company's compressed air piping system*

***b) Expansion and modernisation***

In contrast to new projects, expansion programmes involving existing systems can usually provide sufficient reference points for new, needs-based design solutions. KAESER provides the user with measuring processes and equipment that can be used to precisely determine the compressed air demand in various locations and at different times. It is important to determine maximum and minimum values as well as averages **(Fig. 8, page 31)**.

***c) Testing the efficiency of an existing air station***

It is recommended that the efficiency of an existing air system be checked from time to time with the help of a computer-aided analysis system, in order to determine whether the compressors are (still) correctly loaded, whether any master control systems are (still) correctly programmed and whether leakage rates remain within tolerance. ADA should also be used if older compressors are to be replaced by new ones. This will provide an opportunity to avoid potential errors when selecting the correct amount of power, improve the compressors' operating characteristics (partial load range!) and select the optimal master control system.

***d) Changes in operating conditions***

It is well worth consulting a specialist when the conditions change under which a compressed air system is operated. In many cases, simple changes to treatment methods or pressure matching can be made to suit the new circumstances, achieving significant cost savings.

**3. Operator information**

***a) Layout plan***

A layout plan of the operation should be available for general orientation **(Fig. 3)**. It should show the air station's main compressed air line, connecting lines and feed-in points. Details of pipe dimensions and materials, the main air consumption points and any discharge points for air at special pressures and quality must also be shown.

***b) Compressed air applications***

As compressed air is a highly versatile medium, it is essential for the user to provide exact details regarding the specific application: for example, whether the compressed air is to be used as control air, for surface treatment, to rotate tools, for cleaning purposes or as process air, etc.

***c) Installed compressors***

As well as their model and type, the technical specifications for the existing compressors should also be provided, such as working pressure, flow rate, power consumption, type of cooling and if any heat recovery is installed.

***d) Compressed air treatment***

As far as treatment is concerned, it is important to know whether the compressed air is treated centrally or locally and which quality classes are required. Obviously, the technical specifications for the components should be listed and a flow diagram provided as an overview **(Fig. 4, page 30)**.

***e) System control/monitoring***

As the efficiency of a compressed air station is significantly influenced by both the characteristics of the individual compressors and the way in which they interact with one another, it is also

# Air Demand Analysis (ADA): Determining the current situation

important to include details regarding the control and monitoring systems used.

**4. Discussions between operator and specialist**
Once all of the above information has been made available, the compressed air specialist should be familiarised with the relevant documents and then a discussion should follow detailing any problems with the compressed air supply. Such issues may include: low or fluctuating pressure, poor air quality, inadequate utilisation of compressors or problems with cooling.

**5. Inspection of the compressed air system**
The most revealing phase in the process is the inspection of the compressed air system. This should always start in the most critical zone, i.e. where the greatest pressure drops or poor air quality are to be expected **(Fig. 5)**. Experience shows that these are usually the compressed air discharge points.

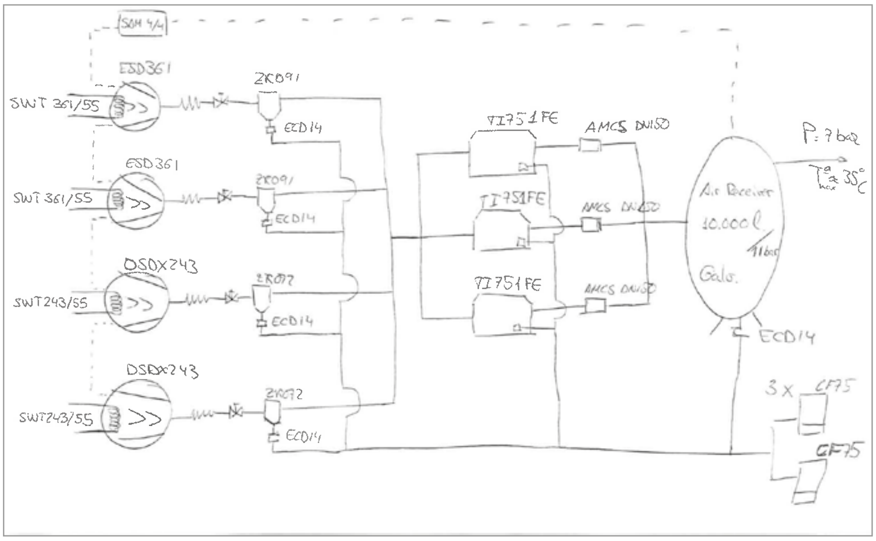



*Fig. 4: Hand-drawn flow diagram of a compressed air station*

***a) Connection hoses, pressure regulators, water separators***
Often, the hose connections to the compressed air consumers are particularly susceptible to leaks. These areas should be checked for damage and sealing problems. If pressure regulators are installed, their settings (inlet and outlet pressure) should be checked under load conditions **(Fig. 6)**. Water separators installed upstream of the pressure regulators should be checked for fluid accumulation and contaminant build-up.
The same applies to outlet pipes that lead vertically downwards **(Fig. 7)**.

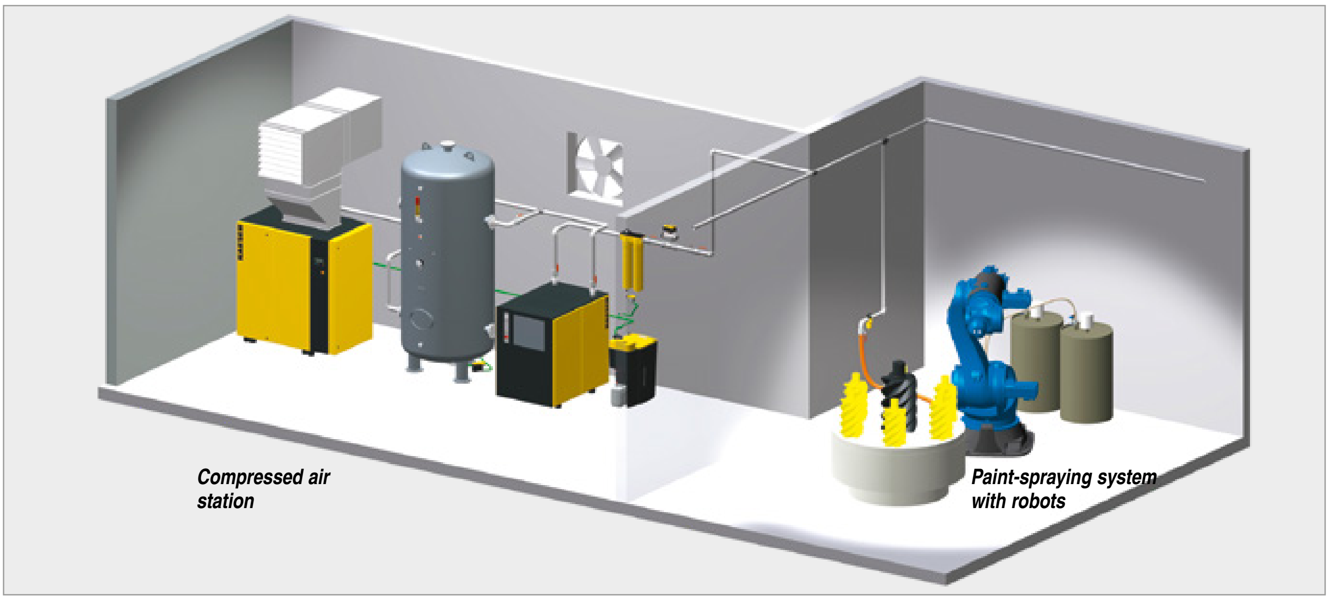



*Fig. 5: Insightful: Compressed air system inspection*

*Fig. 6: Maintenance unit with pressure regulator*

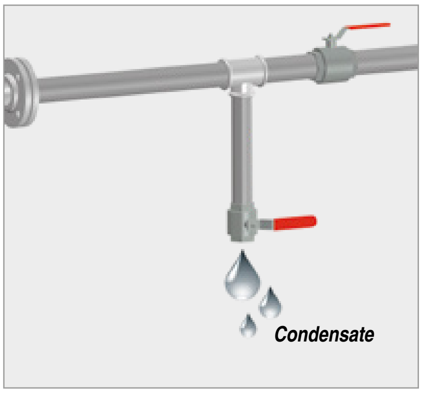



*Fig. 7: Check compressed air outlet lines for moisture*

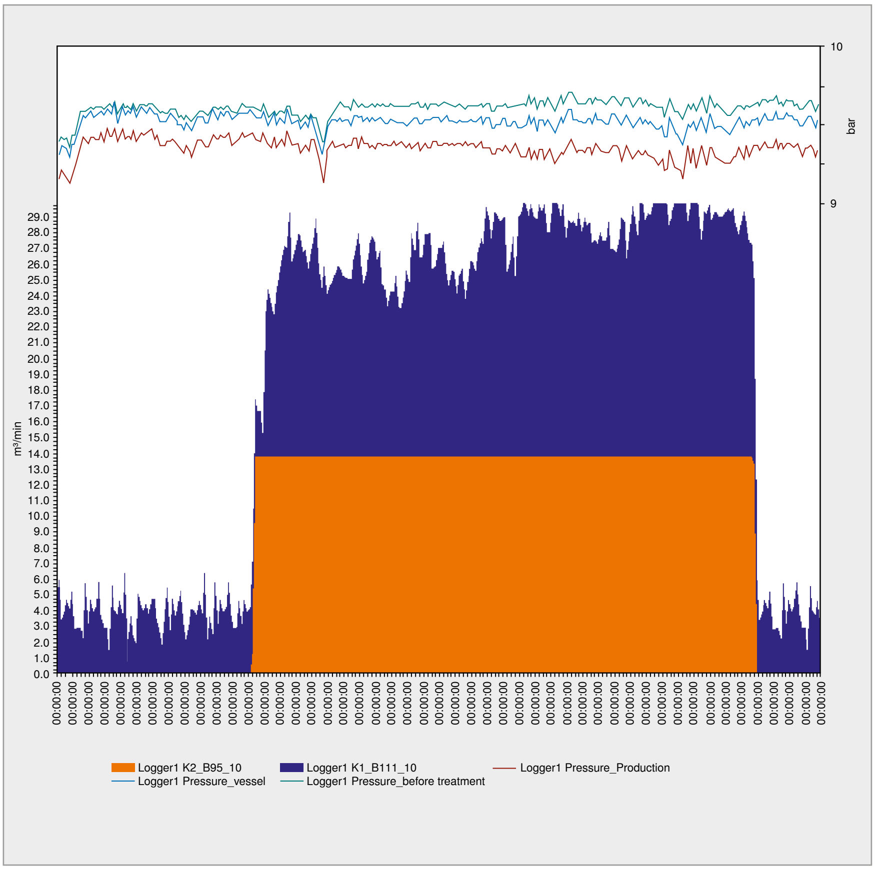



*Fig. 8: An industrial operation's pressure and compressed air consumption structure measured with ADA*

### *b) Shut-off devices*

The condition of the connection lines leading away from the main network has a significant influence on system efficiency. Shut-off devices also play an important role: they should be sufficiently dimensioned, full-flow ball / butterfly valves, not inefficient water stop or angle valves.

### *c) Main pipe network*

The most important point is to determine the causes of pressure drops, such as narrower sections of the network.

### *d) Compressed air treatment system*

The most important inspection criteria here are the pressure dew point achieved (degree of dryness) and the pressure drop across each component. Further quality checks may be required, depending on the application.

### *e) Compressed air station*

Of course, the compressed air station itself may have its own shortcomings. In particular, the installation of the compressors, ventilation system, cooling and pipework should all be checked, as should the overall switching pressure differential of the compressors, the size of the air receiver and the location of the measuring points from which the compressors are controlled.

### *f) Determining measuring points*

Once the inspection has been completed, the specialist and the operator together decide at which points the measurements for the demand analysis should be taken. The minimum requirement is to take measurements upstream of and downstream from the treatment system and at the outlet of the compressed air network.

## 6. Measuring pressure and air consumption (ADA)

When measuring pressure and air consumption, the operation of the compressed air station is monitored over a period of at least 10 days with the aid of advanced data-logger technology. The data logger collects all relevant measured values and transfers them to a PC, which then uses these data to create a detailed consumption profile **(Fig. 8)**. The graph shows pressure drops, fluctuations in pressure and demand, idling profiles, load and standstill periods for the compressors, as well as the relationship of individual compressor performance to respective air consumption. In order to complete the picture, leakages also have to be determined during this measuring process. This is conducted as described in **chapter 10, page 26/27** and requires selective shut-off of particular areas of the network over the course of a weekend.

Chapter 12

# Determining the most efficient design

With meticulous compressed air system optimisation, it is possible to save more than 30% of the average compressed air costs for a European industrial operation. Approximately 70 to 90% of their costs are accounted for by their energy requirement. In view of increasing energy prices, it is therefore more important than ever for users to determine the most efficient compressed air concept for their business.

Using the optimisation calculation from the KAESER Energy Saving System (KESS), it is possible to compare various compressed air supply system solutions for the respective application and identify the most suitable one. In the case of new systems, the completed design questionnaire provides the basis for this calculation. For existing compressor stations, the calculation is based on the characteristic daily profile determined by the Air Demand Analysis (ADA) **(see page 31, Fig. 8)**.

**1. Computer-aided analysis**

Before an existing station can be optimised, all of the technical data relating to it and any available new variants are entered into the program. KESS then calculates the optimum system design and the potential cost savings. The particular energy consumption at a defined air demand point, including all losses, is also calculated.

What's more, it is possible to obtain a precise picture of the specific package input power profile for the compressor station throughout the entire running period **(Fig. 1)**, meaning that any weak points in partial load operation can be detected in advance and resolved. The overall result is a clear statement of the potential cost savings and the amortisation period.

**2. It's the right mix that counts**

In most cases, a precisely coordinated configuration comprising compressors of different capacities proves to be the best solution. This mix generally consists of large base load and standby compressors, combined with smaller peak load machines.

The task of the master controller is to ensure the most balanced specific package input power requirement possible. To do this, it must be able to automatically select the most energy-efficient combination of base load and peak load machines from up to 16 compressors, whilst keeping within the smallest possible pressure fluctuation range above the required pressure without dropping below it. Intelligent master control systems such as the SIGMA AIR MANAGER 4.0 are capable of meeting these complex requirements. They can also be connected via a KAESER-specific network to central control systems, compressors and other components such as condensate drains, dryers, etc., allowing data to be exchanged.

**3. Structural optimisation**

A newly designed or modernised compressor station should make optimum use of the space in which it is installed. Modern design systems such as those used by KAESER provide valuable support in this regard. During the design process, they not only make use of floor plans and P & I diagrams (flow diagrams), but advanced 3-D computer-generated plans and animations as well. This means, for example, that it is often possible to take advantage of efficient air-cooling despite cramped conditions in the compressor room. This can save between 30 and

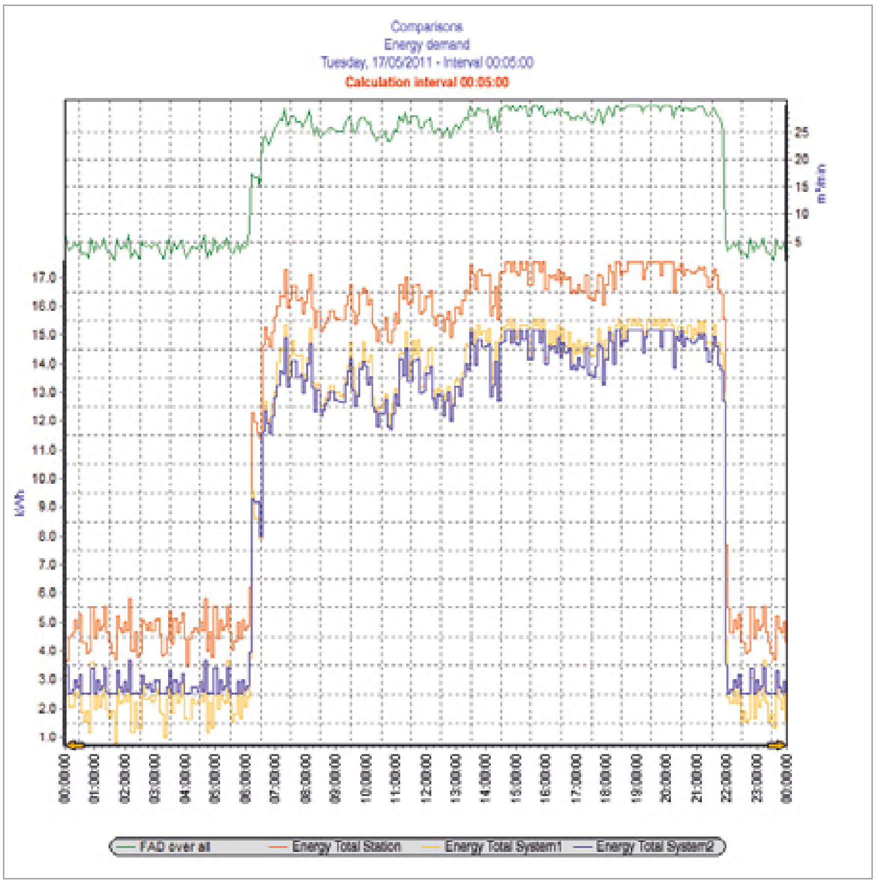



*Fig. 1: Energy consumption comparison of an existing compressed air station versus new, alternative systems during a working day, dependent upon air demand*

40% of the costs normally associated with water-cooling. **(Figs 2a to c)**.

**4. Operational optimisation and controlling – Compressed air management**

In order to ensure a cost-efficient compressed air supply over the long term, an optimised cost/use ratio and complete transparency via an effective control system are essential. This is where KAESER's integrated, industrial PC-based SIGMA CONTROL comes into to its own, as it features five pre-programmed control modes and is able to gather data and transfer them to a data network. At the master controller level, a further industrial PC is used: the SIGMA AIR MANAGER 4.0 (see diagram on page 18/19). Its task, in addition to optimised control and monitoring of the air station, is to collect and process all relevant data and, where applicable, pass these on to a central control system. By means of visualisation via Internet technology, SIGMA AIR MANAGER 4.0 provides an overview on demand of all components in the station and their key operating data. This shows at a glance whether the system is functioning perfectly, whether maintenance or fault messages are pending and how high the working pressure is.

To reduce both the environmental impact and costs of a business, the DIN EN ISO 50001 standard defines how companies should systematically and continuously improve their energy efficiency. Compressed air management systems such as the SIGMA AIR MANAGER 4.0 can provide effective, time-saving support when producing the associated certification reports. They provide secure storage of operating data from the compressed air system, as well as supplying key performance indicators, detailed analyses and energy balance reports.

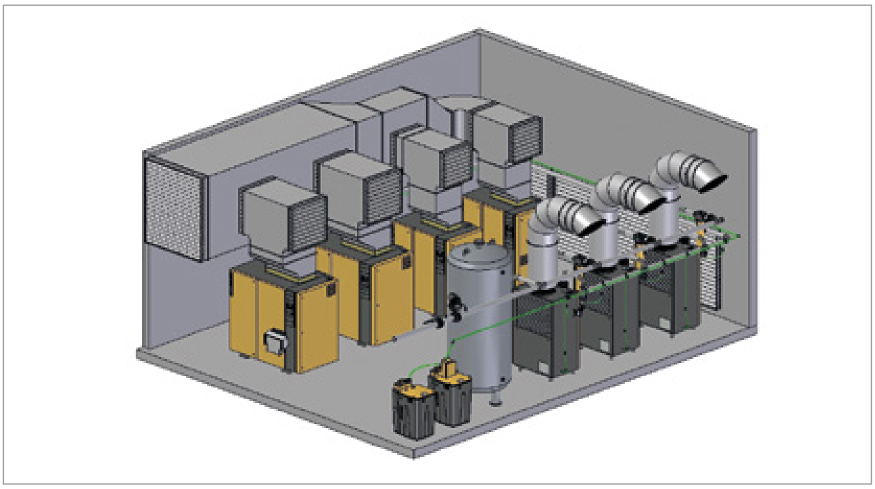


*Fig. 2a: CAD-optimised 3-D planning of a compressed air station*

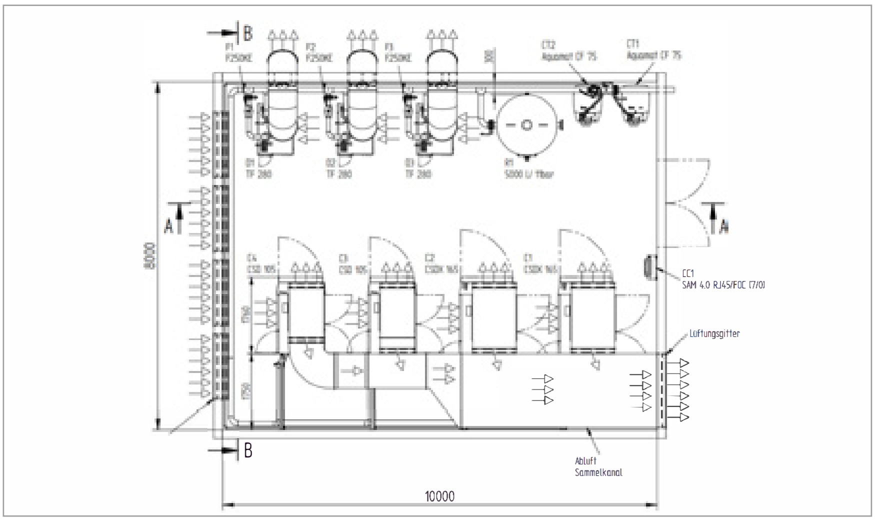



*Fig. 2b: Floor plan of a compressed air station*

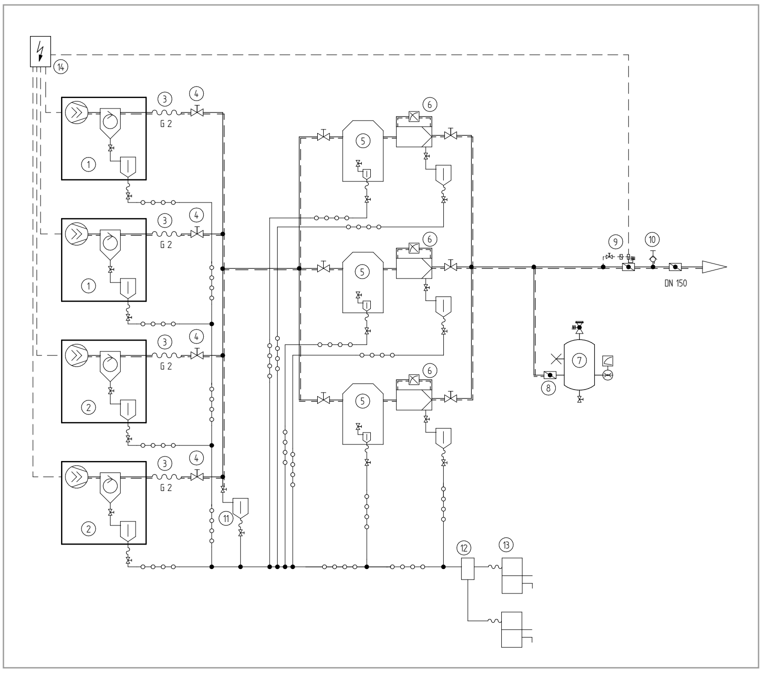



*Fig. 2c: P&I diagram for a compressed air station*

Chapter 13

# Efficient compressed air station cooling

Compressors convert 100% of the electrical power supplied to them into heat. Even a relatively small 7.5 kW compressor generates enough surplus thermal energy to heat a typical family home. This is why efficient cooling is essential for reliable operation of a compressed air station.

The exhaust heat generated by compressors is an ideal means of saving energy. With the help of a heat recovery system, up to 96% of the energy supplied to the compressor can be recovered and reused, significantly reducing the costs of compressed air generation (see chapter 8, page 22). However, even for compressed air systems equipped with heat recovery, an effective cooling system is required. The costs for air cooling can be up to 30% lower than those for water-cooled systems. This is why air-cooled systems should be given preference wherever possible.

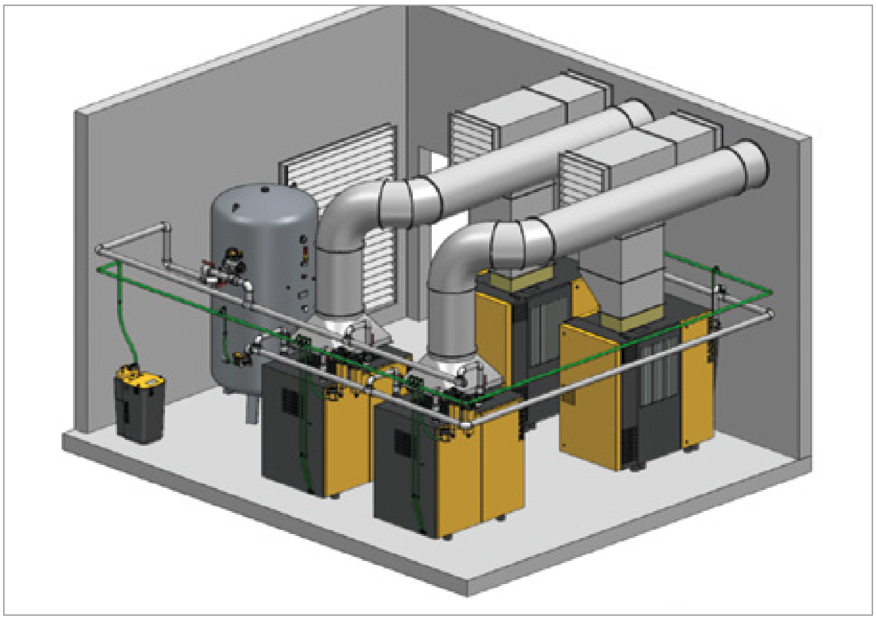


*Fig. 1: Example of a compressed air station with exhaust air system and thermostatically controlled supplementary ventilation for the refrigeration dryers*

### 1. The compressor environment

#### 1.1 Clean and cool is best

The Employer's Liability Insurance Association rule "Operation of work equipment" (DGUV rule 100-500 / BGR 500, section 3) states: "In general, the ambient temperature should not exceed +40 °C for stationary air compressors with oil-lubricated pressure chambers and air cooling." Furthermore, "the intake openings on air compressors should be arranged in such a way that dangerous admixtures cannot be drawn in." These are minimum requirements, the purpose of which is to keep the risk of accidents as low as possible. Cost-efficient, low-maintenance compressor operation, however, demands rather more.

#### 1.2 The compressor room is not a storage area

The compressor room should be kept free from extraneous equipment, dust and other contaminants; the floor should also be abrasion-resistant if possible. Under no circumstances must cooling air, or the air for compression, be drawn into the compressor room from an environment contaminated with dust, rust particles or similar without the use of intensive filtration. Even under normal operating conditions, intake and cooling air should be cleaned using appropriate filters.

#### 1.3 A suitable and constant temperature

Temperature has a considerable influence on the reliability and maintenance requirement of compressors; intake and cooling air should be neither too cold (<+3 °C) nor too hot (>+40 °C). For example, summer sun shining on the south- or west-facing walls of a building can increase the room temperature considerably; even at temperate latitudes, room temperatures can reach over +40 °C. For this reason, apertures for inlet and cooling air should be located in shaded areas and not in direct sunlight. The correct size for the apertures is based on the power of the compressors installed and the type of ventilation used.

### 2. Ventilating the compressor room

No matter whether air- or water-cooled compressors are used, suitable ventilation of the compressor room is essential. Whichever the case, radiant heat within the compressor unit and the exhaust heat from the electric motor must be conveyed away. This corresponds to approximately 7% of compressor drive power.

### 3. Different methods of ventilation

#### 3.1 Natural ventilation

Cooling air is drawn in by the compressor, heated, and then rises upwards due to the prevailing overpressure, leaving the compressor room through an aperture placed near the ceiling **(Fig. 2)**. This simple kind of ventilation can only be used, however, in exceptional cases and for compressor powers below 5.5 kW, since even sunshine or wind pressure on the exhaust aperture can disrupt this natural form of ventilation.

### 3.2 Forced ventilation

This method uses a forced flow of cooling air. Ventilation is thermostatically controlled to prevent the temperature in the compressor room from falling below +3 °C during colder times of year. Low temperatures negatively affect the performance of the compressors, condensate drains and treatment equipment. Thermostatic control is necessary because, with forced ventilation, the compressor room is subjected to slight negative pressure which prevents hot air from flowing back into the room. There are two methods of forced ventilation:

#### 3.2.1 Ventilation with an external fan

A external fan installed in the exhaust aperture of the compressor room and fitted with thermostatic control **(Fig. 3)** expels the heated air. An important requirement for this type of ventilation is that the cooling air intake aperture is sufficiently dimensioned (below right in the illustration); if it is too small, it could cause too high a negative pressure, resulting in excessive and noisy airflow. This would put cooling of the station at risk. The ventilation must be designed in such a manner that the rise in room temperature caused by compressor exhaust heat does not exceed 10 K / the max. permissible ambient temperature. Otherwise, a thermal short circuit may occur and cause the compressor to malfunction.

#### 3.2.2 Ventilation via exhaust air duct

Modern, fully encapsulated rotary screw compressors provide an almost ideal way of ventilation by means of exhaust air ducting: the compressor draws inlet air in through an aperture and discharges heated exhaust air into a duct that conveys it directly out of the compressor room **(Fig. 4)**. The advantage of this method is that the temperature of the cooling air flow can be allowed to rise significantly higher, to an approx. 20 K increase. This reduces the volume of cooling air needed. Normally, the standard fans fitted to compressors have sufficient residual thrust to force the exhaust air into the ducting and outside. This means that, in contrast to ventilation with an external fan, no additional energy is required. This applies only, however, if the residual thrust of the fans is sufficient. Ideally, the exhaust duct should be equipped with a thermostatically controlled recirculation air louvre **(Fig. 5)** to prevent the compressor room from cooling down excessively during winter. If air-cooled dryers are also installed, then the compressors and dryers should not be permitted to influence one another's air flows. At temperatures above +25 °C, it is recommended to increase the cooling air flow rate with the addition of a supplementary external fan or thermostatically controlled exhaust air system for the refrigeration dryers **(Fig. 1)**.

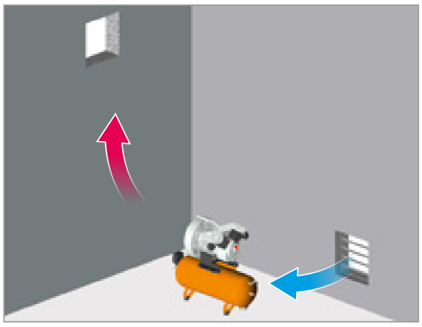


*Fig. 2:* Natural ventilation for compressors up to 5.5 kW

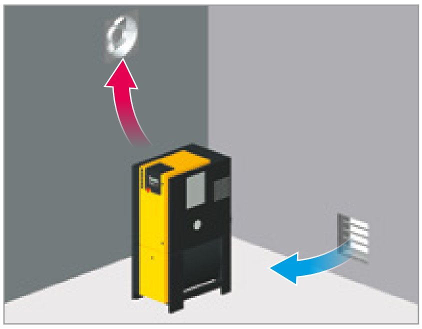


*Fig. 3:* Forced ventilation with fan for compressors *from 5.5 to 11 kW*

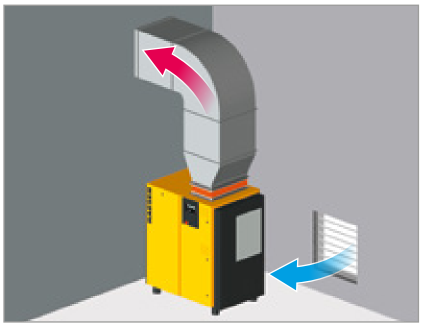


*Fig. 4:* Forced ventilation with exhaust air duct for compressors *from 11 kW*

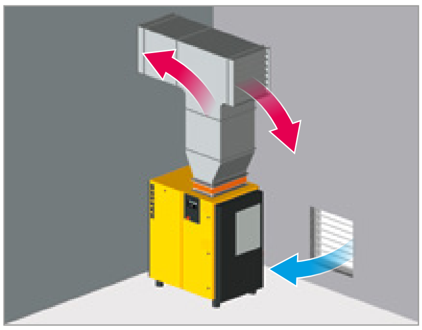


*Fig. 5: A thermostatically controlled recirculation air louvre directs hot exhaust air into the compressor room in winter*

Chapter 14

# Ensuring long-term dependability and cost optimisation

On pages 24 to 27, we covered the aspects that need to be taken into account when installing new and refurbishing existing compressed air networks, and how an efficient compressed air system should be planned and designed. Energy- and cost-conscious planning and implementation, however, only take us halfway. In order to ensure a cost-effective compressed air supply over the long term, efficient operation of the system is vital.

Maximum compressed air efficiency brings triple savings: security of supply increases, whilst compressed air costs and energy consumption decrease significantly. The efficiency potential is impressive, to say the least: one estimate shows that air compressors in Europe consumed 133 billion kWh in 2020. At least 30% of this energy could be saved **(Fig. 1)**.

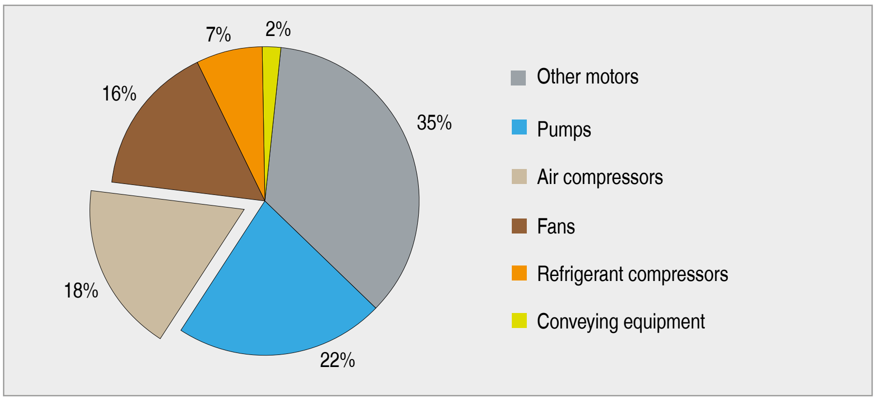



*Fig. 1: Estimated share of the energy consumption of electric drives in industrial operation attributed to air compressors*

### 1. What does optimum efficiency mean?

The cost efficiency of a compressed air system is reflected by its cost structure. The achievable optimum varies according to the company and its production. Critical factors include compressor service life, pressure level and other commercial parameters. Here is an example of an optimised system with an air-cooled compressed air station: service life 5 years, electricity price 15 cents/kWh, interest rate 6%, 7 bar working pressure, compressed air quality as per ISO 8573-1: residual dust content Class 1, residual moisture content Class 4, residual oil content Class 1. The example shows us that, even under optimum conditions, energy consumption still takes up the lion's share of total compressed air costs at around 70% **(Fig. 2)**. A study by the Coburg University of Applied Sciences under the "Efficient compressed air" initiative highlighted the deficiencies of compressed air stations in use in Germany **(Fig. 3)**.

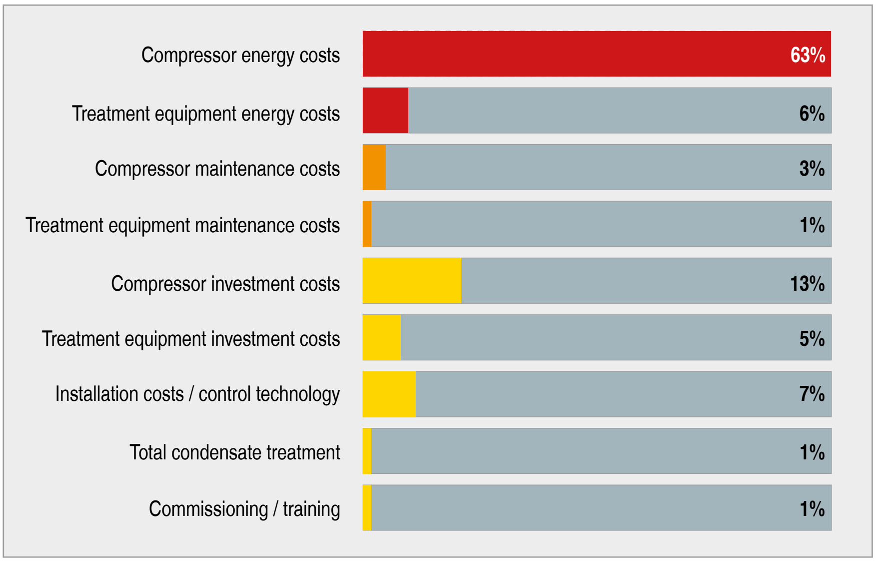



*Fig. 2: Cost structure of an optimised compressed air system*

### 2. Maintaining cost efficiency

Anyone interested in achieving a cost-efficient compressed air supply for the long term should consider the following points carefully:

#### 2.1 Demand-oriented maintenance

Internal compressor controllers such as the SIGMA CONTROL 2, and compressed air management systems such as the industrial PC-based SIGMA AIR MANAGER 4.0, provide precise information regarding the maintenance intervals for the components that constitute an air station. This has made it possible to carry out preventive maintenance and demand-oriented service work, resulting in lower maintenance costs, as well as increased efficiency and reliability of both the compressed air supply and the production operation as a whole.

### 2.2 Matching compressed air consumers

It is only too easy to make "savings" for compressed air generation and consumption in the wrong places, e.g. to use budget-priced production machines that require a higher working pressure. The cost of generating the extra pressure required / expanding the compressed air system would quickly exceed the extra cost for a more efficient machine operating with a lower working pressure of e.g. 6 bar. For this reason, guidelines should be issued for the procurement of production machines that take both the power supply and the compressed air supply into account.

### 2.3 New production-related requirements

#### 2.3.1 Compressed air consumption

***a) Changes in production***

In most production facilities, compressed air demand fluctuates throughout the day. This is often not given sufficient consideration, so that changes to a production process may result in compressors suddenly operating far below capacity in one shift, yet being unable to cover demand in others, to the extent that even the reserve capacity is exhausted. The compressed air supply should therefore be designed to accommodate any such changes.

***b) Expansion of production***

In this case, not only the compressor power ratings but also the pipework and the compressed air treatment equipment must be adapted to meet the new conditions. If production capacity is to be increased by refurbishing an existing compressor system, it is advisable to precisely measure and document the compressed air consumption of the existing system and thereby obtain as much detailed information as possible in order to be able to adapt the supply accordingly.

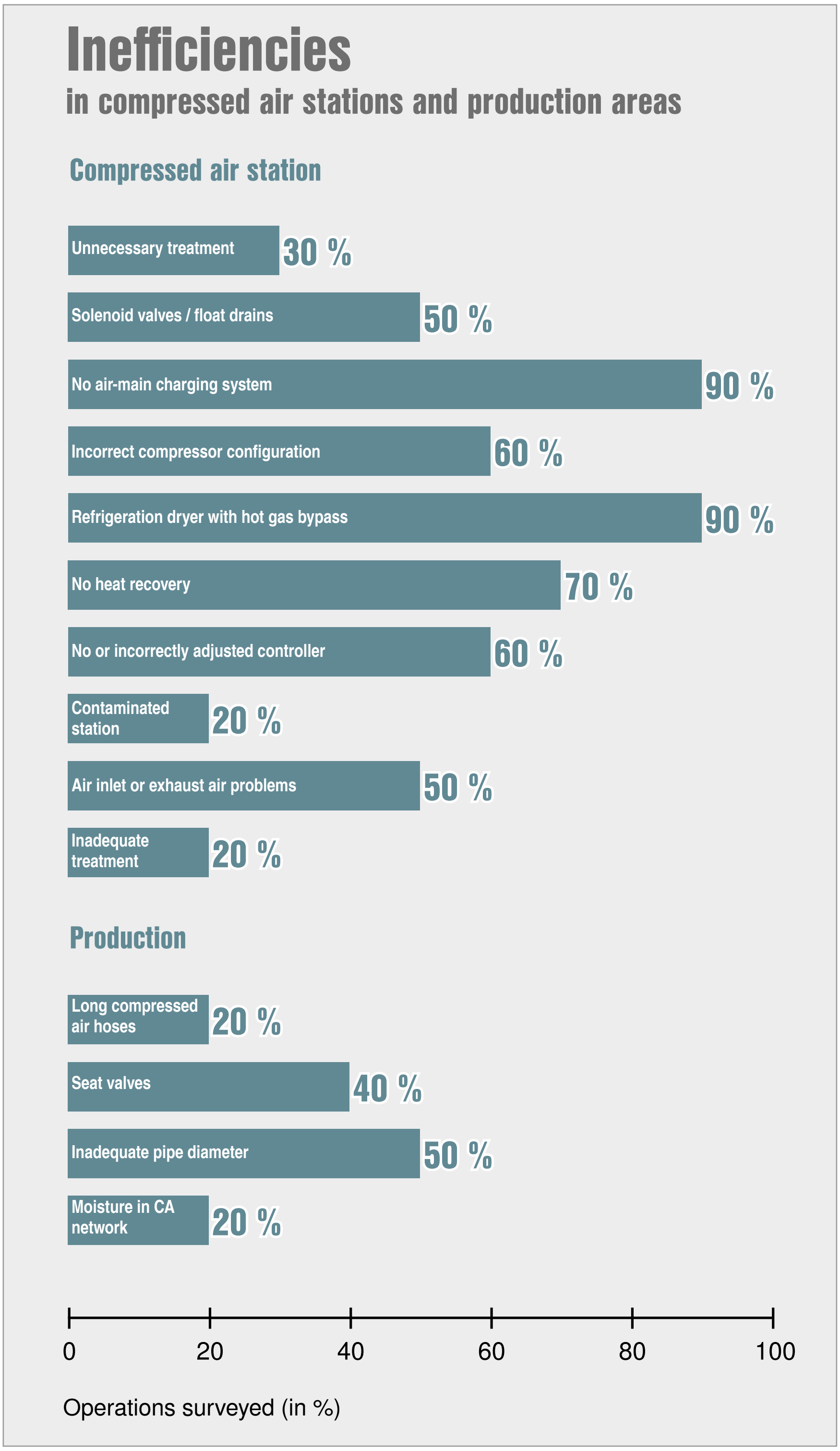



*Fig. 3: Summary of results from the compressed air audits performed by KAESER KOMPRESSOREN within the framework of a study by the Coburg University of Applied Sciences under the "Efficient compressed air" campaign*

# Ensuring long-term dependability and cost optimisation

### 2.3.2 Reliability of supply

It is usual to include a standby compressor in a compressed air station. However, when it comes to compressed air treatment, safety reserves are often dispensed with. The result is that when consumption rises, the standby compressor cuts in, but because of insufficient treatment capacity, the compressed air quality deteriorates. For this reason, a treatment unit (dryer/filter) should be planned for every standby compressor.

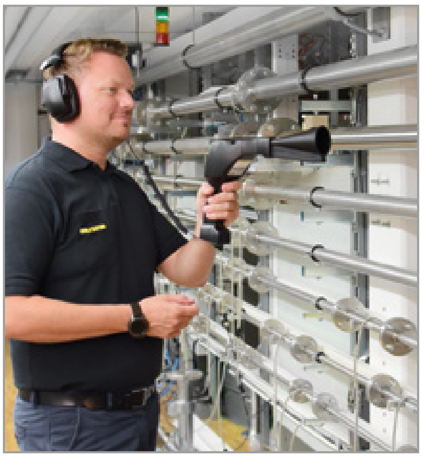


*Fig. 4: Locating leakages using ultrasound*

### 2.3.3 Changes in compressed air quality

If higher air quality is required, the procedure differs depending on whether all areas of production are affected or only one specific area. In the former case, it is not enough to simply re-equip the central compressed air treatment system. The pipework, which previously transported air of lower quality, will have to be cleaned or renewed. In the latter case, a separate treatment system that can provide the required quality is recommended. Airflow through this separate system should be limited, in order to protect it. This ensures that the treatment system cannot be "overrun" by an increase in compressed air volume above that for which it was designed.

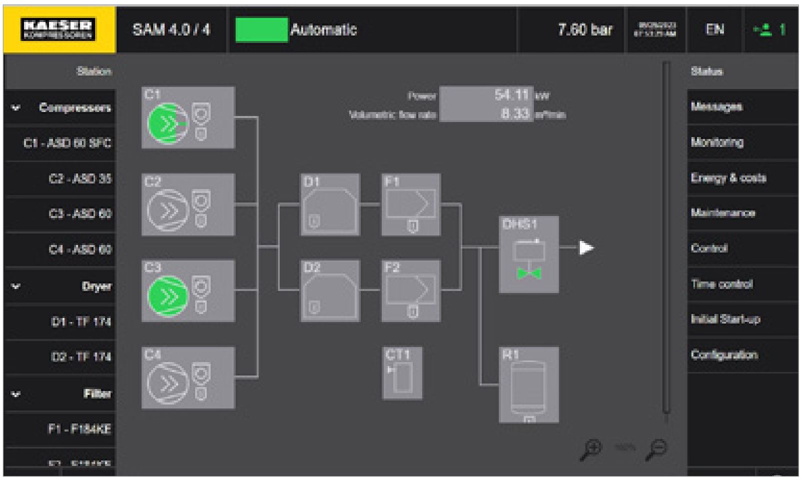



*Fig. 5a: Management system: Station and status overview*

### 2.4 Monitoring leaks

No matter how well maintained, leakages occur in every compressed air network and can lead to considerable energy losses. The main cause is wear on tools, hose connections and machine components. This is why it is vital to keep track of such problems and take prompt action whenever they occur. It is advisable to regularly measure overall leakages with the aid of modern control systems such as the SIGMA AIR MANAGER 4.0. If an increase is recorded, the leaks must be traced and resolved **(Fig. 4)**.

### 3. Cost management ensures efficiency

Information gathered through analysis during the planning phase – updated as


*Fig. 5b: Flow rate and pressure curve with pressure performance monitoring*


*Fig. 5c: Monitoring: Specific package input power*


*Fig. 5d: Energy and costs/time comparison*


*Fig. 5e: Maintenance overview*

necessary – is also relevant for future system operation. Once the system is installed and running, however, no special analysis is needed in order to acquire data, since this task is taken on by systems such as the SIGMA AIR MANAGER 4.0. This forms the basis for comprehensive compressed air audits and effective compressed air cost management **(Figs 5a to e)**. The more users introduce transparency into their compressed air costs, seek out potential savings and prioritise energy efficiency over price when purchasing components, the nearer we will come to achieving the calculated 30% energy-savings potential in compressed air generation. This is good not only for company balance sheets, but for the environment as well.

# Practical tips

Tip 1 – 7

40-51

Tip 1

# Saving thanks to optimal pressure

The cost efficiency of a compressed air system does not only depend on the correct working pressure. Even small measures can often have a large effect.

In many cases, the connection to the compressed air tools is as follows: at rest, pressure at the maintenance unit is 6.1 bar and at the tool 6.0 bar. However, this pressure is not the same as the pressure when air is being consumed.

**Pressure drop at the tool – what can be done?**

Pressure measurement on a working tool often shows a considerable pressure drop. In the example shown here, the drop is 2 bar; in other words the tool delivers only 54% of its potential performance.

The **causes** can often be easily resolved:

***a) Insufficient connection cross section:*** Use a quick-release coupling with wider flow passage.

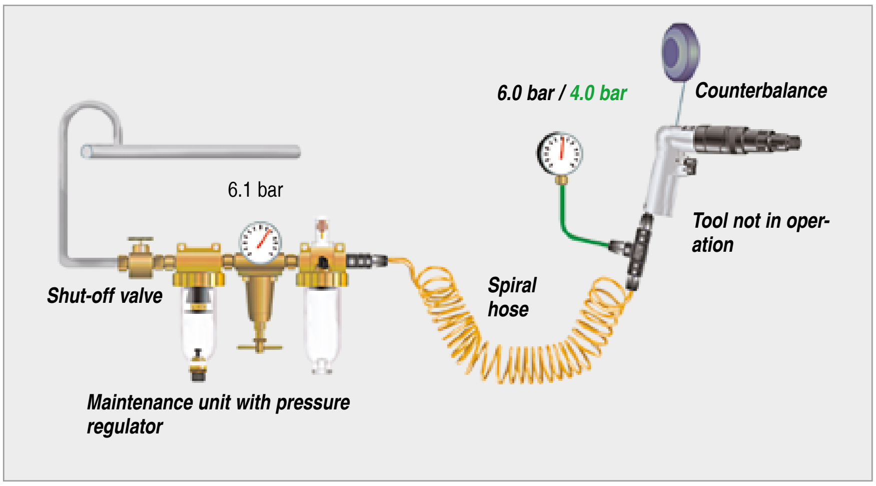
***b) Incorrectly set pressure regulator:*** Open it further.

***c) System pressure too low:*** Increase pressure in the main network or install piping with a wider cross section.

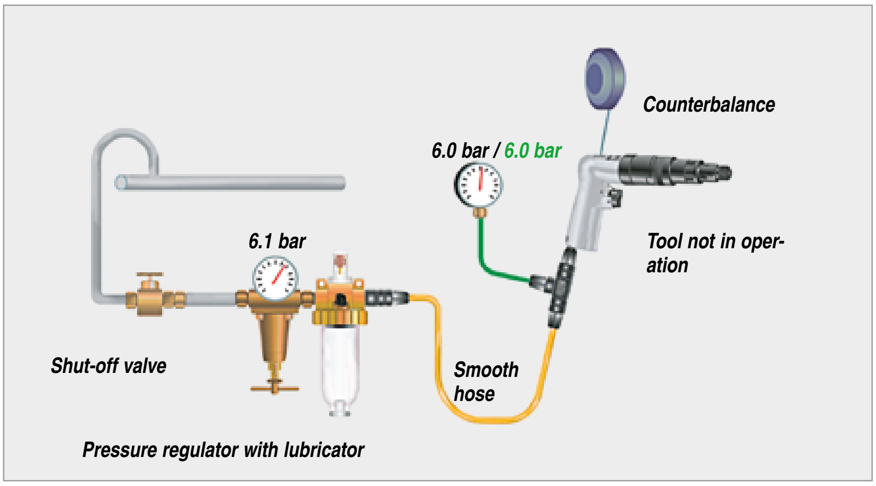
***d) Spiral hose too small:*** Use a larger spiral hose or, even better, use a smooth hose.

***e) Pressure drop in decentralised water separator:*** Dry the compressed air centrally (separator superfluous).

These are simple measures to restore optimal tool pressure (in this case, 6 bar) and performance to 100% capacity.



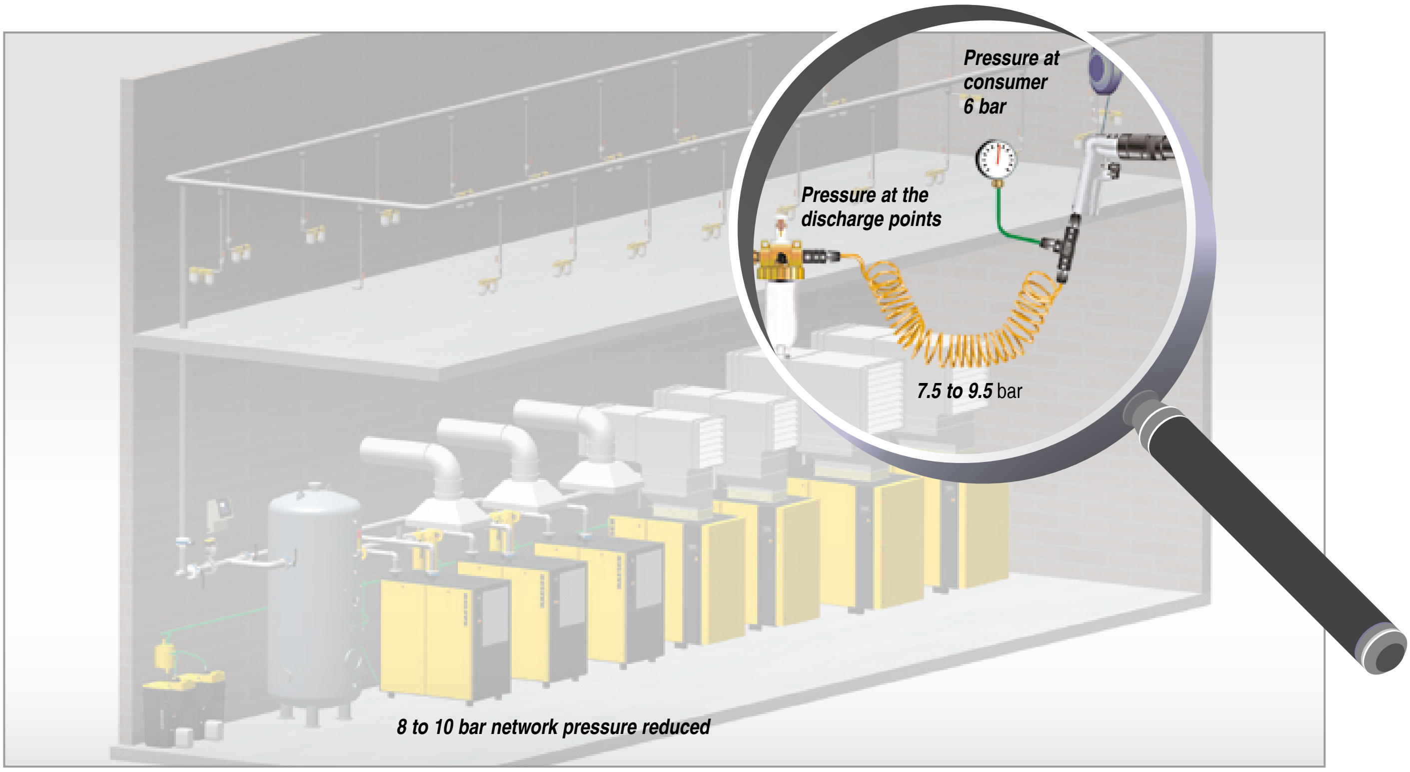

*Tool connection with spiral hose – 6.0 bar pressure at zero compressed air consumption 4.0 bar when tool in operation = 2 bar pressure drop when in operation: only 54% of full performance!*



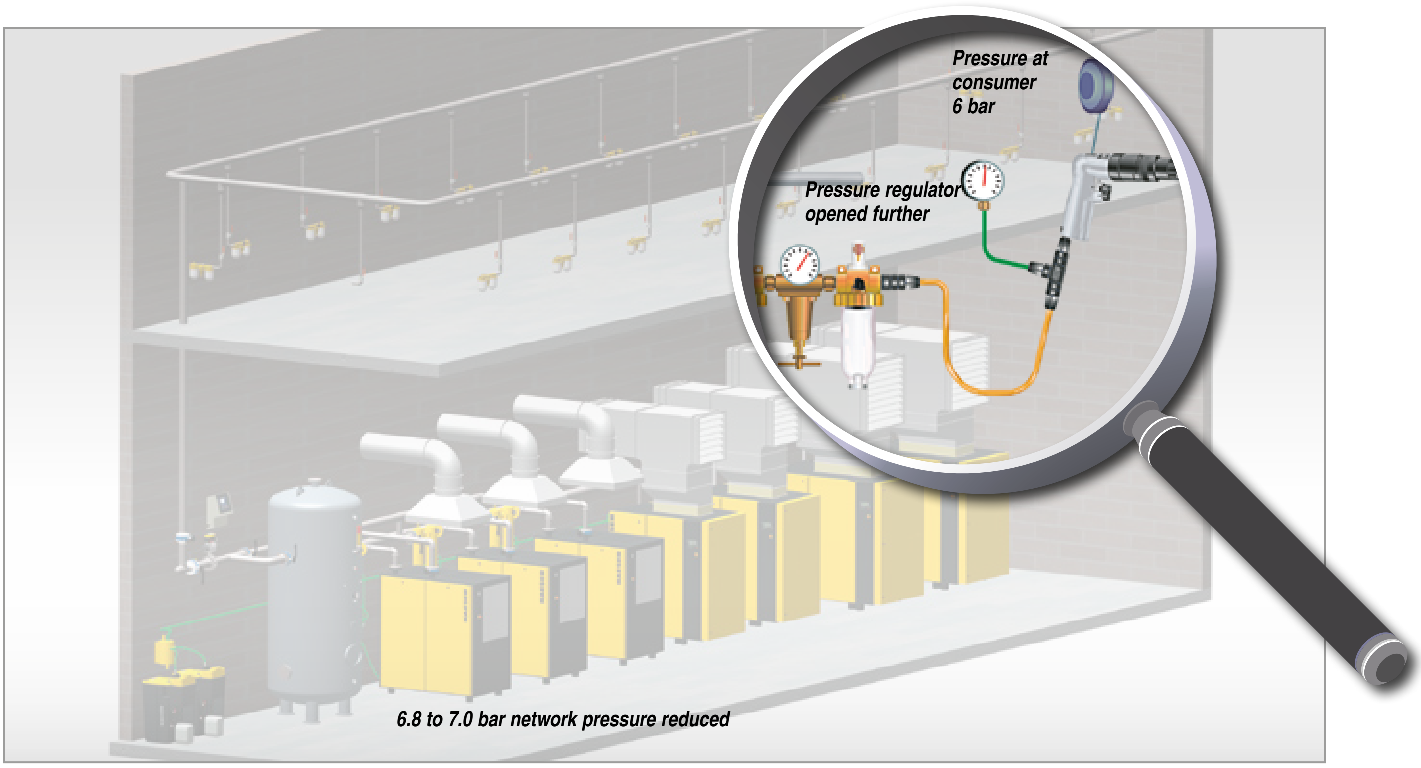

*Water separators and spiral hoses are energy wasters: instead, dry compressed air centrally and use smooth hoses – 6.0 bar when tool in operation, 100% of performance*

**Saving energy – with a right turn**

Pressure regulators affect the efficiency of compressed air usage to a greater extent than is often realised. In this example, the compressed air system is operated between 8 and 10 bar. The pressures of 7.5 and 9.5 bar at the discharge points are reduced to 6 bar by a pressure regulator. To save energy, system pressure is reduced to 6.8 – 7 bar. This means that a pressure of 6.1 bar is available at the network discharge points, but only 4 bar at the tools. This has consequences: work takes longer, unsatisfactory work results due to insufficient tool pressure, and longer compressors run times. On the other hand, the desired savings can be easily and painlessly achieved by not only reducing the system pressure, but also by using smooth hoses, removing superfluous water separators and further opening the pressure regulators on the compressed air consumers.




*A waste of energy, pure and simple: higher compression than necessary, with pressure reductions at the compressed air consumers...*




*...instead, reduce system pressure and open the regulator further*

Tip 2

# Correct pressure at the air connection

The compressor station pressure is actually correct, but pressure is too low at the air consumers. Why?

In this case, hoses, quick-release couplings and pressure regulators are commonly the offending components. But often the pressure at the discharge point of the network is too low: for example, of the 6.8 to 7 bar originally available for the tools, a mere 5 bar remains.
Operators usually turn to a quick fix: "Let's just set the station pressure 1 bar higher, what difference does it make?" But this is in fact critical, because for every pressure increase of 1 bar, compressor station energy consumption increases by 6% and the leakage rate also increases sharply. It is therefore advisable to identify the causes and implement an appropriate remedy.

**Piping network as the source of the problem**
When the pressure directly downstream from the compressor is correct and there is no disproportionately large reduction due to downstream treatment components, the problem can only be in the piping network. This is divided into three sections: Main line, distribution line and connecting line **(Fig. 1)**. In an optimised compressed air system, the following pressure drops are reasonable from a cost efficiency perspective:

| | |
|---|---|
| Main line (1): | 0.03 bar |
| Distribution line (2): | 0.03 bar |
| Connecting line (3): | 0.04 bar |
| In addition: | |
| Dryer (4): | 0.2 bar |
| Maint. unit / hose (5): | 0.5 bar |
| **Total:** | **0.8 bar** |

**Resolving "bottlenecks"**
Upon closer inspection, it often becomes apparent that although the main line and distribution lines are correctly dimensioned, the connecting lines are too narrow. For these, the pipe width should be no less than DN 25 (1"). For precise determination of the cross section, KAESER KOMPRESSOREN offers a convenient online tool: **https://www.kaeser.com/int-en/services/know-how/calculator/pressure-drop**

**Ensuring correct connections**
To prevent disruptions and damage due to humidity, the connection between the distribution and connecting lines should be designed as a flow-optimised "swan neck" **(Fig. 2)**; a pipe leading directly downwards should only be used if the possibility of condensate formation in the pipeline can be excluded with 100% certainty **(Fig. 3)**.
The optimal connection, which has a maximum pressure drop of 1 bar between the compressed air outlet from the compressor and the compressed air tool, is illustrated on **page 42/43**.

**Sudden air consumption**
In the case of compressed air consumers that are not operated continuously, but then suddenly require a high flow rate, a decentralised air receiver can be used as buffer storage in order to compensate for a temporary drop in pressure **(Fig. 4)**. KAESER KOMPRESSOREN offers an online calculation tool for this as well: **https://www.kaeser.com/int-en/services/know-how/calculator/pressure-vessel-size**

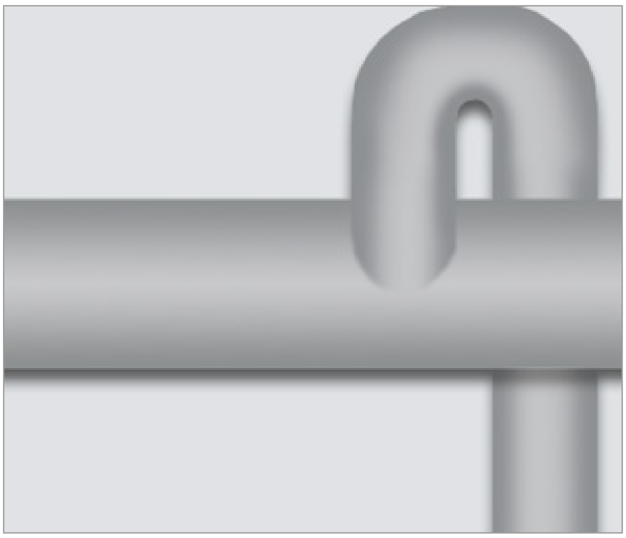


*Fig. 2: Swan neck*

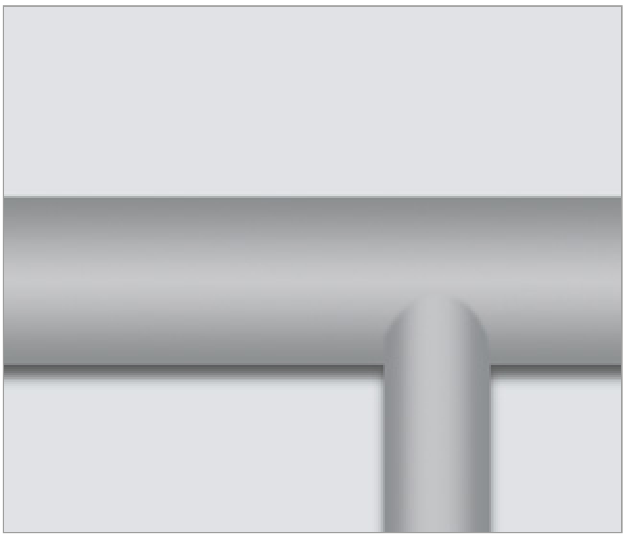


*Fig. 3: Pipe leading directly downwards*

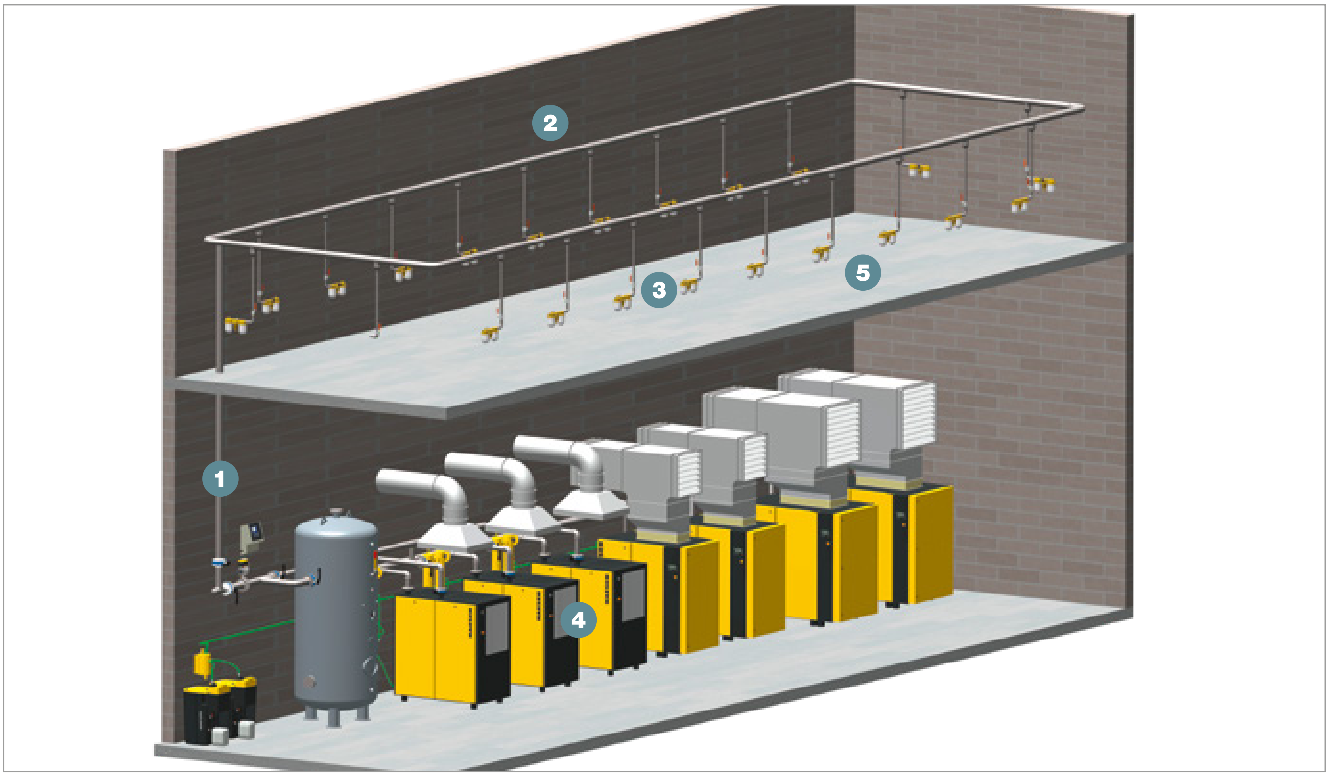



*Fig. 1: Main elements of a compressed air distribution system: Main line (1), distribution line (2), connecting line (3), dryer (4), maintenance unit / hose (5)*

*Fig. 4: Air receiver as buffer storage*

Tip 3

# Efficient compressed air distribution

There are essentially three ways to distribute compressed air from the compressor system to the point of use: via branch line, ring line or distribution network. As to which is most suitable, it depends on the operational circumstances. When looking at efficient compressed air use, it is important not only to focus on energy-saving generation, but also to consider the most efficient method of distribution. To find out how, read on.

**Branch line**
Installing a branch line with various outflow connections to the individual compressed air consumers **(Fig. 1)** is relatively straightforward. The length of piping required is comparatively short, but it must have sufficient conveying capacity to meet the system's entire air demand.
This means that the piping cross section must be significantly larger in comparison to a ring line or distribution network. The connecting lines to the consumers also need to be larger, due to the increased distance from the compressed air station. In addition, this solution does not allow individual sections of the piping system to be shut down in order to facilitate expansion or refurbishment work, for example. Branch line systems are therefore best suited to small operations.

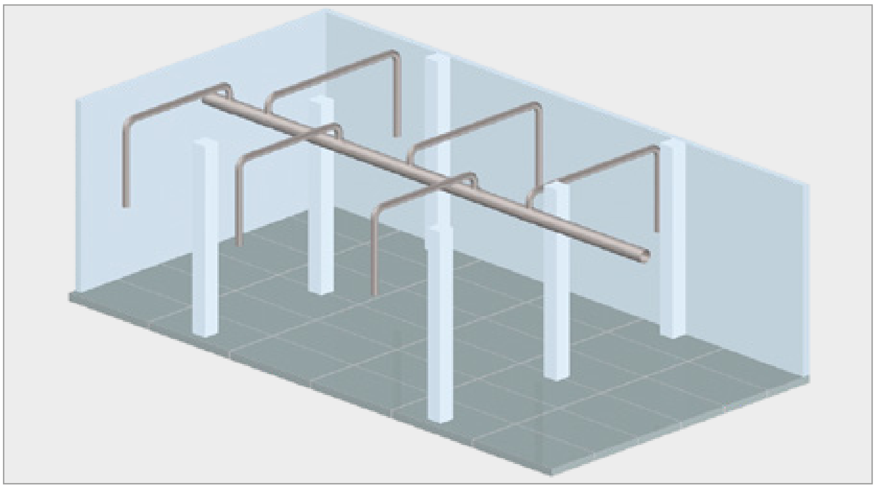


*Fig. 1: Compressed air branch line*

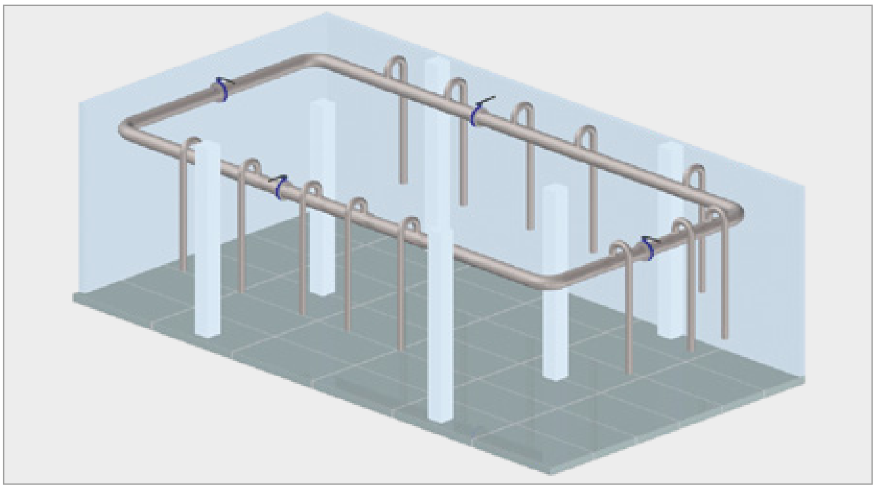


*Fig. 2: Compressed air ring line*

**Ring line**
Installing a ring line **(Fig. 2)** is more complex, but has one considerable advantage over a branch line system: if using consumers each with the same compressed air demand, the connecting pipe lengths and volume can be reduced by half. As a result, piping with a smaller cross section can be used for the same conveying capacity. The connecting lines are short and seldom need to be any larger than DN 25. Sufficient numbers of shut-off units allow individual sections of piping to be taken out of operation for refurbishment and system expansion work, leaving the rest of the installation to operate as normal.

**Distribution network**
A distribution network is recommended for companies with large facilities. The design is similar to a ring line, but includes additional longitudinal and cross connections that transform the system into a true network structure **(Fig. 3)**. Of course, this is the most complicated system to install, but the additional effort is more than rewarded through the advantages that it brings. The network structure provides a reliable and energy-efficient supply of compressed air to large production halls with no need for excessively large pipe dimensions. On the contrary: pipe dimensions can be kept relatively small, as with those in a ring line system installed in a small- or medium-sized operation. The system has the further advantage that individual sections can be shut down as required using shut-off units.

**Designing the main line(s)**
The function of a compressed air system's main line is to connect the separate air distribution lines for the individual work areas (buildings) with the compressed air station (generation). The dimensions and capacity of a compressed air main line are dictated by the total air delivery of the compres-

sors in the system. Care should be taken to ensure that the pressure drop does not exceed 0.03 bar.

**Supply from a single station**

If a single compressed air station supplies air to multiple work areas (e.g. production halls), then the corresponding main lines for the individual areas must be able to convey the maximum volume of compressed air required by that area (pressure loss <0.03 bar). Pipelines bundled together in a collector within the compressed air station provide the advantage of being able to easily shut off entire work areas as required. Furthermore, with the addition of flow rate measuring equipment, the air consumption of individual areas can easily be determined **(Fig. 4)**.

**Supply from multiple stations**

If two or more compressed air stations supply a large main line system, then the piping must have sufficient capacity to be able to convey the maximum delivery volume from the largest station to all production areas. Again, the pressure drop between the individual stations should not exceed 0.03 bar, otherwise complicated and expensive control systems become necessary **(Fig. 5)**.

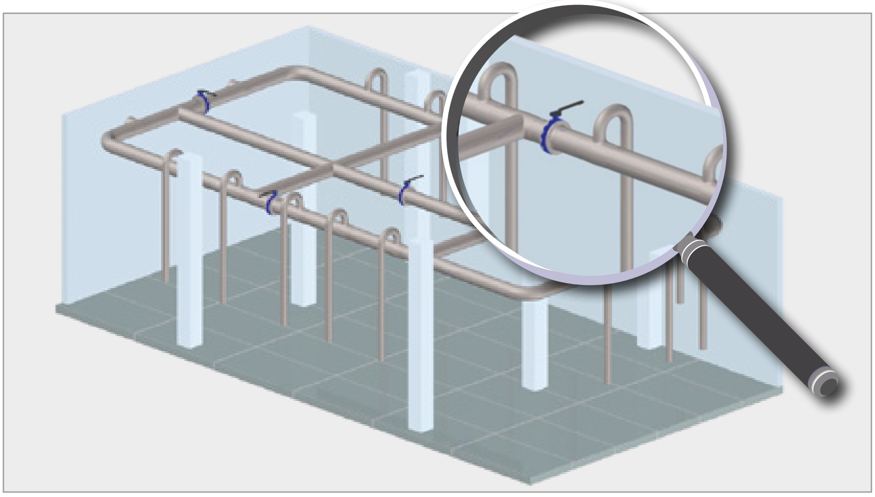


*Fig. 3: Compressed air line network with cross connections*

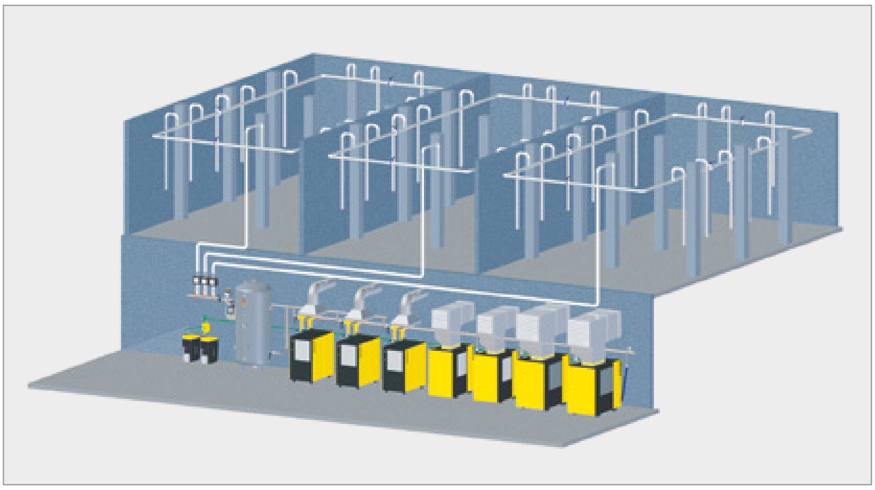


*Fig. 4: Compressed air supply with one central air station for multiple production areas*

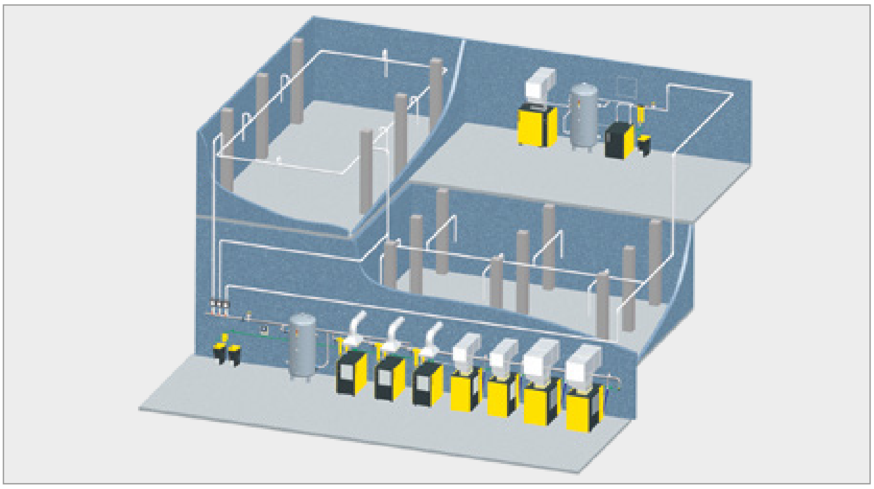


*Fig. 5: Compressed air supply with two stations and central control for multiple production areas*

Tip 4

# Piping in a compressed air station

The piping not only distributes compressed air within an operation, but also connects the compressors and other components in the compressed air station to the whole system. In order to ensure best possible efficiency and reliability, several important factors should be taken into consideration when installing pipework.

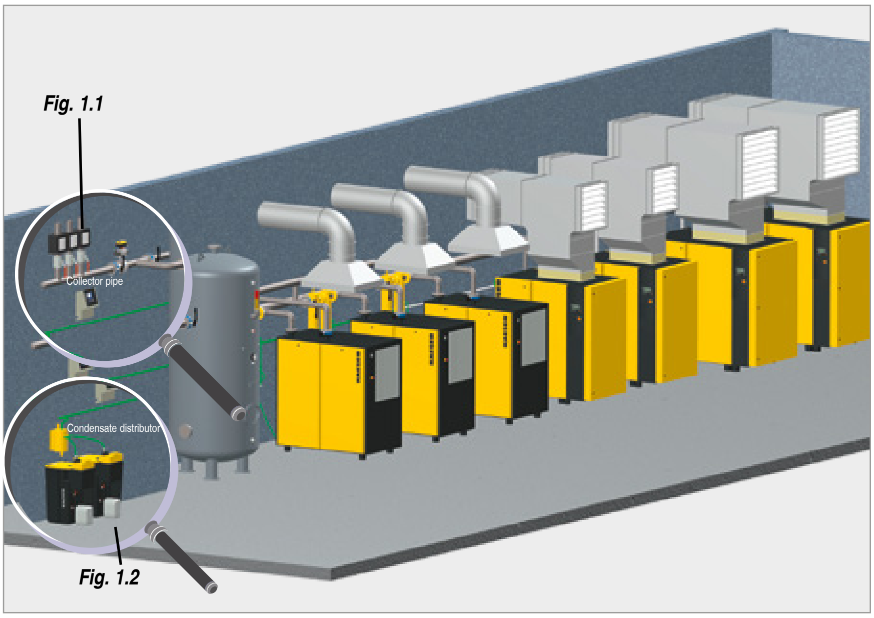



*Fig. 1: Compressed air station with collector pipe*

The piping should generally be laid out in such a way that the pressure loss caused by it remains below 0.01 bar at full flow capacity. It is also advisable to use only metal piping, since the thermal load cannot be defined.

**Connecting the compressed air distribution lines**
The best way of connecting the piping from the compressor station to the compressed air network is using a collector, which acts as a central feed-off point for all the distribution lines **(Fig. 1.1)** and, if necessary, allows the compressed air supply to be shut off for specific work areas.

**Installation in the humid area**
Installation of a water trap in the so-called "humid area", i.e. the piping sections located downstream from the compressors and upstream of the dryers, should be avoided if at all possible. Otherwise, the piping must slope down towards the water trap, which must be drained via a specifically dedicated condensate drain **(Fig. 2)**.

**Connecting components correctly**
The individual components in the compressed air station (compressors, dryers, etc.) should be connected to the main line from above **(Fig. 3a, 3b)**. Connection from the side is also possible with pipe diameters from DN 100, if the main pipe diameter is at least 2 sizes larger than the diameter of the connecting pipe (e.g. DN 100 / DN 65).

**Connecting the compressors**
Flexible connections should be used to connect the compressors to the piping network in order to avoid the transmission of vibrations. Hose connections are suitable for pipe widths <DN 65 **(Fig. 4)**. A vibration-absorbing fastening is attached between the hose and the first pipe bend in order to ensure that any forces are not transferred to the piping **(Fig. 4.1)**. For pipe widths >DN 65, axial compensators must be used instead of hoses **(Fig. 3b)** to implement the vibration-dampening connection between the compressor and piping network.

**Reliable condensate removal**
Dependable condensate removal is essential to ensure optimum compressed air station reliability and availability. There are a few errors worth avoiding, particularly when it comes to the installation of condensate lines.

Despite modern drainage technology, the connection lines to the condensate treatment systems are often incorrectly installed. These problems can be easily avoided, however, by taking the following **tips into account**:

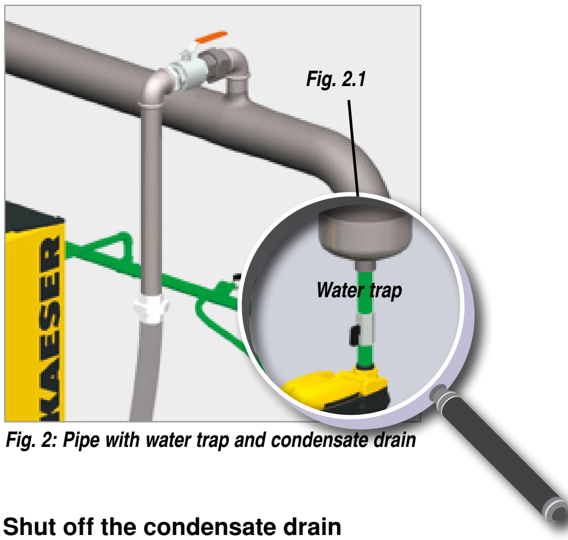



*Fig. 2: Pipe with water trap and condensate drain*

**Shut off the condensate drain**
Condensate drains should be capable of being shut off on either side via a ball valve, so that they can be easily removed from the system when maintenance work is required **(Fig. 2.1)**.

**Correct connection size**
The connection to the collector pipe should be at least ½", in order to prevent unnecessary back pressure.

**Connection from above**
The condensate lines should be connected to the collector pipe from above, so that the drainage points do not negatively influence one another **(Fig. 3a (1))**.

**Sloping, pressure-free line**
The condensate collector pipe should always be installed at a gradient and should not be under pressure. Condensate drains from various system components (e.g. centrifugal separator, air receiver, refrigeration dryer, filters) operating at different pressure levels must only discharge into a pipe that has been installed this way. If this is not possible, then different connection points on the condensate treatment device (AQUAMAT) should be used.

**Multiple treatment devices**
If, due to large volumes of accumulating condensate, it is necessary to use multiple treatment devices, then the main condensate line should be connected via a condensate distributor **(Fig. 1.2)**.

**System pressure above 16 bar**
For systems with a pressure level above 16 bar, a separate high-pressure relief chamber should be used before the condensate is fed into the treatment device.

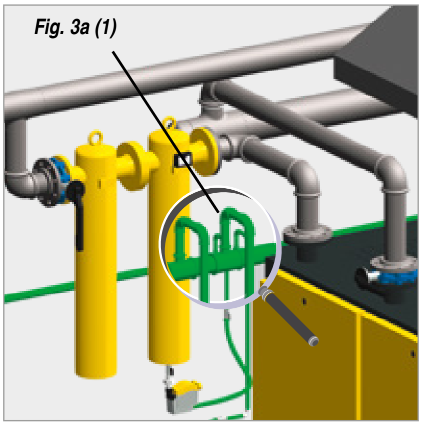



*Fig. 3a: Connection of refrigeration dryer and condensate drain (each from above)*

*Fig. 3b: Vibration-damping compressor connection with axial compensator*

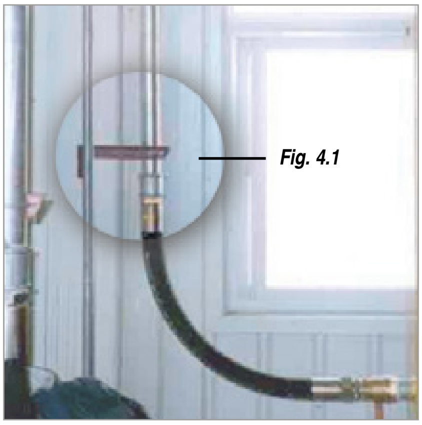



*Fig. 4: Vibration-damping compressor connection with hose*

Tip 5

# Correct compressor installation

The installation and ambient conditions greatly influence the cost efficiency and reliability of compressed air generation. Here are three rules worth remembering.

**1. Keep the air station clean**
The level of cleanliness and the maintenance condition of many compressed air stations leave a lot to be desired, even if they don't look as bad as in **Fig. 1**. Above all, cleanliness means protecting the equipment from exposure to dust. If care is not taken, the compressor intake filters will quickly clog up, which not only increases maintenance requirement and reduces performance, but also adversely affects air cooling. Subsequent consequences may include downtime due to overheating, decreased dryer power and, as a result, condensate accumulation.

*Fig. 1: Neglected compressed air station*

This in turn can cause damage to the compressed air consumers and negatively effect product quality. Therefore, if dust exposure cannot be avoided by finding a dust-free installation location, then central cooling filter mats or filter systems with low pressure loss should be used to clean the intake air **(Fig. 2a, 2b)**.


*Fig. 2a: Central cooling air filter mats*

*Fig. 2b: Cooling air filter system*

**2. Ensure moderate temperatures**
Firstly, the compressed air station should not be exposed to sub-zero temperatures, as this leads to generation and transportation of humid compressed air. In the event of frost, the condensate in the lines would freeze, resulting in disruptions to operation. Secondly, the lubrication performance of the oils and bearing grease used in the compressors is significantly reduced at temperatures below +5 °C. Needless to say, this can also lead to system failures. During the summer months, however, so much compressor exhaust heat is produced that it is important to ensure, as far as possible, that the compressor room temperature does not exceed the temperature outdoors. Otherwise, motors and electrical components are liable to overheat and the dryer may become overloaded due to insufficient recooling of the compressed air. Once again, this leads to condensate accumulation and degraded performance of consumers. In the worst case scenario, insufficient ventilation can result in a build-up of heat, which causes all compressors and dryers to shut down and the compressed air supply system to fail completely.
This can be avoided by the use of cooling systems which automatically regulate the heat balance in the compressed air station via thermostatically controlled air inlet, outlet and recirculation **(Fig. 3)**.

**3. Maintenance-friendly station**
Although modern compressors and treatment devices require significantly less maintenance than older equipment, they are not completely maintenance-free. Therefore, they must be installed in such a way as to ensure easy access to all maintenance-relevant areas. Optimum compressed air system reliability and performance can only be achieved if all three of these points are closely observed.

*Fig. 3: Compressed air station with thermostatically controlled airflow*

Tip 6

# Compressed air station ventilation (intake air)

Correct ventilation of an air station not only enhances compressed air availability, but also helps to minimise maintenance costs.

**1. Correct location of air inlet apertures**

The location of the air inlet apertures is extremely important for effective ventilation of a compressed air station. To ensure optimum operational security and reliability, air that is drawn in from outside should be affected as little as possible by the weather. Therefore, it is advisable to install weather-protected apertures in the lower half of the station's external wall, which ideally should not directly face the sun.

**2. Protection from dust and contamination**

It must be ensured that the compressor system draws in as little dust and as few contaminants as possible. This includes all aggressive or inflammable substances and combustion engine emissions. In particular, HGVs should not be allowed to enter the compressed air station's air intake zone. If high levels of dust or contamination are unavoidable, then appropriate protection measures must be taken. Moderate levels of dust and contamination can be alleviated using cooling air filters. In extreme cases, so-called "dust traps" can be used.

**3. Correctly dimension and equip air inlet apertures**

The size of the air inlet apertures depends on the power of the air-cooled compressors installed. For each kilowatt of installed nominal power, 0.02 to 0.03 m² should be used for the free cross section of the air inlet apertures. This is equivalent to a cooling air volume of 130 to 230 m³/h.

It is important to note the term "free cross section". Weather protection screens, louvres and – in unfavourable intake conditions – filters all considerably reduce this cross section: by between 20 and 60%, depending on the system.

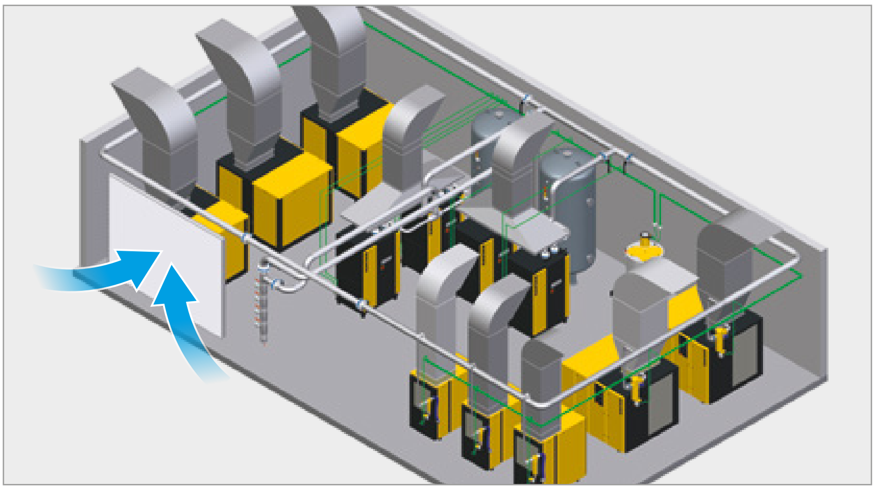


*Fig. 2: Compressed air station with air inlet system*

It is therefore best to use flow-optimised ventilation systems. Whatever the case, compensation should always be made for reductions in cross section caused by protection and control devices.

An air inlet system **(Fig. 1)** generally comprises a weather protection screen, bird protection screen, motor-operated air inlet louvre and, if necessary, air inlet filter. For stations with multiple compressors, it is advisable to install a thermostatically controlled air inlet system and to divide the apertures according to the position and power of the individual units **(Fig. 2)**.

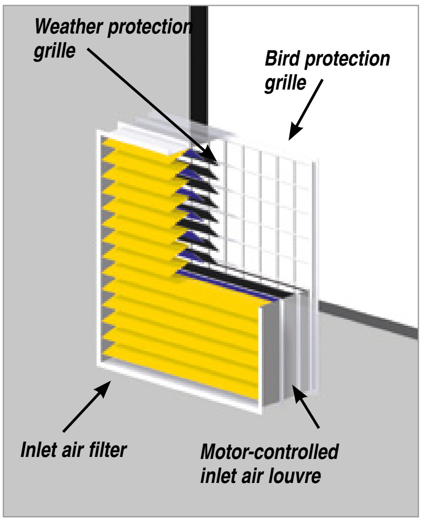



*Fig. 1: Inlet air system (design)*

**4. Ventilate water-cooled compressors**

Water-cooled compressors also require sufficient ventilation, since they are usually powered by air-cooled motors that radiate heat. Approximately 10% of a water-cooled compressor's power is converted into heat, which needs to be removed by cooling air. Appropriately dimensioned air inlet apertures should therefore be provided accordingly.

Tip 7

# Compressed air station ventilation (exhaust air)

In order to safeguard compressed air availability and keep maintenance costs to a minimum, compressed air stations must be equipped with suitable exhaust air ventilation. If the outside temperature falls below +5 °C, then recirculated air should be used to keep the operating room at a suitable temperature for the compressor system.

**1. Simple routing of exhaust air**

Exhaust air ducts perform an important role in compressed air stations: they remove the heated cooling air, as well as the exhaust heat from the motor and the heat radiated by the compressors **(Fig. 1)**. On modern machines, the exhaust heat from these various sources leaves the unit via a single exhaust air opening **(Fig. 1, magnifying glass)**. This must be flexibly connected to the exhaust air duct via a canvas neck connection **(Fig. 2)**. At ambient temperatures above +10 °C, all of the exhaust heat is removed from the compressor room in this way. As older compressors often have separate exhaust air openings, it may be necessary to install individual ducts accordingly.

*Fig. 2: Compressor ventilation connection with canvas duct joint*

**2. Installing a collector duct**

If installation of individual exhaust air ducting is not possible, then an exhaust air collector duct **(Fig. 3)** must be provided. Non-return louvres are required to correctly connect the compressors. When closed, they prevent hot air from flowing back into the station when the corresponding compressor is not in operation. Motor-actuated louvre flaps reduce pressure loss and can be activated in conjunction with the “Motor running” signal. Guide plates should be installed to minimise pressure losses in the collector duct.

**3. Use recirculation air to maintain the temperature**

Air recirculation flaps should be installed in areas where ambient temperatures fall below +5 °C. These should be active from +10 °C, whereby they open to a greater or lesser extent in accordance with the temperature **(Fig. 1)**. If the compressed air station is occasionally shut down completely, then a supplementary heating system should be used to ensure that the temperature in the machine room remains above +5 °C.

**4. Ventilate refrigeration dryers**

Refrigeration dryers generate approximately four times as much heat energy than they consume as electrical energy. They should therefore have their own exhaust air system, equipped with a thermostatically controlled fan **(Figs 1 and 3)**. If the station includes multiple refrigeration dryers, then the fan should have a pacing control system that is activated from +20 °C. As this exhaust air system is not in continuous operation, the exhaust duct cannot be installed directly on the dryer – unless the dryer has a powerful integrated fan with the corresponding residual thrust.

**5. Correctly design and control exhaust air systems**

All exhaust air systems must be designed to ensure that any pressure drop they cause is smaller than the residual thrust delivered by the smallest machine in the system (note manufacturer specifications). Otherwise, exhaust air from this unit would flow back into the compressor room. Additional fans are needed if there is insufficient residual thrust. The flaps should be automatically controlled via room thermostats and compressors. Monitoring via a master control system (e.g. SIGMA AIR MANAGER 4.0) is recommended in order to be able to quickly identify potential malfunctions with the flaps and forward any fault messages to the central control system.

**6. Special case – water-cooling**

As water-cooled compressors emit the equivalent of 10% of the power supplied to them as radiant heat, these systems also require sufficient ventilation.

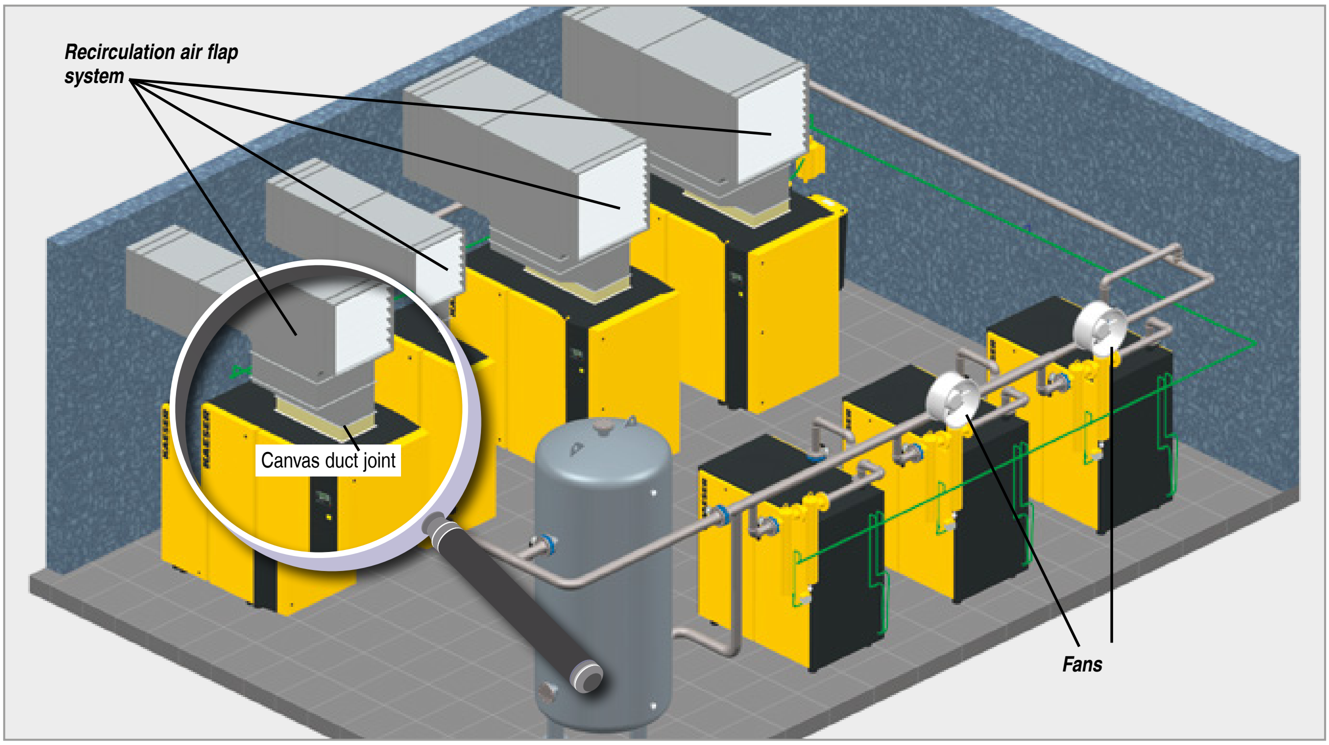



*Fig. 1: Exhaust air system with individual duct per compressor*

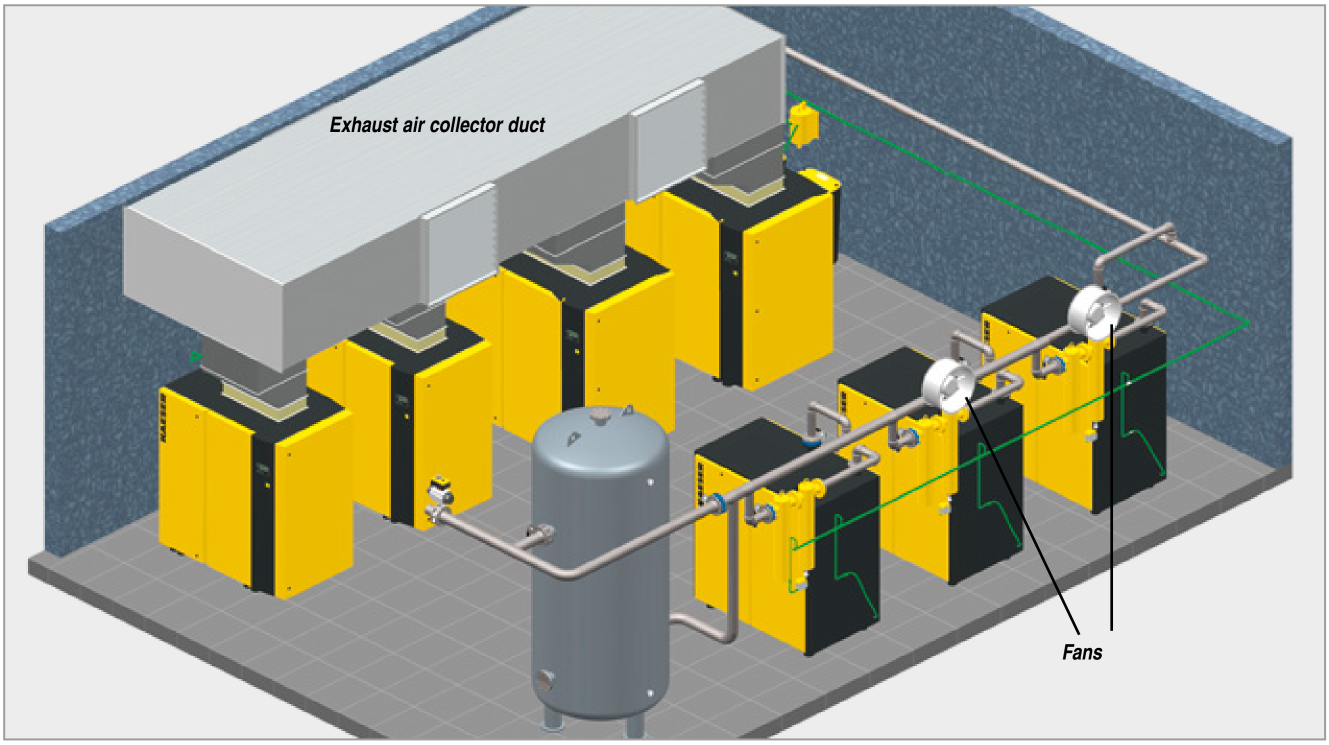



*Fig. 3: Exhaust air system with exhaust air collector duct for all compressors*

# Annexe

Questionnaire
Notes

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# Compressed air station questionnaire

## Energy Saving System Service

KAESER COMPRESSORS

### 1. What free air delivery do the compressors need to provide?

#### 1.1 Air consumption of tools and machines used

| Tools, machines | Air consumption per tool, machine m³/min | | No. of tools, machines | | Load / duty cycle % | | Simultaneity factor % | | Actual calculated air consumption m³/min |
|---|---|---|---|---|---|---|---|---|---|
| | | x | | x | | x | | = | |
| | | x | | x | | x | | = | + |
| | | x | | x | | x | | = | + |
| | | x | | x | | x | | = | + |
| | | x | | x | | x | | = | + |
| | | x | | x | | x | | = | + |

**Air consumption of all tools** = $V_{Tools}$ m³/min

\+

#### 1.2 Other consumers

$V_{Other}$ m³/min

\+

#### 1.3 Compressed air network leakages

$V_{Leakage}$ m³/min

\+

#### 1.4 Reserve

$V_{Reserve}$ m³/min

**Min. req'd free air delivery from the compressors** = $V_{Total}$ m³/min

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# Energy Saving System Service

KAESER COMPRESSORS

## 2. Are compressors already in use?

☐ **No**

☐ **Yes**

| Operator's designation | Manufacturer | Model | Pressure bar$_{(g)}$ | Free air delivery m³/min | Continued use planned? Yes No |
|---|---|---|---|---|---|
| | | | | | ☐ ☐ |
| | | | | | ☐ ☐ |
| | | | | | ☐ ☐ |
| | | | | | ☐ ☐ |
| | | | | | ☐ ☐ |
| | | | | | ☐ ☐ |

**Total free air delivery of existing compressors that will continue to be used**

= $V_{Existing}$ m³/min

## Existing compressed air treatment components:

| Type/model (dryer, filter, drain etc.) | Manufacturer | Designed for m³/min | bar(g) | Remarks e.g. Incorrectly sized |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

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# Compressed air station questionnaire

## Energy Saving System Service

KAESER COMPRESSORS

**3. Have standby compressors been in use up until now (reserve capacity, back-up)?**

☐ **Yes,** how many? ______

☐ **No**

☐ **Planned for the future**

**4. Is a master controller in use?**

☐ **Yes,** which? ______

☐ **No**

**Planned for the future:**

☐ Base load sequencer

☐ Master controller SAM_/_

☐ Master controller VESIS

**5. Is heat recovery used?**

☐ **Yes**, purpose: ______

☐ **No**

☐ **Planned for the future:**

**6. What grade of compressed air quality is required?**

(refer to worksheet “Compressed air treatment, condensate treatment”)

| Centralised Air consumption m³/min | Local Air consumption m³/min | Compressed air quality class as per ISO/DIS 8573-1 Remaining oil content | Remaining dust | Remaining water |
|---|---|---|---|---|
| ☐ | ☐ | | | |
| ☐ | ☐ | | | |
| ☐ | ☐ | | | |
| ☐ | ☐ | | | |

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# Energy Saving System Service

KAESER COMPRESSORS

## 7. What maximum pressure do the compressors need to provide?

| | | | |
|---|---|---|---|
| **7.1 Min. required working pressure at the consumer** | | | $p_{Wmin}$ ___ bar(g |
| **7.2 Pressure losses** | | | |
| **across the pipe network**<br>Pipework material ___<br>Alternative: Length of pipe network ___ m | | | + $p_P$ ___ bar |
| **from the activated carbon adsorber** | $p_{ACmin}$ ___ bar | | + $p_{ACmax}$ ___ bar |
| **from the sterile filter** | $p_{FSTmin}$ ___ bar | | + $p_{FSTmax}$ ___ bar |
| **from the microfilter** | $p_{FXAmin}$ ___ bar | | + $p_{FXAmax}$ ___ bar |
| **from the microfilter combination** | $p_{FXmin}$ ___ bar | | + $p_{FXmax}$ ___ bar |
| **from other filters** | $p_{FVmin}$ ___ bar | | + $p_{FVmax}$ ___ bar |
| **from the dryers** | | | + $p_{Dry}$ ___ bar |
| **7.3 Compressor control deviation** | | | + $p_{Control}$ ___ bar |
| **Required maximum pressure from the compressors** | | = | $p_{MaxReq}$ ___ **bar(g** |
| Minimum pressure from the compressors ($p_{MaxReq}$ - $p_{Control}$) | | | $p_{min}$ ___ bar(g) |

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# Compressed air station questionnaire

Energy Saving System Service

KAESER COMPRESSORS

## 8. Operating conditions

| | | | |
|---|---|---|---|
| **8.1 Maximum intake temperature** | $t_{lmax}$ | | °C |
| **8.2 Minimum air pressure** (at max. intake temperature) | $P_{lmin}$ | | bar |
| **8.3 Maximum relative air humidity** (at max. intake temperature) | $H_{rellmax}$ | | % |
| **8.4 Minimum intake temperature** | $t_{lmin}$ | | °C |

**8.5 Cooling**

☐ **Air-cooled**

☐ **Water-cooled**

| | | | | |
|---|---|---|---|---|
| ☐ Closed cooling system | Cooling water inlet temperatures | $t_{InMax}$ | | °C |
| ☐ Open cooling system | | $t_{InMin}$ | | °C |
| Cooling water quality: | Cooling water return temperatures | $t_{RetMax}$ | | °C |
| ☐ As per KAESER standard | | $t_{RetMin}$ | | °C |
| | Cooling water pressure | $p_{CoolW}$ | | $bar_{(g)}$ |

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Energy Saving System Service

KAESER COMPRESSORS

## 8.6 Heat recovery

☐ **Use of hot air** Purpose:

☐ **Water heating** Purpose:

| | | | |
|---|---|---|---|
| Water inlet temperature | $t_{InHR}$ | | °C |
| Water return temperature | $t_{RetHR}$ | | °C |
| Water volume | $V_{WaterHR}$ | | m³/h |

## 8.7 Compressor room installation conditions

Dustiness

☐ **Low**

☐ **High**

Cleanliness

☐ **Low**

☐ **High**

Ventilation opening

☐ **present,** ____ **m²**

☐ **Not present**

Exhaust opening

☐ **present,** ____ **m²**

☐ **Not present**

# Notes

## Note down the key information:

## More compressed air for less energy

# The world is our home

As one of the world's largest manufacturers of compressors, blowers and compressed air systems, KAESER KOMPRESSOREN is represented throughout the world by a comprehensive network of wholly owned subsidiaries and authorised distribution partners in over 140 countries.

By offering innovative, efficient and reliable products and services, KAESER KOMPRESSOREN's experienced consultants and engineers work in close partnership with customers to enhance their competitive edge and to develop progressive system concepts that continuously push the boundaries of performance and technology. Moreover, decades of knowledge and expertise from this industry-leading systems provider are made available to each and every customer via the KAESER group's advanced global IT network.

These advantages, coupled with KAESER's worldwide service organisation, ensure that every product operates at the peak of its performance at all times, providing optimal efficiency and maximum availability.


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