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Introduction

An investigation was carried out for a water company who operate a vacuum drying facility within a large waste water works.

This case study details the findings and recommendations made as a result of the visit.

Problem Statement

The water company are operating a vacuum drying plant that has performed to design in the past but has deteriorated to the point where insufficient vacuum can be drawn to effectively dry the product.

The Plant had operated satisfactorily for about 9 months since commissioning before problems arose.

Remit

To review the operation, installation and condition of the vacuum plant. The output should be recommendations to-

a) Solve the problem of low vacuum capability
b) Scope further testing to identify exactly where the problem areas are
c) Produce a report detailing the findings and outline a way forward should the vacuum plant be basically suitable or unsuitable for purpose

Brief Description

The system draws vapour from a filter press which in turn dries the product.

The vapour drawn from the press goes through several knock out pots and a water cooled condenser.

The incondensable contents are drawn off by a vacuum pump to maintain the vacuum on the filter press.

The set point for the vacuum desired is 29" Hg Absolute.

The vacuum pump is of a liquid ring type using water as the liquid ring seal.

This type of pump is very commonly used in similar duties.

There is an auxiliary roots blower type booster fitted just upstream of the vacuum pump (see sketch below) but it is believed that the process design is such that the liquid ring pump should not need the booster to function at the duty point.

If this is true the vacuum pump should easily cope with the process conditions.

The liquid ring pump is a two stage device with a recirculating, cooled seal liquid system.

The recirculating seal liquid is process water that is cooled by a chilled cooling water stream in a shell and tube cooler. The chilled cooling water comes from an adjacent 3rd party plant.

Brief History

It is understood that the plant was commissioned from December 2005 onwards and has operated largely satisfactorily from that date until the time of the plant visit.

At the time of writing, the exact number of running hours was unknown but this report details work taking place about 9 months after first commissioning.

There are no written log sheets or logbooks for the plant so the operating history given to me verbally is to a large extent anecdotal in nature. However, it is known that there have been incidents where the product being dried (sludge) has been pulled through the system past the filter press.

A vacuum pump was dismantled in the workshop for inspection, the water company were unsure of its condition.

Furthermore, the water company have been unable to gain any meaningful support from the machines original manufacturer.

The water company have carried out several machine trials which they say have been inconclusive in identifying the root cause of their problems.

It does appear that the vacuum system is still just about capable of pulling the required vacuum, but is unable to sustain it.

The author reviewed the trials so far carried out and believes that there was useful information therein, albeit hampered by the questionable accuracy of the instruments used in gathering the data.

In addition, the water company have tried to identify for themselves what they believe are design shortcomings in the way that the vacuum pumps are arranged, particularly the separator pot.

One example is the separator pot on the outlet of the vacuum pumps is positioned such that it is impossible to have the water level low enough at start up to meet with the OEM's operating instructions.

In fact since the units are supplied pre-erected on a skid ready to install, this is a design flaw introduced by the factory.

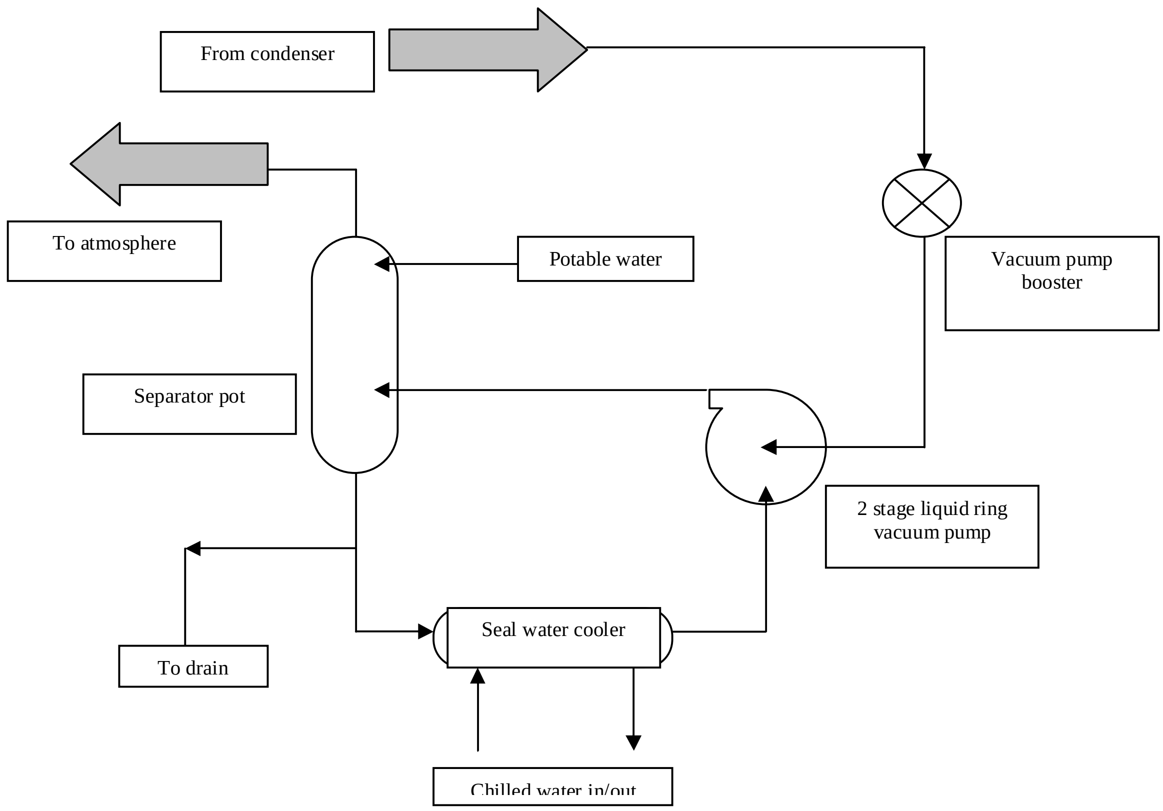
Equipment Description

Vacuum Condenser- Plate type condenser.

Vacuum Booster- Roots Blower type. 5.5kw rated.

Vacuum Pump- Two stage Liquid Ring Type. 37kw rated.

Liquid Ring Pump Seal Water Cooler- Shell and tube type, no technical data. No data plate on the cooler.



Schematic of vacuum pumps.

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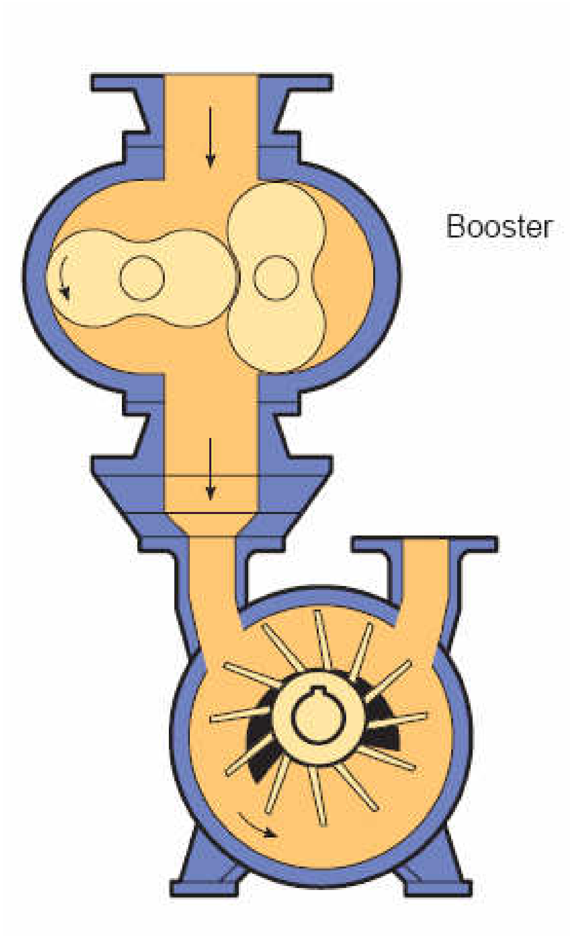

Sketch showing booster and Liquid Ring Vacuum Pump.

Description of the work done during the plant visit

Since the plant was already running steadily a set of data readings was taken from the number 4 vacuum pump train.

New temperature sensors, calibrated vacuum gauge and a clamp on flowmeter were used to ensure the validity of the data.

With the vacuum train running at a steady rate the following data set was collected.

Overall vacuum- 28.5" Hg

Vacuum between booster and liquid ring pump- Not possible to take

Discharge pressure- Atmospheric, plus the pressure drop of the discharge pipe.

Booster running amps- 11a (7.5kW assuming a power factor of 0.95).

Liquid Ring Pump running amps- 48a (32 kW assuming a power factor of 0.95).

Liquid Ring Pump seal water discharge temp ex pump- 31 DegC

Liquid Ring Pump seal water temp into cooler- 31 DegC

(Note- There is a small offset here since the separator tank has ~1M^3/hr of cold potable water being added at 11.8 DegC, therefore the temperature going into the cooler should actually be less than 31 DegC)

Liquid Ring Pump seal water exiting the cooler- 29.1 DegC

Liquid Ring Pump cooling water into cooler- 16.6 DegC

Liquid Ring Pump cooling water out of cooler- 17.3 DegC

Liquid Ring Pump cooling water flow rate- 48.3 Litres/Min

Liquid Ring Pump seal water recirculation flow- ~800 Litres/Min

Liquid Ring Pump Condensate load estimated from the rise in the separator tank level observed- ~4.0 Litres/Min

Design data from the Vacuum Pump Manual

Seal Water Recirculation Rate- 140 Litres/Min

Desired temperature of seal water- ~15 DegC

Observations

1 There is a "Y" strainer on the seal water inlet line to the cooler. It is reportedly cleaned once per shift and is generally found dirty. This is a very frequent cleaning rate indeed and higher than might be expected.

2 The vacuum pumps and vacuum pump boosters trip regularly.

3 The separator tank is being run at a very high level, almost full in fact. There is a vertical piece of pipe about 6" high leading from the vacuum pump discharge to the separator tank. Almost certainly because of the excessive recirculation rate of the seal

water this is running full of water, it should not be so and is adding a static head of maybe 6" water gauge to the vacuum pump load. In practice, this will reduce the potential to generate vacuum by a similar amount of head.

4 The separator tank is too high and the correct level cannot be obtained in the vacuum pump at start up.

5 The booster has a 5.5kW motor installed, therefore the motor is presently running in an overload condition (as measured with a clip on ammeter) and must be on the edge of tripping at all times.

6 The vacuum system knock out pots generally appear to be working and flowing condensate from before and after the condenser.

7 The colour of the water in the knock out pots upstream of the condenser was seen to be very dirty.

8 The condenser has never been opened for inspection.

9 A dismantled pump was heavily scaled internally on both stationary and rotating parts.

10 The dismantled vacuum pump had a snapped shaft. It had failed between the second and first stage impellers. Due to post failure damage it was impossible to gain any failure related information from the fracture faces. The shaft had snapped at a change in section. It was determined that the shaft was magnetic and therefore not a common grade of non-magnetic stainless steel. A material analysis is required if the exact material grade is required to be known. This information is not available in the machines manual.

11 At least one of the four vacuum pumps was cavitating during operation whilst I was in attendance at the plant.

12 Around 1M^3/hr of potable water is being added to the vacuum pump separator pot presently to keep the seal liquid cool. If the potable water is turned off, the seal liquid heats upto 40 DegC and the pump trips. This on its own amply demonstrates the seal water cooler’s ineffectiveness.

<u>Problem areas</u>

1 Probably the most fundamental problem with the vacuum pump sets as observed was the recirculation rate of the seal liquid. This was around 6 times the rate recommended in the machines manual. The effect of this is to reduce the capacity of the pump available to gas. Each revolution of the pump has a fixed swept volume and the more of that volume that is given to pumping water, the less that remains for pumping gas and drawing vacuum.

2 The seal water cooler is ineffective. The cooling water is picking up very little heat from the recirculating seal water. Once the rate of recirculation of the seal water has been brought to near the recommended flow, the cooler needs to be checked again for function.

3 Another fundamental problem is the seal water temperature leaving the vacuum pump is limiting the vacuum that can be pulled by the liquid ring pump. With a temperature of around 30 Degrees C the most that can be pulled is the absolute pressure that corresponds to that saturation temperature. This is around 24 to 25" of Hg.

4 Due to the above reductions in capacity of the vacuum pump, the booster is having to compensate for the shortfall of vacuum. The effect of this is that the amps pulled by the booster motor shows that the 5.5kW motor is running at 7.5kW. This must be right against the motor protection settings and explains why the booster/vacuum pumps trip regularly. Interestingly, the vacuum pump itself is only pulling 32kW versus its rated load of 37kW. Thus demonstrating that the vacuum pump is under loaded and the booster is trying to make up for its underperformance. This is not sustainable longer term and the performance of the vacuum pump must be corrected as recommended below.

5 The running level of water in the separator tank is too high and along with the very high recirculation rate this is providing a higher than normal pressure drop from the pump outlet to the separator tank. This is at least 6" of static water head. Reducing the recirculation rate and ensuring the discharge pipe is not running full of water will immediately make this extra amount of head available to the pump to pull as vacuum.

6 The staff at the plant have identified that the pump separator pot is mounted too high. This means that when the pump is started it has too high a level of water. Once the pump is actually running there is no way of knowing for sure what the level inside the pump is.

7 The rate of draining on the separator pot must be increased to balance the rate of condensation being drawn into the vacuum pump. The level should be sustained at half way up the tank in steady operation. By cleaning the condenser and improving its performance the condensing load inside the vacuum pump will reduce, partially correcting this issue.

8 The addition of potable water to the pump separator pot must be stopped. At the moment it is keeping the pump running by keeping the seal water temperature down below saturation temperature. But it is adding insoluble salts to the system which is causing scaling to the internal surfaces of the pump. Obviously, in order to achieve this, the recirculation rate and related cooler problem must first be addressed.

9 The dirt collecting in the knock out pots and the dirt collecting in the vacuum pump seal water strainer demonstrates a degree of dirt in the process side of the system. Whilst it is obviously impossible to see what is actually inside the vacuum condenser, it is

apparent that some condensing load is being carried over from the condenser into the vacuum pump rather than being condensed in the condenser itself.

This is demonstrated by the rise in water level in the vacuum pump separator pot at a rate of around 4 Litres/minute.

In addition to the suction side capacity being taken up by pulling this amount of vapour over from the condenser, the thermal balance inside the pump is made worse since the latent heat of condensation of this 4 Litres/minute is being dumped into the recirculating water and has to be removed by the (ineffective) cooler.

The water company must get this condensing load back into the condenser where it belongs rather than allowing this degree of condensation to take place inside the vacuum pump.

After nearly a year of operation it would be surprising if the performance of the condenser hasn't degraded to the point where it is requiring cleaning.

These types of condensers (plate type) are very easy to strip and clean, though this unit is a bit more difficult due to the fairly large size of it.

A notable increase in performance from the entire vacuum train should result from a good condenser clean.

Depending on the degree of fouling that is found a judgment can be made on the periodicity of future cleans.

Recommended actions to be taken

1 Reduce the flow of seal water recirculation to around the specified 140 Litres/Minute as per the vacuum pump manual. This can be done by inserting a globe valve temporarily into the water piping and throttling. A restrictor orifice plate should be fitted as a permanent fix.

2 Having done action #1 above, retest the performance of the recirculating seal water cooler. If it is still deficient, then clean the cooler thoroughly. If, after cleaning the cooler it is still deficient, seriously consider a new cooler. It is absolutely vital and fundamental that the seal liquid temperature be brought down. The underlying vacuum problems will not be sorted out until this is done. With a cooling water feed temperature of ~16 DegC it will be impossible to reach a seal water temperature of 15 DegC as suggested by the vacuum pump manufacturers in the manual. However, ~20 DegC should be readily attainable. At a vapour pressure of 29" Hg, the saturation temperature of water is 25 DegC. So an achieved temperature of 20 DegC for the seal water should be fine. Achieving lower than 20 DegC, however, can only be better and give more

margin against vacuum pump cavitation.

3 Clean the vacuum condenser and monitor the effect on plant performance. In my opinion a noticeable increase in performance will be seen. Advice should be sought from the condenser manufacturers regarding the possible reuse of the rubber gaskets on the plates. Also, a procedure for tightening the long plate pack tie bolts on the cooler when rebuilding is required. Leaks will result from incorrect tightening of the tie bolts. Note that should extra condensing surface be required in the future, there appears to be plenty of scope for adding extra plates to the condensers plate pack installed presently.

4 Operate the pump separator pot at a level half way up the tank. This will require rebalancing of the pump separator pot drain versus condensate load. It is envisaged this will be far easier to actually achieve after a condenser clean since the condensing load in the vacuum pump will reduce.

5 Physically lower the actual pump separator pot to give the correct start up level of water in the pump. This requires modifying the on skid piping and the support of the knock out pot.

6 Having implemented all the above actions, the practice of adding cold potable water to the pump separator pot must cease. This will help to keep the pumps free of lime scale.

7 It will be essential to monitor the changes that each of these actions has on the booster and vacuum pump performance. Only in this way will future deterioration in plant performance be detected at an early stage. The entire system should be far better balanced after the above actions have been carried out. Furthermore, it will prove extremely useful if a tapping can be found or made that allows the vacuum to be read in the pipe between the booster and the vacuum pump. Presently, it is not possible to make this measurement.

Conclusions

The actual performance versus design of the plant cannot presently be verified as there is not enough information available.

It appears that the vacuum train has worked well enough in the past and has deteriorated from that point over time.

Several very important parameters have been identified for remediation and in my opinion completing the actions above will restore the vacuum pumps to the best condition that they are capable of.

There appears no fundamental reason for the vacuum system to not perform adequately well.

Having done this only a formal performance test of the plant could verify if the plant is actually meeting its design capacity.

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About the author-

Stephen H Shakeshaft is a Mechanical Engineer based in the United Kingdom. He is the Principal Consultant and Director of Stephen H Shakeshaft Consulting Ltd., an engineering consultancy specialising in optimisation of existing assets and engineering design of new build projects.

Stephen is a registered professional engineer in the UK and is a corporate member of

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www.shs-consulting.co.uk

The consultancy welcomes contact from all who are interested in plant and machinery maintenance, systems and development.