Incident Summary #II-1187393-2021 (#21850) (FINAL)

SUPPORTING INFORMATION	Incident Date		April 13, 2021
	Location		Peace River Region
	Regulated industry sector		Boilers, PV & refrigeration - Refrigeration system
	Impact – Injury	Qty injuries	0
		Injury description	No Injuries
		Injury rating	None
	Impact – Damage	Damage description	Failure of multiple cassettes of a semi-welded plate heat exchanger released ammonia into the brine cycle of a refrigeration plant, rendering the cassettes unusable and contaminating the brine. Significant plant down time occurred as replacement cassettes were not readily available.
		Damage rating	Major
	Incident rating		Major
	Incident overview		In the fall of 2009, an indoor ice surface facility's refrigeration plant, was placed into operation and successfully operated without significant failure until the spring of 2021. When brine samples were taken in April 2021, the brine analysis reports came back indicating ammonia in the brine. The discovery of ammonia in the brine represented a hazard in the refrigeration plant and risk to plant staff. So, the operator shutdown and locked out the plant, and a second set of samples were taken to confirm that there was ammonia in the brine. These new samples came back indicating an even higher levels of ammonia. The higher levels of ammonia prompted operations to request that a refrigeration contractor perform a nitrogen pressure test on the pressure vessel suspected to have failed. This nitrogen pressure test verified that the internal pressure boundary of a semi-welded plate heat exchanger was leaking. The semi-welded plate heat exchanger was then dismantled, and the cassettes were sent for non-destructive examination. The cause of failure was confirmed to be due to a deficiency in the heat exchanger.
INVESTIGATION CONCLUSIONS	Site, system and components		At this recreational facility the ice surface is maintained at sub-zero temperatures by circulating brine through gasket channels and liquid ammonia through welded channels of a semi welded plate heat exchanger (Figure 1). Brine is a solution made of salt, water, and a corrosion inhibitor. Ammonia (NH3) is a common refrigerant composed of nitrogen and hydrogen that is flammable and toxic to humans. The semi welded plate heat exchanger consists of a set of corrugated SA 240 Alloy 254 stainless steel plates with port holes for inflow and outflow of two separate fluids. The corrugated plates are arranged as cassettes in such a way that every second channel is welded, and every other channel is gasketed, (Figures 1 & 2). This configuration is like that of a compressed accordion and for this heat exchanger there are a total of 82 cassettes.

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	The intended design of the semi-welded plate heat exchanger is to keep the brine and ammonia separate from each other. While allowing heat to transfer from the brine to the liquid ammonia, (Figure 2).
Failure scenario(s)	During manufacturing of these cassettes, a weld deficiency was created, and at that time the weld deficiency was not enough for the cassettes to fail during commissioning. However, after years of operational stresses and a corrosive environment at the weld deficiency, the weld fault may have developed into a leak path for the ammonia to escape into the brine.
Facts and evidence	Facts and evidence determined through the course of investigation summarized below. Information gained from site inspection, discussions with service contractors and review of records: • Brine analysis reports indicated ammonia in the brine (Figure 4) and the only cross over point in the system is at the semi-welded plate heat exchanger. • Owner reported that during 2019 and 2021 dismantle of the semi-welded plate heat exchanger, a sludge was observed at the bottom of the heat exchanger and the internal seating surface of the gasket. • 2020 and 2021 brine analysis reports indicated dissolved iron above the control range, which could lead to a corrosive environment where iron deposits form (Figure 4). • Layout of the rubber gasket places a branch off the main gasket, pointing in an upwards direction, where dissolved iron or other suspended solids may have accumulated at the exact location of failure. (Figure 3) • A Pressure test conducted by a refrigeration contractor of the semi-welded plate heat exchanger indicated a leak. The heat exchanger plates were sent to an independent laboratory for analysis to verify the cause of failure. Laboratory testing included the following procedures: • X-ray radiography found weld anomalies at specific locations inside the plates • Visual examination under magnification found deep weld anomalies, heat tinting and weld splatters, (Figures 5 and 6). • Scanning electron microscopy on the weld anomalies found indications of weld manufacturing deficiencies, (Figure 7). • Metallographic examination found a weld defect in the form of shrinkage porosity. (Figure 8). • Positive material identification (PMI) and X-ray fluorescence (XRF) identified the composition of the metal plates to be super austenitic stainless steel, alloy 254. This material is suitable for service in high chlorine environments, such as brine. Failure analysis of the heat exchanger plates conducted by the laboratory engineer concluding the following: • Weld defects were identified in two heat exchanger cassette plates • The weld defects were due to manufacturing issues The laboratory engineer recommended the following: • Examine all the cassette plates recently produced by this manufacturer for the occurrence of similar weld defects. Plates showing similar weld defects should be removed from service. • Review the welding parameters to mitigate the occurrence of such weld defects.

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Causes and contributing factors	The heat exchanger plate failure was very likely initiated by weld defects created during the manufacturing process and accelerated by contact with the brine solution, resulting in a leak path. This allowed ammonia to pass from the welded channel into the gasket channel of the semi-welded plate heat exchanger, contaminating the brine.

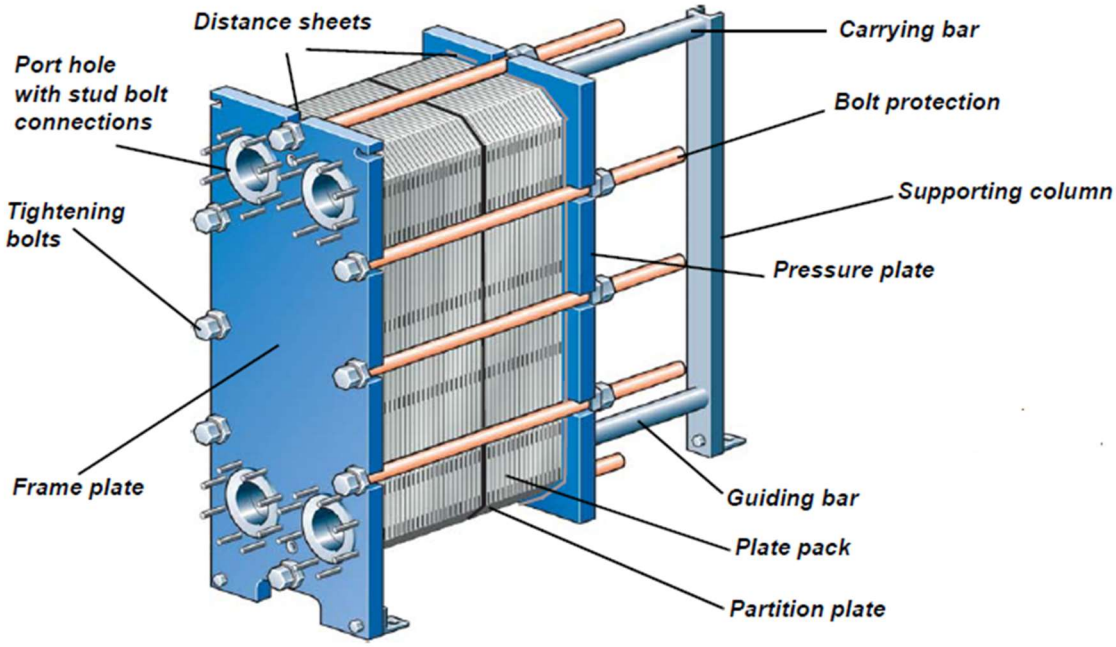

Figure 1: **Semi-Welded Plate Heat Exchanger**

Alfa Laval, General instruction manual, Semi Welded Plate Heat Exchanger 3490006213 rev 2014-07

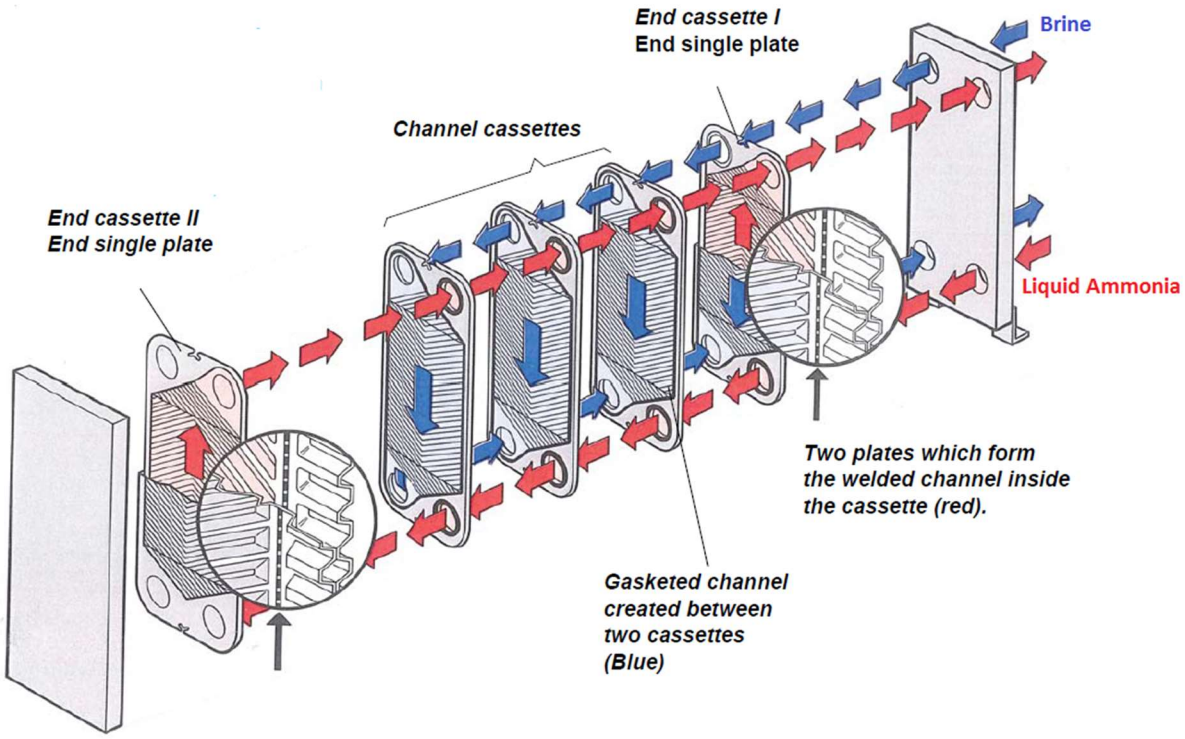

Figure 2: Cassette arrangement forming the Semi-Welded Plate Heat Exchanger

Alfa Laval, General instruction manual, Semi Welded Plate Heat Exchanger 3490006213 rev 2014-07

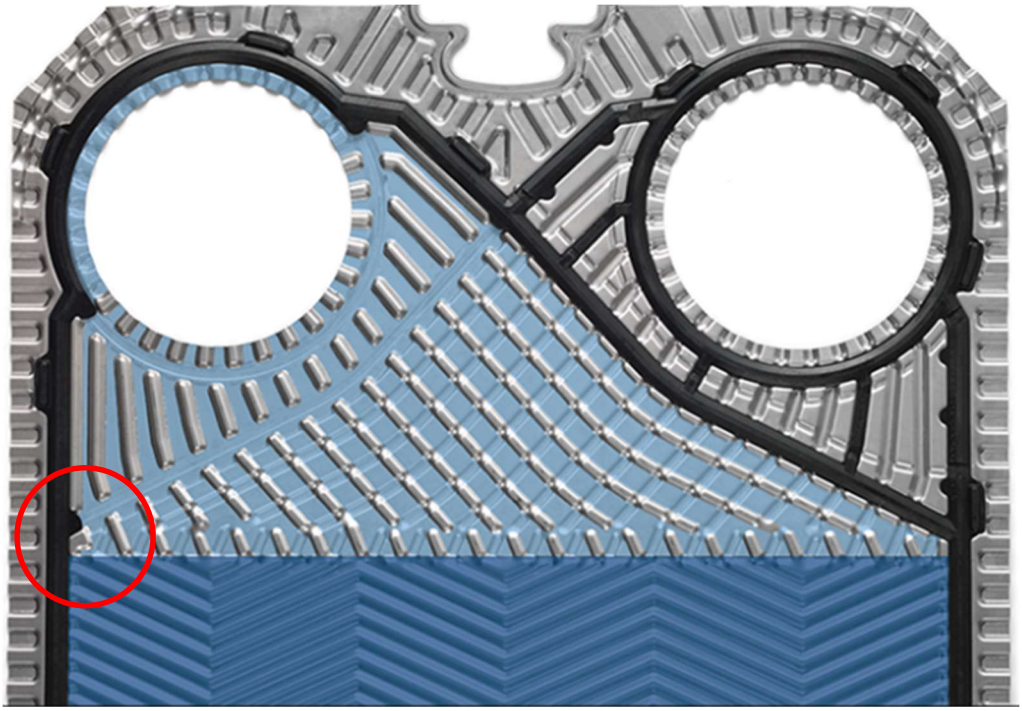

Figure 3: Cassette and gasket identifying location of both weld defects.

CONSTITUENT	C.F.	Control Range
Sample Date	April 13, 2021	
Appearance	Amber/Cloudy	Clean/Clear
Visible Solids	< 30 ppm	< 30 ppm
Specific Gravity	1.23	1.20 Min.
% Calcium Chloride	24.2	21.5% Min
Freezing Point (°C)	-27.20	-5.0 °F or -20.5 °C Min
Visible iron	< 30 ppm	< 30 ppm
Complex Phosphate Inhibitor ($cPO_{4)}$	16 ppm	20/30ppm $cP0_4$ at 1.2% Z-5750
pH	8.66	8.50 to 9.50
Dissolved iron	22 ppm	< 10 ppm
Ammonia	24 ppm	0 ppm

Figure 4: Calcium chloride brine analysis report.

Test performed April 2021 by independent test facility.

Figure 5: Electron microscope view of weld defect. Cassette 7B

Tests performed by an independent test facility.

Figure 6: **Electron microscope view of weld defect. Cassette 8B**

Tests performed by an independent test facility.

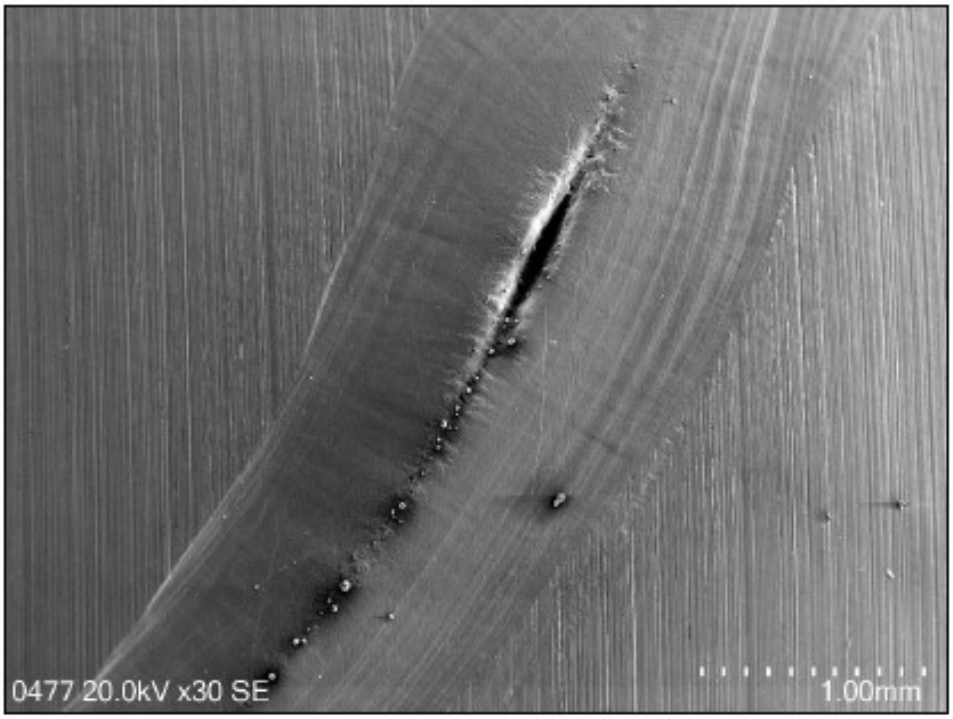

Figure 7: SEM image of the weld anomaly (plate 8B, corner D)

Tests performed by an independent test facility.

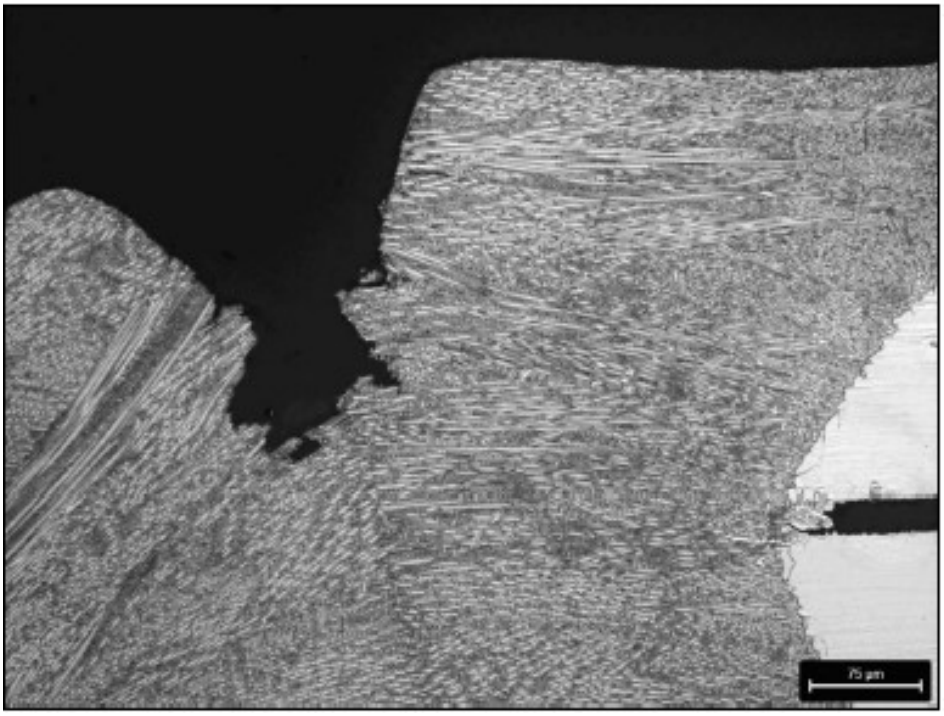

Figure 8: Defective weld after etching

Tests performed by an independent test facility.