

HVAC MADE EASY - Selection tips for Chiller Compressors

Course Content

PART I - REFRIGERATION CHILLERS (VAPOR COMPRESSION MACHINES)

HVAC applications operating on chilled water system require a chiller package, which operate either on the principles of vapor compression or vapor absorption. Vapor compression system use mechanical energy in the form of motor to drive the cooling cycle whereas absorption chillers use heat to drive the process. The classification of vapor compression chiller packages is by the type of compressor. Depending on the application, the chiller can be selected for the following compressor types: reciprocating, centrifugal, screw or a scroll type.

Reciprocating chiller:

Reciprocating compressors are categorized as positive displacement machines. These are available in two basic types: hermetic sealed units and units of open construction. In hermetic sealed units, the motor and the compressor are direct-coupled and housed in a single casing that is sealed to the atmosphere. In open construction units, the motor and the compressor are in separate housings. In general, open construction units have a longer service life, lower maintenance requirements and higher operating efficiencies. The hermetic sealed units are most common particularly in small capacities. Single stage reciprocating machines have an ability to operate at compression ratios of 10 to 12.

The capacity control in reciprocating machine is achieved through 'On-Off' or 'Loading-Unloading' of compressor cylinders.

Reciprocating machines are manufactured in capacities from 0.5 to 150 TR.

The main factors favoring reciprocating machine is low cost. The other advantage is that multiple reciprocating machines can be installed to closely match the building loads. Multiple units allow flexibility to operate machines per the need. If properly managed this could attribute to significant energy savings during low loads.

A major drawback is a high level of maintenance requirement's, noise and vibration. Since the capacity is limited to 150 TR, multiple units cost more than other options. Multiple chiller configurations require large space and consume more energy per ton of refrigeration.

Centrifugal Chillers

Centrifugal chillers are categorized as variable volume displacement units. Like reciprocating machines these are also available in both hermetic and open construction. Commercially the hermetic sealed units are more widely used, despite its lower operating efficiency. Centrifugal chillers for refrigeration applications are generally designed for a fixed compression ratio of 18.

The capacity control is achieved through the use of inlet vanes on the impellers that restrict refrigerant flow.

The centrifugal chillers are manufactured in capacities from 90 to 2000 tons.

The main factor favoring centrifugal machine is their high operational efficiency at full load, compact size and availability in large sizes.

The biggest drawback of centrifugal machine is a very poor part load performance and inability to operate at low cooling loads. At extreme low loads, these chillers are prone to a condition known as surging.

The main limitation is that these are not suitable for air-cooled condenser options and require water and cooling tower.

Screw Chillers

Rotary or screw chillers, like reciprocating machines are positive displacement compressors. Rotary is a wider term that may include vane, eccentric, gear or screw types. The commercial refrigeration installation rely more on screw machines. Screw compressors are available in several designs, both single screw and twin screw, with oil-free and oil-injected designs in both types. Twin-screw oil-injected compressors are slightly more energy efficient at moderate compression ratios. Twin-screw compressors have an ability to operate at compression ratio of 30. Units are available in both hermetic sealed and open construction.

The capacity control in screw compressor is achieved through a moveable slide stop valve, which will vary the compressor internal volume ratio to achieve optimum energy consumption during part load operation.

Screw chillers are available in capacities ranging from 20 to 1000 tons and even higher from few manufacturers.

The factors favoring screw chillers is their compact size, lightweight, quite & vibration free operation and high energy efficiency both in full and part load operation.

The major drawback is their high cost. For smaller loads, reciprocating machines are less expensive to purchase and for large loads centrifugal machines cost less.

Scroll Chillers

Scroll compressors have been used in commercial practice for systems that have capacity less than 30 TR. On such small sizes, these do not affect the life cycle economics drastically and therefore not discussed further.

PART II – COMPARISON OF VARIOUS COMPRESSORS

Installed costs and capital offsets are the vital economic parameters to selection; but a more meaningful economic comparison is based on a wider technical framework. This section provides relative comparison of the three most common chiller compressors.

Capital costs: Capital costs are taken first. The reciprocating compressors are the cheapest followed by centrifugal compressors. Screw compressors are usually more expensive by 10 to 15% than centrifugal at the same operating conditions.

Operating costs and efficiency: The efficiency of the screw compressor and reciprocating compressor, when operating at the similar compression ratio is similar. The screw compressors have an ability to operate at 30 compression ratios that allows much efficient operation than the reciprocating compressor. Typically chiller efficiency is between 0.7 to 0.8 kW per ton, making rotary chillers more efficient than comparably sized reciprocating but less efficient than centrifugal.

Energy consumption per ton of refrigeration is highest with reciprocating machine followed by screw compressors. Centrifugal compressors consume the least power at full load operation.

Parameters	Reciprocating	Centrifugal	Screw
Approximate power usage ratings (kW/TR)	0.85	0.70 for units < 150 TR 0.63 for units >150 & <300 TR 0.52 for units >300 TR	0.79 for units < 150 TR 0.71 for units >150 & < 300 TR 0.63 for units > 300 TR

Operating costs at part load efficiency: Efficiency at part load operation is very important aspect of analysis. Overall economics on life cycle basis demand much more than the peak loading. One must look at how those loads vary on a daily and seasonal basis. Remember, a typical chiller operates less than peak loading more than 90% of the time.

- The screw compressor offer infinite reduction from 100% to 0%, that allows obtaining higher refrigeration capacity from the same machine and affords good part load efficiency.
- The centrifugal machine accomplishes the capacity reduction in stages. When building load decreases, the chiller responds by partially closing its inlet vanes to restrict refrigerant flow. While this control method is effective down to about 20% of chiller's rated output, it results in decreased operating efficiency. For example a chiller rated at 0.6 kW per ton at full load might require as much as 0.9 kW per ton when lightly loaded. Since chillers typically operate at or near full load less than 10 percent of time, part load operating characteristics significantly impact annual energy requirements.
- The reciprocating compressors stepped capacity control is most efficient at minimum load than the twin-screw compressor.

Reliability and maintenance: The number of moving parts is highest in reciprocating compressor while centrifugal compressor has the least number of parts. However the centrifugal machines operate at high speed and are susceptible to unbalance & vibrations. The centrifugal machines shall require more items to be checked regularly. The screw compressor is not subject to unbalance problems with rotors operating at half below the first critical speed. Wear and tear of reciprocating compressor is frequent and requires considerable maintenance.

Field Serviceability: Field serviceability of screw compressor is relatively simple and is serviceable in the field as all parts are removable and replaceable.

- The above is true for centrifugal compressor but may pose significant problems if rotor is failed. Centrifugal rotors are one of a kind and are not standard equipment or a stock item that will fit in a similar unit in the field.
- Most reciprocating compressors are field serviceable but it is tedious due to large number of parts.

Stock availability of spares: Most screw compressors manufacturers have a number of machines in stock, as well as the rotors, bearings seals etc.

- Centrifugal compressors do not stock rotors and require 10 to 12 week delays to fabricate the same.
- Reciprocating compressors are normally available from local stocks.

Design and operating characteristics:

Suction pressure: While designing a refrigeration system, a specific suction pressure is usually specified, and often time's designers forget that this may change dramatically. Lower suction pressure signify lower evaporator temperature, which is the refrigerant temperature required to absorb heat from the medium being cooled. Lowering the evaporator temperature 10 deg from a base of 40F and 105F reduces the capacity about 24%, and at the same time increases the compressor HP per ton about 18%. The twin-screw compressor allows it to handle large variations in suction pressures with small changes in operation efficiency. A reciprocating compressor can also accommodate variations. With the centrifugal compressor, there is little potential variation available and even a small variation can cause considerable problems. In simple words the screw and reciprocating machines can meet additional capacity requirements caused due to expansion or modification just by control settings.

Discharge Pressure: Higher discharge pressure signifies higher condensing temperature, which is the refrigerant temperature required to reject heat to the condensing medium. Increasing the condensing temperature 15 deg from a base of 40 F and 105F reduces the capacity about 13% and increases the compressor HP per ton about 27%. Discharge pressure is of considerable importance in refrigeration systems, particularly in the water-cooled condenser. The lower the temperature of discharge gas, the less fouling with in the condenser. In screw compressor, the discharge temperature of refrigerant gas is held to a minimum due to the lubricant cooling system. The highest system pressure occurs in reciprocating compressor while in centrifugal compressor it is kept low due to inter-stage cooling.

Operating pressures: The screw compressor can operate at any discharge pressure as long as it is within the operating design pressure of the compressor casing. Screw compressors can operate up to 30 compression ratios; reciprocating compressors can operate at compression ratio up to 10. A centrifugal compressor is designed for specific pressure differential and if the suction or the discharge pressures vary, it usually is a hunting or surging condition.

Hunting or Surging: The reciprocating and screw compressors will not hunt or surge. Centrifugal machines are prone to surging at low and high pressures. At low load conditions the centrifugal machines are susceptible to surge condition that cause considerable vibration and may damage the compressor. The other reason for surge is the high discharge pressure, which is a fault condition. Because of nature of compression process the flow through the compressor can become unstable if the compressor is required to produce a pressure rise in excess of its design limit. Typically the faults are:

- Excessive fouling of the condenser,
- A partial failure of the condenser coolant flow,
- Or accumulation of a non-condensable gas in the condenser

Oil Lubrication: The screw compressor has a considerable amount of oil pumped through it at all times and therefore it can absorb liquid slugs in large quantities. Large quantities of liquids during upset conditions can destroy reciprocating compressors but the centrifugal compressors are most susceptible to water. Even small quantities of liquids shall have detrimental effect on centrifugal compressor rotors. In screw compressor, oil is injected into the rotor chamber for sealing and lubrication purposes and is removed in an oil separator. In reciprocating compressors lubricating oil is allowed to circulate with the refrigerant, this avoids the necessity for fitting an oil separator. Centrifugal machines are oil free dry units.

Refrigerants: The use of low-pressure refrigerants to suit the characteristics of the compressor implies that the evaporator operates below atmospheric pressure. It has to be ensured that air and moisture do not leak into the system on those machines that use low-pressure refrigerants. It should be prevented from accumulating, since sludge can interfere with the operation of the plant, cause corrosion and may damage the internals. Centrifugal chillers most commonly use a low-pressure refrigerant such as HCFC-123 or a medium pressure refrigerant such as HFC-134a. Higher pressure HCFC-22 is sometimes is used in unusually large capacity units. The screw and reciprocating machines are positive displacement machines and use higher-pressure refrigerant.

Air or Water Cooled Configurations: Centrifugal chillers require water-cooled condensers. Air-cooled condenser is not a recommended option for the centrifugal machines operating at low-pressure refrigerants. The screw and reciprocating machines are available in both air-cooled and water-cooled condenser options.

Chiller Instrument Controls: The modern chiller control systems are almost exclusively microprocessor based electronic controls that allow precision, programming, flexibility to regulate, reliability and information feedback. All the three chiller options are available with factory installed controllers that allow remote monitoring and sequencing (RMS) features and can be interfaced with building management systems (BMS) or industrial plant distributed control systems (DCS)

- The controllers offer the programmable set points, lead/lag scheduling, optimal start control, compressor soft loading, demand limit control etc as standard features.
- Phase failure/reversal protection, high return water unloading, acoustical enclosures around the compressor are factory installed optional features that are available at extra cost.

New Technology Alternatives and Trends

- 1) Air-conditioning systems consume high energy. The part load efficiency is very critical to minimize the overall energy costs. The problems with centrifugal machine having low part load efficiency and inability to operate during low load to a great extent have been eliminated through the provision of variable frequency drive (VFD). As the cooling load decreases, the VFD decreases its output voltage/frequency, slowing chiller. The result the chiller operates at near full load efficiency for almost the entire operating range. The VFD units allow the chiller to operate as low as 10% of rated output without experiencing surging.
- 2) Gas driven centrifugal machines are an alternative to electric driven chillers in areas where demand charges are high and natural gas rates are low. The gas/turbine driven machines tend to be more than twice as expensive as the electrical driven machines of equivalent capacity. The use of gas/turbine driven machines is recommended for remote locations where either the electric power unavailable or where the high capacity chiller machines, typically above 750 HP demand expensive electrical distribution network, switchgear and transformers.
- 3) In large centrifugal machines, the expansion valve is replaced with 2-phase turbine. With expansion valves, the energy potential available across the expansion valve due to the high-pressure differential is lost. By replacing the valve with a turbine, some of the energy can be recovered and used to help drive the chiller compressor, reducing energy the motor must supply.
- 4) New chillers are larger than the ones they are replacing, even though no change in capacity. Efficiency improvements are primarily the result of: Larger heat exchangers redesigned refrigerant flow aerodynamics and more efficient motor designs. All of these impact the chiller size. With mechanical rooms historically undersized, they simply may not be enough room to install the new, larger chiller.

- 5) New chiller designs include features to significantly reduce refrigerant losses. Before CFC were an issue, a loss rate of 15% per year was considered acceptable. But now the CFC and HCFC refrigerants are both an environmental and an economic concern. The new developments minimize shaft seals; install isolation valves around filter assemblies and use brazed instead of flared fittings. In addition high efficiency purge units can limit the refrigerant losses to less than 0.5% per year, including the losses that occur during system maintenance.
- 6) The new technology chillers available today offer as high as 15 to 20 EER. The current minimum air conditioning energy efficiency standard recommended by ARI is 10 EER and is proposed for revision to 13 EER.

Acronyms:

EER stands for energy efficiency ratio. This represents cooling capacity in Btu/hr divided by power input in watts at a standard conditions specified by American Refrigeration Institute, ARI. EER for refrigeration machine is always above 1.

CFC stands for chloro fluoro carbon compounds. HCFC stands for hydro chloro fluoro carbon compounds. These are the category of refrigerant compounds that are considered major source of ozone layer depletion. CFC has been phased out completely and HCFCs are permitted to use on running machines until year 2020. HCFCs are responsible for ozone layer depletion to certain extent.

PART III - SELECTION CRITERIA FOR RIGHT CHILLER

When selecting a chiller for a new or retrofit application, the following assessment tasks should be carried out to enable an appropriate conclusion to be reached.

- Determine the functional and operational requirements by assessing the cooling load and load profiles including location, hours of operations, number/type of occupants equipment being used etc.
- Determine the required system configuration in terms of number and plant capacity by taking into account the total capacity and operational requirement, reliability and maintenance considerations
- Identify planning and environmental issues, in particular those that would prohibit the use of certain type of equipment or costly treatment or measures required to render the proposed equipment fit for use.

The relevance and details are as follows:

Cooling load profiling:

- Peak load demand determines the overall capacity of the system. The total chiller capacity in tons of refrigeration shall match or exceed the peak building load.
- Part load requirements determine the number and size of chillers required. Cooling load profile will help to determine the type of chiller to use and if single or multiple chillers should be installed. Multiple chiller installations allow facilities professionals to stage their operation to match building loads while keeping the chillers operating at energy efficient loading. With high capacity centrifugal chillers part load application should not be less than 20 to 35% of the full load capacity. If the part load requirement is less than this amount, a reduced capacity chiller should be selected.
- Essential service requirements determine the system reliability requirements. Say in a hospital, the Operation Theater or infectious area call for controlled environment all the time. Therefore the selection of chiller should take into account a dedicated chiller capacity to meet the essential loads.

Operational regimes: It is imperative to determine which portion of the total load required 24 hours operations. Say in a office building operating for 10 hours a day and the data center room requiring 24 hrs operation, it shall be prudent to use multiple chillers with capacity matching nearly the critical essential load for overall economics.

It would be more cost efficient to operate a smaller capacity chiller at full load than a bigger capacity at part load.

Infrastructure Availability:

- The places where the price differential between the electricity and natural gas is high, gas driven centrifugal chillers or absorption chillers could be considered. In some development sites, it may involve huge cost to set up an infrastructure of say 6.6 or 11kV for large chiller capacities or to bring energy to the remote site.
- The places where water is scarce, the chiller machines should be selected for air-cooled condensers. Centrifugal chiller is not a choice for air-cooled configurations.

Materials (Refrigerant): Use environment- preferred products that shall be available for the life cycle of the plant for instance a non-CFC type refrigerant should be used.

All the above chiller machines are available with non-CFC refrigerant options but the new generation scroll and screw machines have been specifically developed for use with R-134a refrigerant, which is a most popular refrigerant today.

To date, the reciprocating compressors available have been converted to R-134a use from original R-22 designs. No authentic data is available on the capacity de-rating/enhanced performance of reciprocating machine with R-134a refrigerant. This should be investigated, should a reciprocating chiller machine be considered.

Microclimate conditions: High humidity, tropic climatic conditions would favor the selection of air –cooled chillers. Centrifugal chillers require cooling tower and make up water. These may not be a good choice in the humid and tropic regions.

Siting: Environmental planning constraints on the proposed plant location need to be considered. The need to minimize noise emission in residential area during out of office hours would go against the air-cooled system option. All the three machines are suitable for water-cooled configurations. As far as noise from the equipment is concerned, screw compressors are the quietest.

System maintenance and serviceability considerations: The facilities professionals must take into consideration the maintenance requirements of different types of chillers. The following must be noted:

- Use technologies that are reliable, can stand long hours of continuous operation, minimum downtime and requires minimal maintenance
- Must consider the level of service and support that can be provided by the manufacturer in that location.

In general reciprocating chiller requires more routine maintenance than centrifugal; and centrifugal chiller require tedious service than the rotary chillers

Physical Attributes: To a great extent space availability will dictate the type of chiller to be installed.

- The area and space requirements for chiller package must be examined. If space is tight, the rotary chiller might be the best solution.

- For a complete package, decision for air-cooled v/s water-cooled chiller package should be evaluated. In addition to availability of quality water concerns, it should be noted that space requirement for the cooling tower is roughly 25% the area needed by the air-cooled system on large installation.
- If the space is adjacent to an area where noise is a major concern, reciprocating chillers are not the best option. Even the high-pitched whine of centrifugal compressor can be a serious problem. Rotary chiller is a best choice.

Health, Safety and Jurisdictions

All the HVAC design & selection must adhere to the statutory codes and regulations. The federal or state local code jurisdictions may not permit the use of some materials. For instance use of hazardous material such as ammonia in buildings is prohibited outright. In some places due to noise concerns air-cooled machines are prohibited. In others for minimizing risk of Legionella bacteria the use of cooling tower is prohibited, therefore centrifugal machines may not be a choice for such places. The safety and building code guidelines must be evaluated thoroughly at a nascent stage itself.

Standby or (N+ 1) strategy: The applications where cooling is required for critical service delivery, the relevant areas need to be classified as essential. For essential services continuity of supply is critical, therefore the provision of cooling cannot be relied on a single chiller. One back up unit would be required. The provision of 1 additional back up unit is known as N+1 strategy. This strategy involves the provision of one more unit than the quantity required for the normal system operations. For example if the total capacity requirement is 1500 TR, 2 units each of 750 TR should be provided instead of one unit of 1500TR if the essential load is less than 50% of the total load. Otherwise 2 units having the capacity equals to the essential load shall be required. A life cycle cost economics of using 3 X 50% option could also be investigated.

Life cycle costing considerations: Carry out LCC analysis to identify the least cost option considering the capital costs, recurrent costs of operation, maintenance and repairs over the same time frame (say 20 to 25 years)

- Capital costs: The capital costs must include the total cost of the complete installation that accounts for the building cost, associated electric power supply reticulation and control costs
- Operating costs: Check energy costs, water treatment costs, maintenance etc.
- Programmed maintenance and servicing costs.