# MAINTENANCE AND RELIABILITY OF INDUSTRIAL REFRIGERATION SYSTEMS

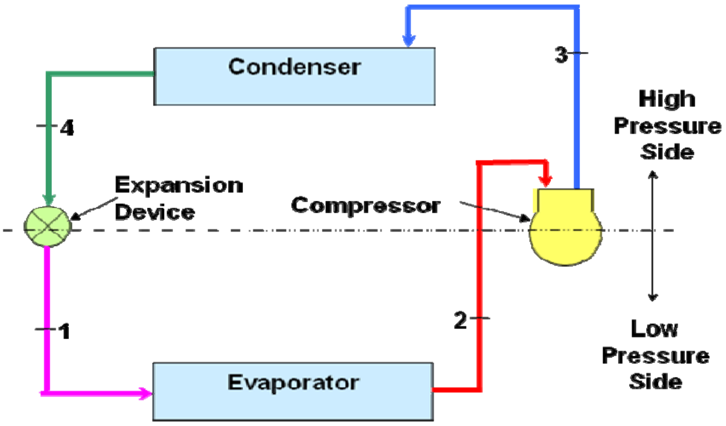
***Milena Otović, University of Belgrade, Faculty of Mechanical Engineering****
***Uroš Milovančević, University of Belgrade, Faculty of Mechanical Engineering***
***Franc Kosi, University of Belgrade, Faculty of Mechanical Engineering***

***Abstract:*** *The objective of this paper is emphasizing the importance of maintaining the cooling systems from the perspective of exploitation safety. The comparative analysis of the natural and synthetic refrigerants is made. An overview of the location of possible operation problems is given. There are cited the most common mistakes of industrial cooling installations that hinder maintenance and lead to incidents followed by leaking in the exploitation conditions. The accent is put on parts of refrigeration installations at high pressure in specific periods of operating (evaporator defrosting). Special attention should be paid on monitoring of leaking in liquid lines (especially with over-flooded systems). Finally, the routes and suggestions for better maintenance and safety improvements are given.*

***Keywords:*** *refrigeration systems, maintenance, defrosting process, maintenance strategies.*

## INTRODUCTION

The basic (simplest) refrigerant system is one stage vapour refrigeration system, with basic components such as compressor, condenser, expansion device and evaporator, whose shematic preview is briefly given in Picture 1. The refrigerant conditions are marked with numbers. State 2 stands for vapor in suction line at low pressure, state 3 marks discharge of compressor at high pressure, state 4 is liquid refrigerant at the outlet of condenser and state 1 is refrigerant state at the inlet of evaporator.



*Picture 1. – Shematic preview of basic vapor refrigerant system*

In Picture 2, it is shown the refrigeration cycle in *log p – h* diagram with respect to the previous marked and explained conditions.

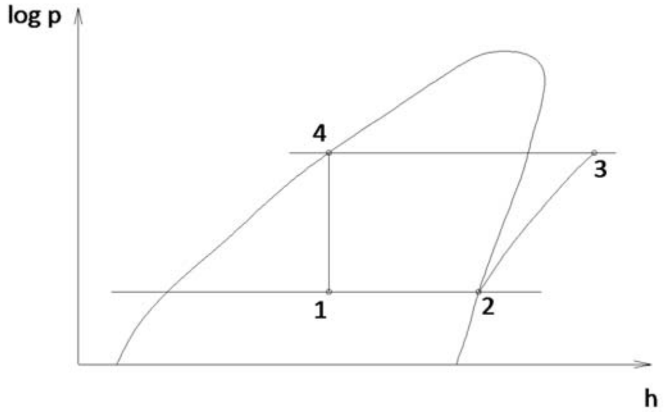
The simple energy balance equation for this one stage system is given with

$$\dot{Q}_{CD} = \dot{Q}_0 + P_{el} \tag{1}$$

where $\dot{Q}_{CD}$ is condenser heat duty, $\dot{Q}_0$ is refrigeration capacity and $P_{el}$ is compressor absorbed power, all expressed in W, kW, or MW.

---

* University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia
*motovic@mas.bg.ac.rs*



Picture 2. – Log p – h diagram of refrigerant cycle

Coefficient of performance (COP) is thermodynamic parameter for defining the quality of refrigeration process, and it is defined as

$$COP = \frac{\dot{Q}_0}{P_{el}} \tag{2}$$

## PROBLEMS OF REFRIGERATION SYSTEMS OPERATION

The running conditions of the refrigeration system are usually given by the room temperatures. Any abnormal change in these conditions often indicates issues with the refrigeration system and it results in poor operation of the compressors. As a rule of thumb it can be considered that an increase of the temperature difference on evaporator and condenser by 1K will lead to increase in power consumption by 3-4 %, so running the refrigeration plant at too low evaporating temperatures or too high condensing temperatures will have a very high impact on the direct running cost. Other issues that need regular checking are vibration levels and shaft seal leakages (open type compressors and pumps). In Table 1 parameters are compared for synthetic refrigerants – freons R404A and R134a, and ammonia R717 which is natural refrigerant. The highest values of COP are calculated for R717, as expected.

Table 1. – Comparison of frequently used refrigerant parameter

| Regime -10°C/40°C | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $Q_o$ [kW] | $Q_{CD}$ [kW] | $P_{el}$ [kW] | COP | V $m^3/h$ | m kg/s | $p_0$ [bar] | $p_{CD}$ [bar] |
| R 404A | 10 | 13.72 | 3.98 | 2.508 | 15.94 | 0.0922 | 4.34 | 18.17 |
| R 134a | 10 | 13.29 | 3.56 | 2.813 | 26.23 | 0.0699 | 2.07 | 10.17 |
| R 717 | 10 | 13.14 | 3.46 | **2.891** | **14.63** | 0.0092 | 2.90 | 15.57 |
| Regime -30°C/40°C | | | | | | | | |
| R 404A | 10 | 16.31 | 6.86 | 1.456 | 36.98 | 0.1035 | 2.05 | 18.17 |
| R 134a | 10 | 15.43 | 5.94 | 1.684 | 65.19 | 0.0766 | 0.85 | 10.17 |
| R 717 | 10 | 15.18 | 5.72 | **1.747** | **34.82** | 0.0095 | 1.19 | 15.57 |

If we speak about maintenance of a cold storage facility, it is necessary to provide safety at the first place, and to ensure proper storage of food so as efficient and economic operation of the facility. Some of the daily routine services can be performed by the operating plant staff. This can typically include checking oil and refrigerant levels, checking for leaks or abnormal running conditions, etc. The operator can also record and compare operation parameters as suction and discharge pressures and temperatures, oil pressures, temperatures and levels. Direct monitoring and registration of some of this data is for a larger system

---

* University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia
motovic@mas.bg.ac.rs

normally done by a control system often mounted on the compressors. It is recommendable to install a data logging system, making it possible to analyze historical trends in the measured data. Such data is valuable in case of breakdowns, but also for optimizing the operation of the system, indicating possible savings. This can provide a solid foundation for making decisions on new investments.

The evaporative condensers can have problems with fouling and corrosion, if the water treatment of the make-up water is not done properly. The condenser may need regular cleaning depending on its type and the ambient conditions. Circulation pumps, fans and fan speed controls have to be checked on a regular basis. Cooling towers have to be treated similarly to evaporative condensers. Air condensers reject the heat to the dry air stream. Distribution of the refrigerant and air flow is the main concern. Dirt can be sucked into the quite narrow gaps between the fins (fin pitch 1 to 3 mm) of the condenser inlet and have to be removed. As the fins are very thin (even 0.12 mm), they are very vulnerable and easy to distroy. More complicated maintenance (and service) problems on the refrigeration system will require specialized knowledge, and had to be done by skilled and authorized personnel. This will also ensure the compliance with local health and safety regulations.

In the past, it was normal to have skilled refrigeration professionals within the cold store staff, but in the the last decades the tendency has shifted to outsourcing this to (sub)contractors. When doing this, it should be taken into account possible differences in the objectives of the owner (having a cold store running at maximum efficiency) and the (sub)contractor (achieving this in the cheapest way). When energy efficiency is the objective, it is a facing problem. For example, by setting the condensing pressure high, the system will always be operating under summer conditions. This will ensure that the refrigeration system will never experience instabilities due to too low condensing pressure on a cold winter day. This is not good for the owner's energy charges, but it may be good for the (sub)contractor who will not receive any complaints from the operator [1]. Goods stored in a cold storage room often have temperature requirements that must be guaranteed during some period of time, otherwise product quality can be suspected. Sometimes, this can result in operation of the room at lower than necessary temperature (especially in rooms with low temperature regimes), which will unnecessarily increase the energy consumption, the negative environmental impact, and deterioration of stored products. If proper cooling of the storage room cannot be maintained, it can be caused by incorrect (or insufficient) maintenance. Regular maintenance and service will provide that the cold storage facility can:

1. maintain safe conditions for the operating staff and the environment,
2. maintain the required conditions in the storage room needed for preserving goods,
3. ensure efficient operation of compressors, fans etc., and so prevent unplanned breakdowns.

The defrost process could cause the occasional damage to equipment and in some cases the rupture of refrigerant lines, resulting in excessive cost and in several cases personal injury. The critical periods during a hot-gas defrost are at its start and at its end. In both situations high pressure vapor that may be moving at a high velocity is brought into contact with cold liquid causing pressure shock waves.

Operators should be cautioned that if there is excessive noise and shaking of pipes during defrost, that this is not a normal condition, and the causes should be corrected. Also, the building typically operates under large temperature differences (for example between the ambient condition during summer time and frozen store condition), which causes relative motion between building components (walls, panels, insulation…). The insulation of the cold room walls must be kept in good condition in order to avoid moisture condensation that leads to excessive heat gains, and in bottom line low temperature room walls could be broken due to ice forming. Also improper insulation repair works on some components like doors, roofs, etc... can lead to same problems. The insulation quality can be checked with an infrared camera (by thermographic analysis). The door on the storages represents the barrier between the inside room conditions with the ambient surroundings. Opening doors will normally lead to infiltration of warm and moist air that lead to the additional heat load on the evaporators. Therefore, air infiltration must be kept to a minimum. In order to avoid continuous infiltration through the crack, doors must be tightly sealed when repaired. If there is heavy traffic through the doors, the risk of damage from the passing forklifts is high (it should be paid attention to a refrigerant pipelines, drainage pipelines, etc. when using forklifts). Protectors can be installed to avoid damage to the doors from forklift. Automatic door mechanisms should be checked for proper opening and closing time (Picture 3).

*Picture 3. – Cold store doors with automatic mechanisms*

In frozen stores, the floor heating system must function properly in order to avoid frosting of the soil below. Temperature sensors are installed below the floor and they are used for the proper functioning and control of the floor heating system. The floor temperature should be kept as low as possible to decrease the heat load to the room, and to decrease the influence on goods. In the case of hydronic floor heating, the antifreeze should be used. One of the examples of poor floor maintenance is cold store room in Serbia where the floor is raised in height caused by ice accumulating because improper floor heating, that decreased the storage capacity and induced some other problems.

The defrost schedule of evaporators at “minus” temperatures should be checked to avoid unnecessary defrosts. On the other hand, if defrosts are not done sufficiently often, the cooling capacity of the evaporator will be decreased (Picture 4). Other evaporators will have to meet the load and this will cause problems in maintaining the desired room temperature, while also increasing energy usage. Also, it should be paid attention when defrosting one evaporator possibly influences the temperature signal controlling another evaporator. When defrosting an air coil using hot gas, the basic procedure is to interrupt the supply of liquid refrigerant to the evaporator, restrict the outlet of the coil, then supply high-pressure (and high temperature) vapor. The interior of the coil then achieves a pressure such that the saturation temperature is high enough to melt the frost on the exterior of the coil. During defrost the evaporator temporarily workes as a condenser [2]. The negative impact of the evaporators’ locations on the operation of the refrigeration system should be avoided. A free air flow in cold rooms is obliged to ensure proper temperature field in the cold store. Air from one evaporator shouldn’t be sucked into an adjacent one. Installed evaporators usually have “long throw” air streams (12 to 15 m, or even more), and they are covering large area of the cold store. Also, this has to be taken into account when loading the room in height near the ceiling. Furthermore, free air intake into the evaporator has to be ensured.

The elements of flooded evaporator with bottom-feed liquid equipped with hot-gas defrost are shown in Picture 5. The mixture of liquid and vapor leaving the coil and passing on through suction valve 1 to the liquid/vapor return line. Entrance of liquid refrigerant to the coil is controlled by a solenoid valve 2 that may serve several purposes. It may be connected to a thermostat that closes the valve when the air temperature in the space is satisfied. The liquid supply valve 2 also acts during the defrost cycle. The

---

* University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia
motovic@mas.bg.ac.rs

balancing valve that follows the solenoid valve 2 in the line is set in conjunction with other coils in the system to insure adequate liquid refrigerant supply to all coils.

*Picture 4. – Evaporator with manually forced defrost iced up (or due to wrong timing of automatic defrosting)*

The two valves that figure into the defrost operation are valve 3, the solenoid that controls the entrance of defrost gas (hot gas) into the coil, and valve 4, a pressure-regulating valve that opens or closes as necessary in an attempt to maintain the pressure upstream of the valve. Thus, valve 4 attempts to maintain the coil pressure constant. During refrigeration the refrigerant supply solenoid 2 and the suction valve 1 are open. The defrost gas valve 3 is closed so as the pressure regulator 4. Valve 4 is closed because during refrigeration operation the upstream pressure is low – much lower than the pressure setting of the valve. The regulating valve does what it can to try to increase the upstream pressure, which is to close. During defrost, the liquid supply valve 2 and the suction valve 1 are closed, which isolates the coil from the normal segments of the refrigeration system. The defrost gas valve 3 opens, allowing vapor from the high-pressure receiver or the compressor discharge line to flow first into the tubes of the drain pan (tray) and then into the coil. The tray must be heated during defrost, otherwise water and frost would slide down from the coil as it defrosts, but then refreeze in the tray. At the start of defrosting the pressure-regulating valve 4 is still closed. Defrost gas flows into the coil, bringing up its pressure. Since the coil is cold, the incoming vapor condenses in the coil, and during the defrost process the evaporator coil temporarily acts as a condenser. The pressure in the coil continues to rise until the pressure setting of valve 4 is reached, which is typically about 6.2 bar for ammonia (6.8 bar for freon R 22). These pressure settings correspond to approximately 10°C saturation temperatures of the refrigerants, and represent a high enough temperature to warm the coil and melt the frost from its outside surfaces.

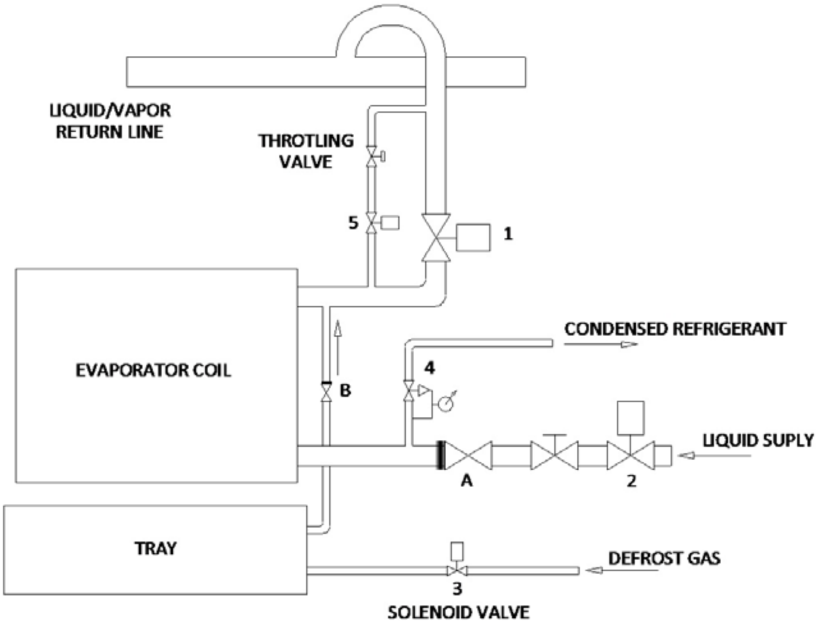
The purpose of check valve A is to prevent high-pressure refrigerant from the coil from backing up through solenoid valve 2 during the defrost process. The pressure in the coil may reach 6.2 to 6.8 bar during defrost and the liquid ahead of valve 2 is only slightly higher than the operating evaporator pressure (0.8 to 1.5 bar). The second check valve, valve B, prevents liquid refrigerant from entering the drain pan during refrigeration operation. If the drain pan became as cold as the coil, it would collect frost which would drop off during the defrost process on product or whatever is beneath the coil and it represents potential danger.

As previously said, the critical nature of the end of defrosting process results when the mixture of liquid and vapor at a pressure of 6 to 7 bar rushes into a low-pressure liquid/vapor return line, perhaps at a pressure below atmospheric (in vacuum). One or both of two phenomena may occur. The high-pressure vapor may drive the liquid in the return line at high velocity to the end of the suction pipe or to an elbow with such force that the pipe ruptures. Other one event may be „condensation shock" [3] wherein the high-temperature vapor condenses so rapidly on the cold liquid and collapses with such force that the resulting shock wave ruptures a pipe. To prevent the extreme stresses at the end of defrost, valve 1 should be

---

* University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia
motovic@mas.bg.ac.rs

equipped with a bypass that slowly drops the pressure in the coil before returning to refrigeration operation. This bypass consists of a solenoid valve 5 in series with a throttling valve, which opens before valve 1 opens to slowly relieve the coil pressure. The throttling valve is set to provide the desired rate of pressure decrease rate. There remains the potential hazard that the bypass line, particularly the throttling valve may become plugged, in which case the bypass does not function. However, many hot-gas defrost processes are managed by a microprocessor-based controller which can sense the pressure in the coil and not open valve 1 until the pressure is low enough to be beyond the danger point. Because valve 1 is usually large, it is often gas-powered, drawing its power pressure from the defrost gas (with a small diameter connecting pipe).



*Picture 5. – Defrost control group of liquid circulation coil equipped with hot-gas defrost*

The defrost process impacts the system beyond the boundaries of the coil itself and its associated defrost piping. For example, many plant operators maintain an artificially high condensing pressure, even when ambient conditions would permit the condensing temperature to drop, to provide sufficiently high defrost gas pressure. Since operating with low condensing pressure saves energy, the maintenance of artificially high condensing temperatures is questioned [4]. Some tests conducted with R 22 in the laboratory and with ammonia in the field [5] indicated that a hot-gas supply pressure of 1 bar above the setting of the pressure-relief valve 4 could still achieve a defrost. Operators would want to be safe and not push this limit, but the values do suggest that some experimentation should be conducted in the plant to determine how low the condensing temperatures can be safely operated.

Because of the frequency of accidents in recent years in industrial refrigeration field that can be attributed to hot-gas defrosts, the recommended procedures are prescribed [6]. The unwanted incidences can occur at the initiation and at the termination of the defrost.

<u>Keep defrost gas mains free of liquid.</u> Even before any defrost steps associated with the coil begin, the condition of the refrigerant in the defrost gas from the machine room to the various coils should be focused on. These lines may run through low-temperature spaces or even above the roof and may be cold at times of the year. The moderately high-pressure defrost gas is likely to continuously condensed, and the resulting liquid can be troublesome when the defrost begins. These pipelines should be equipped with liquid traps (like the float drainers) which continuously separate the liquid from a hot gas feed line.

<u>Pump out the coil.</u> Close the solenoid valve in the liquid refrigerant supply line to the coil. Keep the suction valve open and continue fan operation, which will boil liquid refrigerant out of the coil.

* University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia
motovic@mas.bg.ac.rs

Start defrost. Stop the fan, close the suction valve, and open the valve in the defrost line, preferably in stages. This is one of the crucial moments, because any retained liquid in the defrost lines that has not been purged and liquid remaining the coil after the pump out can be propelled around the coil, resulting in possible damage. Two parallel valves, one small and the other capable of handling the total defrost gas flow, may be controlled so that the small one allows a low flow to build up the pressure in the coil before opening the main valve.

Complete the defrost. Once the defrost is in progress, allow it to continue until all the defrost water has melted and as much as possible drained. Failure to allow the pan to drain adequately will cause a progressive problem with the undrained water freezing in the pan when refrigeration resumes. On the next defrost the thickness of ice increases until it surrounds the lower tubes and possibly crushes them.

Slowly relieve the pressure in the coil. The bypass valve around the main suction valve 1, as shown in Picture 5, is first opened to slowly bleed down the pressure so that high-velocity vapor does not rush into the liquid/vapor return line. A high flow rate of vapor could move the liquid in the line against end caps, elbows or valves. Furthermore, high-temperature vapor contacting cold liquid could cause condensation shock which reverberates throughout the piping. The combination of the bypass and main valves is available in one body with the valve first opening to 10 % of its capacity, and then when the pressure differential has dropped to 1.5 bar the main valve opens.

Open the solenoid in the liquid refrigerant supply line. When this valve is opened, the coil is once again refrigerating, but the fan is not yet started. The reason for the delay is to permit the coil to become cold and freeze droplets of water that cling to the surfaces during defrost. Were the fan started at this time, this water would be blown off the coil and into the space or on product where it would quickly freeze.

Restore fan operation. This final step completes the defrost sequence.

## *CONCLUSION*

As a short conclusion different maintenance strategies for the refrigeration equipment are given:

1. reactive maintenance that means to use all the equipment and run it until some breaks down,
2. time-based preventive maintenance which includes appropriate service intervals, regarding the running time and fixed time intervals,
3. load-based preventive maintenance implies that the amount of service depends on the actual loading time of the components,
4. condition-based predictive maintenance implies condition monitoring (through measurement of temperatures, pressures, vibrations, oil parameters…) with continuous or discreet surveillance of the operating condition of the machinery.

Reactive maintenance is the obsolete method and it is not recommended. However, it is still used, especially in very small cold stores. The major problem is that the actual condition of the equipment is never known and breakdowns tend to occur at the worst possible time, as this is when the system operates under the highest loads.

The most appropriate maintenance strategy for each component depends on the type of the component and its importance. So while reactive maintenance can be the best option for less critical components, preventive or predictive maintenance may be suitable for more critical components. Safety valves are often inspected at fixed time intervals. Traditionally rotating machines like pumps and compressors have also been serviced at regular time intervals.

Non-destructive testing methods, such as vibration, ultrasound or thermographic analysis can be applied to gain better knowledge on the current condition of the equipment, without disrupting its operation. The preferred maintenance strategy will be in the end a choice of the cold store owner.

---

* University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia
motovic@mas.bg.ac.rs

## REFERENCES

/1/ ICEE information pack, Service and Maintenance

/2/ Stoecker, W.F., Industrial Refrigeretion Handbook, McGraw-Hill

/3/ Loyko, L., (1992) Condensation-Induced Hydraulic Shock, Proceedings of 14th Annual Meeting of the International Institute of Ammonia Refrigeration, Washington

/4/ Cole, R.A., (June 1984) Low Head Pressure Operation in Ammonia Systems, Seminary presentation, Annual Meeting of ASHRAE

/5/ Stoecker, W.F., J.J.Lux, and R.J.Kooy, (1983) Energy Considerations in Hot-Gas Defrosting of Industrial Refrigeration Coils, ASHRAE Transactions, 89 (Part II), p. 549–573

/6/ Avoiding Component Failure in Industrial Refrigeration Systems Caused by Abnormal Pressure or Shock, Bulletin No. 116 (1992), International Institute of Ammonia Refrigeration, Washington

/7/ Vujic, S., (1992) Refrigeration devices (in Serbian), Belgrade: Faculty of Mechanical Engineering

/8/ Markoski, M., (2006) Refrigeration devices (in Serbian), Belgrade: Faculty of Mechanical Engineering

/9/ “Soko inzenjering company“ catalogue

---

* University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia
motovic@mas.bg.ac.rs