Optimization of Industrial Refrigeration Plants: Including a Case Study at Stonyfield Farm Yogurt

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ABSTRACT

Industrial refrigeration can be found in many types of applications ranging from ice making to food processing to product preservation. Industrial refrigeration typically represents one of the largest loads in a facility whenever required for manufacturing processes. A refrigeration system is made up of different components including compressors, evaporators, condensers and controls. Each component may be from a different manufacturer in custom engineered systems, or equipment may come as an integral packaged unit. Custom systems are generally an assembly of components that have been tested and rated individually under design operating conditions but not necessarily rated as an integral, coordinated system. Therefore, in the assembled refrigeration plant, there is a possibility that the individual components may not provide optimum operation based on the deviation between the actual operating conditions and the test conditions as well as the interactions between the different components in the system. Consequently, the final refrigeration plant may not operate optimally, resulting in lower operating efficiency and higher operating costs.

The factors that influence the refrigeration system energy use are the inherent efficiency of the design and refrigerant, the condition of the equipment, the control strategy, and the load profile of the system (deviation of the operating cooling loads from the design cooling loads). In many cases, the installed refrigeration plants can benefit from an optimization process that incorporates monitoring of key operating parameters resulting in subsequent control adjustments and or system operational changes based on the assessed data.

This paper will: provide an overview of typical industrial ammonia refrigeration systems; discuss the various components of the system including the compressors, condensers, evaporators and controls that make up a refrigeration system; and present typical energy saving strategies pertaining to the operation of multi-stage compressor systems, the use of evaporative condensers and floating head pressure controls, and sequencing optimization strategies. Furthermore, simple low cost approaches to reduce refrigeration loads will be discussed.

A case study will be presented that illustrates the concepts associated with the refrigeration system energy savings opportunities discussed in the paper. Stonyfield Farm Yogurt, a well-known, environmentally and socially progressive manufacturer of a wide variety of all natural and organic yogurts and ice cream, has undertaken a remarkable set of energy efficiency initiatives at their facility. They have participated in their local utility energy efficiency programs provided by Public Service Company of New Hampshire (PSNH). The studies, assessments, and installation discussed in the case study were developed through technical assistance efforts sponsored by PSNH. We will discuss the details of Stonyfield's refrigeration plant and system, and present results associated with the refrigeration system energy optimization conducted at the facility.

Overview of the US Industrial Refrigeration Market

Table 1 below presents information on the manufacturing industries that are intensive in process cooling and refrigeration (PC&R) energy consumption as monitored by the US Energy Information Administration (EIA). The information in Table 1 indicates that in the Food and Beverage industries, process cooling and refrigeration represent one of the largest electrical end uses, while the Food and Chemical industries use are the largest energy users of process cooling and refrigeration in the manufacturing industries.

Table 1: Energy Consumed as a Fuel by End Use in Manufacturing Installations

Industries	NAICS Code	Energy Consumption (Millions of kWh)		PC&R % of Total (A/B)	% of Total US PC&R (A/D)
		Process Cooling & Refrigeration (PC&R) (A)	Total (B)		
Food	311	17,679	67,390	26.2%	28.6%
Beverage and Tobacco Products	312	2,349	8,242	28.5%	3.8%
Chemicals	325	16,109	215,008	7.5%	26.1%
All Manufacturing Industries	311-339	61,763 (D)	1,025,149	6.0%	100.0%

Based on report generated by EuroMonitor International in October 2004, the US market for industrial air conditioning, refrigeration and heating (HVAC) machinery grew 4.6% to $29.4 billion in 2003 and the market is expected to grow 36.2% over the 2004 to 2008 forecast period, reaching a value of US$39.4 billion by 2008. It is not clear what percentage the refrigeration market represents of the total HVAC&R market, but we believe refrigeration is a significant contributor and therefore an important element in the HVAC&R industry.

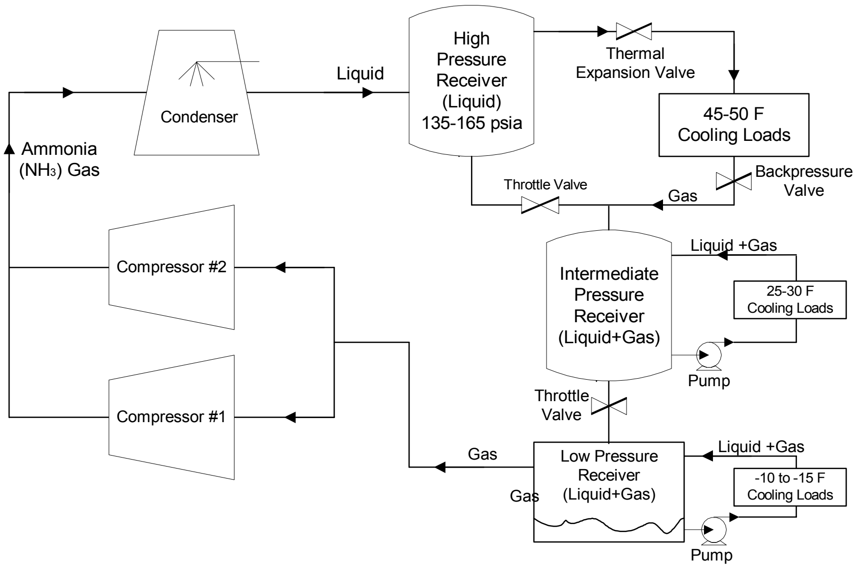
Overview of Typical Industrial Refrigeration System

Industrial refrigeration systems typically use ammonia (R-717) as a refrigerant and can have single stage or multiple stage compression. Different evaporator configurations are common such as: Direct Expansion (DX), Flooded and Liquid Overfeed and a hybrid combination of the above configurations and are based on the process requirements. Secondary coolants and economized compression also factor in different design configurations. Figure 2 presents a schematic of a hybrid DX and liquid overfeed ammonia refrigeration system.

All pumped liquid overfeed systems require receiver vessels that hold two phase refrigerant. Based on the actual design requirements, a refrigeration plant may have several receiver tanks. Figure 2 above shows a system with three receiver tanks. The first is the high-pressure receiver where liquid refrigerant exiting the condenser is stored. Liquid refrigerant from the high-pressure receiver is then throttled either to the intermediate pressure receiver or to the direct expansion evaporators in the 45-50 °F cooling load rooms. The backpressure regulator throttles the refrigerant gas to the intermediate pressure receiver, which is at a lower temperature/pressure. Liquid in the intermediate pressure receiver is then either pumped to the 25-30 °F cooler or throttled again to the low-pressure receiver. Liquid refrigerant from the low-pressure receiver is pumped to the –10 to –15 °F freezer loads with a mechanical liquid re-circulating pump.

All industrial refrigeration system designs have common components including refrigerant, compressors, condensers, evaporators and controls. The following sections present information on the different components, their selection criteria and possible energy saving strategies.

Figure 2: Typical Hybrid DX and Liquid Overfeed Ammonia Refrigeration System



Refrigerant - Why Use Ammonia in Industrial Refrigeration Systems?

Large industrial refrigeration systems typically use ammonia as a refrigerant of choice because:

- Ammonia (NH_3) is the least expensive of all the commonly used industrial refrigerants.
- NH_3 is thermodynamically 3 to 10% more efficient compared with HCFC–22 and HCFC134a.
- NH_3 refrigeration systems tolerate considerable amounts of moisture-other refrigerants do not.
- Most lubricants are immiscible in ammonia and separate out of the liquid easily.
- NH_3 system components are smaller than those used in CFC, HCFC and HFC systems because of NH_3s high latent-heat capacity.
- NH_3 has strong odors that help identify leaks quickly.

Compressor

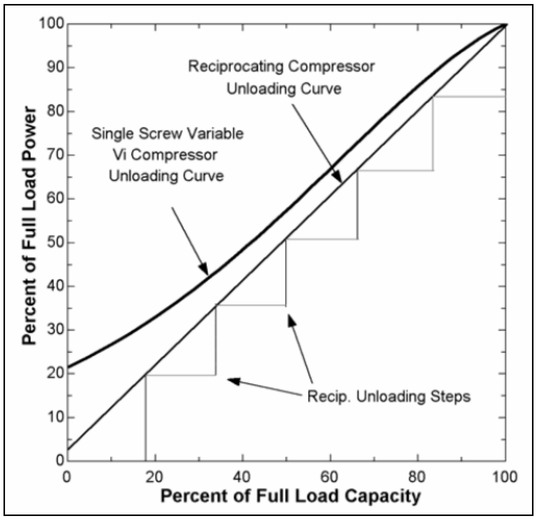
Compressors for industrial refrigeration systems are available in reciprocating (single stage, internally compounded), screw (low-stage or high-stage, with or without economizing) and rotary vane designs and more recently variable speed centrifugal compressors. It is common to see the use of reciprocating compressors below the 100-HP range, and use of screw compressors above 100-HP range. Compressors are also available in open drive and hermetically sealed options. Ammonia systems typically use the efficient open-drive option.

Screw compressors are the choice for most industrial refrigeration systems and are available in the fixed V_i (volume index) with slide valve, fixed V_i with bypass ports and variable V_i with slide valve. The variable V_i screw designs tend to offer better operational flexibility than the other two designs. Compressors account for majority of the energy consumption in a refrigeration system and therefore should be carefully selected and operated. The type of compressor, suction/ discharge conditions, and unloading controls all affect a compressor's hp/ton measure (efficiency).

Reciprocating vs. Screw

Screw compressors are generally more efficient when operating at full-load capacity and are inefficient below the 50% capacity when compared with reciprocating machines. However, reciprocating compressors are better suited for systems that have high load variability. Figure 3 below shows the unloading curves for both the screw and reciprocating compressors.

Figure 3: Part Load Performance of the Screw and Reciprocating Compressor



(Evaporative Condenser Control in Industrial Refrigeration Systems, 2001, K. A. Manske, D.T. Reindl, and S.A. Klein, Mechanical Engineering Department, University of Wisconsin – Madison)

Screw compressors typically use slide valves to vary the capacity from 10 to 100% of its available capacity. Reciprocating compressors unload by reducing the number of cylinders that are providing active gas compression. Based on the information in Figure 3 above, some operational tips that can help optimize compressor operations when a screw and reciprocating compressor are sharing a cooling load are presented below:

- Below 100% capacity, reciprocating compressors use less power than screw compressors
- Reciprocating compressors unload linearly and therefore should be unloaded first
- Screw compressors are better suited for base loading and operation at full load

Compressor Load Sharing

Many of the refrigeration facilities use multiple compressors to meet the cooling loads. The cooling loads vary based on a number of variables such outside temperature, internal gains etc. The optimum compressor operation selection is dependent on the load levels, compressor capacity and the compressor part load performance. Screw and reciprocating compressors have different unloading profiles and therefore provide different results for the same loads. The discussion below presents several scenarios that have been developed by the Energy Center of Wisconsin:

Load sharing with similar size and type of compressors. When a refrigeration system has the same size screw compressors, the following tips can be useful to optimize the compressor operations:

- For loads between 50 and 65% of full capacity should be split equally between compressors.
- Loads greater than 65% of full capacity, one compressor should be fully loaded and the other should meet the balance of the load.

Equal-sized reciprocating compressors have little performance degradation when unloaded, so the relative load distribution between two equal-sized compressors is not very important. However, reducing the suction side pressure loss is critical in maintaining optimum performance.

Load sharing with different size and type of compressors. Since screw compressor performance deteriorates below 50% of full-load, operation of screw compressors should be avoided below 50% load. For intermediate loads, the smaller compressor should be fully loaded. For large loads, the larger compressor should be fully loaded. When both reciprocating and screw compressors operate together, the screw compressor should be base loaded and the reciprocating compressor should be setup to meet the varying load.

One Stage Vs Two Stage Compression

Single-stage compression is most commonly used in single temperature applications with moderate to high suction temperatures. As the temperature requirements fall below –15 °F, the pressure ratios increase at which the single-staged ammonia systems have to operate at higher discharge temperatures, which reduces the compressor efficiency.

Two-stage compression systems are a possible alternative when high-pressure lift (pressure difference between suction and discharge pressures) is required such as in low temperature applications (below 0 °F for ammonia). By using two or more stages of compression, sub-cooling the refrigerant at each stage of compression increases the overall system operating efficiency. Multi-staging is also ideal for applications that require different temperatures. In multi-stage systems, flash-type intercoolers are more efficient than shell-and-coil intercoolers.

Where either single or two stage compression systems can be used, two stage systems require less power and have lower operating costs, but can have a higher initial equipment cost.

Lubricant Cooling

Lubricants in compressors absorb heat from the compression process and subsequently require cooling. The lubricant in screw compressors can be cooled using three methods:

1. **Liquid refrigerant injection** (Decreases compressor efficiency and is a low cost option)
2. **Indirect cooling** with glycol or water in a heat exchanger (Reject the cooling load to a section of an evaporative condenser or a separate cooling tower)
3. Indirect cooling with boiling high-pressure refrigerant used as the coolant in a **Thermosiphon process** (Rejects the lubricant cooling load to the condenser or auxiliary cooling system and is the industry standard and is 10% more efficient than indirect cooling)

In the case of reciprocating compressors, an external heat exchanger using a refrigerant or secondary cooling is usually added.

Factors Affecting Compressor Performance

Total compressor power for a system is a function of its suction pressure, discharge pressure, total system load, part load controls and unloading (specifically in the case of screw compressors which do not unload linearly). A lower refrigerant temperature results in lower suction pressure and increased compressor power requirements. A lower condensing pressure, which is a function of the condenser capacity and operations, results in a lower compressor discharge pressure and less compressor power. A lower condensing pressure usually comes with an increased fan and pump energy consumption penalty. The efficiency of a compressor can be simply stated as the electrical energy in horsepower (HP) or kW that is required to generate a certain cooling output in tons. Therefore, the most efficient compressor is the one with the lowest kW per ton or HP per ton rating for a given load under the same ambient conditions.

Condensers

Condensers are one of the major power users in an industrial refrigeration system and are typically available in the air-cooled and water-cooled versions. Condensers reject energy from the hot and high-pressure refrigerant to the ambient air. The refrigerant condenses from a gas at high temperature and pressure to a liquid at low temperature and high pressure. Condensers can contribute as much as 15-20% of the energy consumption in an industrial refrigeration system and have a direct effect on the overall operational efficiency of the refrigeration system.

For air-cooled condensers, the condensing temperature/pressure of the system must be maintained at a temperature above the outside air dry-bulb. This generally leads to high system head pressures and increased compressor power to provide the lift. Water-cooled condensers can typically operate at much lower condensing pressures because of the evaporative cooling processes occurring within the cooling water. Industrial refrigeration systems typically reject large amounts of heat and therefore careful selection and operations can provide long-term savings.

Condenser Capacity Control Methods

As with any refrigeration system, the cooling loads vary - which affects the condenser operations. In addition, the condenser performance is affected by the ambient conditions. This discussion focuses on evaporative condensers since they are most commonly used in industrial refrigeration systems. An evaporative condenser's capacity can be reduced in two ways:

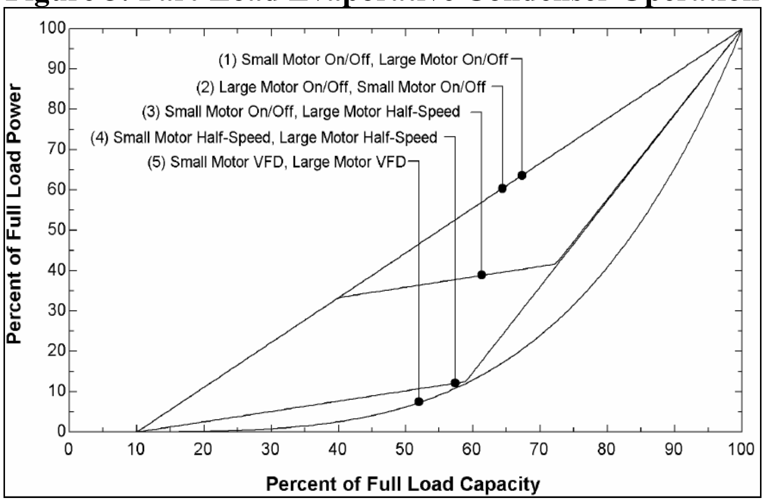
1. Head pressure control by altering the airflow
2. Shutting off spray water (Applicable during the winter months).

Flow rate through the condenser is controlled by the fan. Typical control strategies are as follows:

1. On\Off motor-cycling
2. Two-speed motor cycling (High speed, Low speed, Off)
3. Variable Frequency Drive (VFD) controllers on the motors

Figure 5 below shows the effect of load condenser with different fan operation strategies that were developed by the Energy Center of Wisconsin (ECW). In a given condenser design several variations are possible and those were investigated by ECW. The figure shows that 60% load, the VFD controlled fans (option-5) use 10% of full load power compared to 40% power by option-3.

Figure 5: Part-Load Evaporative Condenser Operation



Condenser Efficiency Issues

- ❑ Use high efficiency motors on condenser fans and pumps
- ❑ The greater the surface area, the greater the potential for improved efficiency
- ❑ Air cooled condenser fins and tubes in a shell and tube unit should be kept clean
- ❑ Oversized condensers, when used with floating head pressure controls, can save significant energy over a correctly sized condenser operating with a fixed head pressure controls
- ❑ Keep evaporative condensers free of hard water and bacterial buildup

Floating Head Pressure Considerations

- ❑ Fixed head pressure control although very simple to implement, results in high-energy costs.
- ❑ All industrial refrigeration systems have a condensing pressure that results in a minimum energy requirement of the sum of compressor and condenser energy. This optimized pressure is a function of the system characteristics such as condenser size, component arrangement, condenser fan control schemes, and load profiles.
- ❑ VFD controlled condensers fans can result in 5 to 10% of the energy savings over an ON/OFF control strategy.

Evaporators

Evaporators are sized for the largest anticipated refrigeration load, which is some combination of warm summer temperatures, and large internal product loads. Several types of evaporator designs are used in ammonia refrigeration systems, some of which are: Direct

Expansion (DX), Pumped Liquid Overfeed, Flooded shell and tube and Plate heat exchangers. Evaporators in the refrigerated space can contribute as much as 10 to 15% of the energy consumption in an industrial refrigeration system and therefore are significant contributor.

1. **Direct Expansion Evaporators (DX)**-These evaporators are not generally recommended in ammonia systems unless the suction temperatures is 0 °F or higher. This is due to lower efficiency of the DX coil and difficulty in providing a uniform liquid to the coil.
2. **Pumped Liquid Overfeed**-This evaporator design is preferred over the DX option. It is available in the bottom feed and top feed options. In this evaporator design, high-pressure ammonia from the system high-stage flashes into a large vessel at the evaporator pressure from which it is pumped to the evaporators at an overfeed rate of 2.5 to 1 to 4 to 1.
3. **Flooded Shell and Tube**-These evaporators are typically used in ammonia systems to provide indirect or secondary cooling through water or brine. These types of evaporators have problems at low temperature operations such as changes in lubricant transport properties and loss of capacity and require high refrigerant charge.

Evaporator Capacity Control Methods

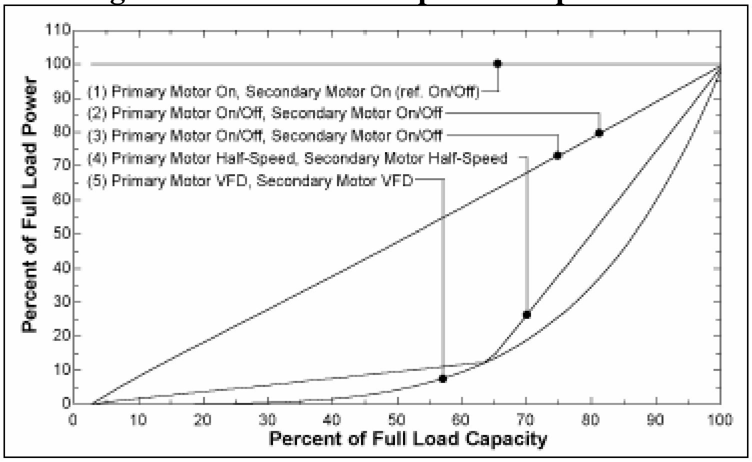
The actual cooling loads for the majority of the operating hours are very small compared to the design loads and therefore the refrigeration capacity delivered by the evaporator must be varied too. Several types of evaporator designs are used in refrigeration systems with the circulation fan being the common link between the different designs. There are three different means of achieving capacity change in evaporators:

1. **Fan Cycling**-Fans are cycled to maintain space temperature at the desired level.
2. **Cycling refrigerant on and off**-Fans operate continuously
3. **Fan Speed Control**-Fan speed is varied to maintain space temperature using either variable speed drives or two speed evaporator fans.

In the shell and tube evaporator designs, capacity control is achieved by controlling the return water/liquid temperature.

Figure 6 shows the performance of different fan control strategies under different loads as developed by the Energy Center of Wisconsin. In a given evaporator design several control variations are possible and those were investigated by ECW. The figure shows that 60% load, the VFD controlled fans (option-5) use 10% of full load power compared to 55% power by option-3.

Figure 6: Part-Load Evaporator Operation



Evaporator Control Conclusions

- Continuous operation at full speed for air circulation increases the combined evaporator and compressor energy consumption by an additional 15%.
- Half-speed evaporator fan motor control has been shown to save over 14% in system energy consumption when implemented with optimum receiver temperature/pressure control.

Evaporator Efficiency Issues

- In DX air coolers, the fin blocks should be kept clear of dirt and adequately defrosted
- The tubes in shell and tube coolers should be cleaned periodically to prevent fouling

Evaporator Defrosting

All evaporators that operate with a refrigerant temperature below the freezing point of water and dew point of the conditioned space will build frost on the coils during operation. Frost accumulation degrades the performance of an evaporator by reducing the heat transfer coefficient and obstructing the airflow. The different types of defrosting methods that are commonly used are: Hot gas, hot water, electric heat, and warm air. Typically, hot gas bypass is the defrosting method of choice in ammonia systems. Defrosting energy consumption can be minimized when done on- demand instead of on a time initiated and time terminated schedule.

Controls and Instrumentations

An appropriate adage for control system is "what you cannot measure and see, is not something you can control". Industrial refrigeration performance optimization cannot be accomplished without adequate instrumentation and data acquisition capabilities. The operator needs sufficient information in order to observe the system performance. This information also needs to be recorded in order to provide the opportunity for historical trending of system operation.

Typical Refrigeration System Energy Savings Strategies

In summary, typical ammonia refrigeration system energy savings strategies are presented below:

- Reduce heat loads (Low Cost Strategies)
  - Turn off lights in unoccupied refrigerated spaces and use more efficient lights
  - Increase insulation
  - Reduce infiltration
  - Check all coils for dirt and debris or missing nozzles in condensers
- Reduce temperature lifts in the refrigeration plant
- Use efficient compressors and operate them optimally (sequencing)
- Ensure that defrost controls are set to optimize defrost effectiveness
- Use optimum size of evaporators and condensers – should be sized to operate at lowest condensing temperature and highest effective evaporating temperature
- Install VFDs on evaporators, condensers and compressors
- Use premium efficiency motors on compressors, condensers, evaporators and pumps
- Computer controls – facilities improved and optimized operating strategies
- Recover heat from at or before the Condenser for process or domestic hot water usage

Case Study-Stonyfield Farms Yogurt

Introduction

Stonyfield Farms in Londonderry, founded in 1983, produces a wide variety of all natural and organic yogurts, as well as organic ice cream. Stonyfield Farm has grown to be one of the four largest yogurt manufacturers in the country, with $90 million in sales a year. The plant occupies an area of about 100,000 square feet. The plant operates 24 hours a day seven days a week, producing approximately 45,000 cases of yogurt products a day.

Refrigeration System Details

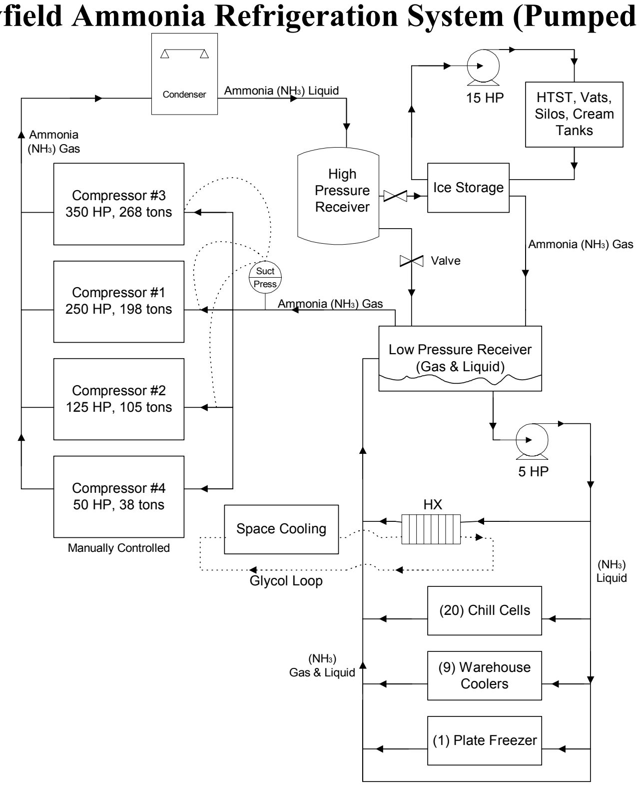
Figure 10 shows a schematic of the refrigeration system.

The Stonyfield Farms facility has a multi-stage ammonia refrigeration system that is comprised of one 350-HP, one 250-HP, one 125-HP and one 50-HP rotary screw compressor. All of the compressor use slide valve capacity controls. The 350-HP, 250-HP and the 125-HP compressors are controlled using a FES sequencer that controls the compressor operations based on the cooling load in the facility. The 50-HP compressor is manually operated based on the plant requirements. The refrigeration system accounts for more than 35% of the electrical energy consumption at the facility. The ammonia system cooling loads include: High Temperature Short Time (HTST) pasteurizers, pasteurized vats, culture vats, silos, cream tanks, chill cells, warehouses, plate freezer and space cooling. The average plant cooling load demand varies based on the different operations being performed at any given point of time. Based on the monitored information, the winter month peak cooling loads are approximately 370 tons and the summer month peak cooling loads are approximately 570 tons.

The authors worked with the facility staff to characterize the existing equipment refrigeration system operations to identify energy savings measures. Public Service of New Hampshire (PSNH), the local utility, sponsored the project. The primary focus of the audit was on the optimization of the refrigeration sequencer controls, other measures - similar to those discussed above – have not been addressed but are under consideration.

Compressors #1, #2 and #3 are connected to the automatic sequencer, which is set to maintain suction pressure at 25 psig. In the existing case, Compressor #4 was manually operated and was primarily used during the weekends. During normal operations, compressors #1, #2 and #3, pressurize ammonia gas from the low-pressure receiver to about 100 psig at 130 °F. This hot ammonia gas is then condensed in the evaporative condenser. The high-pressure ammonia liquid is then throttled to the high-pressure receiver (HPR). A portion of the high-pressure liquid ammonia is directed to the ice making system to remove heat from the chilled water system where the ammonia flashes to gas after extracting the heat from the ice storage unit. Liquid ammonia from the low-pressure receiver is pumped using a 5-HP re-circulating pump to various loads such as the glycol loop for space cooling, the chill cells, and other loads. A mix of liquid and gas ammonia returns to the low-pressure receiver tank after extracting the heat from various sources. Only the gaseous ammonia is fed to the compressors and the whole cycle repeats again.

Figure 10: Stonyfield Ammonia Refrigeration System (Pumped Liquid Overfeed)



Automatic Sequencer

350-HP, 250-HP and 125-HP compressors are connected to the FES sequencer, which is set to maintain a suction pressure of 25-psig in the refrigeration system. The sequencer controls the operation of the compressors based on the measured load levels. Table 2 below presents the existing sequencer set points observed during the initial site visit.

Table 2: Existing Sequencer Set Points

EXISTING	Cooling Load, Tons	250 HP #1	125 HP #2	350 HP #3
Step 1	0 - 30	OFF	OFF	OFF
Step 2	27 - 105	OFF	ON-25%	OFF
Step 3	150 - 198	ON-77%	Backup	OFF
Step 4	209 - 268	Backup	OFF	ON-78%
Step 5	227 - 303	ON-75%	ON-75%	Backup
Step 6	269 - 373	Backup	ON-65%	ON-75%
Step 7	275 - 466	ON-85%	Backup	ON-40%
Step 8	400 - 571	ON-70%	ON-70%	ON-70%

Analysis

A bin spreadsheet analysis tool was developed by ERS to investigate the optimum sequencer set points for the refrigeration compressors under different cooling loads. A profile of the cooling loads and the hours at the cooling loads was developed as a basis for the analysis. Compressor performance data was obtained from the compressor manufacturers. Based on performance data for the four compressors, and the bin analysis spreadsheet tool, the following conclusions were derived:

- It is more efficient to operate a single larger part-loaded compressor than operating two smaller part-loaded compressors.
- Operating the larger compressor at full load and allowing the smaller sized compressor to provide the trim capacity, resulted in the least power draw at higher cooling load levels.
- The 350-HP compressor is the most efficient compressor to operate down to the 40% of the full load capacity.

Table 3 below shows the energy savings summary for the two measures with brief descriptions of the measures below the table.

Table 3: Refrigeration Savings Summary

Energy Efficiency Measure	Energy Savings (kWh)	Demand Reduction (kW)	Installed Cost	Annual Cost Savings	Simple Payback (Years)
EEM-1 Optimization of Refrigeration Sequencer Set Points (Option-1) (Include 50-HP compressor in the sequencer)					
Savings Summary	27,471	0.0	$10,000	$1,997	5.0
EEM-2 Optimization of Refrigeration Sequencer Set Points (Option-2) (Optimize existing sequencer set points)					
Savings Summary	18,322	0.0	$0	$1,332	0.0

EEM-1 optimization of refrigeration sequencer set points (option 1) (include 50-hp compressor in the sequencer). In this option, we investigated including the 50-HP compressor in the sequencer logic so that greater flexibility in operations could be implemented. We estimated that this measure would cost $10,000 to implement. Table 4 below presents the recommended Option-1 sequencer logic.

Table 4: Option 1 - Sequencer Logic

OPTION 1	Cooling Load, Tons	250 HP #1	125 HP #2	350 HP #3	50 HP #4
Step 1	0 - 38	OFF	OFF	OFF	ON-20%
Step 2	50 - 105	OFF	ON-47%	OFF	OFF
Step 3	106 - 268	OFF	OFF	ON-40%	OFF
Step 4	269 - 306	OFF	OFF	ON-87%	ON-100%
Step 5	310 - 373	OFF	ON-100%	ON-75%	OFF
Step 6	374 - 466	ON-100%	OFF	ON-66%	OFF
Step 7	470 - 504	ON-100%	OFF	ON-85%	ON-100%
Step 8	520 - 570	ON-100%	ON-100%	ON-80%	OFF

EEM-2 optimization of refrigeration sequencer set points (option 2) (modify sequencer set points for the existing compressors). In this option, we investigated changing the sequencer set points to provide optimum compressor performance for the given cooling load. This was a no-cost measure. Table 5 below presents the recommended Option-2 sequencer logic.

Table 5: Option 2 Sequencer Logic

OPTION 2	Cooling Load, Tons	250 HP #1	125 HP #2	350 HP #3
Step 1	0 - 30	OFF	OFF	OFF
Step 2	27 - 105	OFF	ON-45%	OFF
Step 3	110 - 268	OFF	OFF	ON-40%
Step 4	270 - 373	OFF	ON-100%	ON-60%
Step 5	374 - 466	ON-100%	OFF	ON-65%
Step 6	470 - 570	ON-100%	ON-100%	ON-60%

Conclusion

Refrigeration system optimization can be defined as a process that produces the desired refrigeration effect for minimum cost (usually life-cycle cost). Often, even though a refrigeration system is producing the desired result, it may not be operating efficiently. Although refrigeration is an inherently energy-intensive process, careful application of engineering principles in design and operation can lead to significant improvements in both capacity and efficiency.

A significant number of the facilities have older compressor systems and refrigeration system components that are operated by trial and error, which does not necessarily result in efficient operations. Low cost strategies are available that can have a large impact on the bottom line. The application of better part load controls on compressors, floating head pressure controls, VFDs on the condensers and evaporator fans along with refrigeration management systems can result in efficient operations and energy savings.

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