Chapter – 4 Compressors Overview & System Annual Power Consumption

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Compressor is the heart of the refrigeration system. The character of the compressor greatly influences the performance and the power consumption of the refrigeration system. Therefore, it is important to realize the characteristics of the compressor when a refrigeration system is being designed. Also, the power consumption and economic balance are to be taken into the consideration when selecting the compressor and the major components of the system.

The industrial refrigeration system is designed to control the process temperature or to keep the evaporative temperature to ensure the quality of the product being made or to meet the process requirement. In order to achieve this sole purpose, the compressor for refrigeration application shall have the following features and capabilities:

(1) The compressor is to be equipped with automatic control devices for partial load operation and should be able to maintain the design temperature in the evaporator under any load variation.
(2) The compressor should have wide range of part load capability.
(3) The lubrication system for the compressor is not to be open to outside atmospheric to avoid contamination.
(4) Oil used should be refrigeration oil.
(5) Seal gas used should be enclosed and shall be the same as the refrigerant being used for the system.

Compressor Characteristics:

FIG. 4-1 shows the compressor group available for industrial refrigeration application. The Internally Compound reciprocating compressor is used mostly for packaged unit; Rotary compressor was used for booster duty and it is now not commonly used; Ejector type compression device and Axial Flow compressors are also not commonly used by industrial refrigeration equipment manufacturers. Therefore, these compressors are not included in this manual.

FIG. 4-2 shows the characteristics of the compressors commonly used for industrial refrigeration application. The horizontal axis represents the flow or capacity and the vertical axis represents the compression head.

Refrigeration Compressors

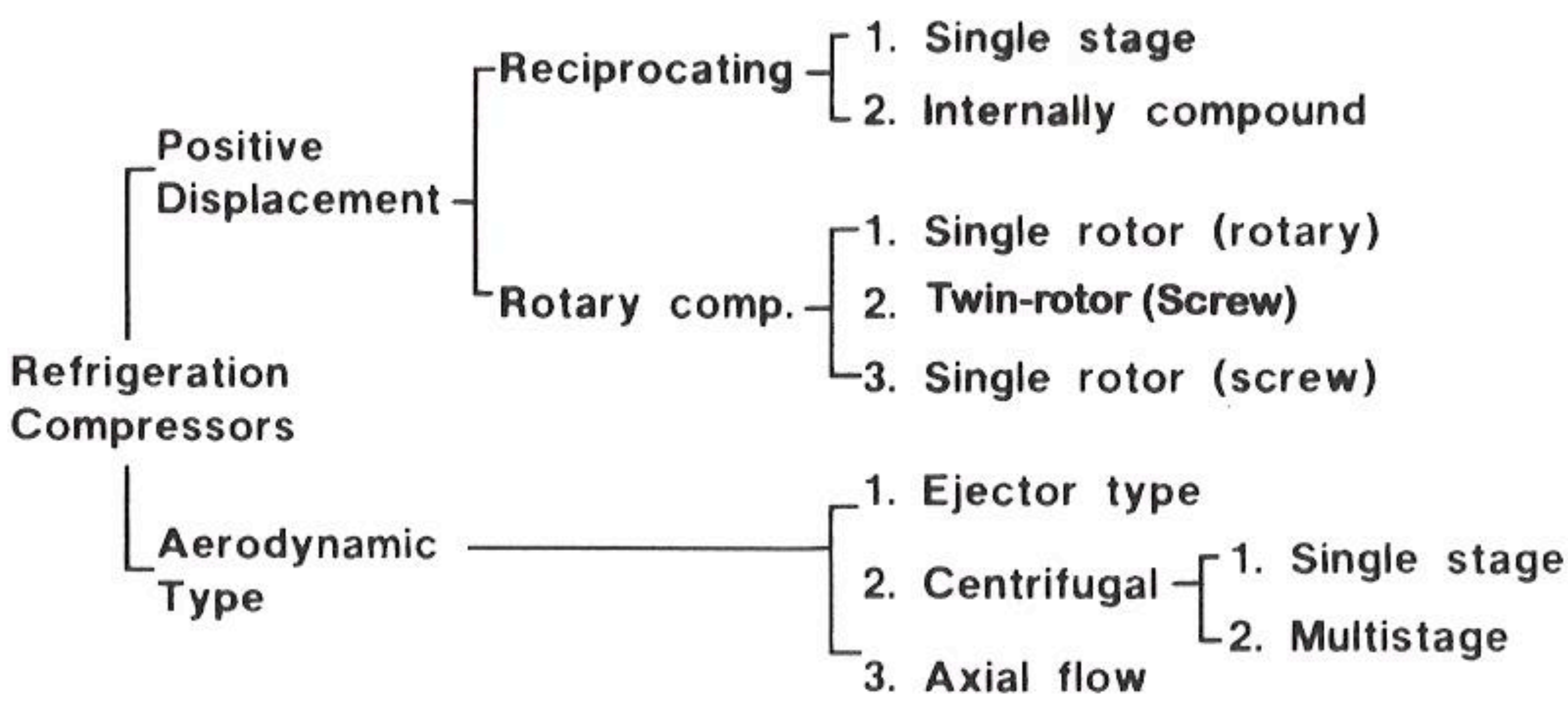


FIG.. 4-1 Various Industrial Refrigeration Compressors

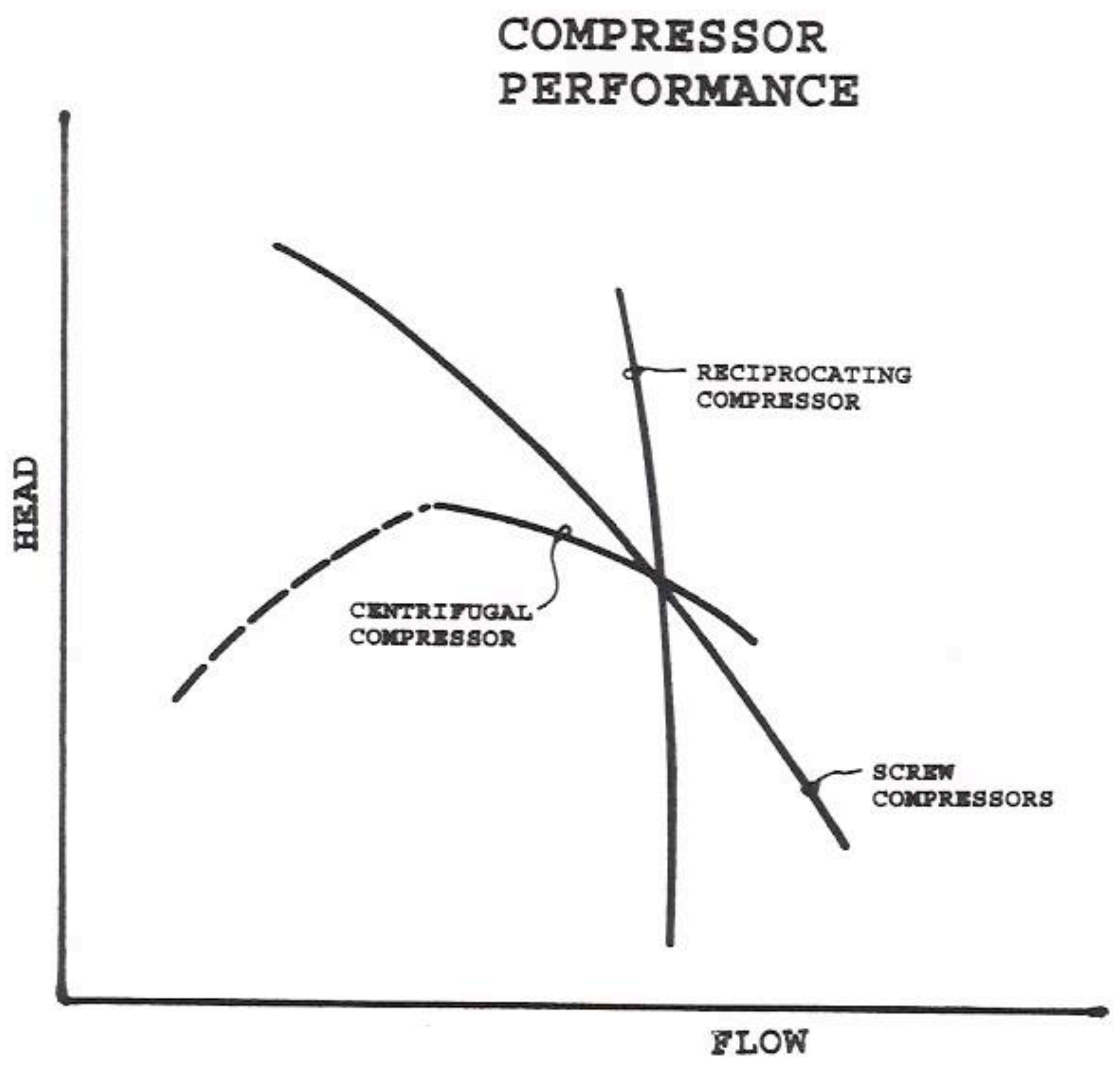


FIG. 4-2 Characteristics of Industrial Refrigeration Compressors

From the FIG. 4-2, the reciprocating compressor performance curve is almost vertical; that means the capacity variation for a reciprocating compressor is very limited, however, the compressor can handle wide range of compression head; Because of this character, reciprocating compressor is referred to as a variable head and constant volume machine.

In the same diagram, the performance curve for centrifugal compressor is almost flat, that means the centrifugal compressor can handle wide range of capacity variation, but, the head change capability is limited; Because of these characters, the centrifugal compressor is referred to as a variable volume and constant head machine. The screw compressor curve lies between the reciprocating and centrifugal compressors; therefore, the screw compressor is a variable head and also it is a variable volume machine. The screw compressor has the advantages of both centrifugal and reciprocating compressors; best of all, it does not have the disadvantages of both centrifugal and reciprocating machine.

Table 4.1 Compressor Comparison – Major Characteristics:

	Reciprocating Compressor	**Screw Compressor**	**Centrifugal Compressor**
Compression Head	Variable	Variable	Constant
Capacity	Constant	Variable	Variable
Suction Volume Flow	Low	Medium	High
Motion	Reciprocating	Rotary	Rotary
Capacity Control	Step Control	Continuous Variable	Continuous Variable

From the Table 4.1, it is very obvious that the screw compressor has all the advantages as compared to other types of compressors for refrigeration application. That is the reason why screw compressors are so popular in the refrigeration industries.

The size of screw compressor is getting smaller; the screw compressors took over the capacity application range which used to be covered by the reciprocating compressor. The size of screw compressor is also getting bigger, particularly the twin-rotor screw, the screw compressors penetrated the areas where the applications are traditionally covered by centrifugal machines.

FIG. 4-3 shows a typical refrigeration system curve. This system curve might change due to load requirement of the process. The industrial refrigeration system operates 365 days per year unless it is scheduled for service and maintenance. The fundamental and primary duty for the compressor for the application is to be able to perform and to fulfill the requirement of evaporative temperature at the full load and to meet the partial load operation.

The installations for industrial refrigeration are usually with open drive. Sometimes, a special driver such turbine or engine is used instead of motor. Therefore, this manual inclines to cover larger size open type compressors instead of hermetic machines.

COMPRESSOR UNLOADING

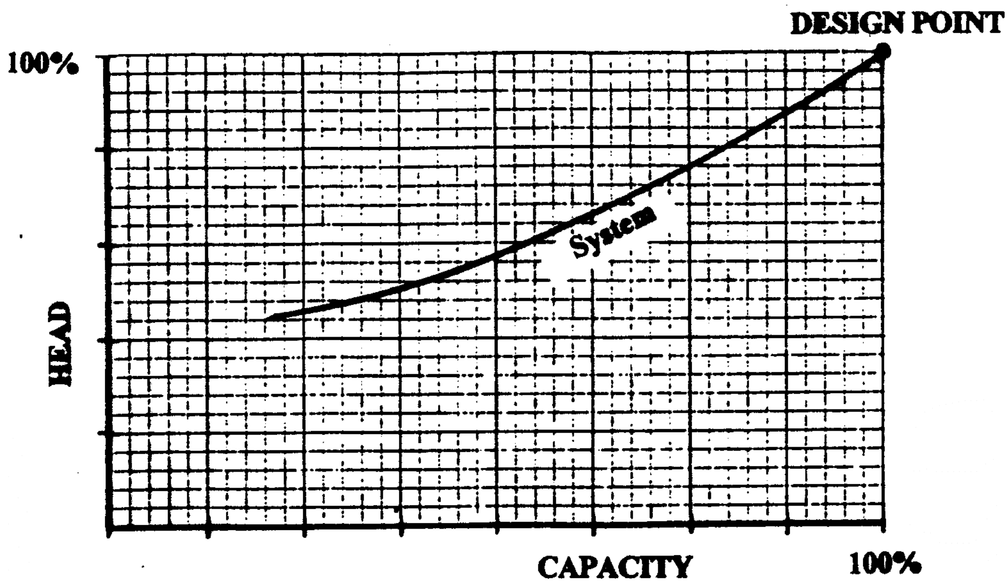
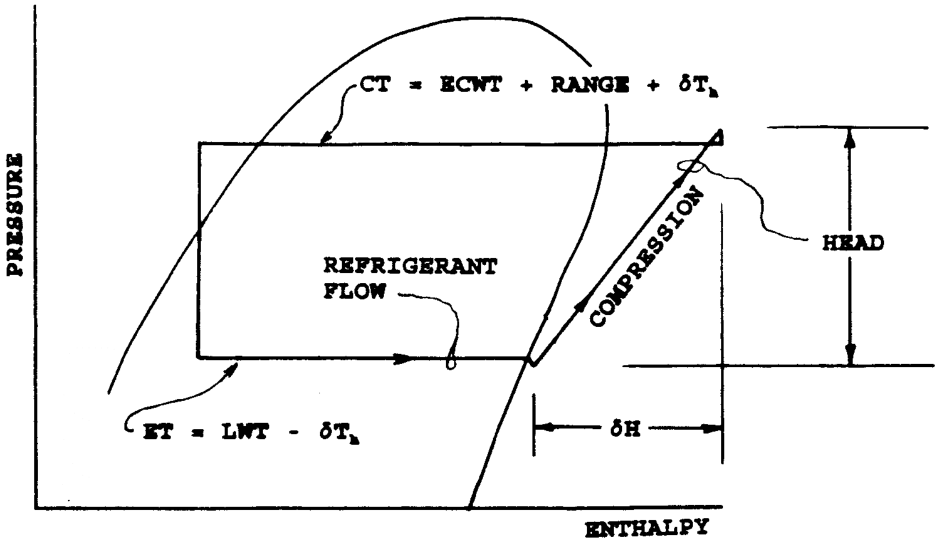


FIG. 4-3 Typical Refrigeration System Curve

System Annual Power Consumption:

Power consumption and energy conservation are the most important considerations for industrial refrigeration systems design these days. Therefore, when designing the industrial refrigeration system, the power consumption, particularly the annual power consumption should be carefully exam. FIG. 4-4 shows the relationships between the major components of the refrigeration system and also the formula to estimate the annual energy use for the system. This formula can also be used as the justification and comparison for the selection between different compressors or systems.

POWER CONSUMPTION



$$BHP = \frac{FLOW \times HEAD}{33000 \times E_{ff}}$$

$$BHP_{(PARTIAL\ LOAD)} \approx BHP_{(DESIGN)} \times \frac{(FLOW)\% \times (HEAD)\%}{(E_{ff})\%}$$

$$\text{ANNUAL POWER CONSUMPTION} = (KW)_{DESIGN} \times \sum_{0}^{HOURS} \left[\frac{HD\% \times TR\%}{\eta\%} \right]$$

Where:	BHP =	Brake HP of compressor shaft input
	Flow =	Lbs/Min of refrigerant flow.
	Head =	Compression head, ft.
	E_{ff} =	Compressor overall efficiency.
	(FLOW)% =	Percent of flow at partial load
	(HEAD)% =	Percent of head at partial load.
	(E_{ff})% =	Percent of E_{ff} at partial load.
	KW =	Power consumption at design point.
	HD% =	(HEAD)%
	TR% =	(FLOW)%
	η% =	(E_{ff})%

FIG. 4-4 Power Consumption Formula

The power consumption calculation for the compressor and refrigerant flow for the load (TR) are as the following (See Chapter-2):

$$\text{Head} = (H_2' - H_1') \times 778 = (\Delta H) \times 778 = \text{Ft.}$$

$$\text{Flow} = \frac{200}{\text{NRE}} \times \text{TR}$$

$$(\text{Compressor HP})_{\text{Design}} = \frac{\text{Flow} \times \text{Head}}{33000 \times E_{ff}}$$

Where: Flow: Refrigerant Flow, Lbs/Min at design point.
Head: Compression Head, Ft. at design point.
E_{ff} Compressor Overall Efficiency at design point.

From the FIG. 4-4, the annual power consumption is greatly depending on the power consumption of the refrigeration system at the design point $(BHP)_{design}$ or $(KW)_{design}$; The annual power consumption also depends on the conditions as how the system is behaved during the partial load operation; It is important that the refrigeration system is to be designed and to be operated in such way that it is able to take the advantages of reduce head (HD%) and reduce capacity (TR%); also the compressor partial load efficiency (η %) is another important factor as shown in the formula.

The compressors for industrial refrigeration are practically to be operated year round. Typical operation time is about 6000 to 8000 hours per year. FIG. 4-5 shows the annual Kw-Hr power consumption evaluation for the refrigeration system with operating hours of 8000 per year; the friction HP loses and oil pump are added for this case.

$$(Kw)_{Design} = \left[\frac{(Flow)_{design} \times (Head)_{design}}{33000 \times (\eta)_{design}} \right] \times 0.7457$$

$$\text{ANNUAL POWER CONSUMPTION} = \left(\text{Design Kw} \right) \times \sum_{0}^{8000} \left[\frac{HD\% \times TR\%}{\eta\%} \right]$$

$$+ (KW)_{FIP} \times 8000$$

$$+ (KW)_{oil} \times 8000$$

FIG. 4-5 Annual Power Consumption Evaluation For 8000 Hours/Year Operation