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For Efficient Dairy Plant Operation

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REFRIGERATION SYSTEM

This bulletin includes technical information, latest developments on products, systems, techniques etc. reported in journals, companies' leaflets, books and based on experience. The technical information would be on different areas of plant operation in different issues. It is hoped that the information contained herein, if employed in the factory, will help in making dairy plant operations more efficient.

Your contributions and suggestions will make the bulletin more useful, and are welcomed.

The theme of information in this issue is Refrigeration System. It may be understood that the information given here is by no means complete.

This issue on Refrigeration System is being brought out at the request of Shri AK Modgil, Managing Director, Udaipur District Cooperative Milk Producers' Union Ktd., Udaipur.

In This Issue

1. REFRIGERATION SYSTEM

Refrigeration is the heart of a dairy processing plant. While it is an important part of a dairy plant, it is expensive, too. It is, therefore, essential that the refrigeration system is operated efficiently.

In dairy plants, the vapour compression system of refrigeration is used universally. The two most commonly used refrigerants are anhydrous ammonia and dichloro-difluoromethane (Freon 12). Ammonia is the most commonly used refrigerant, and is preferred for large and medium size plants. Freon 12 is generally used in smaller plants, and in self contained units like milk cooling cabinets, bulk milk coolers, refrigerated trucks etc. For special applications, such as ice-cream cabinets monochlorodifluoromethane (Freon 22) is also used.

Irrespective of the type of duty performed and refrigerant used, the vapour compression cycle is always the same. The system is made up of four essential items of equipment : compressor, condenser, expansion valve or throttling device and evaporator. They are hooked up in a continuous circuit alongwith other accessories. Fig 1 shows such a basic flow diagram.

In a standard vapour compression system, the saturation temperatures are - 15°C in evaporator and 30°C in condenser. The pressures are maintained accordingly.

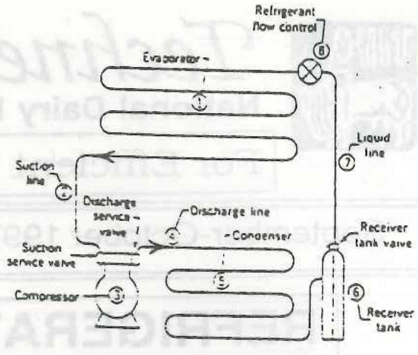

Fig. 1.

In the operation of the system, the liquid refrigerant enters the expansion valve (position 8 in the figure) from the receiver in subcooled condition. Considering standard operating conditions for ammonia, the temperature of liquid refrigerant would be 25°C and pressure 11.84 kg/sq.cm abs. During expansion, the liquid enters the low pressure region of evaporator, and some liquid vaporizes. The mixture enters the evaporator 1 where the refrigerant liquid vaporizes extracting heat from the objects, at saturation temperature (-15°C, 2.4 kg/sq.cm abs for ammonia). From evaporator, the vapour is sucked by the compressor. The gas gains some heat in the suction line 2 so that it is slightly superheated at the compressor inlet (-10°C for ammonia). The gas is compressed by a compressor 3 to high pressure of condenser (11.84 kg/sq.cm abs for ammonia). The compressed vapour is superheated (105.7°C for ammonia). The compressed vapour is condensed in a condenser 5 indirectly by water or air at saturation temperature (30°C for ammonia), and the liquid refrigerant is then subcooled at constant pressure (25°C for ammonia). The liquid is stored in a receiver 6.

Table 1 gives some of the important properties of some commonly used refrigerants at standard operating conditions. At atmospheric pressure, the boiling points of ammonia, Freon 12 and Freon 22 are -33.3°C, -29.8°C and -40.8°C, respectively.

2. REFRIGERATION SYSTEM OPERATING EFFICIENCY

Refrigeration system efficiency is affected by the following factors :

1) **Head Pressure** : Head pressure (discharge, or high side pressure) should be low for efficient operation. See item 3 for factors that tend to raise the head pressure.

2) **Suction Pressure** : Lower than normal suction pressure (evaporator, low-side or back pressure) and hence low temperature results in loss of

Table 1

Properties of some common refrigerants at standard conditions (Evaporator temperature - 15°C and condenser temperature 30°C).

Property	Ammonia	Freon-12	Freon-22
Evaporator pressure at - 15°C, kg/sq.cm abs.	2.4	1.85	3.01
Condenser pressure at 30°C, kg/sq.cm abs.	11.84	7.56	12.22
Liquid density at 30°C, kg/ cu.m.	595.2	1291.2	1174.4
Efficiency (% Carnot cycle)	83	82	81.3
Co-efficient of performance	4.76	4.7	4.66
Refrigeration effect, kcal/kg.	263.8	27.8	38.5
Weight refrigerant circulated per ton, kg/min.	0.191	1.815	1.308
Horse power (HP) per ton of refrigeration	0.99	1	1.01

Note : Ammonia (NH_3) = R - 717
Freon - 12 (CCl_2F_2) = Dichlorodifluoromethane, R-12 or Genetron-12.
Freon - 22 ($CHClF_2$) = Monochlorodifluoromethane, R-22 or Genetron 141.

refrigeration capacity and increased horse power per ton of refrigeration. Hence, low suction pressure, is undesirable. See item 4 for factors affecting suction pressure.

Higher discharge pressure or lower suction pressure than normal, or both, will cause an increase in the compression ratio of the compressor.

3) **Compressor Clearance Volume:** An increase in such volume results in a reduction of its volumetric efficiency decreasing the capacity. The clearance volume in an operating compressor can increase due to wear of its bearing and journals.

4) **Refrigerant Leakage during Compression** : This can occur due to leaky or sticky valves, as well as worn piston rings, and will cause inefficient operation.

5) **Loose Electrical Contacts** : Loose contacts in electrical connections will lead to overheating and subsequent higher rate of power consumption. The worn out contact points also lead to this. Good preventive maintenance in this area will give effective results. Also, after certain hours of use the contacts should be replaced on routine basis.

Following are some useful tips for obtaining high operating efficiency :

1) Ice bank cooling should be done during off-peak power loading.

2) Operations should be scheduled to obtain as uniform cooling load as possible during hours of maximum refrigeration need.

3) Cooling equipment with larger cooling surfaces will permit operation with minimum temperature differences and will consequently require minimum power per ton of refrigeration.

4) In an average milk plant cool room it is best to have a small compressor with a large forced air type space cooler so that the compressor may operate at a higher suction temperature. If the suction temperature is only 5-7°C below the cold room temperature it may be possible to operate with a power consumption as low as 1 HP per ton of refrigeration.

5) Small cooling load and short duration is best with sweet water plant with ice bank for storage of refrigeration.

6) For large plant cooling load and long period direct expansion of refrigerant within a cooling system is economical because of a high suction pressure with a resulting low HP per ton refrigeration capacity.

7) Greatest economy and flexibility are obtained by one common ammonia system with one condenser (usually evaporative)

and several compressors (booster compressor for very low temperature, if required). This arrangement gives :

a) the simplest and best utilization of standby on emergency compressor, and

b) the greatest convenience for repair or replacement.

3. PROBLEM OF HIGH HEAD PRESSURE

1) Faulty Condenser. See item 5.

2) Air or other non-condensible gases in system. Purge

3) Check discharge valves are open and installed correctly.

4) Liquid refrigerant in compressor. Remove excess refrigerant from system.

5) No water in cooling tower. Check ball cock, valves and pump. Repair, open cock or replace as appropriate.

6) Too much refrigerant in the system. Purge refrigerant until level is visible in liquid receiver sight glass.

4. LOW SUCTION PRESSURE

1) Lack of refrigerant. Check for leaks and repair. Recharge system. **Important : Do not mix refrigerants.**

2) Low or no refrigerant supply to evaporators.

a) Blocked liquid feed strainers. Clean.

b) Check and clean evaporator controls.

c) Liquid solenoid valves not working. Check solenoid fuse and PLC (if fitted) fuses. Check solenoid coil. Replace if burnt out and check mechanical function of valve. Replace if necessary.

d) Hand expansion valve closed. Open to recommended setting.

e) Faulty expansion valve (for example, thermal element lost its charge). Repair or replace.

f) Float switch faulty. Repair or replace.

g) Heater element open circuited on liquid level control on flooded evaporator. Test and repair.

3) Partial (or complete) freeze-up of evaporator. Thaw out tubes or defrost fins. Instal hot gas line and controls for rapid thawing.

4) Evaporator fouled. Fouled by oil or product deposits. Drain oil and clean surfaces chemically or mechanically (rod or brush).

5) Compressor short cycles. See item 6.

6) Capacity control not modulating. See item 7.

7) Excessive suction line pressure drop. Check that stop valves are open and clean suction strainer.

8) Evaporator too small. Discuss with refrigeration specialist.

9) Heat loads satisfied or no load.

5. PROBLEM OF FAULTY CONDENSER

1) Poor water supply
   a) Water inlet ball cock jammed. Repair or replace.
   b) Water supply not turned on at mains. Check and turn on.
   c) Water supplied at low pressure. Check and contact water supply agency.
   d) Blocked water sprays. Clean and replace.
   e) Blocked lines. Inspect and clean.
   f) Water pump leaking. Check seals etc. and repair or replace as applicable.
   g) Water temperature into shell-and tube too high. Check and control water temperature.
   h) Blocked strainers on inlet to pump. Clean.

2) Plugged tubes. Check above items on cooling tower.

3) Excessive water consumption
   a) Sump drain plug loose or missing. Tighten or instal new plugs.
   b) Sump or water boxes leaking. Check and repair.
   c) Water boxes on shell and tube condenser internally corroded allowing water bypass. Repair or replace.
   d) Eliminators damaged or installed upside down. Replace or install correctly.

4) Poor air flow.
   a) Blocked air inlet screens. Clean.
   b) Blocked eliminator blades or dampers. Eliminators rusted or collapsed. Clean or replace.
   c) Fans rotating in wrong direction. Check rotation and motor wiring. Repair. Note that air is drawn or sucked through an induced draft condenser but blown through a forced draft condenser.
   d) If condenser is positioned indoors, check doors are open to give adequate air flow.
   e) Dust or plastic bags blocking fins. Remove large objects, brush fins and blow through with compressed air.

f) Air recirculation from exhaust to inlet. Instal ducting. Relocate condenser.

5) Air or other non-condensible gases in system : Purge system.

6) Corroded or fouled tubes or fins: Clean and renew.

7) Check all inlet and outlet valves on both refrigerant side and water side are fully open.

8) Oil in condenser coil. Drain. Check oil return system from separator to compressor.

9) Too much refrigerant in the system. Remove refrigerant until level is visible in liquid receiver sightglass.

10) Check fan belt drive not slipping. Check liquid refrigerant does not hold up in condenser coils (multiple condenser installations). Check piping connections are correctly sized and installed.

6. COMPRESSOR SHORT CYCLES

1) High head pressure. See item 3.

2) Low suction pressure. See item 4.

3) Capacity control not modulating. See item 7.

4) Lack of refrigerant. Check for leaks and repair. Recharge system.

5) Faulty protective switch. Check both electrical and mechanical function of switches. Repair or replace as necessary.

7. COMPRESSOR CAPACITY CONTROL

Plant not responding to changes of product heat load.

a) Capacity control pressure switch set incorrectly or defective. Reset or replace as necessary.

b) Capacity control system faulty or out of adjustment. Check individual components and wiring. Repair, reset or replace as needed.

c) Timing relay faulty or out of adjustment. Replace or reset.

d) Wrong refrigerant. Refrigeration serviceman to change to correct refrigerant.

e) Plant under-sized. Discuss with refrigeration specialist.

8. ALGAE AND FUNGI IN COOLING WATER

In open cooling water system, a serious problem encountered is of development and growth of algae and fungi.

Algae : Algae are coloured green,

blue-green and brown. They produce their own food from air, sunlight and water, and will not grow in the absence of any of these. They may grow as free- floating slime masses on the surfaces of the water, or may attach to the walls of a reservoir or cooling tower, tower fill lumber, mist eliminators, screens, plenum chambers and distribution trays. They best grow at the following conditions :

Type	Temp.°C	pH
Brown	18-36	5.5 - 8.9
Green	30-35	5.5 - 8.9
Blue-green	35-40	6.0 - 8.9

Very little of algae is required to block tubes, tube plates, circulating mains, pumps, channels and nozzles. It aids in sealing by absorbing carbon dioxide from the water. The corrosion is accelerated as oxygen is liberated. It produces slime which form electrolytic corrosion cells prone to pitting. Deposit of dead algae provide food for bacteria and fungi.

For controlling algae, the first important step is manual cleaning. This will remove the worst, but leaves enough seed items for further growth. Filtration of the water, in the range of 5 to 5000 microns is also useful. A very effective method for controlling algae growth in smaller system is to cover cooling tower decks with opaque head pan covers to prevent sunlight from reaching the tower. If necessary chemical treatment may be effected.

Chemicals used are chlorine, quarternary ammonium compounds and other chemicals. Chlorine is most widely used algaecide, but its concentration in water (free chlorine) at the inlet to the cooling tower should be kept within 1 ppm in order to check wood deterioration. Also maintain pH between 6 and 7. If required, a combination of chlorine and other biocide can be used. A combination of chlorine, ammonia and copper sulfate is also effective. In place of chlorine, sodium hypochlorite can be used which is less expensive in application.

Chlorinated phenols are used in the forms of their sodium and potassium salts. Most commonly used are :

2,4,5 trichlorophenol,
2,4,6 trichlorophenol,
2,3,4,6 tetrachlorophenol and pentachlorophenol.

Potassium permanganate is also commonly used. Its concentration should be sufficient to hold a 12 minute pink discoloration immediately after addition of the solution. Fortnightly treatments are usually sufficient.

Copper sulfate, though effective, should not be used alone in cooling water systems, as copper can plate out on ferrous surfaces causing accelerated pitting. In alkaline waters, it precipitates out and is ineffective. However, proprietary compounds are available in which copper is chemically combined in complexes of much greater stability. Their use is safe.

Quarternary ammonium compounds and complex amines are also in common use. They are stable at pH ranges of cooling tower systems. Tributyl tin oxide, used alone or with quats is quite effective. Organo-thiocyanates can also be used. Their activity is not diminished by organic matter, oils, high hardness etc. But as they are slightly soluble in water, they are to be used with a proper solvent - dispersant carrier system, such as quats and other complex amines.

To maintain the effectivenss of algaecides and fungicides, they need to be shock injected to maintain their levels. The first injection should be at 5 ppm for a period of 15-20 minutes, followed by a lower rate - to maintain the concentration at 0.5 to 1 ppm - for another 2 hours. Usually this procedure should be repeated 2-3 times a week.

The sign of successful treatment is the change in colour of the algae and slime from green or blue-green to dead or rusty brown.

Fungi : Fungi are molds and yeasts, and need moisture and atmospheric oxygen for growth. They generally do not grow under water, and may grow on any of the wood components of cooling tower, basin walls and in heat exchangers. They depend on outside food sources, e.g. killed bacteria, dead algae, organic debris gleaned from the atmosphere, etc.

They result in slime and some molds (penicillin) cause invisible internal wood decay and surface rot. Their slime and sludge may deposit on heat exchangers, and prevent corrosion inhibitors from reaching the metal surfaces.

For protection, wood is impregnated with toxic salts, such as copper salts, with excess of salts removed to guard metal from corrosion. Fungi can be controlled by the periodic application of fungicides such as pentachlorophenol salts, tributyl tin compounds and complex amines. Chlorine is not effective.

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