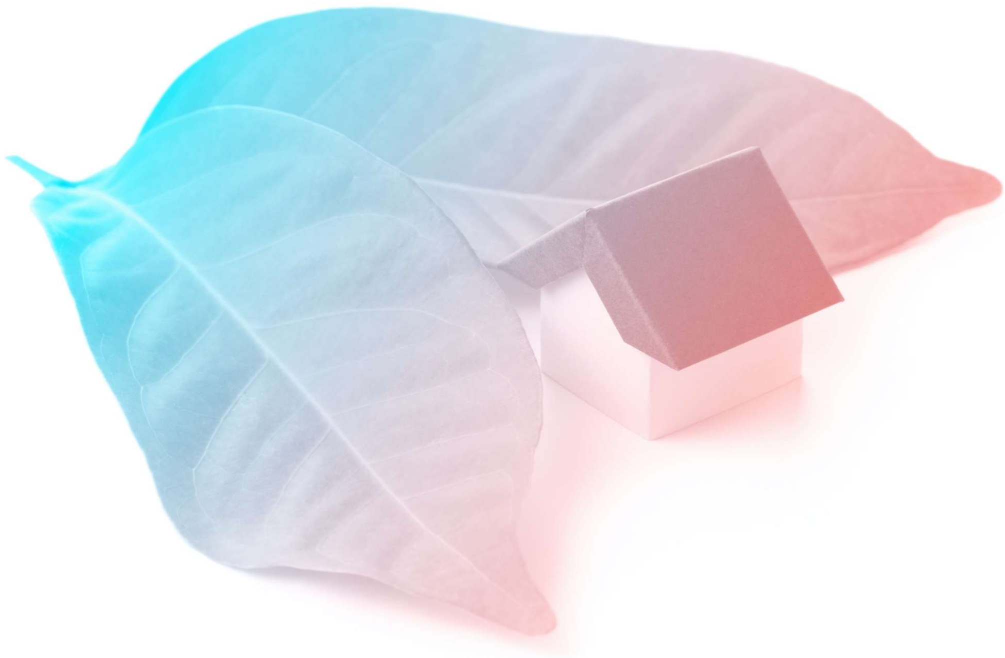
D4.5. Report on manufacture and preliminary test of the TCM unit and PCM units



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D4.5. Report on manufacture and preliminary test of TCM unit and PCM units

Summary			
This report provides a detailed description on the manufacturing process of the prototype for the thermal storage, including the completed assembly of thermochemical material (TCM) reactor, phase change material (PCM) units, heat pump and the ancillary equipment installed in the MiniStor enclosure. Moreover, the factory testing procedure is described, and the results of the tested unit are presented, showing its performance under design conditions.			
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Type of deliverable	R	Report	
Dissemination Level	C	Confidential, only for members of the consortium (including the Commission	
	PU	Public	X

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List of abbreviations

DHW	Domestic hot water
HEMS	Home energy management system
HMI	Human-machine interface
PCM	Phase change material
PID	Piping and instrumentation diagram
PLC	Programmable logic controller
PVT	Photovoltaic thermal
RTU	Remote terminal units
TCM	Thermochemical material
TCP	Transmission control protocol

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1. Development of TCM Reactor for the MiniStor system

This section presents a concise description of the TCM reactor development for the MiniStor project and its integration into the overall system. MiniStor is an innovative thermal storage solution that facilitates sustainable heating, cooling, and energy storage in residential buildings, both newly constructed and retrofitted. The system's thermal storage relies on a thermochemical reaction involving a CaCl2/NH_3 and expanded natural graphite, combined with PCM technology providing additional storage for both sensible and latent heat. For electrical storage, a conventional Li-Ion battery system is employed. MiniStor enables high capacity storage in a compact volume of renewable energy, primarily from PVT systems, and includes a Home Energy Management System (HEMS) to optimize the balance between household energy demand and supply, while adapting to grid limitations and pricing fluctuations.

Within the MiniStor system, the TCM reactor functions alongside an ammonia-based refrigeration cycle through a reversible solid-gas sorption process. The ammonia compressor powers this cycle, and the reactor is housed in a dedicated section of the system for optimal functionality, following compliance with relevant standards, such as EN 378 and the Pressure Equipment Directive (PED) (2014/68/EU).

Figure 1 presents the layout of the MiniStor system, where the TCM reactor is presented within the completed configuration.

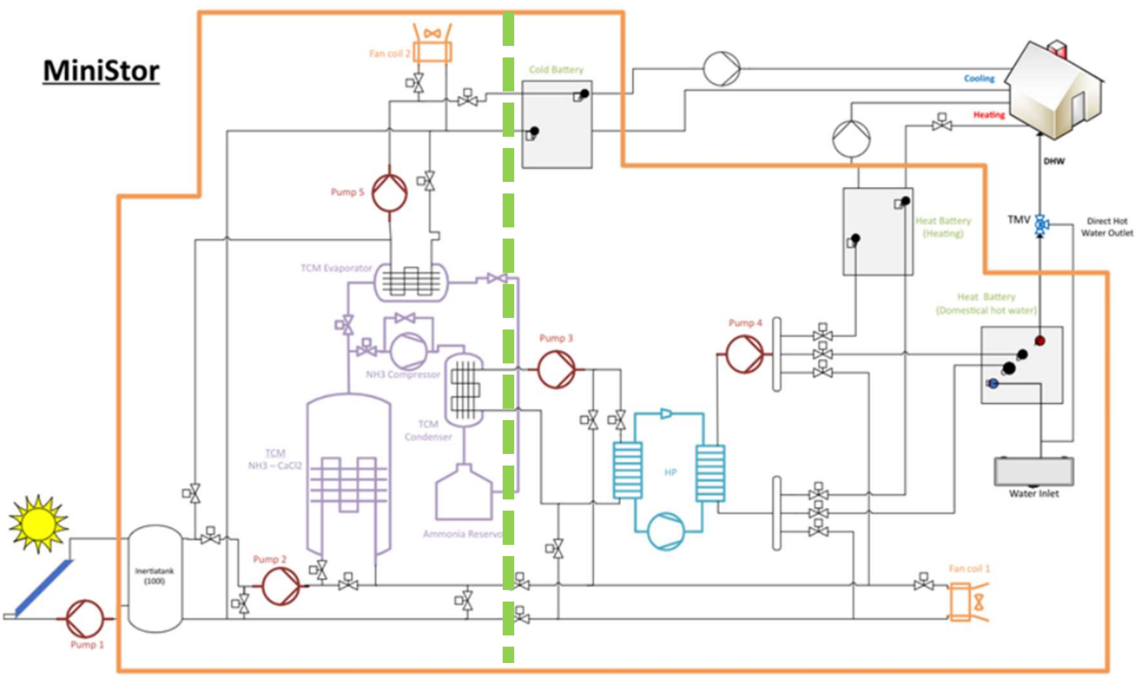

Figure 1. Final schematic thermal layout of MiniStor (source: D3.2 "Design of peripheral thermal equipment") with dashed line indicating schematic location of elements in separated enclosures.

Developed in collaboration with the Coldway Technologies division of Sofrigam and CNRS-PROMES, the TCM reactor was specially engineered for the MiniStor project. It features seven reactor tubes produced utilizing Sofrigam's expertise and differs from standard Coldway systems by employing liquid water as the fluid where heat will be transferred, providing improved performance compared to similar systems and enhancing adaptability for the project's needs for deployment in different heating system scenarios.

The assembly process began at Sofrigam's facilities with the production of the reactive material—a combination of $CaCl_2$ and expanded natural graphite—which was incorporated into the TCM reactor tubes during their construction. After sealing with specialized welding equipment, each tube was carefully tested to detect any leakage.

The reactor components were prepared and assembled, including the fitting of the reactor tubes into the TCM unit, again testing for leakages. None was detected after these tests. This process is presented in Figure 2, while Figure 3 illustrates the TCM assembly and the TCM reactor after the welding and the connection to the test bench, ensuring it was fully prepared for operation. The next steps involved setting up the test bench, filling the TCM reactor with NH_3 for the first time to soak the salt mix, and conducting cycling tests to ensure correct functionality under load. Finally, the completed reactor was evaluated under MiniStor-specific conditions to validate its thermal and operational performance.

Figure 2. Reactor tubes finished and ready to meet TCM reactor.

Figure 3. TCM assembly (left) and the completed TCM (right).

For an effective reaction, the mass of NH_3 inside the TCM after the initial filling should be between 41.515 kg and 45.885 kg. During the measurements, the mass of the empty (no NH_3) TCM was recorded at 259.4 kg, while filled with NH_3, the total mass of the TCM was 304.4 kg. Consequently, the mass of NH_3 absorbed was determined to be 45 kg.

After conducting various tests on the operating conditions of the TCM reactor to confirm its proper functioning during both charging and discharging, the unit was deemed ready for delivery to Greece. Figure 4 illustrates the TCM temperature during charging and discharging. The primary goal of the testing phase was to ensure that the TCM reactor met the required specifications described in D4.1. This involved verifying key parameters such as the mass of the reactive material, the total ammonia required for full charging, and the amount of ammonia cycled during the phase transition from $CaCl_2.8NH_3$ to $CaCl_2.2NH_3$.

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The temperature, the flow and the outlet pressure of the TCM are controlled, and the flow of ammonia is measured.

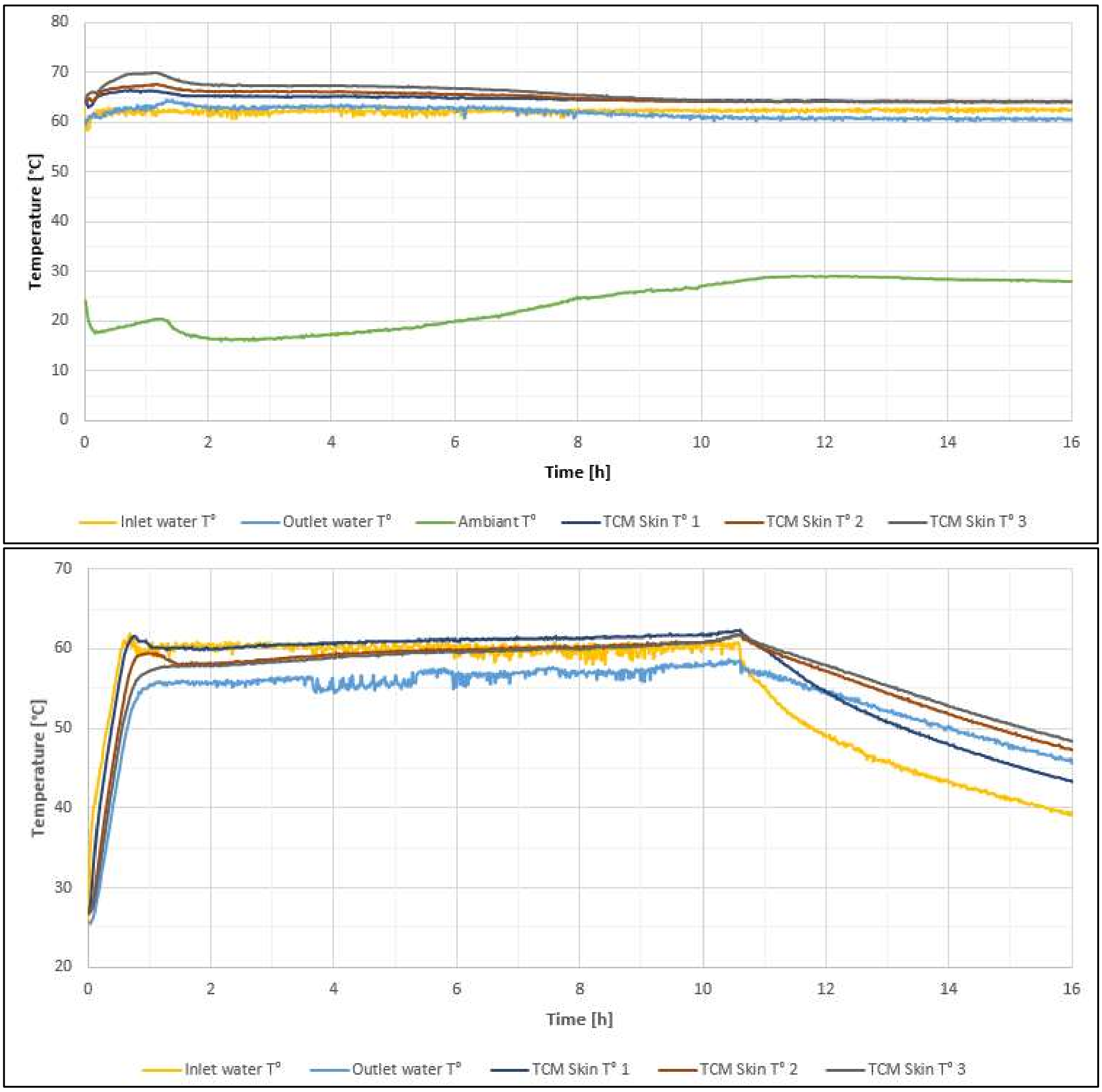

Figure 4. TCM temperatures during charging (up) and discharging (down) for the MiniStor operating conditions.

The main manual valve on the NH_3 circuit had to be replaced after the tests with an automated one prior to shipment. Following this, an insulation jacket was installed around the TCM reactor, and the unit was prepared for shipment to Greece.

The first NH_3 TCM reactor, delivered by Sofrigam, has met the specified requirements as follows:

- Initial NH_3 filling mass: 45 kg
- Cycling NH_3 mass: 32.8 kg
- TCM material mass: 44.16 kg
- Exothermal power during ammonia sorption: 1.88 kW
- Desorption occurs when 2 kW of thermal power is provided to the TCM reactor.

The same procedure and test were repeated for each of the reactors developed in this project (five in total). Certification was applied and provided by the certification body APAVE for compliance with the Pressurised Equipment Directive (PED) (2014/68/EU). The TCM reactor, designed and developed by SOFRIGAM in France, was later transported and integrated with the complete MiniStor system at Psyctotherm's facilities in Greece.

Figure 5. TCM reactor ready to be delivered with insulation jacket installed.

2. Development of enclosure for the TCM reactor, PCM, ancillary and control equipment

To house the TCM and assemble the entire circuit into a reliable, safe system, an enclosure was specifically designed to accommodate all the necessary components and equipment providing a ready to use unit. All parts and materials are designed according to standard EN-378 to meet its requirements regarding ammonia refrigeration systems (e.g. alarm, fire extinguisher, fireproof walls, etc). The enclosure was divided into two sections, with one becoming the machinery room for ammonia components, and the other one for the control unit, heat pump and PCM tanks. Each section is accessible through separated locked doors. Both sections are mounted on a metal base that was constructed with precise dimensions to ensure that components fit securely while allowing for easy transportation to various demo sites. The main structure was built using metal beams, with panels installed around the equipment and on the roof to enclose the system. The metal frame of the enclosure, providing structural support and facilitating transport, is illustrated in Figure 6.

Figure 6. The metal frame of the MiniStor container at the premises of Psyctotherm.

The TCM reactor was successfully integrated into the MiniStor container, where it was hydraulically connected to the appropriate components of the system. As shown in Figure 7 and Figure 8, the reactor was installed during the unit assembly, and the ammonia circuit was designed to function in both charging and discharging modes, enabling the system to provide heating and cooling. The ammonia loop was carefully configured to include essential components such as an NH_3 compressor (responsible for compressing and circulating the refrigerant, paired with an oil separator to remove any excess oil from the ammonia); an NH_3 condenser and evaporator (designed to manage heat exchange processes for both cooling (discharging mode) and heating (charging mode)); an NH_3 separator (installed to divide liquid ammonia from vapor during the cycle, ensuring proper phase distribution); an NH_3 receiver (included to store excess ammonia during the charging and discharging processes), as well as valves for ammonia and oil control. The development of the ammonia circuit involved careful integration of several key components to ensure efficient operation of the TCM reactor. Solenoid valves functioned as expansion valves, controlling the ammonia flow between the high- and low-pressure sides of the circuit. These components were assembled and hydraulically connected with the TCM reactor to create a closed-loop system capable of supporting both heating and cooling functions. An electrical control panel was also installed to manage operation of the unit.

Figure 9 and Figure 10 depict all main components of the circuit, while Figure 14 and Figure 14 illustrate the completed assembly of the Ministor system, including commercial tanks used as solar buffer tank sourced by EndeF. Figure 15 shows the piping that hydraulically connects the water circuit between the TCM reactor and the heat pump, located in the second section of the container. The unit's control system, governed by a PLC, manages the ammonia flow based on the operational mode, with solenoid valves opening and closing as required. The specific characteristics of these valves, integrated into the MiniStor system, were detailed in deliverable D3.3.

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Figure 7. The ammonia circuit during the MiniStor assembly.

Figure 8. The NH_3 compressor, receiver and separator during the MiniStor assembly.

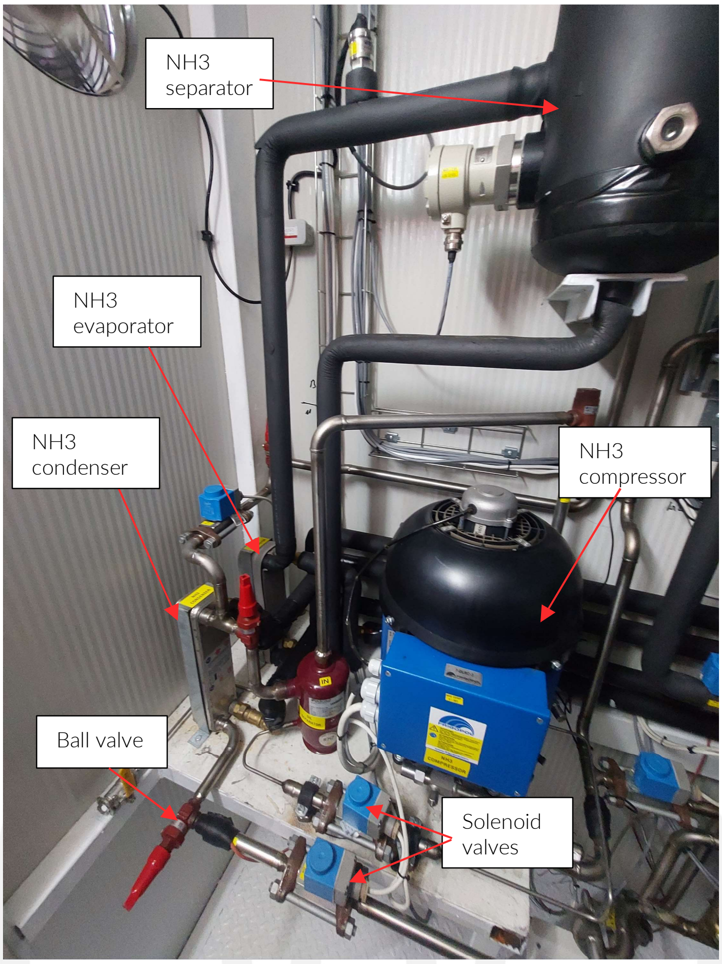

Figure 9. The NH3 circuit presenting the main components.

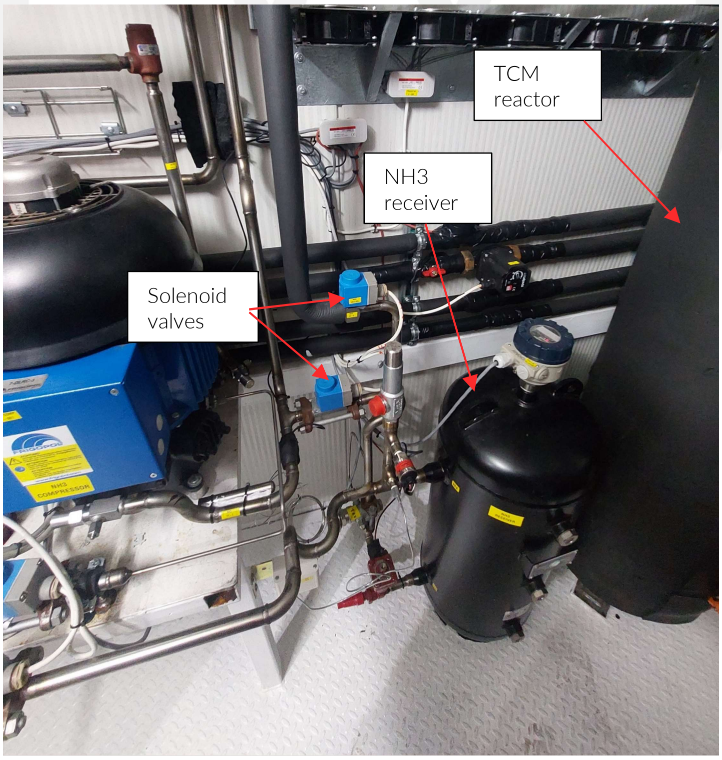

Figure 10. The completed NH3 circuit with the main components.

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Figure 11. Coupling of the NH_3 circuit with the solar buffer tank and the electrical panel under manufacturing.

Figure 12. The TCM reactor with the safety valves completed.

Figure 13. The fully completed MiniStor unit with the integrated TCM reactor.

Figure 14. The TCM reactor integrated with the solar buffer tank circuit.

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Figure 15. Water pumps and piping connecting the TCM with the solar inertia tank and the heat pump side.

Finally, Figure 16 presents the electrical panel of the ammonia circuit, where the inverter of the compressor is placed, alongside the controllers SMP5500/C/S by Eliwell, which are used to receive data from the temperature and pressure sensors, and the NH_3 level transmitter (4-20 mA) to check the ammonia level in the receiver, communicating directly with the PLC of the unit via Modbus RTU.

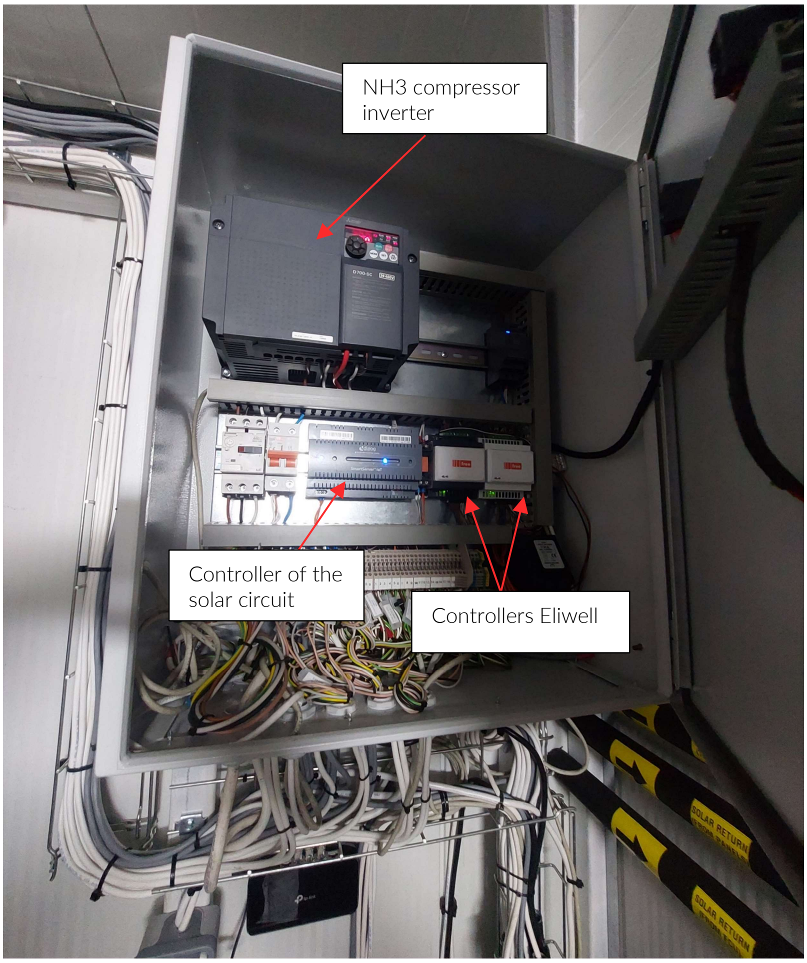

Figure 16. Electrical panel with the control equipment of the NH_3 circuit.

2.1. Ammonia charging and tests to ammonia circuit

The fully assembled unit was charged with ammonia, marking the start of a comprehensive testing phase to evaluate its performance under various operating conditions, including both charging and discharging modes. These tests were crucial for ensuring that the system could handle the dynamic thermal requirements of the MiniStor solution under standalone operation. Figure 17 highlights the unit during this testing phase, where visible frost formation on the piping and ammonia separator can be observed, a common phenomenon when handling refrigerants like ammonia, indicating proper cooling cycle functioning. This frost formed due to the low temperatures in the system before the final insulation was applied to the NH_3 piping and ancillary components.

Throughout the testing process, the system's components were carefully monitored to ensure optimal performance and identify any potential areas requiring adjustment or fine-tuning. Multiple operational modes were tested, with a focus on evaluating the efficiency of the ammonia refrigeration loop and the TCM reactor's ability to store and release thermal energy. Once the tests were successfully completed and no further modifications to the circuit were necessary, a 2.2 cm layer of insulation was applied to the entire piping network of the refrigeration loop. This insulation plays a vital role in minimizing heat loss, enhancing the system's overall efficiency, and ensuring long-term, reliable operation. With the insulation in place, the unit was finalized and deemed ready for deployment at the designated demo sites.

Figure 17. NH_3 circuit's components during testing.

2.2. Integration of heat pump and phase change material for interface with existing heating and DHW system

This section outlines the manufacturing process of the heat pump unit, which is combined with the TCM/ammonia loop and integrated with a PCM to keep thermal energy generated by the heat storage before its interaction with the existing heating, cooling and DHW based on the building's needs. The hot and cold PCM batteries were produced by a commercial vendor and delivered to Psyctotherm for integration into the complete MiniStor enclosure to meet the system's operational requirements. This deliverable focuses on the integration process of the PCM vessels into the overall system assembly.

The unit incorporates three PCM vessels, utilizing two distinct types of phase change materials (PCMs). The hot PCM was selected for its high power and energy density, providing an optimal temperature for space heating and domestic hot water. The cold PCM was chosen for its favourable energy density and excellent material compatibility with various metals and plastics, making it suitable for efficient thermal storage and transfer.

The fully tested PCM vessels were transported to Psyctotherm's facility in Piraeus (Greece), where they were carefully integrated with the heat pump system to enable efficient storage and supply of heating, cooling, and domestic hot water. This integration plays a crucial role in the MiniStor unit's ability to adapt to varying thermal demands of a building. During the charging process, water heated by the ammonia circuit flows to the heat pump's evaporator, where a well-used refrigerant (R134a) undergoes phase change into vapor. The vaporized R134a is then compressed and directed to the condenser, where the generated heat is transferred to the selected PCM vessel. This heat is then stored for future use in space heating or domestic hot water applications.

The heat pump was strategically installed in a separate section of the MiniStor container to ensure safety by avoiding co-location with the ammonia circuit, as presented in Figure 18. This segregation is essential to prevent potential safety hazards associated with ammonia handling, as it minimizes the risk of accidental leaks or exposure within the same enclosed space. By placing the heat pump in a different section of the container, the system adheres to safety protocols while still maintaining operational efficiency.

The installation process involved carefully planning the layout to ensure optimal integration with the rest of the system, including the TCM reactor, PCM storage, and control systems. The separation also allowed easier access and maintenance of both the heat pump and ammonia circuit, reducing the complexity of the overall design while enhancing safety and functionality.

Figure 18. Placement of the PCM vessels on the metal frame of the container.

The integration of the heat pump and PCM vessels are illustrated in the following Figures, including the integration of piping, electrical connections, and safety features that ensure the smooth operation of the unit. Figure 19 and Figure 20 showcase placement of the PCM vessels on the designated base, specifically constructed within the container to support the vessels while maintaining optimal system performance securely. Additionally, the figures illustrate the metal frame that supports both the compressor and the heat exchangers, which are integral for heat pump functionality. Figure 21 provides a closer look at the heat pump compressor, manufactured by Dorin, emphasizing the precision and quality of the components chosen for the MiniStor system. This carefully planned arrangement ensures that all components are securely housed, well-integrated, and aligned with the system's overall design for maximum safety and performance.

All the enclosures developed in the context of the MiniStor project shared the same dimensions, except for the one designated for the Cork demo site. Due to specific shipping requirements that involve a sea crossing, the Cork container had to adhere to particular height constraints, resulting in a variation of its dimensions. This height change necessitated a slight adjustment in the placement of the PCM vessels within the container, from stacked to distributed. As a result, the entire arrangement of components had to be modified to ensure everything fit properly. This adjustment involved careful reorganization to maintain the system's functionality and ensure all components were securely integrated.

Figure 19. Placement of the PCM vessels on the metal frame of the container for all demo sites except Cork.

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Figure 20. The PCM vessels and the heat pump circuit during manufacturing.

Figure 21. Dorin compressor for R134a used for the heat pump.

Figure 22. Manufacturing of the fan coil for the Ministor system.

Figure 23. The heat pump and PCM vessels of the Ministor system for all demo sites except Cork.

Figure 24 and Figure 25 illustrate the main components of the heat pump within the MiniStor enclsoure for the Cork demo site. The key difference between these figures and Figure 23, which shows the PCM vessel arrangement for the other four pilot cases, lies in the height constraints specific to the Cork container. These constraints required adjustments in the internal layout, leading to a variation in the placement of the PCM vessels and overall component arrangement to accommodate the different enclosure dimensions.

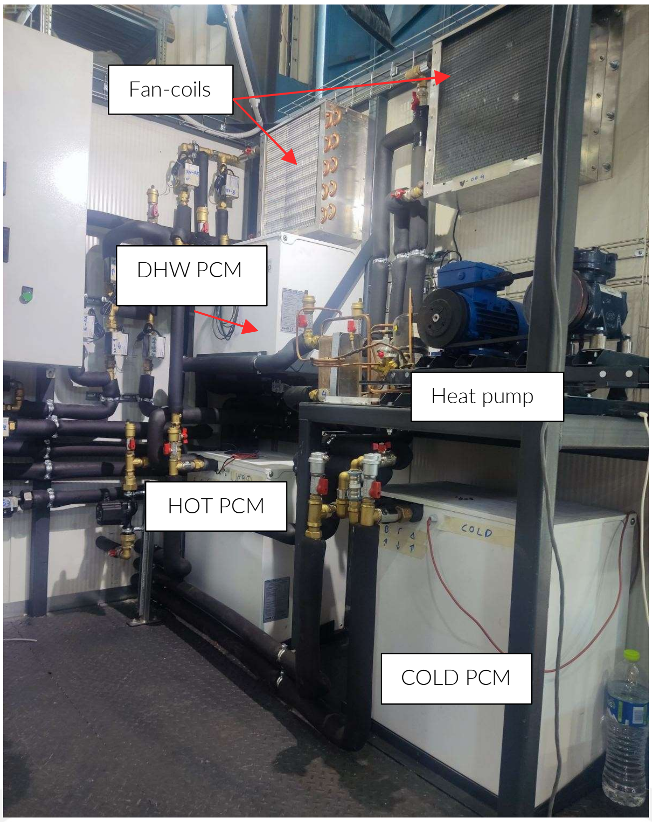

Figure 24. Specific PCM, heat pump and fan coils arrangement for MiniStor in Cork.

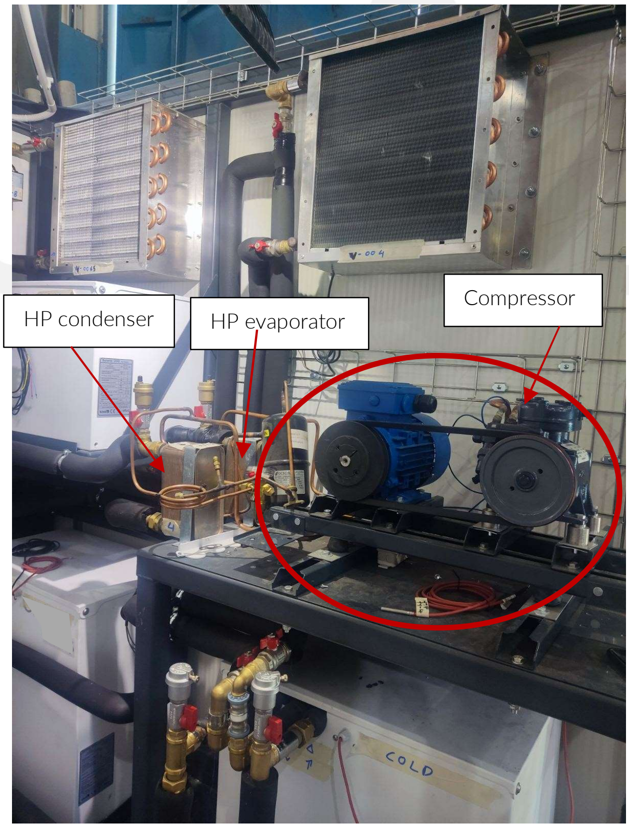

Figure 25. Main components of the heat pump (HP).

The HEMS control system by CARTIF controls how the PCM vessels integrate with the system and with the existing heating or DHW circuit. It intelligently selects the appropriate vessel based on the building's real-time thermal needs. The PCM vessels are designed to optimize the system's energy flexibility by separating the heat output.

Additionally, Psyctotherm manufactured and integrated a fan coil into the system, allowing excess heat dissipation from the stored hot water when required. This fan coil is essential in maintaining system balance, especially during periods of reduced thermal demand, and ensures that the unit can operate without overheating while providing heating and cooling as needed. This integrated setup maximizes energy efficiency and ensures the system is versatile enough to meet the diverse heating and cooling needs of different building environments.

2.3. Electronic and electrical controls

Figure 26 shows the fully cabled electrical cabinet that includes the PLC and controls for the heat pump. The PLC communicates with Cartif's control system via Modbus TCP. At the main panel, the PLC (model FX5U-32MR/ES by Mitsubishi) is positioned at the top, with the sensor cards below it. On the lower left, we have the inverter for the heat pump compressor, and next to it, various fuses for circulation pumps, etc. Below that, there is a relay. The PLC system is equipped with several key components to facilitate efficient data processing and control within the MiniStor project. Specifically, it includes one FX5-8AD module and two FX5-4AD-PT-ADP modules, which are responsible for the analog-to-digital conversion of sensor signals, allowing for precise monitoring of various parameters such as temperature and pressure.

Additionally, the PLC features one FX5-16EYR/ES module, which is utilized for digital output signals, enabling the activation of relays and other control elements within the system. This configuration ensures seamless integration and effective communication between the sensors and control units, enhancing the overall functionality and responsiveness of the MiniStor system.

Figure 27 presents the screen of the PLC used to monitor the MiniStor operation.

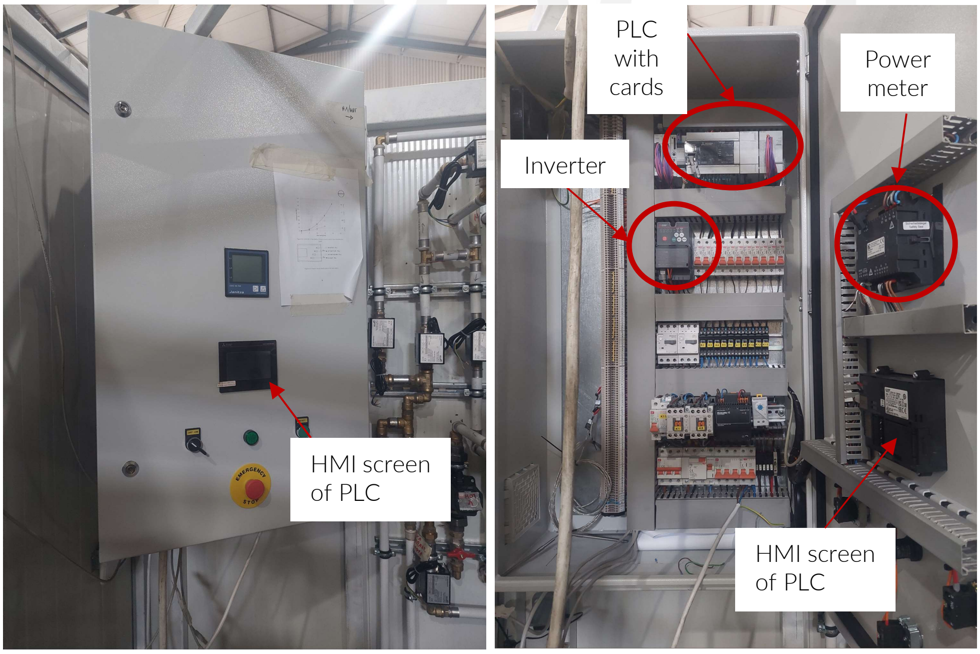

Figure 26. Electrical panel of the heat pump, including the PLC of the MiniStor.

Figure 27. PLC screen for MiniStor.

3. Preliminary testing of the unit

The MiniStor prototype was tested under various operating conditions to evaluate its robustness and ensure proper functionality before delivery, given the complexity of its design. Throughout the testing process, several malfunctions were identified and corrected, while certain measuring equipment was replaced with more suitable alternatives to ensure accurate data collection. The testing focused on both the charging and discharging modes of the system, and the final results confirmed the system's expected performance and reliability under diverse conditions, highlighting the necessary adjustments for optimal operation.

Testing of the MiniStor system was conducted in accordance with the control strategy developed for the PLC program. This strategy encompassed various parameters, including temperature, pressure, and flow rates, to optimize the performance of the whole system and set the appropriate alarms. A series of tests were performed to validate the functionality of the integrated system, confirming that it operates within the designed specifications. To provide a visual overview of this process, several photos are presented, illustrating snapshots of the developed control algorithm within the PLC program.

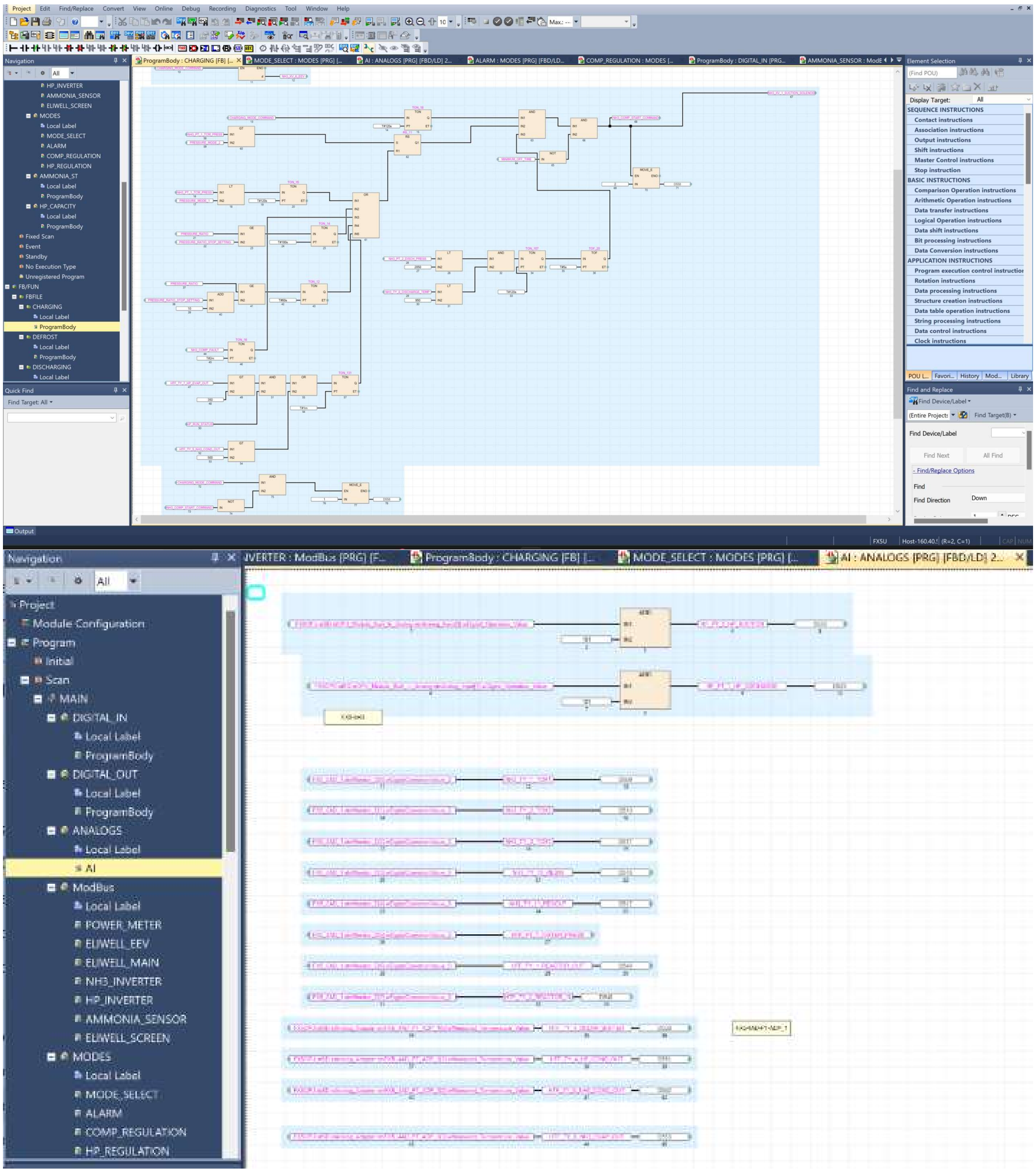

Figure 28. Screenshots of the developed PLC program.

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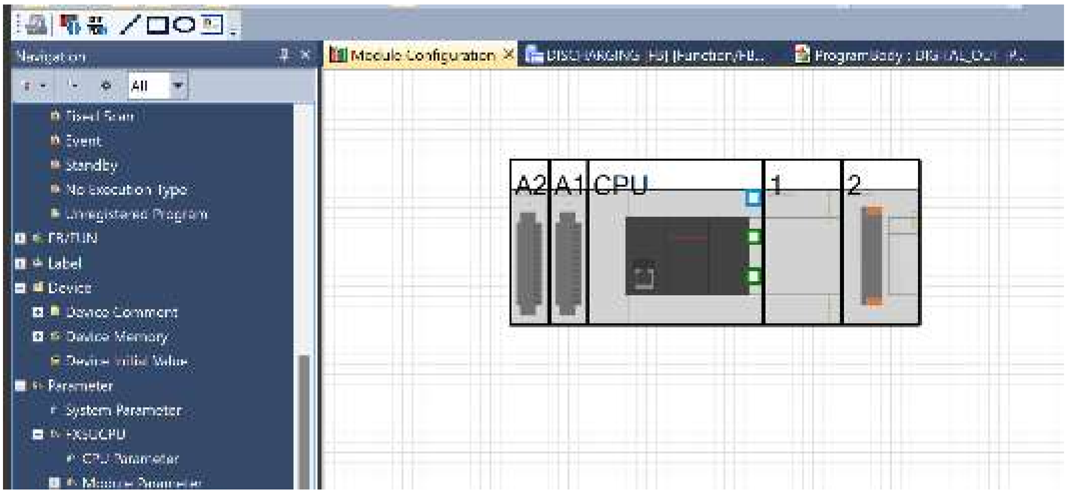

Figure 29. Screenshot of the developed PLC program showing the final version of PLC with cards.

3.1. Ammonia filling process

Before the initial startup and execution of the first charge-discharge cycles, approximately 10 litres of ammonia are introduced into the system through the filling valve located at the TCM reactor outlet. To begin the filling process, the manual ball valve at the reactor's outlet is closed, and an external NH_3 storage tank is connected to the filling valve. Ammonia from the storage tank is then evaporated, condensed via the system's NH_3 condenser and evaporator, and transferred to the liquid receiver. The procedure follows these steps, with the component designations being those of the piping and instrumentation diagram (PID) illustrated in Figure 30:

1. Pump P-003 and fan coil V-004 are activated to circulate water between the NH_3 evaporator and the fan coil.
2. The solenoid valves HTF-XV-12, HTF-XV-10, and HTF-XV-11 are activated, along with pumps P-007 and P-005, to circulate water through the NH_3 condenser, heat pump evaporator, and heat pump condenser with PCM tanks.
3. Heat pump operation is turned on to cool the NH_3 condenser.
4. The manual filling valve is opened.
5. In the ammonia circuit, NH_3-XV-2, NH_3-XV-1, NH_3-XV-5, and NH_3-XV-6 are opened.

Once the liquid receiver reaches the required ammonia level, the filling process is reversed, and the TCM reactor's manual valve is then opened. Initial tests conducted at Psyctotherm's facilities examined both charging and discharging modes to assess system performance across cycles and fine-tune the control algorithm for optimal operation.

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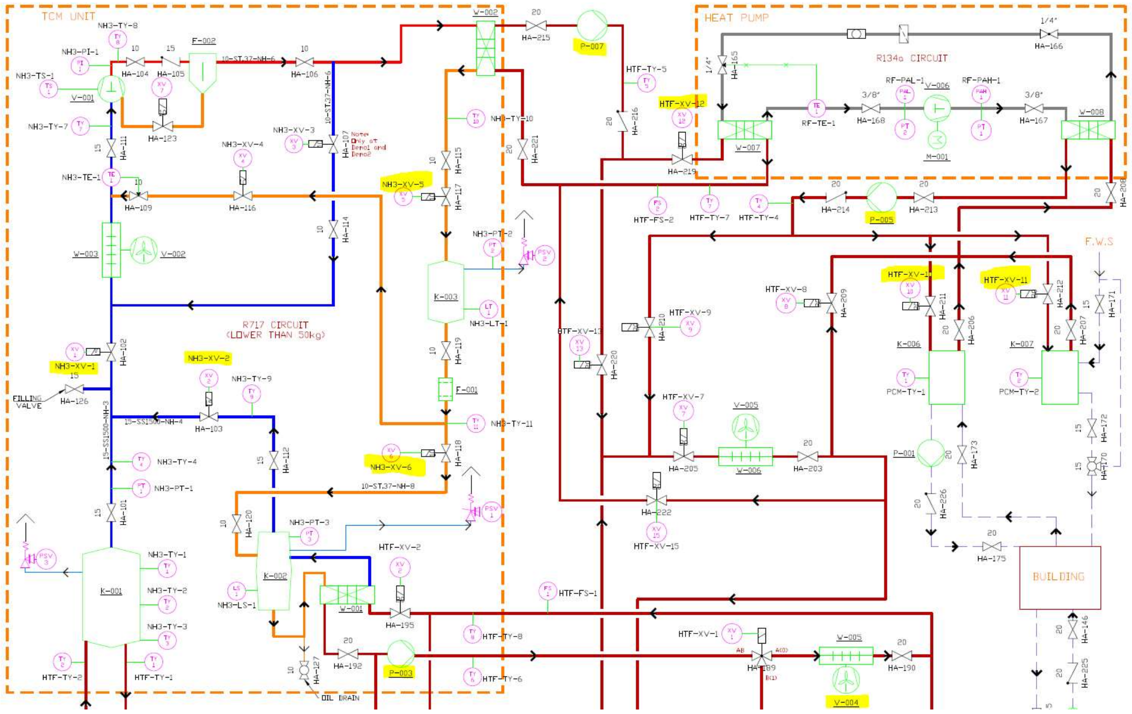

Figure 30. P&ID Highlighting Components (Yellow) for the Filling Process.

3.2. Charging mode (of the liquid receiver)

During the test charging mode, the TCM reactor, where a reversible reaction occurs between calcium chloride and ammonia, is connected to a hot water storage tank. This tank, heated by a gas boiler to simulate solar thermal energy, supplies hot water to the TCM reactor to initiate the charging process.

The process begins by pressurizing the TCM reactor to a minimum target pressure of 2 bar. In this phase, heat is transferred from the hot water tank to the reactor, with all ammonia circuit valves remaining closed. Once the reactor pressure stabilizes, the charging process initiates, activating the necessary pilot unit subsystems. The sequence of operations is outlined below, with the component names being those of the PID diagram:

1. Initiating Water Circulation:
    - Activate solenoid valves (HTF-XV-12, HTF-XV-7, HTF-XV-8, HTF-XV-9) to allow water circulation through the evaporator and condenser of the heat pump.
2. Heat Transfer to the Evaporator and Condenser:
    - Activate water pumps (P-007, P-008) and the fan coil (V-005) to transfer heat from the ammonia condenser to the heat pump evaporator, and then to the condenser of the heat pump, dissipating heat to the ambient environment.
3. Heat Pump Activation:
    - Once the flow switches at the evaporator and condenser are energized, start the heat pump and allow it to stabilize. The compressor speed is adjusted via a PID control loop, based on the cooling demand of the ammonia circuit, with a temperature setpoint at the evaporator outlet.

4. Ammonia Circulation:
   - Open valves NH3-XV-1 and NH3-XV-5 to direct ammonia vapor from the TCM reactor to the compressor, then to the ammonia condenser, and finally to the liquid receiver.
5. Gas Cooler Fan Operation:
   - Activate the gas cooler fan (V-002) when high-temperature ammonia (> 60°C discharge temperature) is supplied to the compressor. The fan operation is modulated based on temperature feedback.
6. Compressor Activation and Pressure Control:
   - Engage the ammonia compressor if the pressure differential between the suction and discharge lines is sufficient (pressure ratio > 5). The compressor speed is dynamically adjusted via a PID controller that maintains the desired pressure ratio.
7. Superheat Management:
   - If the superheat at the compressor suction exceeds 15°C, activate the injection solenoid (NH3-XV-4) to inject refrigerant and lower the superheat.

The charging mode concludes once the liquid receiver is fully charged.

Figure 31 to Figure 37 present the system's behaviour across a complete 9-hour charging cycle. In Figure 31, the reactor, discharge, and evaporator pressures are plotted throughout the process. The evaporator pressure remains constant since the valves in this section of the system stay closed. Between minute 0 and minute 50, reactor pressure rises due to heating, which accelerates the ammonia vapor reaction. This heating also drives an increase in compressor discharge pressure, as the compressor runs at full speed during this period.

In the first two hours, the system reaches a peak discharge pressure of approximately 17 bar, primarily due to elevated suction pressures (around 4 bar) and rapid ammonia vapor production at a high volumetric rate due to the intensified reaction within the TCM reactor. After this initial phase, the ammonia reaction rate begins to slow, causing the reactor pressure to gradually decrease. Consequently, the discharge pressure also falls, eventually stabilizing around 8 bar after four hours of operation.

During the charging phase, the compressor engages in on-off cycles based on the acceptable pressure ratio. These cycles create fluctuations in both reactor and discharge pressures. For instance, between minutes 150 and 180, the compressor is off, which allows the ammonia reaction to increase the suction pressure while discharge pressure remains nearly constant. When the compressor restarts at minute 180, the suction pressure drops sharply as the system resumes operation.

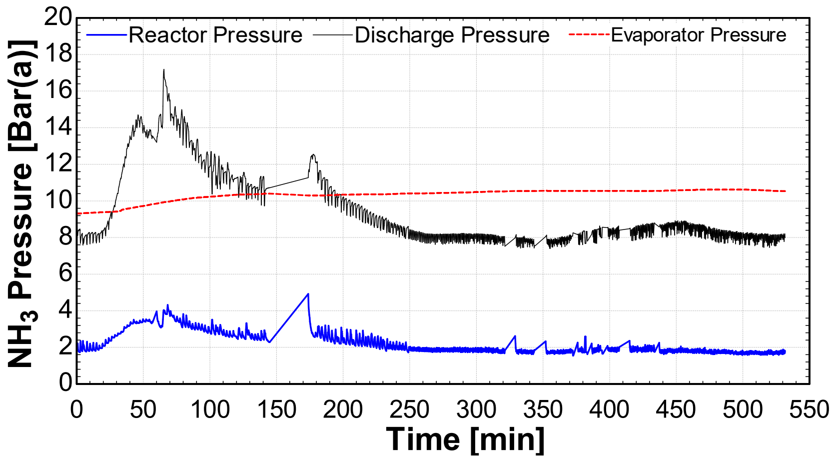

Figure 31. TCM reactor, evaporator and discharge pressure of the NH3 during the charging phase.

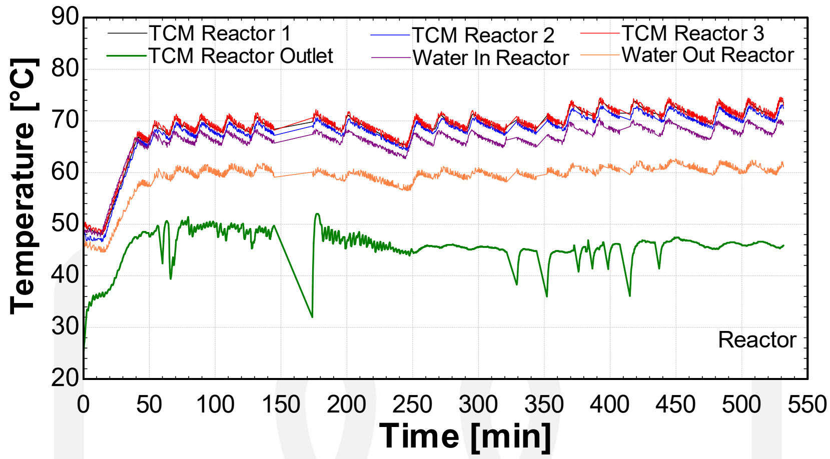

Figure 32. Ammonia and water temperature at the TCM reactor during charging phase.

Figure 34 illustrates the temperature profiles within the TCM reactor, the ammonia temperature at the outlet and the inlet-outlet water temperatures at the TCM reactor. From minute 0 to 50, the TCM reactor is gradually heated to 70°C, after which the temperature is maintained within the range of 65-70°C. Reaching and sustaining a temperature above 60°C is critical for ensuring the compressor operates within an acceptable compression ratio. The diagram also shows that the temperature difference between the inlet and outlet water at the TCM reactor remains between 5-8°C throughout the process. During compressor operation, the ammonia suction temperature stabilizes between 45-50°C. However, when the compressor is turned off, the ammonia temperature at the TCM outlet decreases due to the pressure variations.

Analysing the inlet and outlet temperatures of both water and ammonia at the NH_3 condenser reveals key patterns in system behaviour. Figure 33 presents the ammonia vapor inlet temperature at the condenser peaks close to 70°C during the initial hour, when the system operates under high pressure, and the compressor runs at full capacity. As this period concludes, a gradual decline in ammonia discharge temperature (condenser inlet) occurs, reflecting a corresponding drop in system pressure. This decrease continues throughout the charging process, with a steady reduction in ammonia suction temperature, which also helps to lower the discharge temperature, effectively maintaining the desired pressure ratio.

The diagram also highlights the moments when the NH_3 compressor is offline, evidenced by a significant drop in the condenser inlet temperature. Additionally, the temperature difference between the inlet and outlet ammonia at the condenser ranges between 10-30°C. On the water side, the temperature difference is around 5°C when the condenser is operating at a higher capacity (due to a faster ammonia reaction). However, as the charging speed slows, this difference narrows, reaching as little as 1°C.

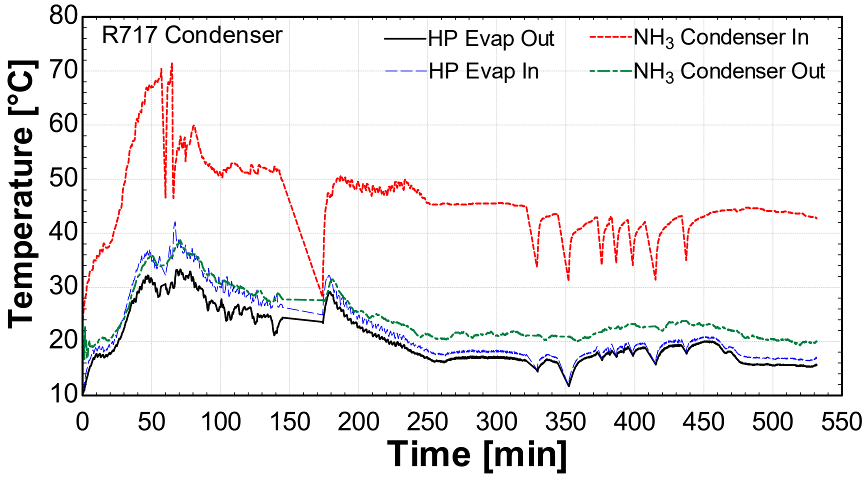

Figure 33. Inlet – outlet temperature of water and Ammonia at the condenser during the charging phase.

On the evaporator side of the ammonia circuit, as shown in Figure 34, the valves remain closed, resulting to zero water flow and no operation of this part. As a result, the temperatures of both the water and ammonia equalize over time. Additionally, the temperature sensor located at the ammonia inlet to the evaporator is influenced by the proximity to the injection line during the charging mode. This causes fluctuations in the temperature profile,

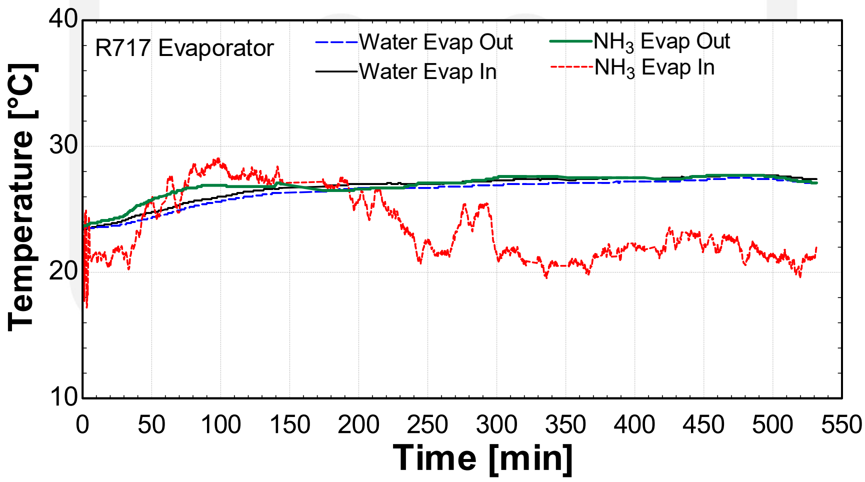

Figure 34. Inlet – outlet temperature of water and Ammonia at the evaporator during the charging phase.

Examining the ammonia inlet and outlet temperatures at the compressor, Figure 35(a) reveals that the suction temperature aligns closely with the TCM reactor outlet temperature (as also shown in Figure 33), though it is approximately 15-20°C lower. This temperature reduction is primarily a result of the cooling provided by the gas cooler, which benefits system operation by keeping the discharge temperature and pressure ratio within optimal ranges.

The discharge temperature trends are consistent with those observed in Figure 33, given that both the compressor discharge and condenser inlet readings are taken from the same temperature sensor. In Figure 35 (b), the evaporating and condensing temperatures of ammonia are derived from the suction and discharge pressures. The suction line superheat is noted to be around 50 K, as the evaporating temperature of NH_3 varies between -20°C and -10°C based on the measured pressures. On the discharge side, the calculated condensation temperature of NH_3 falls between 20°C and 30°C, aligning with the ammonia temperature at the condenser outlet. This correlation between the calculated and observed temperatures confirms consistent performance throughout the system.

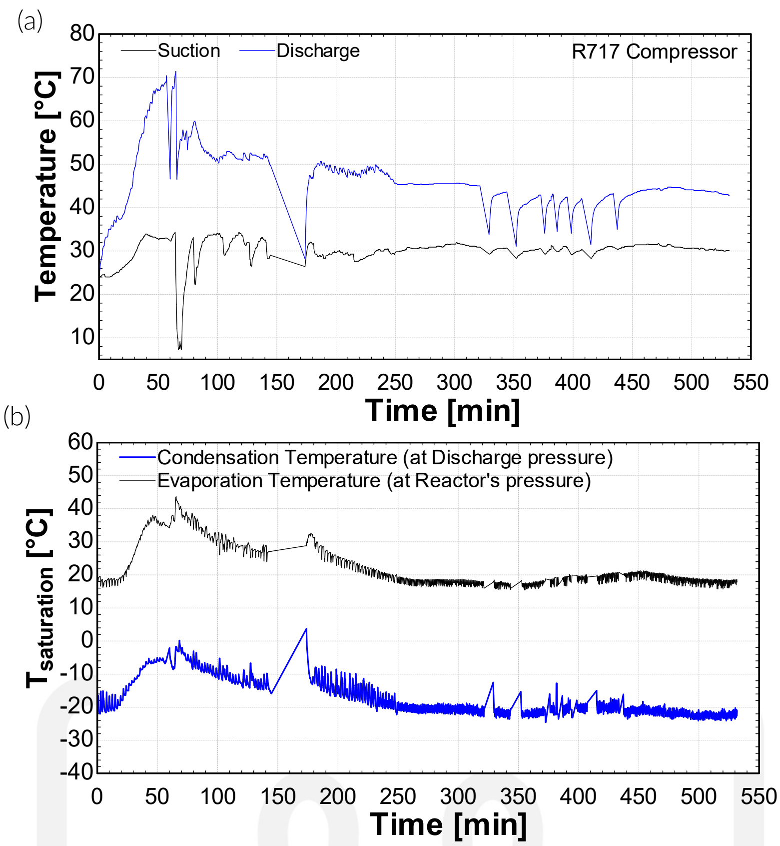

Figure 35. (a) Suction and discharge temperature of the Ammonia compressor during the charging phase. (b) Evaporating and condensing temperature of ammonia during the charging phase.

Figure 36 shows the ammonia temperatures at the inlet and outlet of the liquid receiver. The inlet temperature matches the condenser outlet temperature, fluctuating according to changes in discharge pressure and operating temperature. The outlet temperature of the receiver, on the other hand, reflects the temperature of the receiver tank itself, as the section after the liquid receiver is inactive during charging (with valve NH3-XV-6 closed).

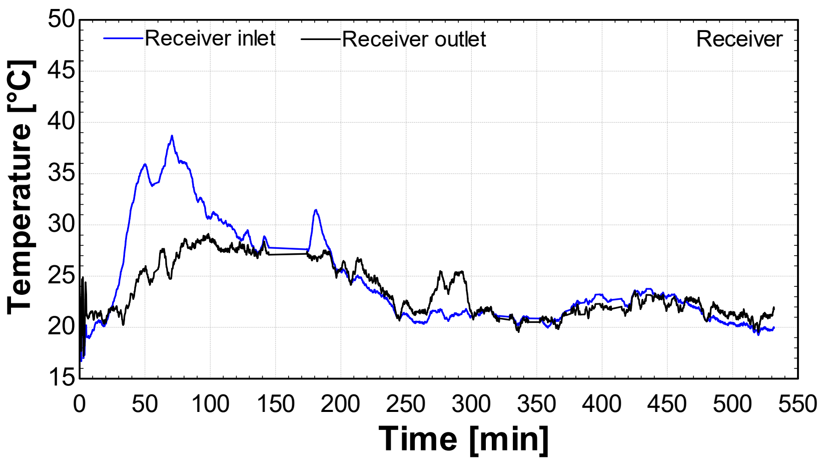

Figure 36. Ammonia temperature at the inlet – outlet of the liquid receiver during charging phase.

Figure 37 depicts the ammonia liquid level throughout the charging process, starting at approximately 4% at minute 0 and reaching around 90% after 9 hours. During the initial phase (0-150 minutes), the charging rate is notably high, reflected in the steep incline of the curve. This rapid rate is due to both the accelerated decomposition of salt in the early stages and the higher speed of the ammonia compressor, which increases the rate of ammonia condensation. As the charging progresses, the rate decreases gradually between 200 and 550 minutes, reflecting the stabilization of reaction rates and compressor operation. Notably, at around 150 minutes, the liquid level sensor transmitter was recalibrated to improve accuracy. This recalibration introduces a sudden shift in the recorded liquid level, with the corrected trend indicated by a red dotted line, ensuring more reliable measurements for the remaining charging duration. The red line in the graph illustrates the trend of the charging phase, represented as a ramp variation. In the initial experiments, the ammonia sensor was still undergoing calibration, leading to a different charging variation pattern.

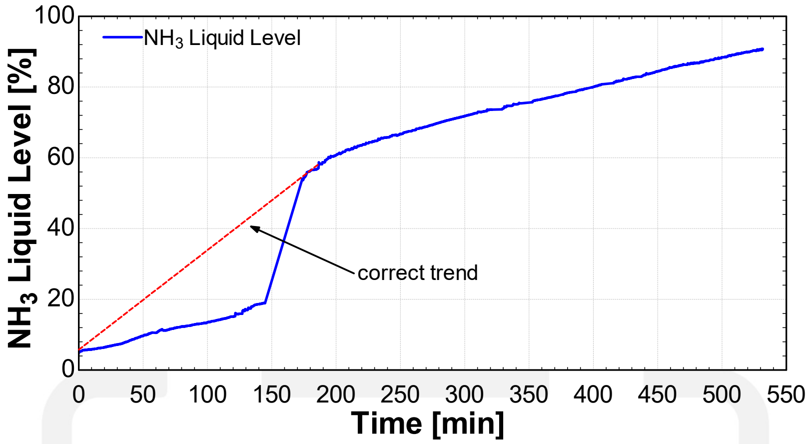

Figure 37. Ammonia Level over time during the charging phase. Sensor recalibration made during minute 150 and corrected trend.

3.3. Discharging mode (of the liquid receiver)

During the test discharging phase, the process is reversed: the liquid ammonia from the receiver is evaporated in the evaporator, and the vapor is transferred back to the thermochemical (TCM) reactor. This procedure simultaneously generates cooling at the ammonia (NH_3) evaporator and heating from the exothermic reaction of ammonia absorption by the reactive salt. The following procedure was followed during the initial tests.

The first step involves depressurizing the TCM tank to ensure that the pressure at the NH_3 evaporator is higher than at the TCM reactor. To achieve this, with all valves closed, the TCM reactor is cooled below 60°C using circulating water from the hot water tank. Once this temperature threshold is reached, the discharging mode is activated.

The water circuit operates as follows, with the components being those of the PID diagram:

1. Pump 003, along with HTF-XV-2 and HTF-XV-1, are energized to deliver cold water to the cold PCM tank. After 90 minutes of operation, HTF-XV-1 is set to off, and fan coil V004 is activated to continue discharging using ambient air.

2. The hot water from the TCM reactor is delivered to either the hot PCM tank (HTF-XV-10 ON), the DHW PCM tank (HTF-XV-11 ON), or both. To circulate water through the PCM tanks, solenoid valves HTF-XV-6, HTF-XV-8, and HTF-XV-9 are energized. Water pump P-006 is also turned ON to maintain circulation.

The ammonia circuit operates as follows:

3. In the ammonia circuit, valves NH_3-XV-6 and NH_3-XV-2 are opened, connecting the liquid receiver to the NH_3 liquid separator. The vaporized ammonia is then sent back to the TCM tank, while the liquid ammonia is directed to the evaporator.

Figure 38 to Figure 42 illustrate the system's behaviour during the discharging cycle. The cycle took approximately 4 hours for the NH_3 level to decrease from 90% to 48%. However, the operation was not continuous, as indicated by the flat, constant-level sections shown in Figure 8. As a result, these initial discharging tests are not meant to draw definitive conclusions or fully evaluate the discharging process. Instead, the tests were conducted to fine-tune the system and explore different modes of operation, such as cooling using the PCM tank or cooling with the fan coil.

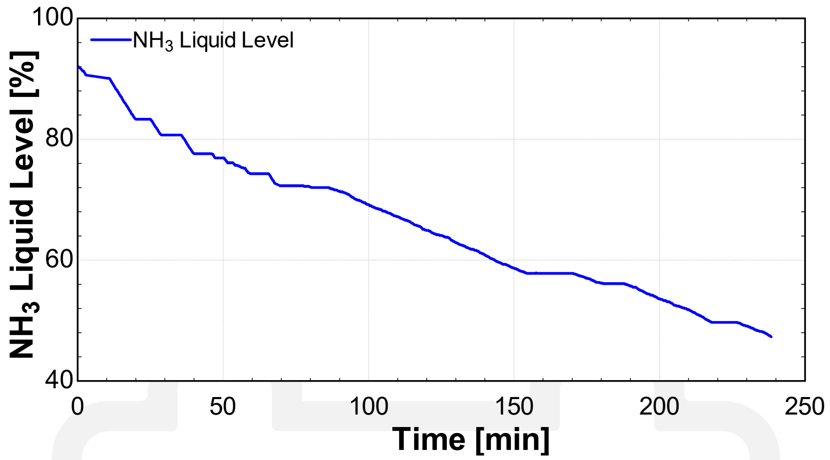

Figure 38. Ammonia Level over time during the discharging phase.

Figure 39 depicts the pressure variation within the ammonia circuit during the discharging phase. The discharge pressure remains steady, as this segment of the circuit is inactive during the discharging phase. A close correlation is observed between the reactor and evaporator pressures, particularly when the solenoid valves are opened, allowing these pressures to nearly equalize. When the discharging process ceases, the TCM reactor pressure drops due to depressurization, whereas the evaporator pressure rises because of continued ammonia evaporation. During the discharging phase, the TCM and evaporator pressures increase gradually, driven by the exothermic reaction in the TCM reactor, which elevates both the reactor and PCM temperatures. This gradual rise reflects the efficient heat transfer within the system, as the ammonia circuit sustains the discharging phase while maintaining optimal pressure balance.

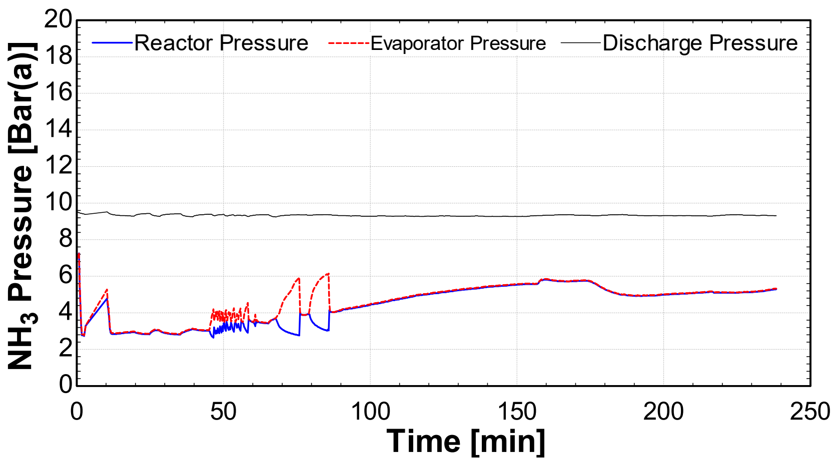

Figure 39. Reactor, evaporator and discharge pressure of the ammonia during discharging phase.

In Figure 40, temperatures at the TCM reactor are shown, along with outlet temperature of the water circulating through it. As also seen in Figure 39, both the pressure and temperature of the TCM reactor gradually increase during the discharging phase due to the progress of the exothermic reaction. This results in a gradual rise in the temperature of the water circulating between the TCM tank and the hot PCM, starting at 40°C and reaching 55°C. At around 180 minutes, the second PCM tank was activated, causing a drop in the temperature of the circulating water. This event, in turn, lowered the temperature of the TCM reactor, helping to accelerate the discharging process. Also, Figure 40 shows the temperature of the ammonia vapor directed to the TCM tank (measured by the TCM reactor outlet sensor), where it is absorbed by the reactive salt.

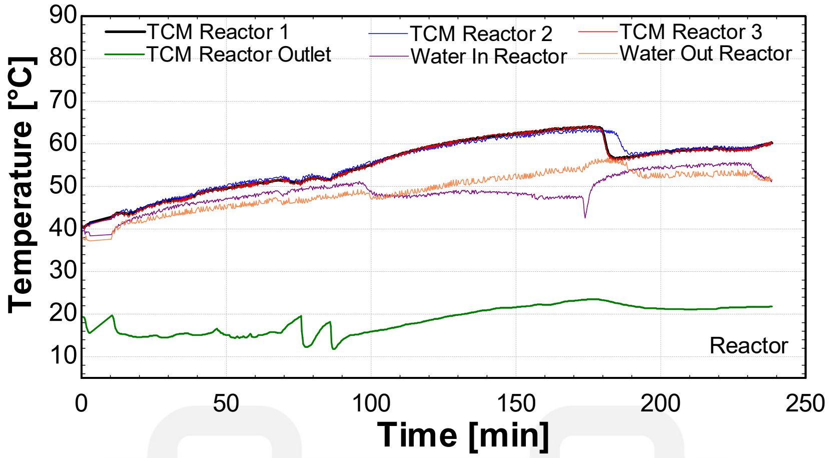

Figure 40. Ammonia and water temperature at the TCM reactor during discharging phase.

Figure 41 shows the temperature profiles for water and ammonia at the system's evaporator during the discharging phase. As liquid ammonia evaporates, the cooling water temperature steadily drops from 23°C to 10°C, with a consistent temperature difference (ΔT) of 5°C to 10°C between the water inlet and outlet. This temperature difference ΔT highlights the system's effective heat transfer, as the cooling effect of ammonia evaporation is transferred to the water loop. Additionally, occasional spikes in the outlet water temperature appear, likely due to pauses in the discharging process. These pauses briefly reduce heat transfer, allowing the water temperature to increase temporarily before stabilizing once the process resumes.

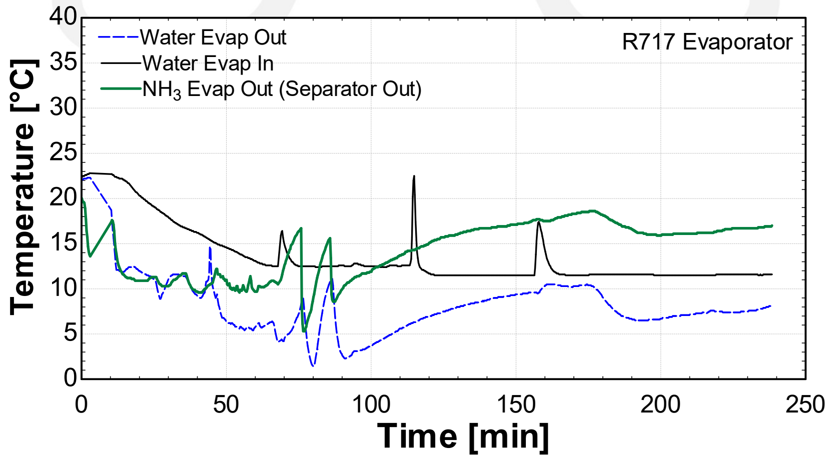

Figure 41. Inlet – outlet temperature of water and Ammonia at the evaporator during discharging phase.

Comparison of the NH_3 evaporator outlet temperature in Figure 41 with the calculated NH_3 evaporation temperature, derived from the operating pressures, confirms that the NH_3 temperature at the evaporator outlet consistently meets the minimum temperature requirements necessary to sustain the TCM reaction. This alignment is essential, as it ensures that the TCM reactor receives sufficiently low temperatures to drive the reaction effectively, thereby optimizing the system's discharging performance.

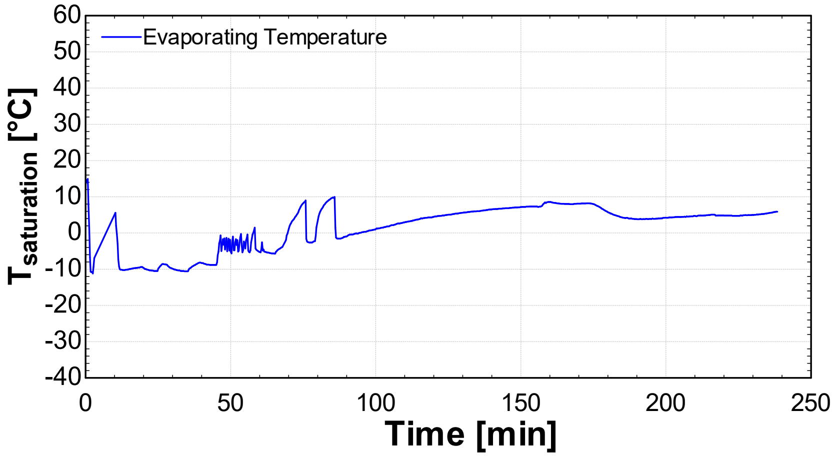

Figure 42. Evaporating temperature of the ammonia during discharging phase.

Finally, for completeness, Figure 43 shows: (a) the inlet and outlet temperatures of both water and ammonia at the NH_3 condenser, and (b) the suction and discharge temperatures of the compressor. As expected, during the discharging phase, both the ammonia compressor and condenser remain inactive, with the closed valves isolating these components from the circuit. This inactive status effectively maintains stable temperatures in these sections, as they are unaffected by the system's operation in discharging mode, ensuring that only the necessary parts of the system are engaged for optimal energy efficiency.

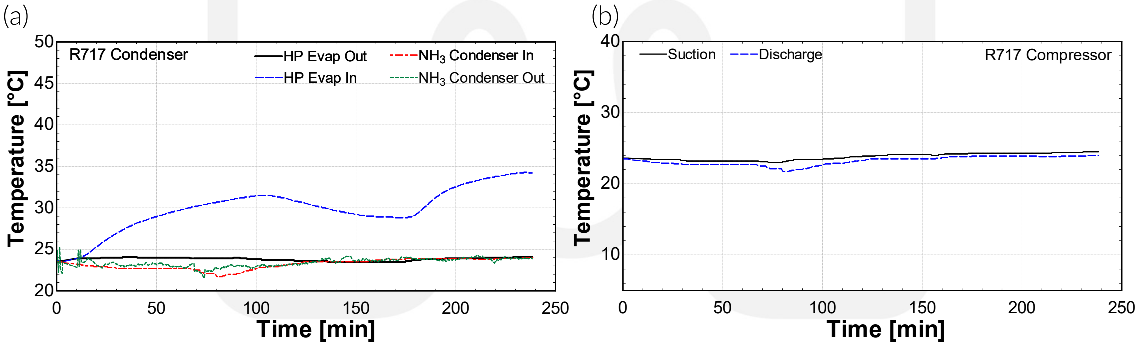

Figure 43. (a) Inlet – outlet temperature of water and Ammonia at the condenser during discharging phase, (b) Suction and discharge temperature of the Ammonia compressor during discharging phase.

Further testing at EMI's premises in Hungary will provide a more extensive dataset on system performance evaluated under real environmental conditions, which is reflected in deliverable D6.2. This real-world testing phase will allow us to assess the system's operational efficiency, reliability, and adaptability in a live setting, providing valuable insights for further optimization.

4. Certification by external bodies and delivery of the completed prototype to the demonstration sites

After finalising the performance testing, the complete prototype underwent a certification process. All components of the prototype have been certified separately, including the TCM reactor by the certified body APAVE in France, previous to delivery by Sofrigam. The certifying body for the complete prototype was Moody Hellas. Relevant documentation is presented in Annex A.

With the manufacturing process finalized for each prototype, these were then shipped to the demonstration sites. Care was taken to load the enclosure with the components using a crane into the back of a semi-trailer truck, using the hoisting points.

Figure 44. The completed and tested Ministor system leaving premises of Psyctotherm (left) and installed at CERTH (right).

5. Conclusions

This deliverable presents a comprehensive overview of the manufacturing and integration process for the TCM and PCM components within the MiniStor system, highlighting the successful development of a complex, multifunctional energy storage unit. The TCM reactor, produced by Sofrigam, and PCM vessels were meticulously designed, assembled, and tested by Psyctotherm to meet the MiniStor project's specifications. The document provides an in-depth description of each manufacturing phase, including the assembly of critical components like the electrical control panel, which regulates the charging and discharging cycles and ensures safe, efficient operation across various modes.

The filling procedure for the TCM system with ammonia was detailed, and initial testing conducted in both charging and discharging modes. These preliminary tests confirmed that the system's components—particularly the TCM reactor and PCM vessels—operated as anticipated, effectively achieving stable temperature, pressure, and reaction rate requirements. By combining TCM and PCM technologies, the MiniStor system efficiently delivers heating, cooling, and domestic hot water, demonstrating the viability of this advanced energy solution for dynamic household needs.

The outcomes underscore the MiniStor project's potential to innovate within energy management, paving the way for further evaluation and performance optimization in real-world applications, and contributing valuable insights for sustainable, integrated energy solutions in residential settings. A more detailed report about the tested MiniStor will be presented in D6.2, including testing results from the Hungarian demo at the premises of partner EMI.

Annex A

This section includes all the certificates for the pressure tests, leakage tests and the material inspection that took place during the manufacturing and testing process at the premises of Psyctotherm, completed by a notified body, as well as the P&ID that the notified body took into consideration.

MOODY HELLAS S.A.
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e - mail: info@moodyhellas.gr, www.moodyhellas.gr

MOODY TOTTRUP HELLAS S.A.

QSF-ID-28
REV. 05

Certificate No: ***110/00.619.402***
Date: ***01/07/2024***

CERTIFICATE OF CONFORMITY
ACCORDING TO DIRECTIVE 2014/68/EU

Job/Ref No:	00.619.402
Item Tag:	**MINISTOR TCM PLANT** ☐ Unfired Pressure Vessel ☐ Piping ☐ Boiler ☑ Assembly
Serial Number:	**RU2403002**
Manufacturer:	G LIGEROS & SIA O.E. - PSYCTOTHERM
Client:	Democritus University of Thrace
Location of Installation:	University Campus, Komotini, GR69100

DESCRIPTION: ***Thermal storage assembly – hot and cold water generation refrigeration unit for heating, summer air conditioning and hot water needs for residential use. The assembly main parts are: thermomechanical storage TCM reactor vessel, ammonia liquid receiver vessel, ammonia separator vessel, oil separator vessel, stainless steel piping DN6, DN15***

Reference document:	TCM DETAIL of P&ID MINISTOR PLANT, MINISTOR 001/23 Rev.2	Dated:	10/01/2024
Applicable Design Code:	EN13445 (for the main vessels), EN 13480 for the piping in part		
Other Community Directives applied:			
Fluid state: Liquefied Gas		Risk category:	IV
Fluid group: 1		Conformity Assessment Module(s):	G

CHARACTERISTICS:	Thermal Storage MINISTOR Unit serial number RU2403002
Maximum allowable pressure:	23 bar high pressure side / 18 bar low pressure side
Maximum allowable temperature:	+100°C
Minimum allowable temperature:	-10°C
Operating pressure:	23 bar high pressure side / 18 bar low pressure side
Operating temperature:	-10° to +100 °C
Volume V or Nominal Size DN:	Liquid Receiver V=57 L PS=23 bar s.n. 800231, TCM Reactor V=10,82 L PS=18 bar s.n. 23003, NH3 separator V=10 L PS=18 bar s.n. 800238, Oil separator V=1 L PS=23 bar s.n. 802773, DN6 AISI304 piping for oil, DN15 AISI304 piping for NH3
Fluid content:	Anhydrous Ammonia (R717)
Application:	Heating and Cooling

EU – Type Examination Certificate No. (only for modules B-Design type + F):	N/A	Date:	-
EU – Type Examination Certificate No. (only for modules B-production type+C2, F):	N/A	Date:	-

FINAL INSPECTION WAS PERFORMED AT:	20/03/2024	Inspection Report No.:	MOODYS 03/2024
PROOF TEST WAS PERFORMED AT:	20/03/2024	Proof Test Report No.:	PSYCTOTHERM 20/03/2024
SAFETY DEVICES WERE INSPECTED AT:	20/03/2024	Inspection Report No.:	MOODYS 03/2024

In case of materials not in compliance with harmonized standards or covered by a European Approval of pressure equipment materials, compliance with the Essential Safety Requirements for Materials acc. to the M.D.74124/ΔΤΒΝ1431 (G.G. 2278B-22.07.2016), Directive 2014/68/EU (PED) has been accomplished by issuing the following Particular Material Appraisals: **PMA Ref. No.: --**

The undersigned inspectors N. Koufakis and K. Diamanti, Engineers of MOODY S.A. - Notified Body ID No.: **0656** - certify that they have:

- Examined the design and construction of the item or the assembly and during manufacture performed appropriate tests as set out in the relevant standard(s) referred to in Article 12 of the Directive 2014/68/EU (PED), or equivalent examinations and tests, to ensure its conformity with the type and the requirements of the Directive which apply to it.
- Checked the affixation of MOODY's S.A. identification number, 0656, on the item or the assembly, the CE marking and the completeness of the name plate. The name plate contains all the above characteristics of the item or the assembly.

This certificate must be kept with its technical documentation by the manufacturer for a period of ten years, after the last of the pressure equipment has been manufactured. The applicant must inform Moody S.A. that holds the technical documentation of all modifications to the approved pressure equipment; these are subject to additional approval where they may affect conformity with the essential requirements or the prescribed conditions for use of the pressure equipment. This additional approval must be given in the form of issuing a new certificate.

	THE INSPECTORS		APPROVED BY
Name:	N. KOUFAKIS	K. DIAMANTI	KONSTANTINOS PSARAKIS
Job position:	Metallurgical Eng. M.Sc	Mech. Eng. PhD	Director of Industrial Inspections & Certifications
Signature:			
Date:	01/07/2024		01/07/2024

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INSPECTION REPORT	Report No: 04.2024 / 00.619.402	Date: 01/07/2024	Page 1 of 4

CUSTOMER DATA

Name:	G LIGEROS & SIA O.E. - PSYCTOTHERM
Address:	Christomou Smirnis str. 72, GR18540 Piraeus
Attn:	Mr. Apostolos Gkountas — Phone: +30 210 411 1186
E-Mail:	agountas@psyctotherm.gr
Copies to:	

MTH DATA

Job/Ref No:	00.619.402
Client P.O./I.O. to MTH:	--
Requisition No:	--
Date of Order:	24.07.2023
MTH Coordinator:	I. KALLIDOU

SUPPLIER/SUB-SUPPLIER DATA

Inspection Performed:	☐ With Customer Supplier ☐ With Sub-Supplier
P.O. No:	Change No: — Requisition No:
Supplier:	
Supplier Job No:	
Location:	
Primary Contact:	
Phone:	Fax:
Sub-supplier:	FLOROS BROS
Sub-Supplier Job No:	
Location:	Vasiladiou 8, GR 18540 Pireaus
Primary Contact:	Themis Floros
Phone:	+30 210 422 1443 — E-mail: info@fbc.com.gr

INSPECTION INFORMATION

Date(s) of Visit(s):	**20.03.2024, 26.04.2024, 21.05.2024**
Date of Previous Visit:	--
Date of Next Scheduled Visit:	--
P. O. Status:	☒ Complete ☐ Incomplete
Project Name:	***MINISTOR***
Pre-Inspection Meeting Summary Attached:	☐ Yes ☒ No
Summary Report Attached:	☒ Yes ☐ No

Materials/Items Inspected:
Thermal storage assembly – hot and cold water generation refrigeration unit for heating, summer air conditioning and hot water needs for residential use.
Main pressure parts:
NH3 Liquid Receiver: V=57 L PS=23 bar s.n. 800233
TCM Reactor: V=10,82 L PS=18 bar s.n. 23004
NH3 Separator: V=10 L PS=18 bar s.n. 800239
Oil Separator: V=1 L PS=23 bar s.n. 802771
Piping: AISI304L DN6 (oil), DN15 (NH3)

INSPECTION DISPOSITION: ☒ Accept ☐ Nonconformance(s) Identified ☐ Placed on Hold ☐ Other (Explain)

INSPECTION SUMMARY AND CONCLUSION:

A. Documentation: OK
B. Raw Material, Pressure Equipment, Safety and Pressure Accessories: OK
C. Welding Procedure and Welders Qualification: OK
D. Manufacturing & Inspection: OK
E. Proof and Final Testing: OK

RECOMMENDED ACTION:

ACCEPTABLE, CE MARKING TO BE AFFIXED

INSPECTION TIME:	☒ DAYS ☐ HOURS	2	TRAVEL HOURS:	N/A	DISTANCE: ☐ MI ☐ KM	N/A
Technical Specialist:	N. Koufakis, K. Diamanti	Date: 01/07/2024	MTH Project Coordinator:	I. KALLIDOU		

Notice: Moody Hellas accepts no liability for the design, integrity or overall conformity of items, materials or components inspected.

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INSPECTION REPORT (continuation page)				Page 2 of 4
Job No: 00.619.402	Report No: 04.2024 / 00.619.402	Date of Report: 01/07/2024	Customer: PSYCTOTHERM S.A.	

SUMMARY REPORT

1.0 ATTENDEES

NAME	COMPANY REPRESENTED	TITLE
Nikolaos Koufakis	MOODY HELLAS	Inspector
Kalliopi Diamanti	MOODY HELLAS	Inspector
Apostolos Gountas	PSYCTOTHERM	R&D

2.0 MATERIAL INSPECTED

ITEM NO.	PRODUCT / PS/ MATERIAL / ITEM NAME	ORDER QUANTITY	PRESENTED THIS VISIT	ACCEPTED THIS VISIT	ACCEPTED TO DATE
1	*Thermal storage assembly – hot and cold water generation refrigeration unit for heating, summer air conditioning and hot water needs for residential use, MINISTOR UNIT serial number RU2405004*	*1*	*1*	*1*	*1*

3.0 DOCUMENTS USED

DOCUMENT NO.	EDITION / REVISION	TITLE	APPROVAL STATUS
PED 2014/68/EE	2014	Pressure equipment directive	
EN13445-3	2021	Design code for the NH3 liquid receiver	
EN13480-5 (partly)	2017+A1:2019+A2:2021	Metallic industrial piping - Inspection and testing	
P&ID	Version 001	TCM DETAIL MINISTOR UNIT Dwg No MINISTOR001/2023 Rev.2 10/01/24	

4.0 SCOPE OF INSPECTION

ITP LINE NO.	ITP ACTIVITY DESCRIPTION	ITEMS	RESULTS	CLAUSE
A	Document Review		OK	6A
B	Material Certificates Review		OK	6B
Γ	Welding Procedure and Welders Qualification		OK	6Γ
Δ	Manufacturing & Inspection		OK	6Δ
E	Proof & Final Testing		OK	6E

5.0 EQUIPMENT AND INSTRUMENTATION USED (TO BE SUPPLIED BY SUPPLIER)

EQUIPMENT / INSTRUMENT DESCRIPTION	CALIBRATION CERT. NO.	EXPIRY DATE
Pressure gauge WIKA 0-60 bar, s.n. DM9981	P-23-927	27.12.2024

MOODY HELLAS S.A.
21 Elvetias Str., Agia Paraskevi, GR 15342, Athens
Company Registration Number: 002189301000
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e - mail: info@moodyhellas.gr, www.moodyhellas.gr

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INSPECTION REPORT (continuation page)			Page 3 of 4
Job No: 00.619.402	Report No: 04.2024 / 00.619.402	Date of Report: 01/07/2024	Customer : PSYCTOTHERM S.A.
SUMMARY REPORT			

6.0 INSPECTION DETAILS

DATES OF INSPECTION: 20.03.2024, 26.04.2024, 21.05.2024

LOCATION: AT PSYCTOTHERM PREMISES, PIREAUS, GREECE

INSPECTED ITEM: MINISTOR TCM ASSEMBLY

INSPECTION ACTIVITY:

A thermal storage assembly, TCM detail of MINISTOR UNIT, used for heating, cooling and hot water generation for residential use, was inspected. The assembly is classified in category IV, based on the highest category of pressure equipment it contains (see Table 1). The equipment is connected with stainless steel piping with diameter DN6 for oil and DN15 for ammonia and respective pressure accessories, which are designed and manufactured in accordance with sound engineering practice, as referred to in article 4(3) of the directive.

Inspection Items:

A **Document Review:** The following items, included in the technical folder were reviewed with acceptable results: technical description of the assembly, hazard analysis, P&ID diagram, bill of materials, material and equipment certificates and datasheets, WPS/WPQR/WATC welding certificates, piping pneumatic pressure strength test report, assembly leakage test report, Declaration of Conformity, CE marking label.

B **Review of Materials:** raw material, pressure equipment, pressure and safety accessories incorporated in the assembly have been reviewed. A detailed list of materials is recorded for each unit.

PED certificates for the main pressure equipment have been reviewed as shown in the following table. The certificates were valid and in line with the equipment category according to the European directive 2014/68/EU.

***Table 1.** Main pressure equipment of the MINISTOR assembly*

Vessel	Description	Category	Declaration of Conformity	Modules	Certificates / Reports
NH3-LT-1	NH3 Liquid receiver	IV	B / 2300949 / 3	B+D	2018-IN-0021 + ZSTS/SWZE/2517
K-001	TCM Reactor	II	TCM UNIT 23001 05/07/2023	A2	Report: 13449499-001-1
K-002	Ammonia separator	III	B / 2300949 / 6	B+D	2018-IN-0021 + ZSTS/SWZE/2517
K-003	Oil separator	art.4 par.3	--	--	Report: TR-2301108-005

Pressure relief safety valves were used to protect the main items of equipment, certified under PED category IV baring CE0045 marking. The following pressure setting certificates were available.

***Table 2.** Pressure relief valves setting certificates*

Part No	Description	Serial Number	Manufacturer	Category	Pressure Setting Certificate	Set Pressure
148F4218	SFA10	105592, 106120	Danfoss	IV	P.O.19934549 14-9-2023	18 barg
148F4223	SFA10	104928	Danfoss	IV	P.O.18919613 19-5-2023	23 barg

3.1 certificates according to EN10204 were available for the stainless-steel piping, elbows and tees, and technical datasheets for the rest of the equipment and pressure accessories.

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QSF-ID-18
REV.02

INSPECTION REPORT (continuation page)			Page 4 of 4
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SUMMARY REPORT

C	**Welding Procedure and Welders Qualification** Piping connection were made using 141 (TIG) method according to ISO4063 by a qualified welder.

Table 3. Welding procedure certification

WPS	PQR	Method
SS01-10	MIR-WPAR-275-10	141 TUBE S.S.

D	**Manufacturing and Inspection** Manufacturing of the assembly in accordance with the P&ID was spot witnessed. Marking of pressure vessels, safety and pressure equipment was confirmed. Spot visual inspection of welded joints was carried out.
E	**Proof and Final Testing** Pressure vessels incorporated in the assembly have been certified according to 2014/68/EU directive and have been pressure tested as part of the certification scheme. Connecting piping has been pressure tested using pneumatic test in a pressure of 1,1xPS n accordance with EN13480-5 par.9.3.3. The results are recorded in the relevant report by Psyctotherm, dated 21.05.2024. Final leakage testing of the assembly was carried out and no leakage was detected. The results are recorded in the relevant report by Psyctotherm, dated 21.05.2024.

7.0 NON-CONFORMANCES

NCR #	DESCRIPTION	DATE RAISED	DATE CLOSED
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8.0 ATTACHMENTS TO THIS REPORT

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END OF THIS REPORT

The inspectors

N. Koufakis
Metallurgical Engineer, M.Sc.

K. Diamanti
Mechanical Engineer, PhD, IWE

MOODY - TOTTRUP HELLAS

PSYCTOTHERM
MARINE REFRIGERATION & AIR CONDITIONING

ΕΚΘΕΣΗ ΣΤΕΓΑΝΟΤΗΤΑΣ ΣΩΛΗΝΩΣΕΩΝ ΣΥΓΚΡΟΤΗΜΑΤΟΣ ΥΠΟ ΠΙΕΣΗ

LEAKAGE TEST REPORT OF A PIPING ASSEMBLY UNDER PRESSURE

ΕΡΓΟ *Project*	Κατασκευή Μονάδας για παραγωγή θέρμανσης, ψύξης για το έργο MINISTOR
ΠΕΛΑΤΗΣ *Customer*	Εγκατάσταση στο Δημοκρίτειο Πανεπιστήμιο Θράκης (Κιμμέρια, Ξάνθη) στο πλαίσιο του έργου MINISTOR
ΚΑΤΑΣΚΕΥΑΣΤΗΣ *Manufacturer*	PSYCTOTHERM
ΜΕΛΕΤΗΤΗΣ *Designer*	PSYCTOTHERM
ΕΤΟΣ ΚΑΤΑΣΚΕΥΗΣ *Year Built*	2024
ΣΕΙΡΙΑΚΟΣ ΑΡΙΘΜΟΣ ΣΥΓΚΡΟΤΗΜΑΤΟΣ/ΜΟΝΑΔΑΣ *Assembly/Unit serial number*	RU2405004
ΣΤΟΙΧΕΙΑ ΣΩΛΗΝΩΣΕΩΝ *Piping Description*	Αρ.Σχεδίου/*Drawing or P&ID:* MINISTOR001/23 Πίεση Λειτουργίας/*Operating Pressure:* LP: max 18 barg, HP: max 23 barg Διάμετρος Σωληνώσεων/ Piping Diameter: DN6, DN10, DN15 Υλικό/*Material:* STAINLESS STEEL AISI 304
ΕΦΑΡΜΟΖΟΜΕΝΗ ΝΟΜΟΘΕΣΙΑ/ΠΡΟΤΥΠΑ *Applicable Legislation/Standards*	Οδηγία / Directive 2014/68/ΕΕ EN 13480 part 5 : 2017 + A1:2019 + A2:2021
ΔΟΚΙΜΗ ΠΙΕΣΗΣ *Pressure Test*	Πραγματοποιήθηκε δοκιμή στεγανότητας στις σωληνώσεις και τις συνδέσεις με τον εξοπλισμό του συγκροτήματος στην πίεση λειτουργίας 23 barg για το τμήμα υψηλής πίεσης και 18 barg για το τμήμα χαμηλής πίεσης for 1 hour. *Leakage test of the piping and connections to the equipment of the assembly was performed at a pressure of 23 barg for the high-pressure side and 18 barg for the low-pressure side for 1 hour.*
ΗΜ.ΔΟΚΙΜΗΣ *Test Date*	21/05/2024
ΑΠΟΤΕΛΕΣΜΑΤΑ ΕΛΕΓΧΟΥ *Test Results*	Οι συνδέσεις ελέγχθηκαν με αφρίζον μέσο. Κατά την δοκιμή δεν παρατηρήθηκαν διαρροές και πτώση ένδειξης μανομέτρου. *The connections were checked with foam. During the test no pressure drop or leakage was detected.*

Ημερομηνία: *Date: 22/05/2024*	**Για τον Κατασκευαστή:** *For the Manufacturer:*	**Για τον Φορέα Επιθεώρησης:** *For the Inspection Body:*
	ΨΥΚΤΟΘΕΡΜ Γ. ΑΥΓΕΡΟΣ & ΣΙΑ Ο.Ε. ΨΥΚΤΙΚΑ ΧΡΥΣΟΣΤΟΜΟΥ ΣΜΥΡΝΗΣ 72 - ΠΕΙΡΑΙΑΣ	MOODY HELLAS S.A. Reviewed Witnessed Date 21 MAI 2024

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under the grant agreement No 869821

PSYCTOTHERM

MARINE REFRIGERATION & AIR CONDITIONING

ΕΚΘΕΣΗ ΔΟΚΙΜΗΣ ΠΙΕΣΗΣ ΑΝΤΟΧΗΣ ΣΩΛΗΝΩΣΕΩΝ ΣΥΓΚΡΟΤΗΜΑΤΟΣ ΥΠΟ ΠΙΕΣΗ

PIPING STRENGTH PRESSURE TEST REPORT OF AN ASSEMBLY UNDER PRESSURE

ΕΡΓΟ *Project*	Κατασκευή Μονάδας για παραγωγή θέρμανσης, ψύξης για το έργο MINISTOR
ΠΕΛΑΤΗΣ *Customer*	Εγκατάσταση στο Πανεπιστήμιο του Santiago de Compostela (Santiago, Spain) στο πλαίσιο του έργου MINISTOR
ΚΑΤΑΣΚΕΥΑΣΤΗΣ *Manufacturer*	PSYCTOTHERM
ΜΕΛΕΤΗΤΗΣ *Designer*	PSYCTOTHERM
ΕΤΟΣ ΚΑΤΑΣΚΕΥΗΣ *Year Built*	2024
ΣΕΙΡΙΑΚΟΣ ΑΡΙΘΜΟΣ ΣΥΓΚΡΟΤΗΜΑΤΟΣ/ΜΟΝΑΔΑΣ *Assembly/Unit serial number*	RU2405004
ΣΤΟΙΧΕΙΑ ΣΩΛΗΝΩΣΕΩΝ *Piping Description*	Αρ.Σχεδίου/*Drawing or P&ID:* MINISTOR001/23 Πίεση Λειτουργίας/*Operating Pressure:* LP: max 18 barg, HP: max 23 barg Διάμετρος Σωληνώσεων/ Piping Diameter: DN6, DN10, DN15 Υλικό/*Material:* STAINLESS STEEL AISI 304
ΕΦΑΡΜΟΖΟΜΕΝΗ ΝΟΜΟΘΕΣΙΑ/ΠΡΟΤΥΠΑ *Applicable Legislation/Standards*	Οδηγία / Directive 2014/68/ΕΕ EN 13480 part 5 : 2017 + A1:2019 + A2:2021
ΔΟΚΙΜΗ ΠΙΕΣΗΣ *Pressure Test*	Πραγματοποιήθηκε πνευματική δοκιμή αντοχής στις σωληνώσεις του συγκροτήματος στην πίεση των 25 barg. *Pneumatic test of the piping was performed at a pressure of 25 barg.* Η πίεση των 25 barg διατηρήθηκε για δεκαπέντε λεπτά (15'). *The pressure 25 barg was maintained for fifteen minutes (15').* Εξοπλισμός που χρησιμοποιήθηκε: Διάταξη φιάλης αζώτου, διακριβωμένο μανόμετρο WIKA 0-60, Σειριακός Αριθμός: DM9981 *Equipment used: Nitrogen cylinder arrangement, calibrated*
	manometer WIKA 0-60, Serial No: DM9981
ΗΜ.ΔΟΚΙΜΗΣ *Test Date*	21/05/2024
ΑΠΟΤΕΛΕΣΜΑΤΑ ΕΛΕΓΧΟΥ *Test Results*	Κατά την δοκιμή δεν παρατηρήθηκαν: Διαρροές - παραμορφώσεις και πτώση ένδειξης μανομέτρου. *During the test: No leakages - No deformations - No drop in manometer pressure indication were observed.*

Ημερομηνία:
Date: 22/05/2024

Για τον Κατασκευαστή:
For the Manufacturer:

ΨΥΚΤΟΘΕΡΜ
Γ. ΛΥΓΕΡΟΣ & ΣΙΑ Ο.Ε.
ΨΥΚΤΙΚΑ
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ΑΦΜ: 082447746 - ΔΟΥ: Ε' ΠΕΙΡΑΙΑ

Για τον Φορέα Επιθεώρησης:
For the Inspection Body:

MOODY HELLAS S.A.
Reviewed
Witnessed
Date 21 MAI 2024

Ammonia loop P&ID