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Analysis of Non-Optimal Evaporation Process in the Provision Refrigeration System on Board LPG/C Mariner

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Abstract

The provision refrigeration system is essential for preserving food supplies on board vessels during extended voyages. This study analyzes the causes of non-optimal evaporation in the provision refrigeration system on board LPG/C Mariner and proposes corrective measures to restore normal system performance. During the author's sea practice period, the food storage room temperatures deviated significantly from the instruction manual specifications: the meat and fish compartment rose from the required –21°C to –3°C, while the vegetable and lobby storage rose from the normal range of 2–8°C to 17°C. Investigation using a descriptive qualitative approach with problem-solving analysis identified two principal causes. First, the storage room temperature instability was attributed to a damaged expansion valve with a clogged orifice that restricted refrigerant flow to the evaporator, compounded by refrigerant leakage in the circulation system piping that reduced the total refrigerant charge available for heat absorption. Second, the non-optimal evaporation process was caused by a malfunctioning oil separator, in which a blocked lubricating oil return passage and a broken internal spring allowed lubricating oil to enter the refrigerant circulation system. The oil contamination formed ice particles and frost deposits on the evaporator coil pipes, progressively reducing the heat transfer surface area and evaporation efficiency. Corrective measures included replacement of the damaged expansion valve orifice, welding repair of leaking refrigerant pipes, overhaul and component replacement of the oil separator, and application of electric defrosting heater and hot gas defrost systems to remove ice accumulation from the evaporator coils and refrigerant piping.

Keywords: *provision refrigeration, evaporation process, expansion valve, oil separator, defrosting, refrigerant leakage*

I. INTRODUCTION

The provision refrigeration system is one of the critical auxiliary machinery systems on board merchant vessels, responsible for maintaining food supplies at appropriate temperatures throughout the duration of a voyage. Food provisions are categorized into two groups: perishable items such as meat, fish, vegetables, and fruits, which require cold storage at sub-zero or near-zero temperatures; and dry provisions such as eggs, spices, and packaged goods, which require cool storage conditions. Without a properly functioning refrigeration system, perishable food items deteriorate rapidly due to bacterial growth, resulting in significant economic losses and potential health risks to the crew.

The provision refrigeration system operates on the vapor compression refrigeration cycle, which utilizes a refrigerant medium that circulates through four principal components: the compressor, condenser, expansion valve, and evaporator. The refrigerant absorbs heat from the food storage compartments through the evaporator, undergoes compression to a high-pressure high-temperature state in the compressor, releases the absorbed heat to the environment through the condenser, and is then expanded through the expansion valve to return to a low-pressure low-temperature state before re-entering the evaporator. The effectiveness of this cycle depends on the proper functioning of all components and the integrity of the refrigerant circulation system.

During the author's sea practice period on board LPG/C Mariner, an LPG carrier with a gross tonnage of 17,980 tons owned by PT. Kemas Sejahtera Lestari and chartered by Pertamina, several critical problems were observed in the provision refrigeration system. In September 2021, while the vessel was sailing from Tanjung Priok to Tanjung Emas (Semarang), the temperature in the meat and fish storage compartment rose from the specified –21°C to –3°C, and the vegetable and lobby storage temperature increased from the normal range of 2–8°C to 17°C. These temperatures were far outside the acceptable range specified in the Sabroe instruction manual book. Further investigation revealed additional problems including a non-functional dryer allowing moisture into the refrigerant system, a malfunctioning oil separator with blocked oil return passages, refrigerant leakage in the circulation piping discovered in January 2021, and excessive frost accumulation on the evaporator coil pipes.

Based on these operational challenges, this research was conducted to analyze the causes of the storage room temperature deviation and the non-optimal evaporation process, and to propose appropriate corrective and preventive measures. The study addresses two primary research questions: (1) What causes the food storage room temperature to deviate from the instruction manual specifications? (2) How can the refrigerant evaporation process be optimized to restore normal refrigeration performance?

II. LITERATURE REVIEW

A. Provision Refrigeration System Principles

According to Daryanto (2010), a refrigeration machine is a device used in the cooling process by transferring a quantity of heat from one medium to another using an intermediary substance, the refrigerant. Hundy (2016) defines the refrigerator as an auxiliary machinery system that functions to cool food provisions on board vessels. The primary function of the refrigeration system is to absorb unwanted heat from a compartment using a refrigerant medium that circulates within the system, achieving cooling through the phase changes of the refrigerant driven by pressure differentials.

B. Principal Components of the Refrigeration Cycle

The four principal components of the vapor compression refrigeration cycle are the compressor, condenser, expansion valve, and evaporator. The compressor is a mechanical device that provides energy to the refrigerant gas, compressing it from low-pressure vapor to high-pressure vapor and driving the refrigerant through the system. The condenser receives the high-pressure high-temperature refrigerant vapor from the compressor and removes heat through condensation, converting the vapor back to liquid. The expansion valve controls the flow of liquid refrigerant into the evaporator by reducing its pressure through throttling, causing the refrigerant to change into a saturated liquid-vapor mixture at a lower temperature. The evaporator is a heat exchanger that absorbs heat from the storage compartment through its surface, causing the low-pressure liquid refrigerant to evaporate and change into vapor state.

C. Oil Separator and Filter Dryer Functions

The oil separator is an auxiliary component that separates lubricating oil carried by the refrigerant from the compressor discharge. The separated oil is returned to the compressor crankcase through a return passage. If the oil separator malfunctions, lubricating oil enters the refrigerant circulation system, where it can form particles and frost deposits on the evaporator coil surfaces, reducing heat transfer efficiency and evaporation capacity. The filter dryer (dehydrator) removes moisture and solid contaminants from the refrigerant. If the dryer fails, moisture enters the system and can freeze at the expansion valve or within the low-temperature sections of the refrigerant circuit, causing flow restrictions and system instability.

D. Evaporator Types and Defrosting Methods

Evaporators in provision refrigeration systems are classified into dry-type and wet-type configurations. In both types, the refrigerant absorbs heat from the storage compartment through the evaporator coil surface. Over time, moisture from the air inside the storage compartment condenses and freezes on the evaporator coil, forming frost deposits that insulate the coil surface and reduce heat transfer efficiency. Two primary defrosting methods are employed: electric defrosting, which uses heating elements installed near the evaporator coil controlled by an automatic timer to periodically melt the frost; and hot gas defrost, which diverts high-pressure high-temperature refrigerant gas from the compressor discharge directly to the evaporator to melt ice deposits from within the coil.

III. RESEARCH METHODOLOGY

This research was conducted during the sea practice period on board LPG/C Mariner (IMO No. 8917807), an

Indonesian-flagged LPG carrier with a gross tonnage of 17,980 tons, a length overall of 159.0 meters, and a B&W Mitsui 6S50MC (Mark V) main engine. The vessel is owned by PT. Kemas Sejahtera Lestari and chartered by Pertamina, registered in Batam. The study employed a descriptive qualitative approach using the problem-solving method to identify, analyze, and resolve the refrigeration system problems.

A. Data Collection Techniques

Data were collected through three techniques. Direct observation was conducted on the provision refrigeration system during normal operation and malfunction conditions, including monitoring of storage room temperatures, compressor pressure readings, refrigerant level in the receiver sight glass, expansion valve outlet pipe temperatures, and evaporator coil frost conditions. Interviews were conducted with the Second Engineer and the electrician responsible for refrigeration system operation and maintenance on board LPG/C Mariner. Documentation review included the Sabroe provision refrigeration plant instruction manual book, the engine log book, and maintenance records.

B. Data Analysis Method

The collected data were analyzed using descriptive analysis with the problem-solving technique. This method involves systematic identification of the problem symptoms, investigation of root causes through observation and technical analysis, development of alternative corrective measures, evaluation of each alternative based on advantages and disadvantages, and selection of the most effective solution. The analysis was supported by cross-referencing observed parameters against the manufacturer's specified normal operating values in the instruction manual book.

Table 1. Food Storage Room Temperature Comparison

Storage Compartment	Capacity (m³)	Normal Temp. (°C)	Incident Temp. (°C)	Deviation
Meat Room	14.4	–21	–3	+18°C
Fish Room	14.4	–21	–3	+18°C
Vegetable Room	15.7	+2 to +8	+17	+9 to +15°C
Lobby / Dry Prov.	43.0	+8	+20	+12°C

IV. RESULTS AND DISCUSSION

A. Storage Room Temperature Deviation

The investigation into the abnormal food storage room temperatures identified two contributing causes that acted in combination to degrade the refrigeration system's cooling capacity.

First, the expansion valve for the meat and fish storage compartment was found to be malfunctioning. The outlet pipe of the expansion valve was not cold to the touch as expected under normal operating conditions, indicating insufficient refrigerant flow. Upon disassembly and inspection, the orifice inside the expansion valve was found to be clogged with contaminants that had entered the refrigerant system. The blocked orifice restricted the flow of liquid refrigerant into the evaporator, reducing the volume of refrigerant available for heat absorption in the storage compartment. Consequently, the evaporator could not absorb sufficient heat to maintain the required sub-zero temperature, and the compartment temperature rose from –21°C to –3°C. The corrective action involved cleaning the clogged orifice by soaking it in thinner solvent and blowing it with compressed air. In cases where the orifice was irreparably damaged, replacement with a new orifice matching the specification in the instruction manual was performed. Each orifice has a specific pressure rating corresponding to the particular storage compartment it serves, making correct selection critical.

Second, refrigerant leakage was detected in the circulation system piping. The indicators of leakage included a decreasing refrigerant level in the receiver sight glass, abnormal high-pressure (HP) readings at the condenser outlet, and abnormal low-pressure (LP) readings at the compressor suction. Under normal conditions, the HP gauge reads 14.5 kg/cm³ and the LP gauge reads 0.7 kg/cm³, but during the incident these values had dropped to 10.0 kg/cm³ and 0.2 kg/cm³ respectively, and the sight glass level had fallen from 80% to 40%. The reduced refrigerant charge meant that insufficient refrigerant was available to absorb heat in the evaporator, directly contributing to the elevated storage room temperatures. The corrective action involved identifying the leak locations through visual inspection and soap bubble testing, followed by welding repair of the leaking pipe sections. Pipes that were too corroded for repair were replaced with new sections. All repair work was preceded by a pumping-down procedure to collect the remaining refrigerant in the receiver before opening the system.

B. Non-Optimal Refrigerant Evaporation Process

The second major problem, identified in February 2022 while LPG/C Mariner was sailing from Banyuwangi to Makassar, was the non-optimal evaporation of refrigerant in the evaporator coils. The root cause was traced to a malfunctioning oil separator. Upon inspection, the oil separator exhibited two specific failures: the lubricating oil return passage to the compressor crankcase was blocked by accumulated deposits, and an internal spring component had broken and ceased to function. These failures allowed lubricating oil to overflow from the oil separator and enter the refrigerant circulation system.

The presence of lubricating oil in the refrigerant system had several compounding effects on evaporator performance. The oil, together with moisture from a degraded dryer unit, formed particles that deposited on the evaporator coil pipe surfaces. These deposits, combined with the normal moisture condensation from the storage compartment air, created thick layers of ice and frost on the coil surfaces. The frost accumulation progressively insulated the evaporator coils from the surrounding air in the storage compartment, dramatically reducing the effective heat transfer area and the rate of heat absorption. As the frost layer thickened, the evaporation process became increasingly inefficient, and the refrigerant could not absorb sufficient heat to maintain the required storage temperatures. Additionally, the oil and moisture contamination caused freezing within the refrigerant circulation piping downstream of the evaporator, further restricting refrigerant flow and compounding the system performance degradation.

C. Corrective and Preventive Measures

The corrective measures for the oil separator malfunction involved complete disassembly and overhaul of the oil separator unit. The blocked oil return passage was cleaned to restore normal lubricating oil flow back to the compressor crankcase. The broken spring was replaced with a new spare component. All internal components were inspected, cleaned, and reassembled, with any worn components replaced according to the instruction manual specifications. Regular periodic maintenance of the oil separator at intervals corresponding to the engine running hours specified in the manual book was recommended as a preventive measure.

For the frost and ice accumulation on the evaporator coils, two defrosting methods were applied. The electric defrosting heater, installed as part of the provision refrigeration system, was configured using the automatic defrost timer to perform defrost cycles at regular intervals as specified in the instruction manual, typically three to four cycles per 24-hour period with each defrost lasting 12 to 30 minutes. For ice formation within the refrigerant circulation piping downstream of the evaporator, where electric heaters are not installed, the hot gas defrost system was employed. This system utilizes high-pressure high-temperature refrigerant gas from the compressor discharge to push through and melt the frozen refrigerant within the piping. A waiting period of 1.5 to 3 minutes after defrost completion is required before the compressor motor and fan motor resume operation, allowing melt water to drain from the evaporator cabinet.

V. CONCLUSION

Based on the analysis and discussion presented in this study, the following conclusions are drawn regarding the non-optimal evaporation process in the provision refrigeration system on board LPG/C Mariner.

The food storage room temperature deviation from the instruction manual specifications was caused by two interrelated factors: the failure of the expansion valve due to orifice clogging, which restricted refrigerant flow to the evaporator and reduced cooling capacity; and refrigerant leakage in the circulation system piping, which reduced the total refrigerant charge available for heat absorption. Both conditions resulted from inadequate maintenance of the refrigeration system installation. The corrective measures included replacing the damaged expansion valve orifice with the correct specification part and performing welding repair on leaking pipe sections, with pumping-down procedures conducted before all maintenance activities.

The non-optimal refrigerant evaporation process was caused by the malfunction of the oil separator, attributed to a blocked oil return passage and a broken internal spring component resulting from lack of regular maintenance and inspection. The malfunctioning oil separator allowed lubricating oil to enter the refrigerant circulation system, where it combined with moisture to form frost and ice deposits on the evaporator coil surfaces and within the downstream refrigerant piping. These deposits severely reduced the heat transfer efficiency and evaporator performance. The corrective measures included complete overhaul of the oil separator with component replacement, application of automatic electric defrosting on the evaporator coils, and utilization of the hot gas defrost system for ice removal from the circulation piping. Regular periodic maintenance of all refrigeration system components in accordance with the instruction manual running hour schedules, combined with proper defrost timer settings and ensuring that storage compartment doors are not left open, are essential preventive measures to maintain optimal evaporation performance.

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