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Performance Evaluation of Shell & Tube Heat Exchanger used in Vacuum System

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Abstract

The paper discusses the need of some effective heat exchange in the vacuum system for the effective cooling of the suction vapours of the process. Vacuum system is a combination of vacuum pumps, mechanical boosters and condenser. Such system is used in pharmaceutical, chemical and process industries. Vacuum being very crucial for processes the efficiency of plant depends on the operating parameters of vacuum system. This study discusses the results obtained by testing of vacuum system alternatively with conventional shell & tube heat exchanger and plate heat exchanger. On the basis of it the cost implication and effectiveness of both heat exchangers are highlighted.

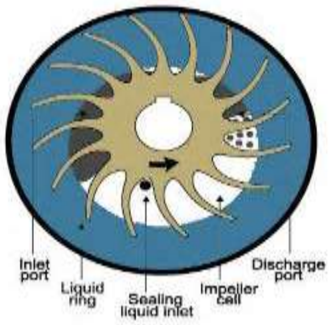
Keywords*- Vacuum, vacuum system, Heat Exchanger, Piping Volume, Mechanical Boosters, Vacuum Pumps*

I. INTRODUCTION

Vacuum refers to the zone of pressure below atmospheric pressure. It has no perfect definition it just represents the emptiness of air. There is a pressure which is exerted on us by atmosphere, its value is standard measured as**1.01325** bar **OR 760 mm Hg.** lowering the pressure below this value means creating vacuum, It is very useful in industries, varied applications of vacuum are as follows;

- In food processing & beverage industries for drying, deodorizing purposes.
- In dairy industries for making milk powder, making cheese, under vacuum sterilization.
- In chemical industries for evaporation, distillation, deodorization etc.
- In Pharma industries for evaporation, API Plants, bulk drugs, formulation etc.
- In paper industries for drying of paper, cardboards.
- In textile industries for decadizing, drying of cloth etc.
- In confectionary industries for manufacturing of candies, chocolates etc.
- In breweries for alcohol manufacturing.
- In thermal power stations for condenser exhaust, waste oil refining.

1. Vacuum pump [1]



Vacuum pump is device which creates vacuum Vacuum is generated by the evacuated portion created by centrifugal action of eccentrically mounted rotor or impeller in the vacuum pump. This principle is for water ring vacuum pump.

The water ring is formed by the rotating impeller in the casing which creates the region devoid of air in the central portion which entrains the surrounding air to fill and thus suction force s developed obtained with the help of the ports provided in the control plates.

Vacuum pump is mounted such that vapors or the air from the process enters the vacuum pump and the same is discharged on the other end, normally at the discharge end, a separator tank is provided which separates water from the air or gas.

The vacuum pump construction consists of following parts Impeller, Casing, Control plates, Bearing cover, Shaft, Side Cover.

Vacuum pump can be coupled with various devices to boost up & maintain the continuous vacuum. This advantage makes it possible for using vacuum pump in many critical processes.

2. Vacuum system

The vacuum pump when coupled with Twin Lobe Roots Booster the vacuum level of vacuum pump increases.
Vacuum system is a combination of following components;

Twin lobe Roots Booster
Vacuum pump
Intercondenser or Heat Exchanger
(This is generally a shell & tube condenser)
Suitable piping between various components.
Suitable valves & gauges.
Recirculation system (Optional)

A common base frame over which the entire system is mounted.

2.1 Twin Lobe Roots Booster [2]

Booster is a construction made up with the assembly of lobular rotor mounted with the help of gears on either end enclosed in the suitable shaped casing; The rotors are duly balanced and mounted on the shaft with the alignment on the gear wheels. The bearings and the gears are normally oil cooled on the drive end and non drive end.

A lobular construction can be available in twin lobe eight shaped structure, in mechanical booster system this serves to carry the load at the same time reducing the excess load on backing vacuum pump, and increasing its vacuum and efficiency with same power.

The booster can be operated in directly coupled drive with motor or else to make the beltdriven arrangement in the same. Very good load handling can be done with homogenous vacuum generation.

2.2 Intercondenser (Heat Exchanger)

It is provided between the mechanical booster discharge and vacuum pump suction, it can be a shell & tube heat exchanger or a plate heat exchanger with the capability of cooling down the suction vapour to the acceptable limit of 40 degree Celsius near the suction of the vacuum pump.

The intercondenser serves the purpose of maintaining the acceptable temperature of the vapours that are coming in the vacuum pump; it in turn regulates the vacuum in the system as the amount of vacuum generated depends on the temperature maintained.

Intercondenser area is decided/selected based on the vacuum pump sealing water temperature required, availability of cooling water as well as the process in which the vacuum system is employed. It is an inevitable component in the vacuum system.

2.3 Shell & Tube Heat Exchanger:

Currently the fixed tube sheet type shell & tube condensers are widely used in the mechanical booster system due to their lower intial cost ,ease of maintenance, also the performance of the same is satisfactory as intercondenser as well as pre condenser.

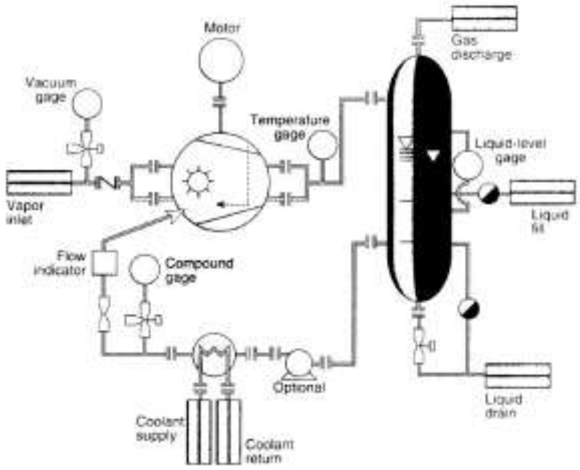
The standard material of construction used are carbon steel for shell and stainless steel for the tubes and tube sheet design, A sturdy construction helps such condensers maintain in few adverse process conditions in the acidic conditions also.

3. Mechanical Vacuum Booster System

Apart from all of the above there are various other parameters like that of the altitude of the place, its location, ambient conditions etc. on which designing is based.

The principle of using the mechanical booster backed with positive displacement vacuum pump is used in various industries for achieving many products, the possible outcome are discussed in the literature survey about the same,

(1)



(2)

Fig.1. *(a)* ***Vacuum Pump in Process***
(b) ***Mechanical Vacuum Booster System***[3]

II. Set up of Test System & Testing Method

The test system is a complete mechanical booster system with the assmebly of following components in the same,

1.) Mechanical booster **(3 H.P /2850 RPM)**
2.) Vacuum pump **(7.5 H.P /1450 RPM)**
3.) Shell& tube condenser **(Surface Area 1m^2)**
4.) Interconnecting Piping
5.) Temperature Gauge
6.) Vacuum Gauge

It is a complete package which maintaines a high vacuum in various continuous systems.

The test method involves the phyisical testing of vacuum system and thereby rating the same shell & tube heat exchanger for the existing vacuum system ,

(3) 

Fig.3 ***Set up of the Experimental System***

Data for Shell & Tube Heat Exchanger

Shell	*Tube*
*Length of shell without flange =**520 mm***	*Length of tubes = **450mm***
*Length of shell with flange =**580mm***	*Number of tubes* N_t *= 20*
Inner diameter of shell D_o *= 111 mm*	*Outer tube diameter* d_o *= 17mm*
Outer shell diameter D_i *= 115mm*	*Inner tube diameter* d_i *= 14mm*
*Thickness t= **04 mm***	*Tube thickness **t = 3 mm***

Table 1.

III. Procedure

Testing on vacuum system commenced by first starting the vacuum pump, thereafter subsequently mechanical booster was started

Readings were taken for achieved vacuum , capacity , inlet & outlet temperatures of condenser , vacuum pump sealing outlet temperature.

Some readings of testing of the system is presented herewith.

Air Leakage through Picola Nozzle (Capacity)	***Vacuum Achieved***	***Hot Water (°C)***		***Cold Water(°C)***	
		Inlet	***Outlet***	***Inlet***	***Outlet***
6kgf /cm^2	*752 mm hg.*	*36 to 38*	*32 to 33*	*27*	*30*
8kgf /cm^2	*745 mm hg.*				
14 kgf /cm^2	*730 mm hg.*				
22 kgf /cm^2	*720 mm hg,*				
32 kgf /cm^2	*712 mm hg,*				

- Current heat exchanger is 1 m^2 which does the cooling of seal water as per the readings of the table 1.
- In order to confirm the design we have checked it in opposite direction with the help of theoretical calculation through LMTD method.
  Q=UAΔT

1. Theoretical Calculations

1.1 Shell Side Heat Transfer Coefficient [4]

It is obtained with the help of Bell Delaware method. The correlation used can be described as below.

$$h_{id} = j_i\, c_p\, \frac{\dot{m}_s}{A_s}\left(\frac{k_s}{c_p\,\mu_s}\right)^{\frac{2}{3}}\left(\frac{\mu_s}{\mu_{s,w}}\right)^{0.14}$$

$\dot{m}_s$ Mass flow rate = 09 LPM =0.15 kg/s

D_S = Shell diameter =0.115m

d_o = outside tube diameter = 0.017m

B=Baffle spacing = 0.2

$N_{TC} = D_S / P_T$

C_p = 4.187 kJ/kg.K

μ_S = coefficient for water temperature of 34 degrees

$A_S = (D_S - N_{TC}\, d_o)\, B = 0.0076\ m^2$

$$j_i = 0.37 R_e^{-0.395}$$

Reynolds number $R_e = 411.$

Therefore $h_{id} = 508.35\ W/m^2k$

1.2 Tube side heat transfer coefficient.[5]

First the flow in the tube was determined with the help of Reynolds number by the equation,

$$R_e = \frac{4\dot{m}_o}{\frac{N}{2}\pi\mu d_i}$$

Mass Flow Rate m_o = 21 LPM=0.30 kg/s
Reynolds number achieved is R_e = 3568, Hence Turbulent Flow

Using the Petukhov-Kirillov correlations for finding Nusselt number,
N_u= 25.8

Therefore hi= Nu.k/d_i =1213.46 W/m^2K.
Hence overall heat transfer coefficient achieved U = 132.3 W/m^2K.

The value of U is obtained from the **h** values for the shell & tube seperately.The h values are obtained wiht the help of several correlations for the type of flow ,

The type of flow in the shell is found to be laminar for which the value of h is achieved to be around 500 W/m^2K.

Similarly the flow in the tube is turbulent hence the value of h achieved is around 1200 W/m^2K.

Overall Heat Transfer Coefficient **U= 132.3 W/m²K.**

Now **$\Delta T = \Delta T_m \times 0.9 = 3.89$**

So , area acheived by placing this values in **Q=UAΔT** , is **A = 7.8 m^2 .**

All the calculations done are based on the outlet water temperature of 30 degrees which is required to be achieved.

A total required heat transfer area required for effective heat excfhnager and to achieve this temperature is 7.5 m^2 . Thus the current used heat exchnager is smaller in size.

Conclusion

Concluding form the literature review and the theoritical calculations done for the vacuum system with 01m^2 heat exchnager the following things were found.

1. Current 1 m^2 hest eschnager is smaller and requires to be modified as per the required area.
2. The temperature achieved of seal water is 03 degrees higher than the optimum temperature required.i.e 30 degree celsius.
3. The heat transfer on shell is very much less which reduces the overall heat transfer coefficient , a reason for the undersize of heat exchanger.
4. Need for the larger size heta exchnager with the possible flow of seal fluid in tube side and flow of cooling water on shell side for achieving better heat exchange.

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Future scope:

1. Future scope of this study can help to find more suitable heat exchnagers like Gasketed Plate Heat Exchnager which are cost comparative, effective and highly compact for us in such system.

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