

Energy savings potential for compressed air generation in the pharmaceuticals industry

A practical guide^{*)}

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This article is intended as a supplement to Dr Detlef Werner's book "Druckluft in der pharmazeutischen Industrie" ("Compressed air in the pharmaceuticals industry") [1]. Since the book was published, much has changed in terms of the boundary conditions associated with compressor operation in industrial environments. Some of these changes will be discussed over the course of this article.

Introduction

Seen from the point of view of ever-increasing energy costs, the need for energy savings and energy efficiency should be self-evident. In preparation for drafting the Ecodesign Directive, the EU commissioned a "Preparatory Study on Low Pressure & Oil-free Compressor Packages" [2], in which the authors concluded that – amongst other things – heat recovery is an integral aspect of energy saving in compressed air generation. This applies not only to the use of exhaust heat from compressors, but from all heat-emitting components within a compressed air station. Today, companies with more than 250 employees must either establish an energy management system in accordance with ISO 50001, assuming this is not already covered within the framework of an Ecological Management and Audit Scheme (EMAS) [3], or as a

minimum, conduct an energy audit in accordance with DIN/EN 16247. Nevertheless, many pharmaceutical companies that use compressors remain unaware of the energy-saving potential concealed within their systems. This publication is intended to make potential energy savings more transparent, and thereby to assist in identifying them and subsequently using them as the basis for an energy assessment of both new and existing systems. The ultimate objective is to plan new systems for maximum energy efficiency and, if required and feasible, to convert existing systems to achieve continuous energy savings. For those who operate compressors, the possibilities for saving energy are numerous and often require deep technical expertise and extensive know-how. These potential options will be presented in this article and their significance discussed. In some cases, operators are recommended to contact the compressor manufacturer or a specialist engineering service provider, in order to achieve the optimal design for their compressed air station.

Compressed air station analysis

The basis for a comprehensive evaluation of the function and utilisation of a compressed air station is an Air Demand Analysis. This provides a precise consumption profile of the entire station, which in turn enables the actual compressed air demand for all parts of the business to be determined at different load levels. The Air Demand Analysis

- identifies weak points in an existing system
- provides information regarding the correct dimensioning for the compressors
- forms the basis for the next step towards designing the optimal compressed air station and calculating the potential energy savings

The Air Demand Analysis is not only intended to assist in designing new systems, but can also be used to evaluate the efficiency of existing systems.

Data capture for the audit is achieved via a data logger, which records and saves all of the required data without the need to interfere with the piping network. Figure 1 depicts a typical compressed air demand curve over an 11-day period, whilst Fig. 2 shows the measuring equipment for an Air Demand Analysis.

When conducting an Air Demand Analysis, the sensor shown in the image can record the performance data for compressors from different

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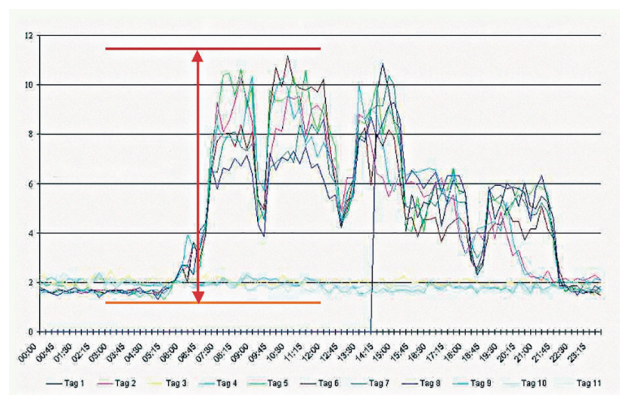


Figure 1: Compressed air demand curve over a period of 11 days (source for all illustrations: Kaeser Kompressoren SE).

manufacturers without being connected to the electronics or the air flow of the devices in question, i.e. without interfering with the system.

Savings can be achieved in ways such as the following [4]:

1. Reducing the idle current and other control losses (air losses during each switching operation, energy consumption up to actual air delivery)
2. In a compressor network, reducing the maximum working pressure via a narrow pressure band (only one pressure differential for all compressors) in lieu of using a pressure cascade
3. When using partial load control: selection of energy-efficient par-

tial load control modes / operation in the economical control range

Digital twin

In order to evaluate the data from an Air Demand Analysis and thereby optimise the compressed air system, planners increasingly rely on simulations produced by means of a digital twin. Taking the calculated compressed air demand as a basis, numerous potential designs are compared with one another in order to extract maximum cost-efficiency. The performance characteristics of the station over a measured reference time are also taken into account, so as to identify in advance any possible weak points in the partial load range and resolve them. Optimally matching all components in a compressed air station from an energy point of view saves the operator up to 30 % in energy costs for the entire system on average – sometimes even more.

Therefore, for example, when selecting new compressors the following aspects should be taken into account [4]:

- Selection of the compressors is dependent on the structure required. Typically, it involves determining the models required for base, medium and peak loads; if the con-

troller is customised to the daily and weekly consumption profiles, it makes sense to combine different sizes of compressor. As a rule, this means selecting large base load and matching standby machines combined with smaller peak load ones. Ideally, for each typical demand profile a combination featuring a minimal amount of idling time should be available.

- The delivery volume of the combined peak load machines must be equal to or greater than that of the next-largest medium or base load machine. This is the only way to optimise compressor load whilst minimising energy consumption.
- A master controller decides which compressor should cut in or out, depending on compressed air demand or system pressure.

Importance of air receivers

Air receivers (Fig. 3) are indispensable when it comes to dependable operation of a compressed air system. On the one hand they reduce unwanted pulsations emitted by the compressed air generators, whilst on the other they significantly improve compressor switching operations. It is therefore imperative that air receivers are installed when large fluctuations in demand are expected in the system over short time periods. Such transients often cannot be accommodated by either fixed-speed or frequency-controlled compressors.

With the aid of a digital twin of the compressed air station, the energy consumption can be calculated for each individual component. In certain cases, the correct choice of size for the air receiver can deliver energy savings of up to 10 %.

Compressor and compressed air system controllers

Where multiple compressors are used to supply a compressed air net-



Figure 2: Measuring equipment for an Air Demand Analysis.



Figure 3: Air receivers.

work, it pays to install a master controller. Thanks to their intelligent control concept, this ensures that compressors can be operated at their optimum operating point and switched on or off according to demand. Remote dryers and heat exchangers can be integrated into modern compressor controllers in order to achieve optimal use of energy and exhaust heat. The ultimate objective here is always to operate each individual component in a compressed air station at its most efficient operating point, thereby minimising the energy consumption of the entire station. Figure 4 shows the control unit for a compressed air station.

When it comes to master controllers coordinating operation of multiple compressors, significant differences in operating mode and efficiency exist. The following types of control are of importance here [4]:

1. Cascade control
Each compressor is assigned a pressure band with its own cut-in and cut-out point. This very simple method of control can also be achieved via the pressure switch installed in the compressor.
2. Pressure band with setpoint pressure

3. A setpoint pressure is defined at which the compressor should cut in. A pressure band is set around the setpoint with defined switching points for each individual compressor.
4. Configured similarly to 2.1, but with the reaction time and dead time characteristics of the station taken into account (e.g. the time required by a compressor for pressure build-up or relief during a switching operation). As a variation to this, compressors can be divided into groups which define a certain cut-in sequence.

Heat recovery

Reuse of the exhaust heat emitted during compressed air generation is advisable for reasons of cost effectiveness and energy efficiency. It is also required within the framework of the previously cited energy management system in accordance with ISO 50001. Fundamentally, this concerns the following energy sources:

1. Thermal energy from the compressed air
2. Thermal energy from the compressors

The decision as to whether one of these energy sources should be used, and if so which, depends on the circumstances of the individual company. Ultimately it comes down to the options for heat dissipation



Figure 4: Control unit for a compressed air station.

and the prospective use for the recovered energy.

The use of exhaust heat for thermal process steps in pharmaceuticals production must be reviewed critically. Depending on the product range, a multitude of steps exist with a requirement for some heat input. However, full control of these processes in accordance with Good Manufacturing Practice (GMP) standards requires heat always to be available in sufficient quantities, and thus for there to be no operating states where this is not the case.

Here are some examples of thermal process steps in pharmaceuticals production:

- For solid dosage forms: granule drying, drying air for sugar-coating and other coating processes
- For semi-solid dosage forms: Melting processes
- For liquid dosage forms: Solution of solid substances, sterilisation
- General cleaning processes using hot water

Normally, the heat requirement is covered either by controllable electrical heaters or wet steam from a central boiler.

Heat recovery can be installed at multiple locations in a compressed air system. The first thing to consider is the compressor. Generally, each compressor is equipped with an electric motor; this and the compressor stages become heated during operation and require cooling. The 2 basic designs available to achieve this are air-cooling and water-cooling. In the case of air-cooling, air from the room (or sometimes from outdoors) is generally blown into the installation room and through the machine that requires cooling by means of a fan. The exhaust heat is dissipated into the room, or sometimes discharged outdoors via air ducting, and thus is lost to further reuse. State-of-the-art machines therefore use water-cooling, in which a liquid (usually water) circulates within a closed cooling circuit.

Here, the energy dissipated in the machine's internal cooling circuit can be made available for external applications by means of a heat exchanger. Thus, depending on the required heat quantity and temperature, the compressor exhaust heat can be reused for a variety of purposes. The simplest method is to use this recovered energy for space-heating purposes or hot water production. However, as mentioned above, there are also a multitude of possibilities for using this energy for individual process steps, such as melting and heating fats and additives during the production of creams and ointments. Should a higher temperature be required, and provided there is enough energy available in the cooling circuit, it may be cost-effective to install an additional heat pump in order to generate process heat to a higher energy level. Of course, when considering such a solution, the additional energy requirement for the heat pump must be taken into account.

The amount of recoverable exhaust heat produced during compressed air generation only represents a small proportion of the heat required by a pharmaceuticals manufacturer. What is more, the technical hurdles are not insignificant. By their very definition modern energy-efficient compressors generate little exhaust heat, meaning that relatively little dischargeable thermal energy accumulates inside them. In addition to the quantity of heat dissipated, the driving temperature difference at the heat exchanger during the transfer between the compressor cooling system and the building's HVAC system is also of significance when it comes to efficiency.

In the event that a heat pump is installed downstream of the heat exchanger in order to raise the temperature level of the heat transfer medium high enough that the heat can be put to an appropriate use, this means that additional energy is required to operate the heat

pump, and that incremental installation costs are also incurred. It must be checked on an individual basis whether the cost of installing and operating a heat recovery system is justified by the expected benefits.

Should the areas that require heat be located at a distance from the compressed air station, heat losses on the transfer route and the costs for installing pipe insulation must also be taken into consideration. In the pharmaceuticals industry, compressed air generation is often integrated into the building systems and therefore not located directly near to the production areas.

Active heat recovery using a heat of compression dryer

A further use for the hot compressed air is compressed air drying by means of a heat of compression (HOC) dryer. As a rule, compressed air must be dried before being used for a production process, so as to prevent condensation

from entering the equipment or coming into contact with the product itself.

In a heat of compression dryer, moisture is removed from the compressed air via, for example, a molecular sieve in a system consisting of 2 chambers. Hot air is conveyed from the compressor(s) to the dryer's regeneration chamber, where the thermal energy in the hot compressed air is used to remove the moisture from the desiccant that is to be regenerated. The resulting hot and humid air is then directed through a heat exchanger, where it is cooled, thereby causing the absorbed moisture to be expelled as condensate. This condensate is then separated and removed via a condensate drain. The air subsequently flows onwards into the second chamber, where the desiccant absorbs any residual moisture, thereby achieving compressed air of the desired quality. By exchanging the sequence in which the air flows through the chambers, regeneration or absorption can take place in either one of them.

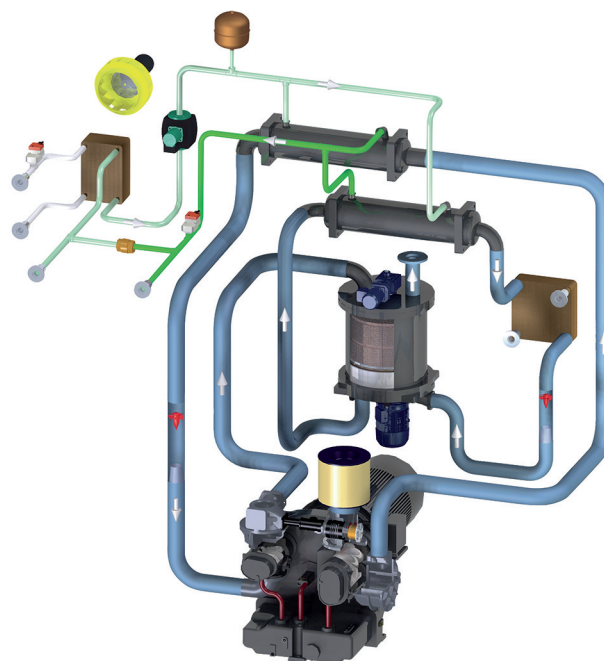


Figure 5: Flow diagram showing active regeneration using compression heat to regenerate a continuous desiccant dryer with rotating adsorption chamber.

One particular design for such discontinuous heat of compression dryers is a version with rotating adsorption chambers, in which adsorption and regeneration take place quasi-continuously in different segments of the cylindrical adsorption chamber (Fig. 5).

Selecting the correct pressure dew point

Moisture in the compressed air can lead to condensation in the compressed air system or even the product itself, resulting in a risk of contamination due to microbial growth. This means that for pharmaceutical processes that use compressed air, particular attention must be paid to selecting the correct pressure dew point. Compressed air purity classes are laid out in the ISO standard 8573-1/2010, which is a group of international norms describing the quality and purity of compressed air that has been mandatory for automation via pneumatic systems since the year 2010. Thus classification

of compressed air takes place in accordance with this standard; it stipulates the different purity classes used to define the principal contaminants – solid particles, moisture and oil – using 3 corresponding indicators, namely particle size, residual moisture content and oil content per cubic metre of compressed air. The 1 in the designation refers to “Group 1”; there are 8 further groups. Groups 2–9 test the compressed air system for one or more specific contaminants (tab. 1).

Since the air pressure in walk-in clean rooms lies only just above ambient pressure, but the pressure dew point relates to the compressed air, for the majority of processes a PDP of $\leq -20^\circ\text{C}$ meets all technical requirements regarding the prevention of condensate formation and contamination in the system. In terms of the energy required to achieve the necessary pressure dew point, this value also represents the optimum from a technical process point of view. It therefore does not make sense from an energy-efficiency perspective to consume addi-

tional energy in achieving lower pressure dew points. In individual cases, the question of the correct pressure dew point will need to be reappraised with regard to the respective process, in order to select the necessary PDP for the associated hygiene requirements to be met whilst consuming the minimum amount of energy.

Heat of compression dryers are currently the most efficient devices for compressed air drying and are therefore particularly well-suited to applications in the pharmaceuticals industry. Their combination of technical dependability and energy efficiency provides the ideal solution.

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■ Table 1

Group 1 as per ISO 8573-1:2010 [5].

ISO 8573-1:2010	Solid particles				Water		Oil
	Maximum number of particles per m ³			Mass concentration	Pressure dew point Vapour	Liquid	Total oil content (liquid aerosol, mist)
	0.1–0.5 µm	0.5–1 µm	1–5 µm	mg/m ³	°C	g/m ³	mg/m ³
0	Demands stricter than Class 1, determined by the user						
1	≤20 000	≤400	≤10	-	≤-70	-	0.01
2	≤400 000	≤6 000	≤100	-	≤-40	-	0.1
3	-	≤90 000	≤1 000	-	≤-20	-	1
4	-	-	≤10 000	-	≤+3	-	5
5	-	-	≤100 000	-	≤+7	-	-
6	-	-	-	≤5	≤+10	-	-
7	-	-	-	5–10	-	≤0.5	-
8	-	-	-	-	-	0.5–5	-
9	-	-	-	-	-	5–10	-
X	-	-	-	>10	-	>10	>10

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classes in accordance with ISO 8573-1:2010.

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