INDUSTRIAL REFRIGERATION OPTIMIZATION SYSTEMS WITH SUCTION SEPARATION SCHEMES - BEVERAGE INDUSTRY

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Abstract. *This study aims to raise the energy efficiency in the beverage industry refrigeration systems by separing suction schemes. In this kind of industry it was found that the refrigeration system is responsible for 35 to 40% of electrical consumption in the whole plant, showing how the efficiency increasement of refrigeration systems may reduce electric energy consumption and the retrenchment this industry may achieve with those measures. Usually the refrigeration systems meet several processes and production stages which differ in the product's temperature requirements. However for the simplicity and to make it easier to construct and to project these industries have a single collector, corresponding to a single suction regimen for compressors and the temperature and evaporation's pressure which are controlled by the evaporator expansion valves. However, in new plants the new separation schemes concept have already been used to increase the systems electric efficiency, which has a higher coefficient performance (COP) when operating with a evaporation temperature enough to attain certain process, showing that for each 0,1 bar raise in suction pressure, increases the systems' efficiency average in 3%. Considering the several processes involved in production, as well the variations of quantity produced in these industries, the results attained with energy economy through separation schemes is quite significant and presents an economic attractiveness for its implementation.*

Keywords*: Refrigeration, separation schemes, energy efficiency, beverage industry*.

1. INTRODUCTION

Thermal systems operate most of the time at off-design conditions. In industrial refrigeration systems, the operation in partial loads occurs for many different reasons and the power consumption is a function of the refrigeration cycle pressures (Salvador, 1999).

This work proposes an energetic optimization of the compression refrigeration systems by the operation using separated regimens.

Systems with suction separation schemes are cooling systems, by vapor compression, which have two or more levels of low pressure (Venturini and Pirani, 2005). It is understood that low pressure prevailing between the expansion device and compressor suction. Systems that rely on separation schemes may be found, for example, in beverage, dairy, meat, etc. where an evaporator operates at -5.0 ° C to meet particular process, while the other evaporator operates at 0.5 ºC to water cooling.

Depending on several processes in the production of beer, for example, with different temperature requirements, the proposal described in this paper is that it operates with independent collectors of coolant fluid in order to maximize the system's efficiency.

That is, instead of having one single suction regimen for all compressors, and use the evaporation temperatures and pressures control through expansion valves, we can operate with two independent ammonia collectors and dedicated compressors to each one of these two systems, which differ in the parameters of suction pressure set point in accordance with the procedures met.

Currently the proposed separation of regimens presents a very high project cost, besides the need for adjustment of stops, which also represents some losses by stop producing.

Therefore, any decision to implement separate regimens in industries that already operate with a unified system, should be based on an economic analysis (Eletrobrás/Procel, 2001)

The reduction in power consumption needs to offset the cost of additional equipment to warrant such investment. Factors like the type of the coolant, the compressors type in the engine room (alternative, screw, centrifugal, etc.) and cooling capacity of the system also influence the final decision.

In the our case study, the machine room (Fig. 1) consists of 9 compressors, screw type, as follows:

- # 1, 2 and 3: Sabroe VMY 347 M with 600 hp engines and with soft starter drives
- # 4, 7 and 8: Mycom N 250 VSD TS with 500 hp engines and variable speed drives
- # 5 and 9: Mycom N 250 VSD TS with 500 hp engines and with soft starter drives
- # 6: Sabroe SAB 202 LM with 450 hp engine

Figure 1: Machine room

Linked to compressors, there are 6 chiller/cooling units model APV 9GN5S LR (Fig. 2), of which 4 are used as NH3 evaporators/ethanol coolers, and 2 are used as NH3 evaporators/water coolers.

Figure 2: Cooling units / NH3 evaporators

The processes in this beverage industry require cold ethanol solution (25%), with temperature of -4.0 °C (total of 5,435,680 kcal/h) and chilly water at a temperature of 2.5 degrees C (Q = 2,467,087 kcal/h)

2. REQUERIMENTS FOR REGIMENS SEPARATION

The energy efficiency work performed in this industry presented a great opportunity to work with the division of regimens, however several requirements were checked and actions to be taken to enable the unit to operate efficiently and have energy savings in cooling system.

These actions are described below:

A. Installation of new pilot suction solenoid valves to allow the system to operate with unified or separated schemes:

Must be installed in the main valves of two cooling units circuits to generate chilly water, parallel to the existing main valves PM3 line (pressure evaporation control and modulation), a new pilot EVM solenoid 24V, with digital signal input and output in the existing PLC, to avoid an automatic operation of suction systems with separated or unified (in case of need for maintenance of compressors, for example)

On supervisory software system's screen should be available operating conditions with a unified system and separated system.

On unified system condition, all compressors operate with suction pressure between 2.1 to 2.3 kgf/cm², enable the existing solenoid and keeping the new solenoid pilots disabled.

For operating condition with separation schemes, the compressors for the ethanol system operate with suction pressure between 2.1 to 2.3 kgf/cm² and the compressors for the chilly water circuit enable the NEW solenoid pilots, keeping the existing solenoid disabled. The suction pressure in compressors for chilled water generation system should be adjusted to 3.3 kgf/cm².

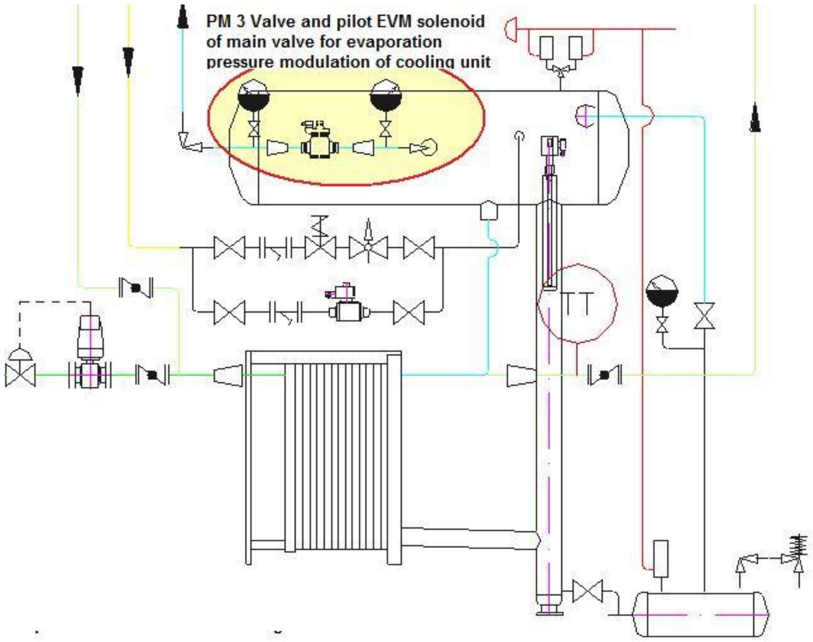

Figure 3: Cooling unit Schematics and suction control valves.

B. Create two independent groups of control lines of the compressors.

The proposed configuration is aimed to maintain the compressors which have Variable Speed Drives always as masters of each regimen, in order to saving energy using this modulation.

Separation schemes configuration:
Cold Water System→
Should comply with the following conditions:
- Normal Setting:
Compressor #4 (MASTER), Compressor #6 (SLAVE)
- Configuration 2:
Compressor #4 (MASTER), Compressor #7 (SLAVE)
- Configuration 3:
Compressor #7 (MASTER), Compressor #6 (SLAVE)
Ethanol System →
Should observe the following conditions:
- Normal Setting:
Compressor #8 (MASTER), Compressors #9, #5, #3, #2, #1 (SLAVES in order of rotation that must be changed in the supervisory system's screen, allowing any combination among them)
- Configuration 2:
Compressor #7 (MASTER), Compressors #9, #5, #3, #2, #1 (SLAVES in order of rotation that must be changed in the supervisory system's screen, allowing any combination among them)

Unified system configuration:
Compressors #4, #7, #8 (MASTERS in order of rotation that can be changed in the supervisory system)
Others (SLAVES in order of rotation that can be changed in the supervisory system, allowing any combination between them)

Main control variables (existing pressure transmitters):
Suction pressure of Ethanol system;
Suction pressure of Cold Water system.

When the system operates in unified regime should follow only the pressure transmitter of the "Ethanol System".

C. Configuration and starting/stopping sequences – separation schemes

Sequence starting and ethanol system row:

Master Compressor #8 (or possibly compressor #7) will turn on and does the capacity increase (using its SV "Slide Valve" and VSD "Variable Speed Drive") until it reaches the set point of suction pressure.

If the MASTER compressor's capacity reaches 100% and not achieve the established set point for a period of time X (to be determined), it sends a signal to the PLC to enable the next SLAVE compressor in the row, which increases its load (SV) seeking to attain the suction pressure set point.

In case of the suction pressure be satisfied before the SLAVE compressor reaches 100% of its capacity, the MASTER compressor will reducing its capacity by using only the modulation through VSD and SLAVE compressor keeps 100% in its Slide Valve capacity.

If the the suction pressure is not achieved and the two compressors (MASTER + SLAVE) remain with 100% load for a time X (to be determined), a signal must be sent to the PLC to enable the next SLAVE compressor SLAVE in the row, which will be increasing their capacity using its SV, seeking to attain the established suction pressure's set point.

And so on.

Note: Suction pressure set point of Master compressor must be higher (0.1 bar) than the Slaves compressors' set point.

Stopping sequence of ethanol system:

In the case of the suction pressure be satisfied, and the compressors are at 100% of its capacity, the MASTER compressor will be reducing its capacity by using only the modulation through VSD up to 40% of the nominal frequency (60 Hz) and will remain so for a time Y (to be determined)

If the suction pressure continues to be answered after the time Y, a signal is sent to the PLC to shut down the first SLAVE compressor of the row , and MASTER compressor back to modulate, seeking to attain the established suction pressure's set point.

And so on.

Sequence starting of cooling water system:

Master Compressor #4 (or possibly compressor #7) will turn on and does the capacity increase (using its SV "Slide Valve" and VSD "Variable Speed Drive") until it reaches the set point of suction pressure.

If the MASTER compressor's capacity reaches 100% and not achieve the established set point for a period of time X (to be determined), it sends a signal to the PLC to enable the SLAVE compressor, which increases its load (SV) seeking to attain the suction pressure set point.

In case of the suction pressure be satisfied before the SLAVE compressor reaches 100% of its capacity, the MASTER compressor will reducing its capacity by using only the modulation through VSD and SLAVE compressor keeps 100% in its Slide Valve capacity.

Note: Suction pressure set point of Master compressor must be higher (0.1 bar) than the Slave compressor's set point.

Stopping sequence of cooling water system:

In the case of the suction pressure be satisfied, and the compressors are at 100% of its capacity, the MASTER compressor will be reducing its capacity by using only the modulation through VSD up to 40% of the nominal frequency (60 Hz) and will remain so for a time Y (to be determined)

If the suction pressure continues to be answered after the time Y, a signal is sent to the PLC to shut down the SLAVE compressor, and MASTER compressor back to modulate, seeking to attain the established suction pressure's set point.

And so on.

D. Installation of Level Transmitter in the cold water tank and automation logic that enable the modulation of compressors dedicated to this scheme.

Use of cold water level in the chilly water tank on 4 to 20 mA signals for formulate the new control logic for modulation of proportional valves input water cooling units, to ensure operation without peaks with the separation schemes.

Importantly, the cold water tank supplies two processes, so that logic must take into account two conditions, according below:

Condition 1: Two consumers in simultaneous operation

To enable the proportional – integral – derivative control (PID controller) of existing NH3 screw compressors, with their deadband and proportional band, attend the variations of thermal load of the of cold water circuit, must be defined that:

- until 70% of level of cold water tank, the water flow to Cooling Units (given by the flow set point into each cooling unit) must be the nominal design (100%);
- between 70% and 80%, reduces the flow rate of 2 x Cooling Units in 75% of nominal flow through the modulation of proportional valves;
- Between 80% and 90%, reduces the flow to 50% of nominal capacity;
- 90% - 100%, flow rate is reduced to 25% of nominal;
- at 100%, closes control valves and throttle valves with on/off electro-pneumatic actuator in water input.

For the system re-starting:

- below 90%, logic must define water flow at 50% of nominal capacity;
- between 70% and 79%, increases the flow rate to 75%;
- below 69% = 100% water flow in Cooling Units.

Condition 2: One or no consumer operation

To enable the proportional – integral – derivative control (PID controller) of existing NH3 screw compressors, with their deadband and proportional band, attend the variations of thermal load of the of cold water circuit, must be defined that:

- until 60% of level of cold water tank, the water flow to Cooling Units (given by the flow set point into each cooling unit) must be the nominal design (100%);
- between 60% and 70%, reduces the flow rate of 2 x Cooling Units in 75% of nominal flow through the modulation of proportional valves;
- Between 70% and 80%, reduces the flow to 50% of nominal capacity;
- 80% - 100%, flow rate is reduced to 25% of nominal;
- at 100%, closes control valves and throttle valves with on/off electro-pneumatic actuator in water input.

For the system re-starting:

- below 80%, logic must define water flow at 25% of nominal capacity;
- between 70% and 79%, increases the flow rate to 50%;
- 60% - 69%, increases the flow rate to 75% of nominal;
- below 60% = 100% water flow in Cooling Units.

3. RESULTS AND CONCLUSIONS

By implementing all of the actions described in section 2, the total investment was R$ 293,000.00, considering equipments acquisition (new valves and control devices, pipes, etc), and labor costs to assembling.

In the industry of this case study, refrigeration system accounts for 38,06% of the total electricity plant's consumption, and the cold water circuit represents 31.22% of total electric consumption of the refrigeration system.

Annual Electricity Plant's Consumption: 39,941 MWh/year
Annual Electricity Consumption of Refrigeration System: 15,200 MWh/year
Cold Water Circuit (Refrigeration System): 4,746 MWh/year
Annual Energy Saving: 1,362 MWh/year

The increase of suction pressure obtained in compressors with separation schemes represents a COP raise of 21%.

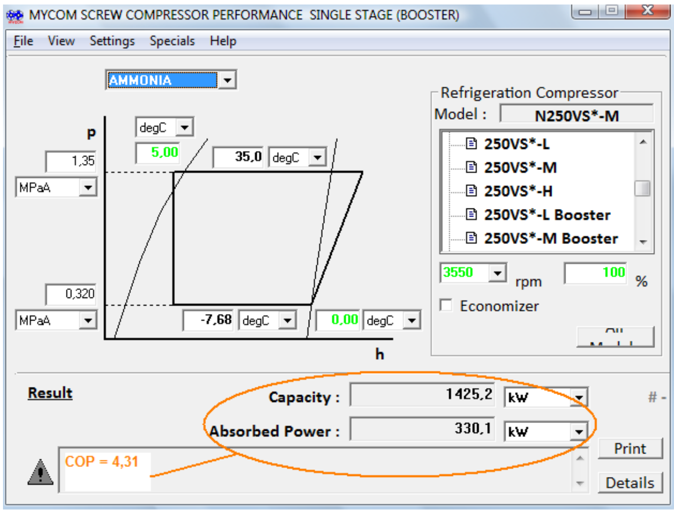

Fig 4. MYCOM N250 VSD compressor's suction pressure at 2.2 bar.

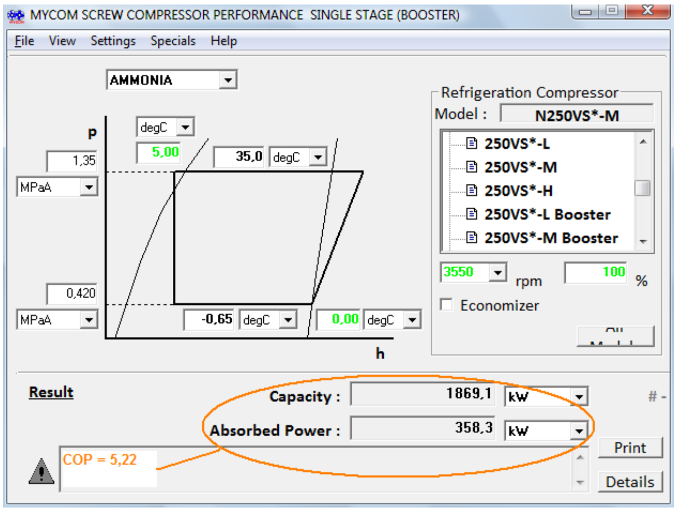

Fig 5. MYCOM N250 VSD compressor's suction pressure at 3.2 bar.

Considering the amount of operating hours of equipments, and electricity costs, the annual savings achieved with the implementation of suction separated regimens, in the industry of this case study was R$ 223,390.00, equivalent to a saving of 1,362 MWh/year.

These savings represent 8.96% of electricity consumption for refrigeration system and 3.41% of total electricity plant's and presenting simple pay-back like 9 months.

It is worth mentioning that additional advantage of using separate compression schemes is that it reduces the pressure differential at the compressor operating, thereby reducing the damage on bearing surfaces.

Besides the division of regimens that can be implemented in plants in operation, for new plants to be designed / constructed, can be used multi-pressure systems for cooling ethanol solution in cascade circuit, which is proposed for continuation of this presented paper.

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5. RESPONSIBILITY NOTICE

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