



HVAC SYSTEMS - CEM REFRESHER ONLINE TRAINING COURSE

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FACTORS AFFECTING REFRIGERATION AND ENERGY SAVINGS FOR ENERGY PROFESSIONALS

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WHAT SHOULD YOU LEARN





Factors Affecting Performance & Energy Efficiency of Refrigeration Plants

Energy Saving Opportunities

DESIGN OF PROCESS HEAT EXCHANGERS

There is a tendency of the process group to operate with high safety margins which influences the compressor suction pressure / evaporator set point. For instance, a process cooling requirement of 15°C would need chilled water at a lower temperature, but the range can vary from 6°C to say 10°C. At 10°C chilled water temperature, the refrigerant side temperature has to be lower, say -5°C to +5°C.

The refrigerant temperature, again sets the corresponding suction pressure of refrigerant which decides the inlet duty conditions for work of compression of the refrigerant compressor. Having the optimum / minimum driving force (temperature difference) can, thus, help to achieve highest possible suction pressure at the compressor, thereby leading to less energy requirement.

This requires proper sizing of heat transfer areas of process heat exchangers and evaporators as well as rationalizing the temperature requirement to highest possible value. A 1°C raise in evaporator temperature can help to save almost 3 % on power consumption. The TR capacity of the same machine will also increase with the evaporator temperature, as given in Table 4.1.



TABLE 4.1 EFFECT OF VARIATION IN EVAPORATOR TEMPERATURE ON COMPRESSOR POWER CONSUMPTION

Evaporator Temperature (°C)	Refrigeration Capacity* (tons)	Specific Power Consumption	Increase in kW/ton (%)
5.0	67.58	0.81	-
0.0	56.07	0.94	16.0
-5.0	45.98	1.08	33.0
-10.0	37.20	1.25	54.0
-20.0	23.12	1.67	106.0

* Condenser temperature 40°C

Towards rationalizing the heat transfer areas, the heat transfer coefficient on refrigerant side can be considered to range from 1400 - 2800 watts /m²K.

The refrigerant side heat transfer areas provided are of the order of 0.5 Sqm./TR and above in evaporators.



TABLE 4.2 EFFECT OF VARIATION IN CONDENSER TEMPERATURE ON COMPRESSOR POWER CONSUMPTION

Condensers in a refrigeration plant are critical equipment that influence the TR capacity and power consumption demands. Given a refrigerant, the condensing temperature and corresponding condenser pressure, depend upon the heat transfer area provided, effectiveness of heat exchange and the type of cooling chosen.

A lower condensing temperature, pressure, in best of combinations would mean that the compressor has to work between a lower pressure differential as the discharge pressure is fixed by design and performance of the condenser. The choices of condensers in practice range from air cooled, air cooled with water spray, and heat exchanger cooled. Generously sized shell and tube heat exchangers as condensers, with good cooling tower operations help to operate with low discharge pressure values and the TR capacity of the refrigeration plant also improves. With same refrigerant, R22, a discharge pressure of 15 kg/cm² with water cooled shell and tube condenser and 20 kg/cm² with air cooled condenser indicate the kind of additional work of compression duty and almost 30 % additional energy consumption required by the plant. One of the best option at design stage would be to select generously sized (0.65 m²/TR and above) shell and tube condensers with water-cooling as against cheaper alternatives like air cooled condensers or water spray atmospheric condenser units.



TABLE 4.2 EFFECT OF VARIATION IN CONDENSER TEMPERATURE ON COMPRESSOR POWER CONSUMPTION

Condensing Temperature (°C)	Refrigeration Capacity (tons)	Specific Power Consumption	Increase in (kW / TR) kW/TR (%)
26.7	31.5	1.17	-
35.0	21.4	1.27	8.5
40.0	20.0	1.41	20.5

* Reciprocating compressor using R-22 refrigerant.
Evaporator temperature: -10°C

The effect of condenser temperature on refrigeration plant energy requirements is given in Table 4.2.

MAINTENANCE OF HEAT EXCHANGER SURFACES

Maintenance of Heat Exchanger Surfaces After ensuring procurement, effective maintenance holds the key to optimizing power consumption.

Heat transfer can also be improved by ensuring proper separation of the lubricating oil and the refrigerant, timely defrosting of coils, and increasing the velocity of the secondary coolant (air, water, etc.). However, increased velocity results in larger pressure drops in the distribution system and higher power consumption in pumps / fans. Therefore, careful analysis is required to determine the most effective and efficient option.

Fouled condenser tubes force the compressor to work harder to attain the desired capacity. For example, a 0.8 mm scale build-up on condenser tubes can increase energy consumption by as much as 35 %. Similarly, fouled evaporators (due to residual lubricating oil or infiltration of air) result in increased power consumption. Equally important is proper selection, sizing, and maintenance of cooling towers. A reduction of 0.55°C temperature in water returning from the cooling tower reduces compressor power consumption by 3.0 % (see Table 4.3).

TABLE 4.3 EFFECT OF POOR MAINTENANCE ON COMPRESSOR POWER CONSUMPTION

Condition	Evap. Temp (°C)	Cond. Temp (°C)	Refrigeration Capacity* (tons)	Specific Power Consumption kW/Ton	Increase in (kW/ton) (%)
Normal	7.2	40.5	17.0	0.69	-
Dirty condenser	7.2	46.1	15.6	0.84	20.4
Dirty evaporator	1.7	40.5	13.8	0.82	18.3
Dirty condenser and evaporator	1.7	46.1	12.7	0.96	38.7

* 15 ton reciprocating compressor based system. The power consumption is lower than that for systems typically available in India. However, the percentage change in power consumption is indicative of the effect of poor maintenance.

MULTI-STAGING FOR EFFICIENCY

Efficient compressor operation requires that the compression ratio be kept low, to reduce discharge pressure and temperature. For low temperature applications involving high compression ratios, and for wide temperature requirements, it is preferable (due to equipment design limitations) and often economical to employ multi-stage reciprocating machines or centrifugal / screw compressors. Multi-staging systems are of two-types: compound and cascade – and are applicable to all types of compressors. With reciprocating or rotary compressors, two-stage compressors are preferable for load temperatures from -20 to -58°C , and with centrifugal machines for temperatures around -43°C .

In multi-stage operation, a first-stage compressor, sized to meet the cooling load, feeds into the suction of a second-stage compressor after inter-cooling of the gas. A part of the high pressure liquid from the condenser is flashed and used for liquid sub-cooling. The second compressor, therefore, has to meet the load of the evaporator and the flash gas. A single refrigerant is used in the system, and the work of compression is shared equally by the two compressors. Therefore, two compressors with low compression ratios can in combination provide a high compression ratio.

For temperatures in the range of -46°C to -101°C , cascaded systems are preferable. In this system, two separate systems using different refrigerants are connected such that one provides the means of heat rejection to the other. The chief advantage of this system is that a low temperature refrigerant which has a high suction temperature and low specific volume can be selected for the low-stage to meet very low temperature requirements.



MATCHING CAPACITY TO SYSTEM LOAD

During part-load operation, the evaporator temperature rises and the condenser temperature falls, effectively increasing the COP. But at the same time, deviation from the design operation point and the fact that mechanical losses form a greater proportion of the total power negate the effect of improved COP, resulting in lower part-load efficiency.

Therefore, consideration of part-load operation is important, because most refrigeration applications have varying loads. The load may vary due to variations in temperature and process cooling needs. Matching refrigeration capacity to the load is a difficult exercise, requiring knowledge of compressor performance, and variations in ambient conditions, and detailed knowledge of the cooling load.



CAPACITY CONTROL AND ENERGY EFFICIENCY

The capacity of compressors is controlled in a number of ways. Capacity control of reciprocating compressors through cylinder unloading results in incremental (step-by-step) modulation as against continuous capacity modulation of centrifugal through vane control and screw compressors through sliding valves.

Therefore, temperature control requires careful system design. Usually, when using reciprocating compressors in applications with widely varying loads, it is desirable to control the compressor by monitoring the return water (or other secondary coolant) temperature rather than the temperature of the water leaving the chiller. This prevents excessive on-off cycling or unnecessary loading / unloading of the compressor. However, if load fluctuations are not high, the temperature of the water leaving the chiller should be monitored. This has the advantage of preventing operation at very low water temperatures, especially when flow reduces at low loads. The leaving water temperature should be monitored for centrifugal and screw chillers.



CAPACITY CONTROL AND ENERGY EFFICIENCY +

Capacity regulation through speed control is the most efficient option. However, when employing speed control for reciprocating compressors, it should be ensured that the lubrication system is not affected. In the case of centrifugal compressors, it is usually desirable to restrict speed control to about 50 % of the capacity to prevent surging. Below 50 %, vane control or hot gas bypass can be used for capacity modulation.

The efficiency of screw compressors operating at part load is generally higher than either centrifugal compressors or reciprocating compressors, which may make them attractive in situations where part-load operation is common. Screw compressor performance can be optimized by changing the volume ratio. In some cases, this may result in higher full-load efficiencies as compared to reciprocating and centrifugal compressors. Also, the ability of screw compressors to tolerate oil and liquid refrigerant slugs makes them preferred in some situations.

MULTI-LEVEL REFRIGERATION FOR PLANT NEEDS

The selection of refrigeration systems also depends on the range of temperatures required in the plant. For diverse applications requiring a wide range of temperatures, it is generally more economical to provide several packaged units (several units distributed throughout the plant) instead of one large central plant. Another advantage would be the flexibility and reliability accorded.

The selection of packaged units could also be made depending on the distance at which cooling loads need to be met. Packaged units at load centers reduce distribution losses in the system. Despite the advantages of packaged units, central plants generally have lower power consumption since at reduced loads power consumption can reduce significantly due to the large condenser and evaporator surfaces.

Many industries use a bank of compressors at a central location to meet the load. Usually the chillers feed into a common header from which branch lines are taken to different locations in the plant.

MULTI-LEVEL REFRIGERATION FOR PLANT NEEDS +

In such situations, operation at part-load requires extreme care. For efficient operation, the cooling load, and the load on each chiller must be monitored closely. It is more efficient to operate a single chiller at full load than to operate two chillers at part-load. The distribution system should be designed such that individual chillers can feed all branch lines. Isolation valves must be provided to ensure that chilled water (or other coolant) does not flow through chillers not in operation.

Valves should also be provided on branch lines to isolate sections where cooling is not required. This reduces pressure drops in the system and reduces power consumption in the pumping system. Individual compressors should be loaded to their full capacity before operating the second compressor. In some cases it is economical to provide a separate smaller capacity chiller, which can be operated on an on-off control to meet peak demands, with larger chillers meeting the base load.

Flow control is also commonly used to meet varying demands. In such cases the savings in pumping at reduced flow should be weighed against the reduced heat transfer in coils due to reduced velocity. In some cases, operation at normal flow rates, with subsequent longer periods of no-load (or shut-off) operation of the compressor, may result in larger savings.

CHILLED WATER STORAGE

Depending on the nature of the load, it is economical to provide a chilled water storage facility with very good cold insulation. Also, the storage facility can be fully filled to meet the process requirements so that chillers need not be operated continuously. This system is usually economical if small variations in temperature are acceptable.

This system has the added advantage of allowing the chillers to be operated at periods of low electricity demand to reduce peak demand charges - Low tariffs offered by some electric utilities for operation at night time can also be taken advantage of by using a storage facility. An added benefit is that lower ambient temperature at night lowers condenser temperature and thereby increases the COP.

If temperature variations cannot be tolerated, it may not be economical to provide a storage facility since the secondary coolant would have to be stored at a temperature much lower than required to provide for heat gain. The additional cost of cooling to a lower temperature may offset the benefits.

The solutions are case specific. For example, in some cases it may be possible to employ large heat exchangers, at a lower cost burden than low temperature chiller operation, to take advantage of the storage facility even when temperature variations are not acceptable. Ice bank system which store ice rather than water are often economical.

SYSTEM DESIGN FEATURES

In overall plant design, adoption of good practices improves the energy efficiency significantly. Some areas for consideration are:

- ✓ Design of cooling towers with FRP impellers and film fills, PVC drift eliminators, etc.
- ✓ Use of softened water for condensers in place of raw water.
- ✓ Use of economic insulation thickness on cold lines, heat exchangers, considering cost of heat gains and adopting practices like infrared thermography for monitoring - applicable especially in large chemical / fertilizer / process industry.
- ✓ Adoption of roof coatings / cooling systems, false ceilings / as applicable, to minimize refrigeration load.
- ✓ Adoption of energy efficient heat recovery devices like air to air heat exchangers to pre-cool the fresh air by indirect heat exchange; control of relative humidity through indirect heat exchange rather than use of duct heaters after chilling.
- ✓ Adopting of variable air volume systems; adopting of sun film application for heat reflection; optimizing lighting loads in the air conditioned areas; optimizing number of air changes in the air conditioned areas are few other examples.

ENERGY SAVING OPPORTUNITIES

- ✓ Cold Insulation : Insulate all cold lines / vessels using economic insulation thickness to minimize heat gains; and choose appropriate (correct) insulation.
- ✓ Building Envelope : Optimise air conditioning volumes by measures such as use of false ceiling and segregation of critical areas for air conditioning by air curtains.
- ✓ Building Heat Loads Minimisation : Minimise the air conditioning loads by measures such as roof cooling, roof painting, efficient lighting, pre-cooling of fresh air by air-to-air heat exchangers, variable volume air system, optimal thermo-static setting of temperature of air conditioned spaces, sun film applications, etc.
- ✓ Process Heat Loads Minimisation : Minimize process heat loads in terms of TR capacity as well as refrigeration level, i.e., temperature required, by way of:
 - ⇒ Flow optimization
 - ⇒ Heat transfer area increase to accept higher temperature coolant
 - ⇒ Avoiding wastages like heat gains, loss of chilled water, idle flows.
 - ⇒ Frequent cleaning / de-scaling of all heat exchangers

ENERGY SAVING OPPORTUNITIES +

At the Refrigeration A/C Plant Area

✓

Ensure regular maintenance of all A/C plant components as per manufacturer guide- lines.

✓

Ensure adequate quantity of chilled water and cooling water flows, avoid bypass flows by closing valves of idle equipment.

✓

Minimize part load operations by matching loads and plant capacity on line; adopt variable speed drives for varying process load.

✓

Make efforts to continuously optimize condenser and evaporator parameters for minimizing specific energy consumption and maximizing capacity.

✓

Adopt VAR system where economics permit as a non-CFC solution.

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