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Final Performance Report, Phase 2
Refrigeration System Conversion to R-434A (RS-45)

For

Advanced Refrigerant Technologies (ART)
1613 Highway 3, South
League City, TX 77573

For

Occidental Chemical Co.
Choromethanes II
Wichita, KS

Project 201708
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Texas Engineering Firm F-2055

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Introduction

The final performance evaluation (Phase 2 of 2) as proposed to ART in P-201708 dated January 23, 2017) was completed for the Chloromethanes II Refrigeration System, installed in Occidental Chemical Company's (Oxy) Wichita, KS plant. The final report provides additional technical details and modifications to the preliminary (Phase 1) report submitted February 16, 2017, for conversion of the system, presently operated with Refrigerant R-22, to operation on Refrigerant R-434A (trade name RS-45). Some information contained in the preliminary report has been revised due to the more detailed performance evaluation done for this report. Therefore, the results of the preliminary report are superseded by this report. Written information was supplied by Oxy. Also, operating experience and technical information was provided (and greatly appreciated) by Gene Koester, Production Supervisor for the plant, during a visit on Feb. 1 and 2, 2017.

The present system is a two-stage system using two parallel trains, consisting of two economized rotary screw booster compressors (operating at -20°F sat. evaporating temperature and +40°F sat. intermediate temperature) and two economized rotary screw high-stage compressors (operating at +40°F sat. evap. temp. and 105°F sat. condensing temp.), each compressor is equipped with a vertical oil separator. Major refrigeration components consist of low-stage and high-stage, flooded, shell and tube economizers, an intermediate-temperature flooded shell and tube sub-cooler, low-stage and high stage suction accumulators, a water-cooled refrigerant condenser, and a high-pressure receiver. Oil cooling for the compressors is provided by a thermosiphon oil cooling system including pilot receiver and a shell and tube oil cooler for each compressor. Each compressor is equipped with a lube system with mechanical oil pumps and filter system.

The process system includes low-temperature loads at -20°F, and at +40°F. For the existing system, refrigerant is supplied to the low-temperature loads at 5.3°F and to the intermediate loads at +74°F.

System details are shown on Vilter original system P&IDs (1997), Oxy P&IDs (6-1-5-080009, 6-1-5-12617, -12622, -12632, dated 1990). Existing system operation is shown on Oxy PFD 6-1-5-08695 dated 2007; this PFD was used for the existing system performance on R-22.

Refrigerant R-434A technical information and thermodynamic properties were provided by Refrigerant Solutions, Ltd, Cheshire, UK, and by ART. R-22 data and properties were provided by ASHRAE publications.

Compressor performance for R-22 was also verified using a computer rating program for Howden compressors (the Vilter VRS-1900 uses a Howden compressor unit, WRV-193.36, and the Vilter VRS-1500 uses a Howden WRV-145.22 unit). Frick Coolware 9, a computer rating program from Frick Div., Johnson Controls Waynesboro, PA, was used to provide the estimated compressor ratings for R-434A (Models RWFII-316 booster, RWFII-270 high-stage). The Frick compressors have displacements (swept volumes) slightly higher than the Howden units. Performance of system with R-434A was determined using ratios of the displacements. The Howden program does not include ratings for R-434A, but Frick does.

Section 1.0 contains a discussion of the findings of the Phase 2 detailed evaluation. Section 2.0 contains conclusions and recommendations regarding the conversion to R-434A. Spreadsheet 201708-Htbal-1, showing the mass flow analysis, compressor capacities, and other Phase 2 calculations, is submitted with this report. Flow Diagram 201708-PFD-1 is also included for the converted system.

1.0 Phase 2 Findings

1.1 Process Load Basis

For the Phase 2 evaluation, the present plant heat loads were determined for the R-22 mass flows as stated on the Oxy PFD. The -20°F load was considered equivalent to the maximum capacity of both boosters running at 100% capacity including normal losses (revised for this report). The -20°F load, at 698 tons (8,376,000 BTUH), is the load basis used for the Phase 2 evaluation. The +40°F process load was <u>estimated</u> using the R-22 mass flow shown on the Oxy PFD at 108,680 lb/hr. That flow rate equates to 641 tons (7,692,000 BTUH), plus the booster heat rejection at 860 tons, or 1,501 tons going to the high-stage compressors. The High-stage 100% capacity is 1,596 tons or 95 tons more than required. Therefore, the high-stage compressors, with R-22, presently operate at 95% capacity when the boosters are at 100%.

The evaluation also considered that the 40°F loads (641 tons) are not independent of the heat loads at -20°F because of process operations (changes in -20°F loads) are reflected in the +40°F loads.

Because the heat loads are independent of the refrigerant used, the loads used for the R-434A performance evaluation are: 693.4 tons, loads at -20°F, and 641 tons, loads a +40°F (the -20°F load at 693.4 tons is within 1% of the R-22 load and considered equal). Evaporating temperatures must remain the same (-20°F and 40°F) to achieve the required process operating temperatures, however the evaporating and condensing pressures will increase for R-434A. Also the average evaporating temperatures for the economizers (EX 33542 and EX 33543) are the same, but pressures will increase.

1.2 Heat and Mass Flow Evaluation

The flow diagram, 201708-PFD-1, prepared for the Phase 1 report, was revised for the final report, and shows the mass flow rates for the system operated on R-434A. It also provides performance information and other evaluation calculations for the converted system.

A detailed heat and mass-flow analysis (201708-Htbal-1, submitted with this report) was prepared for the converted system. Section I of the spreadsheet shows the mass flows for the streams shown on 201708-PFD-1. Section II shows the Booster and High Stage compressor ratings. Section III shows an evaluation of the Refrigerant Condenser (EX-33540), and Section IV shows evaluations of the Economizers (EX-33542 and EX-33543), the Refrigerant Intermediate Sub-Cooler (EX-33541), and Accumulators (VS-33510 and 33511).

Section V provides a discussion of the oil separators, SE-33516, 33521, 33526, and 33531. A check of the Level Control Valves for the Economizers, Sub Cooler, and process exchangers is included in Section VI of the spreadsheet. An evaluation of the system refrigerant pipe sizes is provided in Section VII.

Section VIII of the spreadsheet discusses oil return considerations with R-434A, and Section IX discusses the compatibility of Camco 4214 lube oil (presently in the system.

1.3 Evaluation Results

The Phase 2 evaluation confirms the findings of the Phase 1 report and the feasibility of conversion to operation on R-434A. Results show that essentially the same booster and high stage capacity as provided with R-22, will be provided with R-434A. This means that the existing system will adequately handle the process loads at -20°F and the intermediate process loads at +40°F. The BHP, will however, will increase by an estimated 2% for the boosters, and an estimated 5% for the high-stage compressors. Low-Temperature (-20°F) mass flow at 119,985 lb/hr is about 24% higher for R-434A, and High-Temperature (40°F) mass flow at 130,783 lb/hr is about 23% higher for R-434A. The preliminary evaluation results (same capacity, slight increase in BHP, and higher mass flows) track closely with the findings for similar industrial systems previously evaluated for conversion to R-434A.

1.3.1 Compressors

Each Booster compressor will provide 346.7 tons of capacity for a total of 693.4 tons with R-434A vs. 698 tons total on R-22. BHP each will be 386.6 bhp for a total of 773.3 BHP. Each High-Stage compressor will provide 794.8 tons, or a total of 1,589.6 tons, requiring 845.5 BHP each or a total of 1,691 BHP, if operated at 100% capacity. But the high-stage load requirement is limited to the booster total heat rejection plus the process load at 641 tons, or 1,462.4 tons, meaning the high-stage compressors operate at about 92% of full capacity (731.2 tons each), requiring 812 BHP.

1.3.2 Condenser

The condenser capacity must match the total heat rejection of the high-stage compressors (at 92% compressor capacity) or 21,680 MBH. The capacity of EX-33540 is 23,172 MBH, providing 1,492 MBH of excess capacity. It was found that the total heat rejection to the condenser is lower for R-434A due to the lower discharge temperature for R-434A. This means there is a bit more condenser capacity available if cooling water is a bit higher. The existing condenser is adequate.

1.3.3 Heat Exchangers and Vessels

The Economizers, EX 33542 an EX 33543, and the Sub Cooler EX 33541 all will provide adequate capacity and are sized to provide good liquid/vapor separation to prevent refrigerant liquid carryover. The evaluation shows vapor velocities all equal (or adequately close) to or less than allowed. The Accumulators VS 33510 and VS 33511 were also shown to provide good liquid/vapor separation (based on vapor velocities shown).

1.3.4 Oil Separators

The compressor rating programs did not indicate that non-standard oil separators are required for R-434A. (The rating program lists a warning if standard oil separators are not adequate). The ratings were based on POE oil (Camco 4214). Therefore, the existing oil separators should be adequate.

1.3.5 Level Control Valves

The increased flows, to process loads (low-temperature and high-temperature process users) will require level control valves to operate about 20 to 30% wider open. The existing valves should be capable of handling the higher flows. Note that for the low-temperature loads, the load distribution among EX 539, EX 508, and EX 510 is not known, so the percent increase in opening is stated as the percent increase in total flow to the low-temperature loads. Valve capacities should be confirmed by valve supplier.

1.3.6 Refrigerant Pipe Sizing

The pipe sizes were checked for adequate capacity for the estimated refrigerant loads (at the flows shown) for R-434A. The piping appears to be adequate based on the comparison for R-22 (the lowest allowed equivalent feet only about 15% less than that for R-22). Therefore, the piping should be adequate. The basis for sizing is ASHRAE pipe data for other refrigerants (R-22, R-404A, and R-507) with R-434A data estimated from that basis. The sizing allows for 2°F per 100 equivalent feet of pipe for vapor suction lines at -20°F, 0.3°, 40°F, and 69°F, discharge vapor lines at 1°F per 100 equivalent fee of pipe, and 1°F per 100 equivalent feet of pipe for liquid lines (at nominal 105°F condensing temperature).

It should be noted that an increase of 1°F per 100 equivalent amounts to a very small change in system loss, approximately ½% per degree.

1.3.7 Oil Return Considerations

The compressor lube oil system installed after initial commissioning of the system, and stated by Oxy to be operating acceptably for the existing system, appears to be adequate to properly return oil with R-434A in the system. There may be some minor changes in the rate of return, but the changes should be insignificant because the existing oil separators were shown, according to ratings on R-434A, to be adequate. Previous conversion evaluations indicate that oil return from evaporators should not be a concern.

1.3.8 Lube Oil Compatibility

The Camco 4214 Lube oil presently used in the existing refrigeration system was checked for compatibility with Camco, the oil supplier, and according to Camco, the POE oil is correct for use with R-434 A. Also, Camco indicated that Type 4214 is stated by Howden to be acceptable for use in Howden compressors. R.A. Corbett Engineering requires the end user to select lube oil in cooperation with the compressor manufacturer and does not specify lube oils.

1.3.9 Zeotropic Blends

There is some concern that conversion to R-434A, a zeotropic blend, could result in performance degradation associated with system leaks due to fractionation of the refrigerant blend components. Recent experience has shown that fractionation due to leaks has not been a significant problem. Leaks would likely cause performance degradation due to inadequate charge before degradation due to fractionation would occur. Never the less, judicious leak checking and repair should be done to minimize performance degradation due to either cause.

Also, regular testing of the refrigerant composition, could provide indication of when the refrigerant would need replacing and that, coupled with an arrangement with the refrigerant supplier to reclaim or recondition the refrigerant, could minimize the cost of maintaining refrigerant quality and system performance.

2.0 Recommendations and Conclusions

Recommended procedures for doing the conversion and some summary conclusions are included in the following:

2.1 Recommendations for Conversion

There are some procedures that are recommended to be followed for converting the system to operation on R-434A to ensure proper removal of the R-22 and existing oil, and to minimize converted system problems due inadequate startup procedures.

2.1.1 After shutdown of the existing system, the entire R-22 and lube oil charge is to be removed from the system by technicians and equipment certified in accordance with 40CFR, Part 82 to ensure regulatory compliance for the removal. Document and file the actual amount of R-22 removed to ensure compliance with regulatory requirements. Based on information from the refrigerant manufacturer, Camco, a small amount of oil left over after recovery should not be a problem.

2.1.2 It is recommended that the system should be evacuated using a suitable industrial vacuum pump to a minimum pressure of 29" Hg vacuum to ensure complete recovery of R-22.

2.1.3 The existing refrigerant should analyzed by a qualified testing laboratory to check for water or any other contaminants that might be present. Any water found would indicate the need to check the water-cooled condenser for leaks, and the need for thorough drying of the system using a dry-nitrogen purge followed up with a vacuum-rise test before charging new refrigerant

2.1.4 After removal of R-22 and oil and checking for water, it is recommended that a thorough leak check of the system and components should be conducted using nitrogen at a test pressure of about 150 psig. Note that the pressure test is not to confirm the maximum allowable pressure of the system, but to check for system leaks that may need to be repaired before charging new refrigerant. Performing other preventative maintenance tasks may also be desired during the conversion down time.

2.1.5 A sample of the lube oil should also be analyzed for contaminants and appropriate action taken if contaminants are found.

2.1.6 Before charging new refrigerant, R-434A, the system should be evacuated to at least 1 mm Hg absolute pressure, but 500 microns Hg absolute is a preferred target.

2.1.7 Prior to charging refrigerant and oil into the system, conduct a pre-startup safety review as required by the standard operating procedures and safety requirements for Occidental Chemical Co.

2.1.8 Charge oil into the system, while the system is under vacuum, to the amount as required by system operating and maintenance requirements and Howden compressor instructions.

2.1.9 Refrigerant liquid only is to be charged into the system because R-434A is a blend. It is particularly important to follow the refrigerant manufacturer's recommendations for charging and topping off. Since R-434 liquid density is slightly lower than R-22 liquid density, a rough estimate of the amount of R-434A charge is estimated to be a bit less than the amount required for the R-22 charge. The actual amount charged into the system, after satisfactory performance at full process refrigeration load is achieved, must be documented and that amount retained on file to comply with regulatory requirements.

2.1.10 After charging refrigerant and oil into the system, follow Oxy operating procedures for startup of the system.

2.1.11 Be aware that the operating conditions for the system, particularly the normal operating suction pressures at full process heat loading, will be different than those for R-22. Also, some tweaking of control set points will likely be required as experience is gained with the new refrigerant.

2.1.12 Finally, it is recommended that regular and thorough leak checking be done to maintain, as close as possible, a leak free system, and coordination with the refrigerant supplier be maintained to check the refrigerant composition in order to maintain maximum performance of the system.

2.2 Conclusions

The findings of the Phase 2 preliminary evaluation of the Chloromethanes Refrigeration System at Occidental Chemical Company's Wichita, KS plant did not reveal any circumstances that rule out conversion of the system to operation on R-434A.

System capacity appears to remain essentially the same as operation on R-22, however some changes might be required (such as level control valves and controller settings, etc.). Set point changes will likely be needed for pressure regulators and compressor control.

Finally, the circumstances of using a near-azeotrope blend refrigerant (R-434A) may cause concern for performance loss due to leaks, but with regular leak checking, refrigerant analysis, and the ability of the refrigerant supplier to reclaim off-specification refrigerant, the concerns may be reduced, if not eliminated.

It should be understood that converting the system from R-22 to R-434A could result in unknown performance and compatibility issues not anticipated or revealed by the preliminary and detailed evaluations because of limited (but growing) experience with using R-434A in large refrigeration systems. Of course, continuing operation with R-22, and considering other conversion possibilities (ammonia, hydrocarbon refrigerants, etc.) present issues as well. Also note that no guarantee (or warranty) of system performance is provided by this report, or by R.A. Corbett Engineering.

Attachments

201708-Htbal-1
201708-PFD-1