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REDUCING THE EFFECTS OF ICE ACCUMULATION IN EVAPORATORS USING TRIZ

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Abstract: *Frozen products are heavily consumed by families in cities. Logistical process of these products usually includes their storage in cold rooms. The component of cooling system, responsible for this cooling, is the evaporator. This article aims to evaluate control of ice accumulation process in industrial cold room evaporators, which is a critical factor for higher performance for this component. Using the TRIZ methodology, the problem was diagnosed and classified with the appropriate tools, and solutions were presented for delaying accumulation and also provide quick removing of ice in evaporators. The result is the generation of alternatives for reducing this undesired effect, providing a cooling system with lower energy consumption and increased safety in food products.*

Key words: *Evaporators; Industrial Cold Rooms; Cold chain; Defrost systems; TOP-Triz analysis.*

1. INTRODUCTION

The consumption of frozen products increases proportionally with the development of societies. On the route between food production and the consumer's table, these products frequently pass through large cold rooms, located in distribution centers. The internal temperature of cold rooms is around -20°C. The component of cooling systems, which is responsible for internal air cooling, is the evaporator. Its good performance is crucial for keeping stored products frozen, with the lowest possible energy cost.

One of the critical factors for evaporator performance is the control of ice formation between evaporator fins. Ice formation occurs due to air moisture inside the cold room, usually coming from the outside. This moisture freezes on the surface of the fins. The efficiency of these systems drops considerably when this occurs in excess. Thus, it is always important to consider ice formation process in evaporators as a critical point in cold room design. A refrigeration designer must work on two main points to reduce negative impacts of ice formation on evaporators: delaying ice accumulation during refrigeration process, and controlling the moment when defrost process needs to start (DE AGUIAR et al., 2018).

A good method for detecting ice formation protects cooling systems against evaporator damage, and avoids excessive expenses with a longer than necessary defrost process (MALDONADO et al., 2020).

Ice formation in industrial evaporators is, therefore, an important undesired effect, and its control is a decisive factor in terms of efficiency and safety in cold rooms operation. In this article, we analyze the problem and propose alternative solutions, using the TRIZ methodology.

The remainder of this paper is organized as follows: first, the specific way TRIZ is used is presented (methodology section). Then, problem analysis, problem formulation, and development of conceptual solutions are described.

2. METHODOLOGY

In this paper, the chosen approach to TRIZ is an adaptation of the one proposed by TRIZ Master Zinovy Royzen (ROYZEN, 2009). The steps followed are:

- Problem diagnosis: thorough analysis of the system, problem analysis, previous solutions, and available resources;
- Problem formulation: classification of the type of problem and identification of possible solution alternatives;
- Problem resolution: by applying strategies related to the chosen problem types;
- Evaluation of results.

The summary of this methodology can be seen in **Fig. 1.**

3. RESULTS AND DISCUSSION:

The problem diagnosis, formulation and resolution are described below.

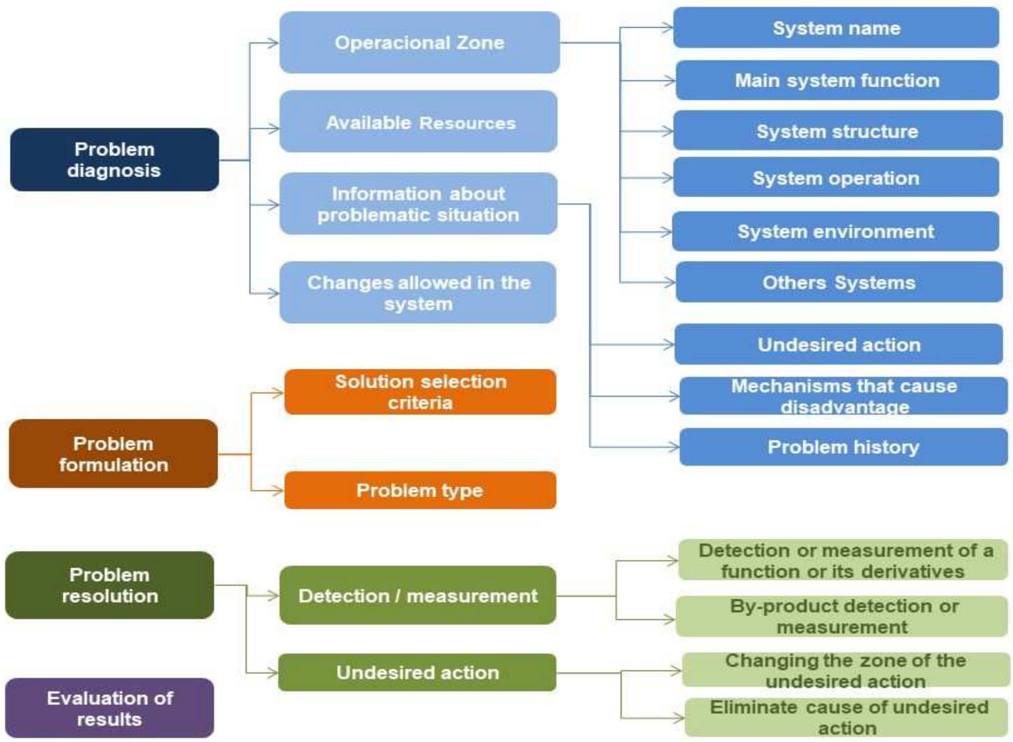

Fig. 1. Methodology

Source: prepared by the authors

3.1 Problem diagnosis

Information about the system (product or process) and the super-system (environment in which it is inserted):

System name: the studied system in this work is a forced air evaporator.

Main system function: the main function of an evaporator is cooling air. This occurs when warmer flow air, accelerated by fans, transfers thermal energy to a cooler surface, that are the evaporator fins. Thus, there is a tool in this system (air), acting on an object (evaporator).

System structure: the main components of the system are shown in **Figure 2**.

- Pipes: usually made of copper or aluminum. Refrigerant fluid circulates inside them. There are two functions for tubes: confine refrigerant fluid in a closed circuit; and receive thermal energy from the fins.
- Fins: metallic plates, physically connected to the tubes, wherefrom they indirectly receive refrigerant fluid thermal energy. Heat transfer occurs when air is forced through spaces between these plates. The greater the contact area between fins and air, the greater the amount of heat transfer. Fins, therefore, increase “heat exchange area”, providing much greater capacity to the equipment. An important design factor is exactly this space between fins on an evaporator, which form

"channels" through which air can flow. The smaller this space, the greater the thermal exchange, but also the quickest the accumulation of ice.

- Fans: positioned in front of the fins. They promote air flow through the "channels" formed between adjacent fins.

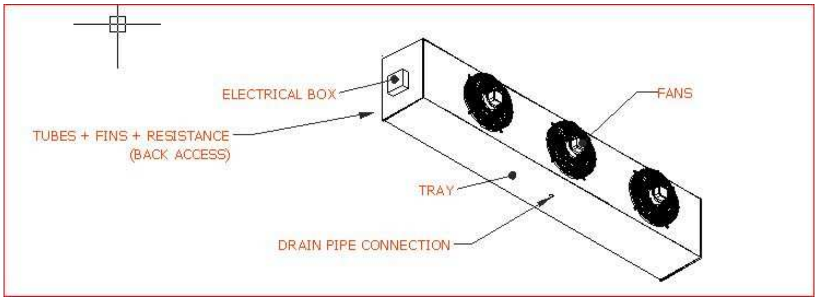

Fig. 2. Evaporator components

Source: prepared by the authors

- Tray: removable piece, positioned at the bottom, which collect water resulted from the defrost process.
- Electrical resistances: used only in frozen rooms, provide ice melting during defrost.
- Electrical box: space where all electrical connections are made.
- Cabinet: protects the assembly against mechanical shocks.

Operational zone: heat transfer inside a cold room follow the path shown in **Fig. 3**. Cooled air is moved by the fans and circulates inside the thermally insulated environment. The frequent door opening and closing and the presence of air leaks in the cold environment promote warmer and wetter external air infiltration, which will eventually flow between the evaporator fins. The moisture present in the external air freezes and settles on the fins.

System environment: the evaporator is part of two main super-systems:

- Cooling super-system, composed by four main components: compressor, condenser, expansion valve and evaporator (**Fig. 4**).
- Cold room super system, which is made by walls and doors, stored products, users (operators, maintenance personnel), internal equipment (lamps, forklifts) (**Fig. 5**).

The evaporator interacts with super-systems, according to the following:

During operation (cooling mode):

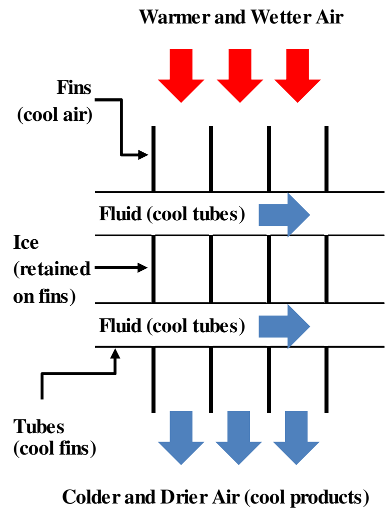

Fig. 3. Operacional Zone: thermal energy path inside evaporator.

Source: prepared by the authors

- Refrigerant fluid circulates among the four main components of the cooling super-system, including evaporator.
- Evaporator is usually fixed under the roof of the cold room, using screws. For bigger and heavier designs, an outside structure is necessary, which supports the component.
- Electrical connections are made through external supply, connected to fans and resistances through electrical boxes.
- Air flows through the channels between the fins, moved by fans.

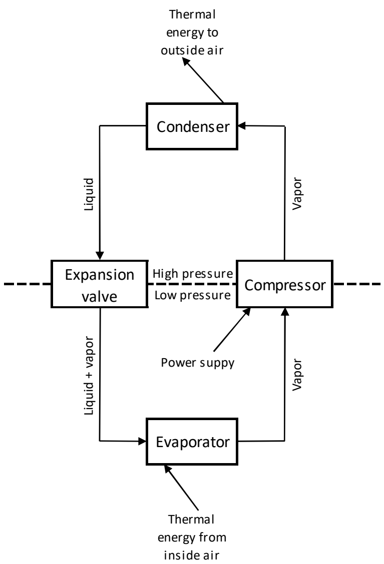

Fig. 4. Cooling Super-system

Source: prepared by the authors

- Air moisture frosts on the fins during the cooling process, forming a layer with increasing thickness over time.

During defrost time:

- With the electrical resistance turned on, water resulting from ice melting flows to the tray and then to the drain pipe.
- During defrost, fans must remain turned off, for keeping hot air from food products. They return to operation only after the refrigeration process has been restarted.

Other systems: the two super-systems discussed, cooling system and cold room system, are greatly affected by the external environment: external air temperature, incidence of sunlight and wind, in case of outdoors cold rooms. The outside air relative humidity is also an important factor in cold room performance.

Available resources: the following resources are potentially available for use in problem solving:

- Substance: evaporator components: copper tubes, aluminum fins, fairing and fan blades, electric fans motors, electrical resistances, doors, air and moisture.
- Energy: kinetic (wind generated by fans); electrical; thermal capacity supplied by cooling system.
- Field: temperature of cooled liquid inside evaporator tubes, gravitational and magnetic by the Earth, and also magnetic field generated by electric motors.
- Space: volume of tubes and fins; space between the fins; space between fins and the fairing and tray; space between fins and fans.
- Time: cooling period and defrost period; doors opening duration and frequency.
- Information: increasing evaporator weight through ice accumulation; quick increasing internal temperature if evaporator is blocked; increasing fans speed if the amount of air passing through them decreases; decreasing fan amperage if the air resistance is lower.
- Function: air cooling during cooling period; ice elimination during defrost period.

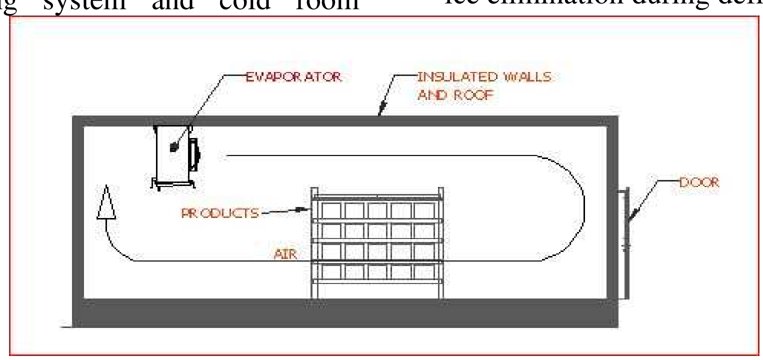

Fig 5. Cooling super-system

Source: prepared by the authors

Information about the problematic situation

Undesired action: as previously mentioned, the main function of an evaporator is cooling the air. But there is water in air, which, when cooled to 0°C or below freezes and settles on the evaporator fins. This process is cumulative, and if no action is taken, results in complete blockage of the spaces between fins. Reduction in air flow also cause decreased heat transfer between fins and air, which affects the internal temperature and consequently stored products quality. In extreme cases, the cooling system becomes ineffective and stored products are lost.

Mechanisms that cause the disadvantage some factors may accelerate the process of ice accumulation in evaporators. In cooling system: colder refrigerant fluid than necessary; in the cold room system: high air moisture, caused mainly by doors open for long time and warmer products than specified.

Problem history: many solutions have already been used for minimizing causes and effects of ice accumulation on evaporators:

- In cooling super-system: use of double space fin. Ice accumulates mainly in air entrance area, in the first stages of air cooling. So fin space may be increased only in this region;
- In the cold room super-system: an anteroom, set with intermediate temperature, may work as a barrier for moisture entry; plastic curtains can also reduce external air entry when doors are opened. Another solution is installing dehumidifiers in the adjacent environments. In this case, when they are opened, only dry air enters the cooled environment.

Changes allowed in the system

The greater spacing between fins, the longer the evaporator can keep working without defrost needs. But this also results in lower capacity. That can be compensated by increasing of evaporator size. But this solution is not desirable, because it increases costs. The double fin technique can be used to solve that. But there is a risk of undesirable compromise solution, when the larger fin space area is too small. That results in a partial loss of capacity, not increasing ice accumulation resistance enough, and also not increasing the useful cooling period.

3.2 Problem formulation

The system is already defined. The objective in this step is classifying the problem.

Solution selection criteria

The solutions options should be able to improve the following system characteristics:

- Increased cooling period, which indicates greater resistance to ice formation on the fins.
- Detection of exact moment when the defrost period should start. It is difficult to set constant defrost periods all the time. There are moments when ice accumulation is faster.

Which is the problem type?

We chose to work with these problem types:

- Detection / measurement: accumulated ice should be detected for removal at the right time, so that the defrosting process does not start earlier or later than necessary.
- Undesired action: the air cooling process produces an undesired effect, which is air moisture freezing;

3.3 Problem Resolution

Conceptual solutions generated through each problem solving path are described below.

Creation of a detection or measurement system

- Eliminate the need for detection or measurement – eliminate the undesired action that creates the need for detection or measurement. Existing solutions for eliminating moisture before the air enters the cold room.
- Eliminate the need for detection or measurement – convert the action requiring measurement into a self-regulatory process. Periodic defrosting.
- Replace measurement by detection. Use an ice sensor in the evaporator.
- Create a measurement system – apply a field to a substance. Use photodetectors – when ice builds, flow of light or other electromagnetic wave is blocked.
- Detection or measurement of a by-product. This can be done in three ways: measurement of weight, which increases with ice buildup; measurement of amperage variation of fan electric motors - air flow decreases with ice closure in the evaporator. Fans work easier with lower air resistance, providing decreased amperage. The third conceptual solution is measuring the internal temperature of the cold room, which increases quickly in case of evaporator blockage. However, this detection is best for the purpose of activating security systems, used in extreme cases.

Decreasing, eliminating or neutralizing an undesired action

- Direct ways - contradict the undesired action. Defrost process provides ice melting, that is the contrary of ice accumulation. Defrost should promote low energy consumption in short periods. When evaporator keep in defrost time, the desired action, which is cooling products, is suspended.

- Direct ways – change the amount of the zone of the harmful action, it duration or both to decrease the harmful action or eliminate it completely. Increase evaporator size.
- Indirect ways – eliminate the cause of the harmful action. Admit only dry air into the cold room, by adding an anteroom, or air dehumidification.
- Indirect ways – eliminate the consequences of a harmful action. Again, the periodic defrosting solution.
- Parallel action – use of two smaller evaporators. One used for cooling and other for defrosting at the same time, avoiding the complete interruption of system operation.

Other solutions were devised, which we are not allowed to report here.

3.4 Evaluation of results

With the use of TRIZ, it was possible to obtain conceptual solutions to address the issue of ice accumulation in cold rooms.

Some of the solutions found are already in use, as the increasing of evaporator size, or the using of two evaporators instead of only one. And others solutions are promising and can lead to innovative future developments.

The combination of these alternatives and others available on market can contribute to build safer and more efficient systems.

4. CONCLUSION

Control and removal of ice formation in evaporators is one of the most important factors for good performance in a cooling system. This article aimed, with the use of TRIZ methodology, to generate alternatives for the problem solution, which can be combined with available products on the market to minimize this undesired effect. The suggestion for future research is development of systems that make these concepts feasible. That is possible by designing of cheaper solutions, for example, than process of air dehumidifying at the entrance of the cold rooms. The great benefit of these solutions is a construction of more efficient cooling systems, with an acceptable degree of ice accumulation on evaporators.

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Reducerea efectului acumulărilor de gheață în evaporatorii cu ajutorul TRIZ

Rezumat: Produsele congelate sunt consumate de familiile din orașe. Procesul logistic al acestor produse include de obicei depozitarea lor în camere frigorifice. Componenta sistemului de răcire, responsabilă de această răcire, este evaporatorul. Acest articol își propune să evalueze controlul procesului de acumulare a gheții în evaporatoarele industriale, care este un factor critic pentru performanțe mai mari pentru această componentă. Folosind metodologia TRIZ, problema a fost diagnosticată și clasificată cu instrumente adecvate și au fost prezentate soluții pentru întârzierea acumulării și, de asemenea, asigură îndepărtarea rapidă a gheții din evaporatoare. Rezultatul este generarea de alternative pentru reducerea acestui efect nedorit, oferind un sistem de răcire cu consum redus de energie și siguranță sporită în produsele alimentare.

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