

Possibilities for saving energy in part load



by: Edo Wissink
Development Engineer,
Grasso Products b.v.

Introduction

Energy consumption is by far the largest cost centre of a refrigeration plant. The stiff climb in the price of electricity soon mounts up. The fact that a refrigeration plant runs most of the time in part load and that the price of frequency controllers has dropped makes it very worthwhile having a look at the energy-saving options with part load.

In four steps this article shows that an industrial piston compressor is the best energy solution under all operating conditions. A frequency controller can sometimes push the savings even further.

a. You can't avoid capacity fluctuations, but you can limit them

In refrigeration technology, the required cooling capacity depends on the cooling process, as well as the outside temperature. The degree to which these two factors exert any influence depends greatly on the application.

For freezing applications, the influence of the process predominates. In that case it is about the variation of the quantity of products to be frozen per hour. There is a clear distinction between production hours and night/weekend operation. The capacity is used in the weekend at the most to maintain the temperature of the products. See figure 1.

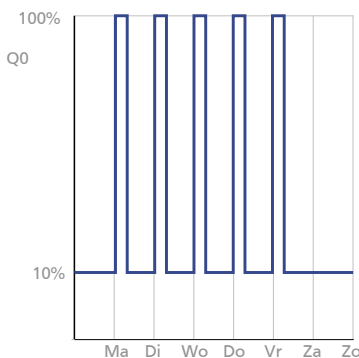


Figure 1: Typical capacity variations in a freezing process

For fruit storage, the seasonal influence prevails. At the end of the summer there is a large amount of fruit that must be kept cooled, as it can still be quite warm outside. In the winter the fruit only has to be maintained at a low ambient temperature. Figure 2 shows a simplified view of the influence of the seasons on fruit refrigeration.

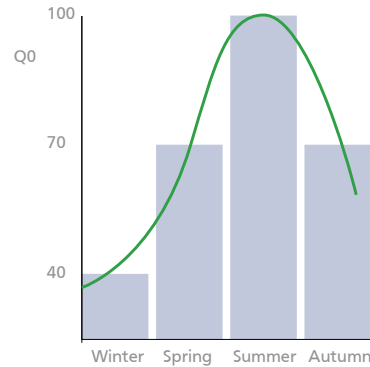


Figure 2: Typical capacity variations in fruit storage

The summer is characterized by a high condensation temperature and a lot of full load operation. To save energy costs it is important to keep the pressure difference between suction and discharge as small as possible. Cheap plants, characterized by things like air-cooled condensers with a low amount of heat transfer surface, will have a higher average pressure difference due to the larger delta T over the condenser. However, this will also fluctuate greatly during variations in load. This undesirable change of condition in turn has a negative influence on the available capacity, just at the moment that a lot of capacity is demanded.

There will always be variation in refrigerating capacity, because cooling is part of a business economics system.

b. Compressor selection and capacity variations

Refrigeration is often part of a much larger business process, so its availability is the first matter of importance. The capacity of the plant is explained on the basis of the maximum expected demand for cooling. The starting point in selecting compressors is that this must take place from a business economics point of view. That is optimum if the sum of investment, maintenance and energy costs over the total economic lifetime is minimal. Basic principles for realizing this are:

- highest efficiency is realized in full load

Compressors and their drives are designed so that they perform best at full load. Regulating is generally at the cost of efficiency. The capacity drops faster than the required power.

To avoid running unnecessarily at part load at times when less than 30% of the cooling power is demanded, it is advisable to select the compressors according to the one-seventh principle. For a plant with a total of 1400kW for instance, one compressor is chosen with a capacity of



$1/7 \times 1400=200\text{kW}$, one with a capacity of $2/7 \times 1400=400\text{kW}$ and one with a capacity of $4/7 \times 1400=800\text{kW}$. An alternative is the one-sixth, one-third and one-half principle, with the advantage that with failure there is always more than 50% of capacity available. This in connection with the increase in T_0 and decrease in T_c .

Compressors from the same series are often chosen for practical reasons such as parts in stock.

- aim for minimum number of compressors

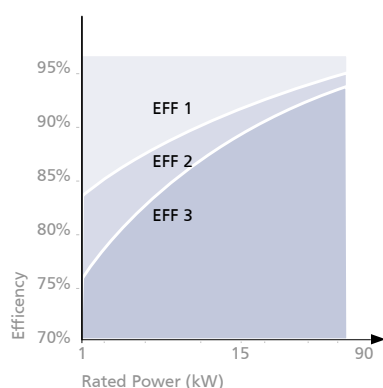
Large machines are more efficient than smaller machines. The same applies to compressors and electric engines. This means that the choice of the number of compressors will influence the efficiency.

One engine that is often used is the four-pole motor (50 Hz, 1500 rpm). Figure 3 shows the EFF classification for four-pole electric motors up to 90 kW, in which the rising trend is clearly visible. The reliability and availability of refrigeration determine the lower threshold for minimizing the number of compressors. If there is no cold buffer the minimum number of compressors is two.

Figure 3: EU CEMEP classification for the standard

- Compressor efficiency outside the design condition

Compressors are selected on their design condition. In



practice, a compressor does not run on one condition but on a range of conditions whose pressure ratio can vary significantly from the design condition. What are the consequences for the energy consumption if a compressor runs outside the design condition?

The advantage of a piston compressor is that it automatically adapts to the condition imposed by the refrigeration system. The differential pressure-controlled valves take care of that. By contrast, the screw compressor was designed for a fixed pressure ratio. That means that in practice a screw will encounter either overcompression (expansion of superfluous built-up pressure during the starting phase of expulsion) or undercompression (flow back of compressed gas in the compression volume during the starting phase of expulsion). These extra losses can only be prevented by equipping a screw with a variable VI control.

- compressor efficiency in part load

Both the piston and the screw have their own part load characteristic. With piston compressors, cylinders are switched off; with screw compressors, a part load slide is used to shorten the effective rotor length. Figure 4 shows the efficiency variation in part load for the design condition. It is worth noting that the piston and screw are equivalent in full load. Both part load systems give a loss in COP. This loss is greater with screws than with pistons, as is shown in the divergent graphs.

A common error is thinking that frequency regulation is a part load mechanism. It is a way of controlling the capacity but the compressor is in full load.

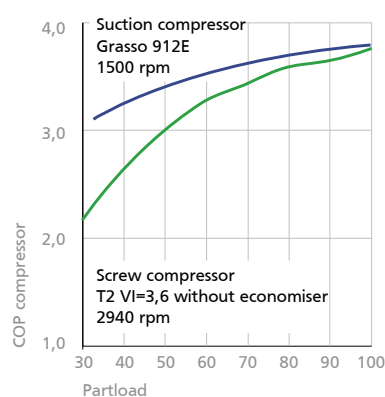


Figure 4: Comparison of COP for different capacities of piston and screw compressors.

An industrial piston compressor is the most efficient solution for part load and running outside the design condition.



c. Possibilities for saving energy with frequency regulation

Application of frequency regulation on an industrial piston compressor forms an energy-lean and maintenance-saving alternative for controlling capacity:

Mechanical load

The mechanical load decreases with lower speeds of revolution and lower discharge gas temperatures. Frequency regulation can control the capacity by both lowering and raising the speed of revolution with respect to the nominal speed of revolution. With small screw and scroll compressors, the revolutions are often increased because the revolution decrease is limited by the drop in the swept volume. With pistons and larger screw compressors the revolutions are often lowered because these machines are less prone to leaking. With large screws the leakage is relatively small in comparison with the pumped output and with piston compressors the piston springs ensure that the compression chamber is well sealed. A lower revolution speed gives a lower machine temperature. With piston compressors that have several cylinders there is the added advantage of all pistons having an equal load, so the heat load is distributed evenly. The lower mechanical load and the equal distribution of the wear translates into longer maintenance intervals.

Energy efficiency

The first saving can be achieved on system level. The capacity supplied can be matched optimally to the capacity demanded. This reduces the average pressure difference between discharge and suction. The greatest saving is achieved in systems with relatively large capacity steps and many variations of load. The second saving in energy comes from the compressor itself. The electric capacity (P_e) that a compressor package needs is cooling capacity (Q_0) divided by the product of the COP of the compressor and the efficiency of the drive (η_{drive}).

That is:

$$P_{elec} = \frac{P_{shaft}}{\eta_{drive}(n,T)} = \frac{1}{\eta_{drive}(n,T)} * \frac{Q_0}{COP(P_o, P_c, dTo, n, part\ load)}$$

P_{shaft}	required shaft capacity for compressor
P_o, P_c	suction and discharge pressure on the compressor flanges
dTo	superheating of the suction gas
n	rpm
part load	part load system of compressor
T	shaft torque

With frequency regulation, the η_{drive} is a product of the frequency regulator ($\eta_{freq.reg}$) and the electric motor (η_{e-mot}). That is:

$$\eta_{drive}(n,T) = \eta_{freq.reg}(T,f) * \eta_{e-mot}(n,T,f)$$

f: switch frequency

The efficiency of a PWM (pulse width modulation) frequency-controlled drive is roughly independent of the switching frequency f , because the efficiency of the frequency regulation drops and that of the electric motor increases with the switch frequency.

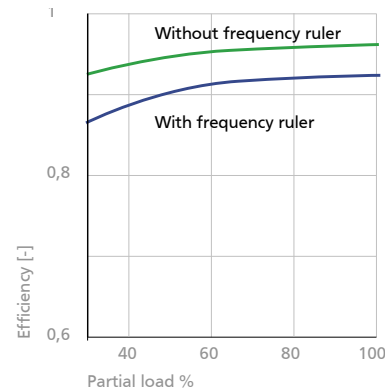


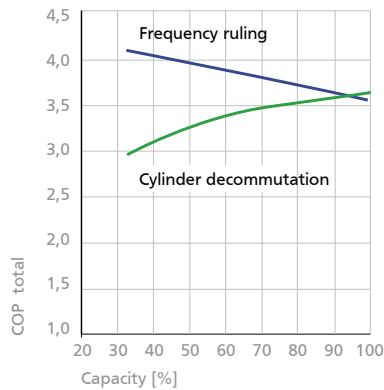
Figure 5: Comparison of drive efficiency with and without frequency regulation

Figure 5 shows that the efficiency of a drive controlled by frequency regulation is less than that of a motor that is connected directly to the network. The frequency regulator itself has switching losses and does not provide a totally sinusoidal motor current. This in turn causes harmonic losses in the electric motor, which puts an extra thermal load on the electric motor. The heating is intensified because the amount of cool air drops with the number of revolutions and the torque to be supplied remains constant. To maintain the same temperature class, a larger motor will often have to be selected.

So where is the efficiency gain then? It is supplied by the compressor, because the compressor runs at full load at a lower rpm. The improvement in COP of displacement compressors with rpm control comes about due to:

- elimination of losses that arise from the part load system (for example, pump losses from part load cylinders in piston compressors)
- losses that decrease more than linearly with the rpm (for example, flow losses due to the suction and discharge valves).

Figure 6:



Comparison of COP Grasso 912E with and without frequency regulation

In figure 6 the COP_{total} ($= Q_o / P_{elec}$) of a Grasso 912E piston compressor is compared with and without regulation at a constant condition. This figure shows that using frequency regulation has a negative effect on energy at loads higher than 92% and a positive effect at loads lower than 92%.

d. Example of calculation of energy savings

The aim of this example is to give an indication of how much electrical energy can be saved with a frequency regulator. For the example we chose:

Compressor:	Grasso 912E
Refrigerant:	NH ₃
Motor:	ABB IP55 355kW
Frequency regulator	ABB ASC800 400kW
RPM:	500-1500 rpm

The user profile is given in table 1.

	summer	autumn	winter	spring
T _o [°C]	-10	-10	-10	-10
T _c [°C]	35	25	20	25
Running hours	2000	1000	500	1000
100% load	60	20	0	30
66% load	40	50	30	50
33% load	0	30	70	20

Table 1: User profile in the energy savings calculation

The results are given in table 2. The energy savings realized in this example are 10.4%, which equates with 2,330 Euro/year. The energy saving that can be achieved depends to a great extent on the number of running hours per year and the degree to which part load is run.

The amount that can be saved was calculated here at the current price of 0.05 Euro/kWh but this should actually be the average of the price in the coming 5 years.

	without frequency regulation	with frequency regulation	
weighted yearly average COP _{electric}	4.06	4.53	
electricity consumption	449,207	402,612	kWh
electricity costs/year at 0.05 Euro/kWh	22,460	20,131	Euro
energy saving		10.4	%
energy saving		2330	Euro

Table 2. Outcome of energy saving potential of example.

Conclusion

Energy saving starts with the business-economic selection of a compressor on the basis of the maximum cooling capacity expected and variations on it.

- Large industrial compressors have a better COP_{electric} than smaller ones, because the efficiency of the drive as well as that of the compressor is better.
- Aim for compressors that run at full load
- For part load and strongly varying conditions, a piston compressor is the best solution energy-wise

Using a frequency regulator in piston compressors saves energy at part load. As far as energy goes, it is best to have one rpm-regulated piston compressor per installation; it copes with most of the variations in capacity. Whether the extra investment in a frequency regulator is economically feasible has to be calculated for each case, because the possible energy savings depend strongly on the number of running hours and the amount of part load.

Next month the Grasso article will be all about valves. If you would like to react to this article or one of the previous articles, or have questions, you can contact: Grasso Products b.v., Jan-Pieter Habraken
jphabraken@grasso.nl

