Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 123 (2018) 52035-52038

ISSN: 2229-712X

Analysis of Screw Compressor Performance in Refrigeration System

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ARTICLE INFO

Article history:
Received: 12 September 2018;
Received in revised form:
8 October 2018;
Accepted: 18 October 2018;

Keywords
Compressor,
VCRS,
Condenser,
Refrigeration System.

ABSTRACT

A compressor is the heart of vapour compressor system. The function of refrigerator compressor, being an integral part of the system, is related to relate to other components. Hence its capacity, life, breakdown, etc. are very much influenced by the performance of other components like condenser, evaporator, throttling device etc. in this present paper the reciprocating compressor is being replaced by a screw compressor. The performance analysis is conducted and further a comparison analysis is done. It has been found that the screw compressor with certain limitation is more effective and saves the power.

Introduction

The basis of modern refrigeration is the ability of liquids to absorb enormous quantities of heat as they boil and evaporate. The process involves two thermodynamic concepts, the vapour pressure and the latent heat. A liquid is in thermal equilibrium with its own vapor at a pressure called the saturation pressure, which depends on the temperature alone. The second concept is that the evaporation of liquid requires latent heat during evaporation. If latent heat is extracted from the liquid, the liquid gets cooled. The temperature of ether will remain constant as long as the vacuum pump maintains a pressure equal to saturation pressure at the desired temperature. This requires the removal of all the vapors formed due to vaporization. If a lower temperature is desired, then a lower saturation pressure will have to be maintained by the vacuum pump. The component of the modern day refrigeration system where cooling is produced by this method is called evaporator.

It pump and circulates refrigerant through the just as the heart pump and circulates blood through the body. In general, a compressor performs following function; It remove low temperature and low pressure vapour from the cooling coil through the line called suction line. It compresses this vapour by increasing the pressure and temperature resulting in an increase of boiling point of refrigerant. It discharge the vapour in high temperature and pressure from the condenser through the line called discharge line, The refrigeration is different from those used in other application, such as or gas compressor.

Refrigeration Systems

At present comfort air conditioning is widely used in residences, offices, commercial buildings, air ports, hospitals and in mobile applications such as rail coaches, automobiles, aircrafts etc. Industrial air conditioning is largely responsible for the growth of modern electronic, pharmaceutical, chemical industries etc. Most of the present day air conditioning systems use either a vapour compression refrigeration system or a vapour absorption refrigeration system.

The capacities vary from few kilowatts to megawatts. The refrigeration effect is obtained in the cold region as heat is extracted by the vaporization of refrigerant in the evaporator. The refrigerant vapour from the evaporator is compressed in the compressor to a high pressure at which its saturation temperature is greater than the ambient or any other heat sink. Hence when the high pressure, high temperature refrigerant flows through the condenser, condensation of the vapour into liquid takes place by heat rejection to the heat sink. To complete the cycle, the high pressure liquid is made to flow through an expansion valve. In the expansion valve the pressure and temperature of the refrigerant decrease. This low pressure and low temperature refrigerant vapour evaporates in the evaporator taking heat from the cold region. It should be observed that the system operates on a closed cycle. The system requires input in the form of mechanical work. It extracts heat from a cold space and rejects heat to a high temperature heat sink. A refrigeration system can also be used as a heat pump, in which the useful output is the high temperature heat rejected at the condenser. Alternatively, a refrigeration system can be used for providing cooling in summer and heating in winter. Such systems have been built and are available now.

Literature Review

The twin screw compressors with water injection can be used to supply the clean compressed air for the Proton Exchange Membrane (PEM) fuel cell systems. The effects of internal leakage and air-water heat transfer were taken into account simultaneously in the present mathematical model. Author suggested that the results show that the predictions of the model are in reasonable agreement with the experimental data **Jianfeng Li at el.[2009]. T**he study investigates the experimental performance of an automotive air conditioning (AAC) system for the cases of employed fixed and variable capacity compressors (FCC and VCC). Author suggested that the operation with the VCC usually yields a higher COP than the operation with the FCC in expense of a lower cooling capacity **Alpaslan Alkan& Murat Hosoz [2010]**.

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Pierre Podevin at el. [2011] worked on reciprocating compressor worldwide, there are no standard guidelines for the correct measurement and calculation of turbocharger maps at low speeds. A special torque meter was fitted in a cold turbocharger test bench, affording measurements from 30,000 rpm to 120,000 rpm. Author suggested optimize the efficiency of reciprocating compressor. Screw compressors are at present a widely used means of compressing air, process gas and refrigerants. Computer simulation programs, verified by experimental data and improved by recent advances in mathematical analysis, form a powerful tool for process analysis within these machines and hence for a comprehensive check of innovative suggestions and design optimization. One consequence of this is that screw rotors lobe profiles have been developed over the past few years which lead to enhanced machine performance. (**N. Stosic at el., 2013). Jin-Hyuk Kim at el**. [2014] worked on transonic axial compressor with circumferential casing grooves is optimized to improve operating stability. Through realistic comparison between thermodynamic first and second law analysis, optimum generator temperature corresponding to maximum *COP* and minimum exergy destruction is evaluated. It is found that the optimum generator temperature corresponding to exergy approach is 11 °C lower as compared to energy approach. Optimum generator temperature is a strong function of evaporator and condenser temperature (**Vinay Kumar, 2017).**

Screw Compressor

Rotary screw compressors use two meshing helical screws, known as rotors, to compress the gas. In a dry running rotary screw compressor, timing gears ensure that the male and female rotors maintain precise alignment. In an oil-flooded rotary screw compressor, lubricating oil bridges the space between the rotors, both providing a hydraulic seal and transferring mechanical energy between the driving and driven rotor. Gas enters at the suction side and moves through the threads as the screws rotate. The meshing rotors force the gas through the compressor, and the gas exits at the end of the screws.

Table1. Technical data sheet of system.

TECHNICAL DATA SHEET OF SYSTEM		
PARAMETER	UNIT	VALUE
SCREW SIZE	MM	70
CMPRESSOR VOLTAGE	VOLT	400V/3Ph/50
COMPRESSOR MOTOR	KW	110
SPEED	RPM	2900
CHILLER CAPACITY	TR	115.7
REFRIGERENT		R-134a
REFRIGERENT CAPACITY	KG	120
CHILLER WATER INLET	*C	10
CHILLER WATER OUTLET	*C	5
CHILLER FLOW RATE	M3/HR	70.0
CHILLER FOULING FACTOR	FPS	0.0001
PRESSURE DROP ACROSS CHILLER.	BAR	0.4
CONDENSER TYPE		Shell & Tube
CONDENSER WATER INLET	^{0}C	32
CONDENSER WATER OUTLET	^{0}C	37
CONDENSER WATER FLOW RATE	M3/HR	85.5
CONDENSER FOULING FACTOR	FPS	0.00025
PRESSURE DROP ACROSS CONDENSER	BAR	0.43
SPC @ 100%LOAD	KW/TR	0.65

FORMULAE

Tons of Refrigeration

One ton refrigeration is the amount of cooling obtained by one ton ice melting in one day: 3024 Kcal/h, 1200BTU/h, or 3.5 KW thermal loads. The cooling effect produced is quantified as tons of refrigeration (TR). 1 TR of refrigeration = 3024 Kcal/hr heat rejected.

The refrigeration TR is assessed as

TR = M x Cp x (Ti – To) / 3024

Where M is mass flow rate of coolant in m^3/hr

C_p is coolant specific heat in Kcal /kg °C

T_i is inlet, temperature of coolant to evaporator (chiller) in °C

T_o is outlet temperature of coolant from evaporator (chiller) in °C.

KW/ton Rating

It is commonly referred to as efficiency, but actually power input to compressor motor divided by tons of cooling produced, or kilowatts per ton (kW/ton). Lower kW/ton indicates higher efficiency.

Measurement of compressor power

The compressor power can be measured by a portable power analyzer which would give reading directly in kW. If not, the ampere has to be measured by the available on-line ammeter or by using a tong tester. The power can then be calculated by assuming a power factor of 0.9

Power (kW) = (√3 x V x I x cosφ)/1000

Determining correct refrigerant charge level

The refrigerant charge level is correct when the measured evaporator approach and discharge superheat are within the permissible limit. Liquid refrigerant will be visible in the evaporator sight glass. The refrigerant level cannot be properly determined by viewing the liquid refrigerant level in the evaporator sight glass.

Definitions

Evaporator approach= (S.E.T)-(L.E.L.T)

Discharge superheat= (C.D.G.T)-(S.C.T)

When:

S.E.T = Saturated Evaporator Temperature

L.E.L.T =Leaving Evaporator Liquid Temperature

C.D.G.T =Compressor Discharge Gas Temperature

S.C.T = Saturated Condensing Temperature

Sample Calculation

Sample Calculation of reciprocating compressor

Calculation of TR at time 16:00PM data taken

T_i=11.0, T_o=9^{0}C, Running pump capacity=150m^3/hr.

TR = M x Cp x (Ti – To)/3.024

TR = 150X1X (10-9)/3.024

TR =49.6≈50

Calculation of Power (kW) at time 16:00PM data taken

V (Volt) =410, I(AMP)=155, Power Factor(cosφ)=0.9

Power (kW) = (√3 x V x I x cosφ)/1000

Power (kW) = (√3 x 410 x 155 x 0.9)/1000

Power (kW) = 99.06 ≈ 99.1

Sample Calculation of Screw compressor (TR)

Calculation of TR at time 16:00PM data taken

$Tchw_i$=11^{0}C, $Tchw_o$ =8.2^{0}C, Running pump Capacity =150m^3/hr.

TR = m x Cp x (Ti – To) / 3.024

TR = 150X1X (10-7.3)/3.024

TR =134

Calculation of Power (kW) at time 16:00PM data

V (Volt)=410, I(AMP)=155, Power Factor(cosφ)=0.9

Power (kW) = (√3 x V x I x cosφ)/1000

Power (kW) = (√3 x 410 x 120 x 0.9)/1000

Power (kW) = 77.69 ≈ 77.7

Results and Discussion

Analysis shows the performance of Reciprocating chiller in 24 hours; considering some important parameters such as Flow rate of chilled water, temperature of CHW (Chilled water) inlet, & temperature of CHW outlet. These parameters are measured every hour by Ultrasonic flow meter, mercury glass thermometer and digital temperature indicator respectively. An average value of TR is found 78. The compressor power is being measured by a portable power analyses which would give reading directly in kW. If not, the ampere has to be measured by the available on-line ammeter or by using a tong tester. The power can then be calculated by assuming a power factor of 0.9 and average power is found 104kw.

Specific power data is commonly referred to as efficiency of compressor, but actually power input to compressor motor divided by tons of cooling produced, or kilowatts per ton (kW/ton) and it is found 1.61 kw/TR. Lower kW/ton indicates higher efficiency.

Measurement Data with Screw Compressor

Further analysis shows the performance of Screw chiller for 24 hrs; again, in this important parameters such as Flow rate of chilled water, temperature of CHW inlet, & temperature of CHW outlet. These parameters are measured every hour by Ultrasonic flow meter, mercury glass thermometer and digital temperature indicator respectively and average TR is 111.

The compressor power can be measured by a portable power analyses which would give reading directly in kW. If not, the ampere has to be measured by the available on-line ammeter or by using a tong tester. The power can then be calculated by assuming a power factor of 0.9 and this value is found 76kw.

Specific power is commonly referred to as efficiency, but actually power input to compressor motor divided by tons of cooling produced, or kilowatts per ton (kW/ton). Lower kW/ton indicates higher efficiency with 0.68.

The results obtained from the analysis are shown by means of graphs as shown below:

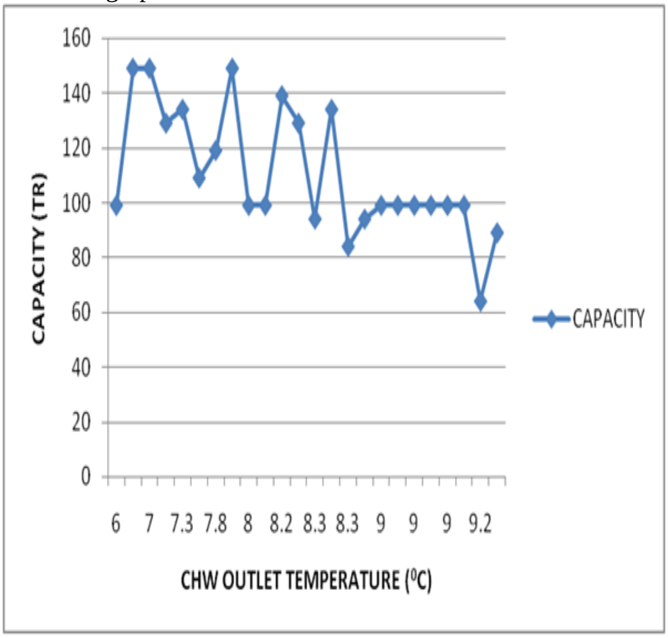

Fig 1. Graph between capacity and cooling water outlet Temperature.

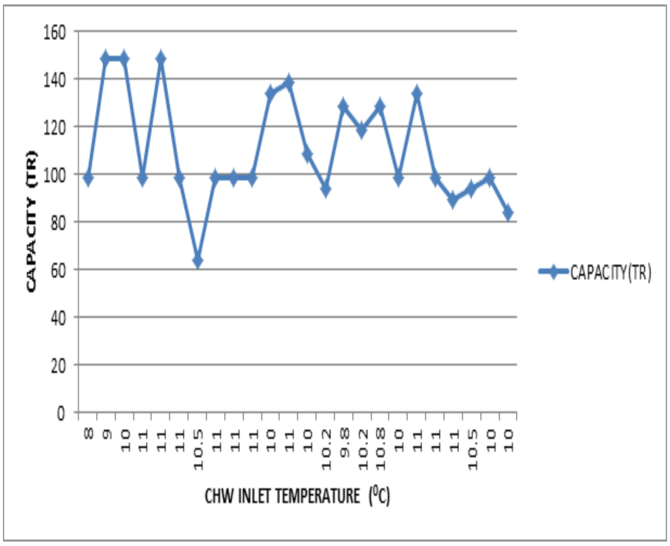

Fig 2. Graph between capacity and CHW inlet temperature.

On the basis of physical data made available a graph 2 has been drawn between CHW inlet temperature and the capacity. In this case to the nature of graph is erratic. This simply depicts that the erratic behavior is on account of the external factors.

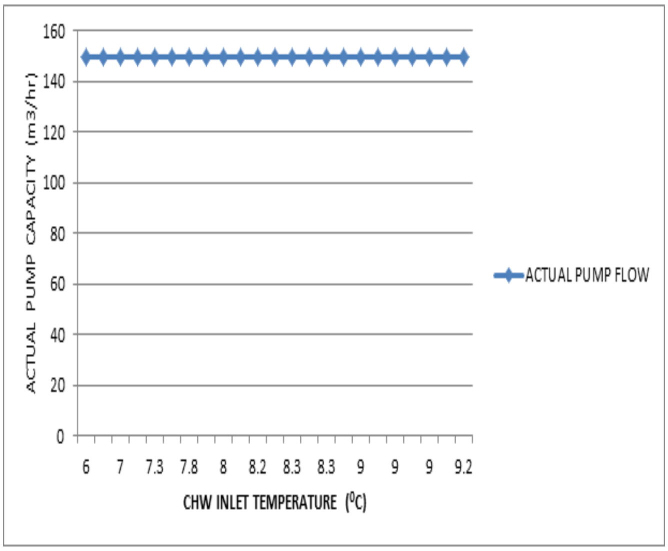

Fig 3. Graph between actual pump capacity and CHW inlet temperature.

Conclusion

Replacement of the reciprocating compressor in VCRS system by the introduction of screw compressor results to

- Increase in refrigeration effect represented by the temperature drop range.
- Reduction in the specific power consumption of compressor
- Reduction in the maintenance cost.
- Considerable increase in the running period between one consecutive maintenance- shut down (from 45 days to 90 days).

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