Transcritical CO_2 Systems at Tottus and Jumbo, Chile
Verification Report
April 2017

This report is the final report for the project "Implementation of refrigeration systems based on transcritical CO_2 technology". It is based on:

- Information provided by the Chilean Ozone Unit Climate Change Division;
- Visits to Tottus Santiago and Jumbo Valdivia for a visual inspection of the installations;
- Discussions with the Claudia Paratori Cortes and German Fuentes Duran of the Ozone Unit;
- Discussions with representatives of the supermarkets;
- Discussions with Pier Zecchetto of Nuova Service, installer of both systems.

The systems are tried and tested CO_2 transcritical booster systems, similar to those used in several hundred supermarkets in the UK (and elsewhere in Europe). The installations at both supermarkets use similar SCM packs, but at Tottus the gas cooler is integral to the pack and uses an adiabatic cooling system. The packs were commissioned by Massimo Pellizzari of SCM who will return in May to check the systems.

The remainder of this report describes the installations in more detail with recommendations for changes for these and for future CO_2 systems. All comments relate to both installations unless stated otherwise. Relevant photos are referenced in the text and included in Appendix 1.

Contents

Plant

The multi compressor packs used are from SCM Italy and incorporate the low and high stage compressors, oil return system, high pressure and medium pressure valves, pressure relief valves, liquid receiver, liquid line filter / drier and suction accumulator. The Tottus pack also incorporates the gas cooler which has been fitted with an Eco Mesh water spray system. The installer is aware that the hard water in Santiago will cause deterioration of the Eco Mesh assembly and the gas cooler, and that regular maintenance and cleaning of both is essential for continued reliability.

The liquid receivers are 300 litres – larger than typically used in the UK to enable pump down.

There are two high pressure valves (which control the gas cooler pressure) piped in parallel so there is redundancy in case of failure (photo 1). There are also two medium pressure valves (which control the receiver and liquid line pressure) for the same reason. Experience in the UK is that these valves are reliable and therefore rarely fail or need replacement.

The filter drier in the liquid line has a bypass to enable the core to be replaced without stopping the system. The filter drier is also the charging point for the system.

Adequate gauges are fitted to enable all operating pressures to be checked.

Adequate access and isolating valves are fitted, with the exception of the Temprite coalescent oil separator. This does not have a bypass so the system must be stopped if the core needs to be replaced (as it should be after commissioning). At the time of the site visits these had not been replaced.

The gas cooler at Jumbo is remote from the pack, mounted on the roof above.

Resilience units running on R134a are fitted to maintain the pressure below the PRV vent pressure in the event of total plant or power failure. These should be on an essential services supply (e.g. generator) but this was not checked on site.

Various CO_2 cabinet types are used. They have been fitted with electronic expansion valves by the installer. There appears to be one pressure transducer per cabinet. Standard practice is to use one transducer per ten cabinets. The wiring connections (photo 2) are such that they have the potential to fill with water / ice which will affect their reliability.

The cold room CO_2 evaporators are also fitted with electronic expansion valves. Leak detection has been installed in the cold room – see the section of leak detection for more information.

Filter driers are fitted in the liquid line before each evaporator / cabinet. These have bypass / non return valves assemblies to prevent trapped liquid and issues associated with pressure rise in trapped liquid (see photo 3).

Plant Location and Access

The plant at Jumbo is located in a machine room adjacent to a large car park below ground level. Machine room ventilation is good, with extract to an outside area. There are gas detectors at low level adjacent to each pack, see the section on leak detection for more information.

Pipe work is routed across the roof of the machine room and car park and to underside of the cabinets on the shop floor.

The gas cooler is located on a roof above the plant and is accessed by a fixed ladder.

The plant at Tottus is located in an enclosure on a roof accessed by a fixed ladder. Pipe work routes down to the below ground car park to the underside of the cabinets on the shop floor.

Access to the plant is difficult with equipment, e.g. to charge the system. It is planned to install a fixed charging line so cylinders do not have to be lifted onto the roof. This system is commonly used in the UK. The charging line is typically 3/8 inch copper tube, rated for the pressure (e.g. 60 bar g). The charging procedure must specify that after charging liquid is vented from the line so it contains a gas charge only (so that expansion of trapped liquid will not cause the line to rupture). It is also essential to ensure a vapour holding pressure is maintained in the charging line to prevent system contamination.

Pressure

Information provided prior to the visit indicated that the maximum allowable pressures (PS) for the systems are:

- 120 bar g high side;
- 60 bar g intermediate / liquid;
- 52 bar g medium temperature (MT) suction;
- 30 bar g low temperature (LT) suction.

These are appropriate for transcritical booster systems. In compliance with EN 378[1] the pressure relief valves (PRVs) must have vent pressures equal to PS for each part of the system protected and the strength test must be carried out at 1.1 x PS.

Operating pressures are typically:

- 90 bar g maximum high side, the pressure typically set by the Danfoss controller when operating transcritically;
- 38 bar g intermediate / liquid, the pressure set by the Danfoss controller for the Tottus and Jumbo systems;

[1] EN 378-2:2016 Refrigerating systems and heat pumps – Safety and environmental requirements, Part 2: Design, construction, testing, marking and documentation. There is similar guidance in ISO 5149-2:2014 Refrigerating systems and heat pumps – Safety and environmental requirements, Part 2: Design, construction, testing, marking and documentation

- 27 bar g MT suction, a function of the evaporator size and air on temperature, the Tottus and Jumbo systems were running at approximately this pressure;
- 13 bar g LT suction, a function of the evaporator size and air on temperature, the Tottus and Jumbo systems were running at approximately this pressure.

There is sufficient difference between PS and the operating pressures for the PRVs not to vent unless there is actually a fault (i.e. the PRV vent pressure will not be reached during normal variations in the operating pressures). Significant refrigerant loss through PRV venting has occurred on systems in the UK because the intermediate / liquid PRV vent pressures have been too close to the operating pressure. This potential problem has been avoided on the Tottus and Jumbo systems.

The Tottus and Jumbo systems appear to have 60 bar g pressure relief valves fitted to the MT and LT suctions instead of 52 bar g and 30 bar g as specified. It should be noted that the PS values for at least some of the cabinets are 60 bar g liquid / 45 bar g suction (based on a check of a small sample of the cabinets installed). The PS values for the LT suction should be no higher than 45 bar g because the cabinet evaporators are not rated for a pressure higher than this. The PS values for all the cabinets and cold room evaporators should be checked and the PRVs replaced with PRVs which have the appropriate vent pressure.

The orientation of some of the PRVs on the installed pipe work at Tottus is such that there is danger to anyone standing in the area if the valves vent. Also water is collecting in the valve, see photo 4. The valves should be re orientated.

The intermediate / liquid and the LT and MT suction operating pressures are as expected on both sites. The high side pressure on the Jumbo installation was 75 bar g during the visit (indicated on the gauge). This is just into the transcritical region (pressures above 71.6 bar g are transcritical). The ambient was approximately 23^{O}C so transcritical operation would be expected. However, the Danfoss controller usually controls the high side pressure to 90 bar g because this is the optimum pressure for capacity and efficiency, not 75 bar g. This should be discussed with Massimo Pellizzari when he returns to check the SCM packs.

Pipe Work

All site installed pipe work and fittings are reported to be K65 tube (i.e. copper iron alloy tube with a maximum pressure rating of 120 bar g). This is required on the higher pressure parts of the system but not on MT and LT suction. It has been selected to avoid any confusion on site and to eliminate the potential for the wrong pipe to be used (i.e. pipe with insufficient strength on the high side).

Visual inspection of a very small sample of brazed joints indicates the possibility that there is low braze penetration, see photo 5. More heat is required when brazing K65 tube due to its thickness. It is recommended that the technicians braze test pieces which are cut open to check penetration. Penetration of 80% of the overlap is expected. The table below gives recommended fitting depths etc for a range of copper pipe.

Outside diameter (OD), mm	Includes imperial pipe sizes	Minimum fitting depth (B), mm	Clearance (C-A), mm
5 ≤ OD < 8	¼”	6	0.05 to 0.35
8 ≤ OD < 12	3/8”	7	
12 ≤ OD < 16	½” and 5/8”	8	0.05 to 0.45
16 ≤ OD < 25	7/8”	10	
25 ≤ OD < 35	1 1/8”, 1 3/8”	12	0.05 to 0.55
35 ≤ OD < 45	1 5/8”	14	

It is unlikely the brazed joints seen will fail, but greater braze penetration will provide better reliability on future installations.

The pipe support is appropriate for the application (pipe support spacing is better than required in EN 378) as shown in photo 6.

The pipe clamp specification is being provided by the installer. The rubber in some types of pipe clamp can harden, especially when in direct contact with discharge pipework, this can leave pipework in direct contact with the metal clamp and lead to chafing of the copper pipe.

The pipe insulation and jointing of insulation is appropriate for the application. This is important on the suction and liquid lines to reduce heat ingress to the refrigerant which will significantly reduce system performance.

Refrigerant and Moisture

The CO_2 refrigerant for these two installations was produced specially and is reported to contain less than 20 ppm moisture. The standard moisture level for refrigerant grade CO_2 (R744) is 5 ppm and problems can readily occur in CO_2 systems if moisture is present including carbonic acid formation. Due to the higher moisture levels additional liquid line drier core changes should be carried out and samples of the refrigerant in the system taken and analysed for moisture content. This main pack drier core is fitted with a bypass to aid drier core replacement.

Oil Levels

The oil level in the oil reservoirs on both the Jumbo and Tottus installations was below the level of the lower sight glass. To ensure adequate oil supply the level should be between the two sight glasses. It is recommended these are checked again and oil added as necessary.

Leak Detection and Gas Alarms

Leak detection is fitted in the machine room at Jumbo and in the cold rooms in both supermarkets. The systems alarm at 5,000 ppm which is appropriate for CO_2.

There are alarm beacons outside each room but no emergency procedure signs to indicate that rooms should not be entered in the event of an alarm. It is recommended that appropriate signs are fitted and a document prepared outlining the emergency procedure.

During the site visit the alarm in one of the preparation rooms was red, indicating either CO_2 in the air or a faulty alarm. It was brought to the attention of the installer who will check it.

The gas detectors in the plant room are at low level although they are not protected as specified (although this is probably not necessary for their location). The detectors seen at Jumbo are at low level and protected. The detectors seen in the cold rooms at Tottus during the site visit are now at high level due to damage caused during loading / unloading the cold rooms. Sensor tubes are due to be fitted so that the actual sensor is at low level.

The gas detection equipment should be checked with a calibrated gas source (a "bump" test), exposing the detector to the specified CO_2 concentration to create an alarm. This procedure should be included in planned maintenance.

Leakage

Leaks have been experienced on Schrader valves fitted to four evaporators at Jumbo. All Schrader valves have now been removed. Leaks have also been experienced in the UK on Schrader valves. Care should be taken that the correct core is fitted (i.e. suitable for CO_2 and the oil used, and the pressures and temperatures). The cores should be removed during brazing and refitted using a torque tool to ensure the correct tightness. Wherever possible the use of Schrader valves should be avoided.

Energy Efficiency

The stores have not been running long enough to verify the predicted energy consumption / energy efficiency.

Service

The charging equipment seen during the site visit appears to be suitable for the pressures of CO_2.

The technicians have attended training in Europe.

Inspection maintenance visits are planned every two months for each store.

Summary of Recommendations for the Tottus and Jumbo systems

Overall the systems at Tottus and Jumbo are standard transcritical booster systems which have a high specification to ensure reliability. There are some changes recommended to ensure that the safety and performance of these systems is optimum.

1. The PRVs which are used on the suction of the systems appear to have a higher vent pressure than the rated maximum pressure (PS) of the evaporators and cabinets. The PS values for all the cabinets and cold room evaporators should be checked and the suction PRVs replaced with PRVs which have the appropriate vent pressure if necessary.

2. The orientation of some of the PRVs on the installed pipe work at Tottus is such that a CO_2 vent is a serious hazard and water is collecting in the valve. These should be re orientated.

3. The Danfoss controller usually controls the high side pressure to 90 bar g because this is the optimum pressure for capacity and efficiency. The Jumbo systems were operating in the transcritical region during the site visit, but at 75 bar g. This should be discussed with Massimo Pellizzari when he returns to check the SCM packs.

4. The cores in the Temprite oil separators should be replaced (this is standard procedure post commissioning).

5. The oil level in the oil reservoirs on both the Jumbo and Tottus installations was below the level of the lower sight glass. To ensure adequate oil supply the level should be between the two sight glasses. It is recommended these are checked again and oil added as necessary.

6. There are no emergency procedure signs to indicate that rooms should not be entered in the event of an alarm. It is recommended that appropriate signs are fitted and a procedure prepared outlining the emergency procedure. Checking of the gas detection equipment should be included in planned maintenance.

7. The type of cable and the cable terminations into the AKV solenoid coils is such that they will allow water ingress which will affect their reliability. These should be re worked.

Recommendations for Future Supermarket CO_2 Transcritical Booster Systems

For future widespread deployment of CO_2 transcritical booster systems the specification can be modified to reduce cost without reducing performance or reliability. The following recommendations indicate where changes can be made.

1. The PS values specified for the systems are appropriate for transcritical booster systems:

   - 120 bar g high side;
   - 60 bar g intermediate / liquid;
   - 52 bar g medium temperature (MT) suction;
   - 30 bar g low temperature (LT) suction.

   The pressure relief valves should be specified for these values and not greater unless other system components, such as evaporators, are suitable for higher pressures. Pressure testing should be carried out at 1.1 x PS for each section of installed pipe work.

2. The use of K65 tube and fittings on the high pressure and possibly the intermediate / liquid pipe work is recommended. For the suction pipe work standard copper tube and fittings of the correct thickness can usually be used and this will reduce the cost.

3. It is recommended that the technicians who will be brazing K65 tube braze a sample of test pieces which are then cut open to check penetration. Penetration of 80% of the overlap is expected, see the table provided in the section on pipe work for the specified overlap.

4. The current systems have parallel high pressure and medium pressure valves (which control the gas cooler pressure and the intermediate / liquid pressure respectively). Experience in the UK has shown these valves to be very reliable, so there should be no need for the second of each valve.

5. An emergency procedure for the gas alarm should be provided, along with suitable signs on the outside of each cold room and machine room. The maintenance and checking of the detection equipment and alarms should be specified.

6. The use of Schrader valves should be eliminated or at least reduced. Where they are used care should be taken that the correct core is fitted (i.e. suitable for CO_2 and the oil used, and the pressures and temperatures). The cores should be removed during brazing and refitted using a torque tool to ensure the correct tightness.

7. The installation of the electronic expansion valve transducers and probes should be such that wiring connections are reliable and cannot fill with moisture and ice. One pressure transducer per ten cabinets is typically sufficient, confirmation should be sought from Danfoss.

8. The non return valve / bypass arrangements for each cabinet and evaporator which have been used to avoid the possibility of trapped liquid are not necessary if technicians are correctly trained and have clear procedures for service work.

9. A ready and reliable source of refrigerant grade CO_2 is required. The individual filter driers for each cabinet are not necessary and add to the complexity and leak potential of the systems.

10. A source of appropriate tools / charging equipment is required.

11. It is recommended that fixed charging lines are installed on site so that the heavy refrigerant cylinders do not need to be moved / lifted large distances. The charging procedure should avoid the possibility of trapped liquid in the charging line post charging.

Appendix 1, Photos

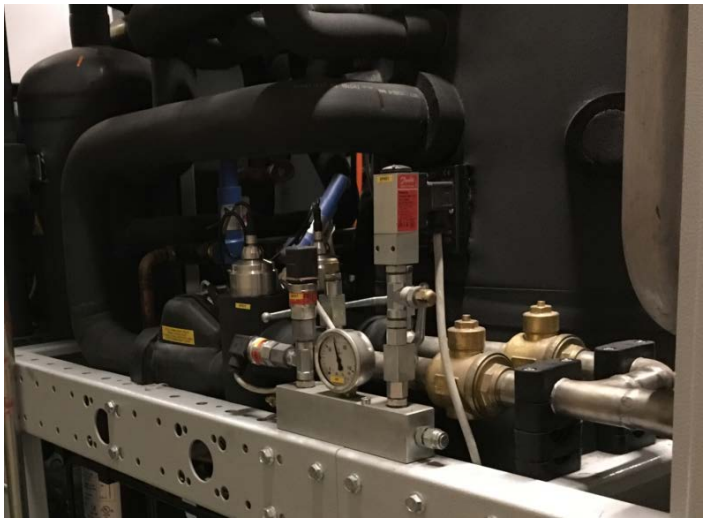

Figure 1 Parallel high pressure valves

Figure 2 EEV installation

Figure 4 Filter and bypass / NRV assembly

Figure 3 Tottus site installed PRVs

Figure 5 Brazing

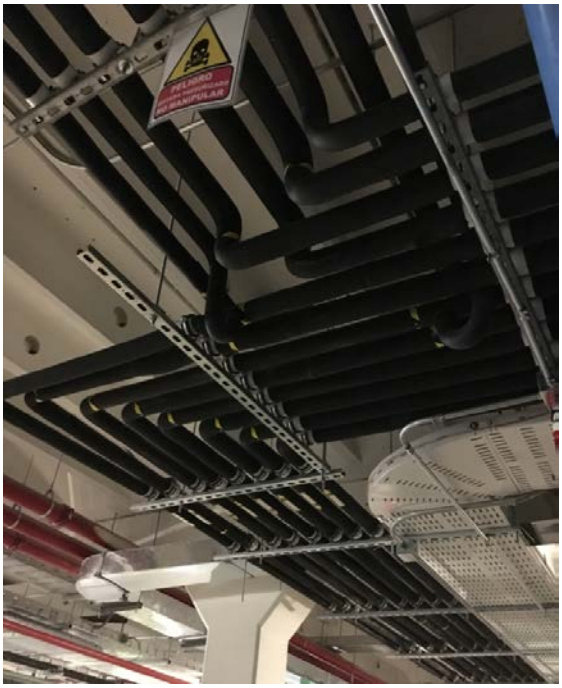

Figure 6 Pipe support and insulation