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Detailed 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

Project 201619
ART P.O. No. 564

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Texas Engineering Firm F-2055

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Introduction

The detailed performance evaluation (Phase 2 of 2 as proposed to ART in P-201619 dated July 27, 2016) was completed for the Residue Refrigeration System, Residue Unit MR-22, installed in XXXXXXXXX Clear Lake Plant in Pasadena, TX, to confirm its performance if the system, presently operated with Refrigerant R-22, is operated with Refrigerant R-434A (trade name RS-45), and to confirm the performance of the components and piping of the system.

As described in the Preliminary Report submitted August 17, 2016, the system consists of the following major components: a Flooded Evaporator (HE-922 chiller) for chilling methanol and water circulated to maintain desired process temperatures, 2 Rotary Screw Refrigeration Compressors (C-103, C-104), 2 Compressor Oil Coolers (HE-920 and 921) an Oil Separator (V-899) common to both compressors, a Flash Economizer unit (V-890) common to both compressors, a Heat Recovery Condenser (HE-923) for recovering heat rejection of the refrigeration system to provide process heating requirements, a Supplementary Condenser (HE-924) to supplement HE-923 when the refrigeration system heat rejection exceeds heat recovery requirements, a Refrigerant Surge Receiver (V-892), and microprocessor controls.

Complete system details are provided on P&IDs, XXXXXXX Drawings 64FA0035-005, -006, and -009, and 64FA0037-006. The system depicted by these drawings and other data and information provided by XXXXXXX were used for the detailed evaluation covered in this report. Refrigerant R-434A technical information and thermodynamic properties were provided by Refrigerant Solutions, Ltd, Cheshire, UK, and by ART.

Compressor performance was determined from Frick Coolware 9, a computer rating program from Frick Div., Johnson Controls Waynesboro, PA. The two screw compressors are Frick TDSH-193L units installed as Frick Package Model RWBII-134, modified for the specific application.

Section 1.0 contains a discussion of the findings of the Phase 2 detailed evaluation. Summary findings are presented in Section 1.1. Section 1.2 contains a discussion and detailed results of the compressor rating runs and component evaluations, as detailed on Htbal 1-201619 and as represented on the refrigerant process flow diagram, 201619-PFD-1. Htbal 1-201619 and 201619-PFD-1 are contained in the Appendix of this report. Conclusions and a discussion of the some recommended conversion procedures are provided in Section 2.0.

1.0 Phase 1 Findings

1.1 Summary Findings

The detailed evaluation confirms that conversion of Refrigeration Unit MR-22 to operation on R-434A will allow the system to maintain equivalent capacity to the system now operating on R-22, as was indicated by the preliminary evaluation submitted on August 17, 2016. The detailed evaluation also found that the major system components, Chiller HE-922, Flash Economizer V-890, Heat Recovery Condenser HE-923, Condenser HE-924, the common Oil Separator V-889, Oil Coolers HE-920 and HE0-921, and the Compressors C-103 and C-104 will provide adequate capacity when operated on R-434A.

Because R-434A will operate at higher mass flow rates than R-22, the level control valves LV-7927 and LV 7929 will have to increase in capacity by changing the valve trim for both. (or replacing the valves) System piping is confirmed to be adequately sized, except the suction piping from the Economizer V-890 to the compressor economizer ports may be slightly marginal at 100% capacity of the system (however the small losses found are likely acceptable with the existing piping).

The lubrication oil for the compressors was examined because the Frick Rating program called for using Frick #13 oil for R-434A vs. Frick #2A for R-22. XXXXXXX is presently using synthetic Mobil Gargoyle Arctic SHC 224 in the MR-22 unit with satisfactory performance. XXXXXXX may want to further investigate the lube oil to be used after conversion since Frick suggests #13 and Mobil indicates SHC 224 is compatible, but recommends using Mobil Arctic EAL series mineral oil (see Section 1.2.11).

The concern for refrigerant property degradation due to leaks, as stated in the preliminary evaluation, remains a concern, but as stated in the preliminary report, judicious leak detection and repair and regular analysis of the refrigerant in the system, the concern may minimize the concern. And coordination with a supplier (such as Advanced Refrigerant Technologies) that is also a qualified refrigerant reclamation service provider will help reduce, or at least control the potential for degradation due to leaks.

Except for the previous statements, the detailed evaluation found no specific circumstances or issues that would suggest that conversion to R-434A should not be done. It should be noted however, that experience with using R-434A in systems of the type and size as XXXXXXX's MR-22 is limited, and issues unforeseen by the scope of this evaluation could arise that might affect performance of the system.

In summary, MR 22 converted to R-434a will provide capacity for maximum refrigeration loads of 294.4 tons (3,522,800 BTUH) at -15.7°F at 100% capacity (both compressors at 100%), and 250 tons (3,000,000 BTUH) at -22.9°F at 100% capacity (both compressors at 100%). Heat recovery available will be 5,163,600 BTUH at -15.7°F and 100%, and 4,832,156 BTUH at -22.9°F and 100%.

Section 1.2 following provides the details of this evaluation, and additional attachments in the Appendix report provide the calculations and data used for the conclusions stated in this report. Section 2.0 provides some recommended procedures for removing R-22 and charging R-434A.

1.2 Evaluation Details

Four operating conditions at average evaporating temperatures were considered for this evaluation and included:

- -15°F saturated evaporating temperature with both compressors at 100% capacity
- -15°F saturated evaporating temperature with one compressor at 100%, one at 75%
- -22°F saturated evaporating temperature with both compressor at 100% capacity
- -22°F saturated evaporating temperature with one compressor at 100%, one at 75%

All four conditions were based on an average condensing temperature of nominally 105°F and with heat recover by HE-923, supplemented by HE-924. The above conditions were chosen to represent maximum capacity available from the MR-22 unit and an estimate of current process refrigeration load. The performance was calculated at -15.7°F and -22.9°F saturated evaporating temperatures and at 105.8°F saturated evaporating temperature (this is due to "glide" for R-434A as discussed in the preliminary report).

System performance for each condition is shown on Spreadsheet Htbal 1-201619 showing the heat loads and refrigerant mass flows for each condition. Compressor ratings are also shown for each condition, as are component and piping analyses. Please refer to notes on Htbal 1-201619 for additional explanatory information. A process flow diagram, 201619-PFD-1, is provided for Htbal 1-201619. Performance comparisons with operation R-22 are not presented here, as they are available in the preliminary report previously submitted.

1.2.1 Item I of Htbal 1-201619 shows the mass-flow results at -15.7°F evaporating temperature. It is based on the total process heat load at 294.4 tons which is equivalent to the maximum capacity available with both compressors operating at 100% capacity. Each compressor provides 147.2 tons of refrigeration. The capacity is based on economized operation with the economizer load at 124.4 tons (each compressor providing 62.2 tons of capacity for the economizer at 25.15°F). Note that the total mass flow to HE-922 is 55,722 lb/hr. With HE-922 mass flow added to the economizer flow at 32,454 lb/hr, the flow from the compressors and to HE-923 is 88,187 lb/hr. Note that the Condenser HE-924 is considered inactive because the entire heat rejection from the system is absorbed by HE-924.

1.2.2 Item II shows the results for -15.7°F with one compressor at 100% and the other at 75%. Note that this represents present system operations. Total load and capacity is 257.6 tons, 147.2 tons for one compressor and 110.4 tons for the other, resulting in 46,757 lb/hr to HE-922 and 77,163 lb/hr to HE-923.

1.2.3 Item III shows the results for -22.9°F.: 250 tons total, 125 tons per compressor, 46,012 lb/hr to HE-922, and 77,673 lb/hr to HE-923, both compressors at 100%.

1.2.4 Item IV shows the results for -22.9°F at 218.8 tons, 125 tons for one compressor and 93.8 tons for the other. Flow to HE-922 is 41,404 lb/hr and flow to HE-923 is 65,526 lb/hr.

1.2.5 Item V of Htbal 1-201619 rates the compressors at the four conditions using Frick Coolware 9. The compressor rating information for each condition is used to calculate the total heat rejection for each condition. The heat rejections are larger than those for R-22 (refer to the preliminary report submitted Aug. 17, 2016). The actual evaporating and condensing temperatures (-15.7°F, -22.9°F, and 105.8°F) provide some conservatism in the ratings since the evaporating temperatures used for the analyses are -15.7°F and -22.9°F respectively, and 105.8°F for the condensing temperature.

1.2.6 Item VI of Htbal 1-201619 shows the results of the analyses of the Flash Economizer V-890 and the Chiller HE-922. Both units were analyzed for vapor velocity to allow good liquid/vapor separation to prevent liquid refrigerant carryover into the compressors. Allowable velocities are determined by the equation shown which uses vapor and liquid densities and a factor to estimate the allowable velocity. The factor used is 0.2 which is based on low to moderate liquid entrainment in the vessel.

For the V-890, a 36" dia., vertical vessel, the allowable velocities are shown for the four conditions, 83 and 89 fpm respectively. In all four conditions, the velocities are conservatively below the allowable.

For HE-922 Surge Drum, a 36" dia., horizontal vessel, the allowable velocities are shown four conditions, also 83 and 89 fpm respectively, but resulting from horizontal flow through the drum and at half of the total flow rate through HE-922. Again, the velocities are conservatively below the allowable.

Based on the results indicated, V-890 and the Surge Drum for HE-922 are adequately sized to prevent liquid carry over, even though the mass flow rates are higher than those for R-22.

1.2.7 Item VII provides evaluation of the heat absorbing capacities for Chiller HE-922, Heat Recovery Condenser HE-923, and the water cooled Condenser HE-924. Note that normally HE-924 is not in service since the total heat rejection is sent to HE-923. However, at -15°F evaporating, the total heat rejection exceeds the capacity of HE-923 and the excess is sent to HE-924.

Based on the data sheet provided by XXXXXXX, HE-922 has a duty of 4,078,800 BTUH for capacity required of 3,532,800 BTUH (294.4 tons), indicating sufficient capacity for conversion to R-434A. The other 3 conditions result in lower capacity so the chiller is adequate for all conditions evaluated.

HE-923 Heat Recovery Condenser comes up a bit short of capacity at -15°F, 5,163,600 BTUH duty per its data sheet for rejection of 5,498,034 BTUH. But the total heat rejected to HE-923 is significantly higher than it would be for R-22 at the same conditions (see the preliminary report dated Aug. 17, 2016). And with HE-924 available, even if the heat rejection approached maximum, there would still be adequate condensing capacity available (for a system upset or during system pull down during startup).

The flow rates of heat-transfer fluid (MeOH) and for cooling water are shown for comparison to present flow rates.

The results of the analyses for Item VII indicate adequate capacity for the existing Chiller HE-922, the Heat Recovery Condenser HE-923, and the water cooled Condenser HE-924.

1.2.8 Item VIII shows the analyses of the refrigerant pipe sizes conducted because of the higher mass flow rates for R-434A compared to R-22. The estimated pressure drop was determined from ASHRAE pipe pressure drop data for at the indicated flow rates for the piping indicated Items VIII A through VIII F. Note that the pipe lengths shown are conservative estimates. Note that the suction piping from the economizer was indicated to be slightly marginal at 2.55, 2.40 and 1.55 psi losses.

Normal design would limit the total loss to about 1.0 psi. It was also noted that a rough estimate for this piping with R-22 showed it also to be slightly marginal. The conclusion is that even though this piping is bi marginal, the performance loss resulting is not high enough to be of concern.

1.2.9 Item IX provides the results of an evaluation of the oil coolers. A search for data during a visit to XXXXXXX on September 2, 2016 found two data sheets that appeared to be HE-920 and HE-921, the oil coolers for C-104 and C-104. That data showed that each oil cooler had a duty of 930,000 BTUH. This is much higher than the oil cooler heat load for each compressor even for operation on R-22 (about 240,000 BTUH each). The P&ID for the oil coolers indicates a duty of l93 MMBTU/hr. This is way too high. The P&ID for the oil coolers also shows 174 5/8” tubes 12’-0” long and 892 sq. ft of surface. But the RECO drawing indicates 650 5/8” tubes 12’-0” long without indicating the surface area. The tube diameter and count would have estimated 1,200 sq. ft of surface. Obviously, there is significant inconsistency in the data for the oil coolers.

But the oil cooler heat loads for R-434A are much lower than any of the data found. For this reason, and noting the physical size of the installed oil coolers, the existing oil coolers should be more than adequate.

1.2.10 Since the oil separator sizing stated on the compressor rating runs indicated a 36” dia. separator with 3 coalescer elements for operation with R-434A vs. a 24” dia. separator with 2 coalescers for operation with R-22, Item X shows an analysis of the common separator installed for the existing system/

The velocities through the 36” separator with demister vessels were calculated for both R-22 and R-434A. The velocities through each of the 3, 9” coalescers were calculated for R-22 and R-434A.

The results indicate that on R-434A the velocity through a coalescer is higher than that for R-22. So to compare, the velocity through each of 2, 9” coalescers for R-22 operated at -8°F was calculated and found to be 290 fpm. Based on that result, the 247.52 fpm for R-434A should not be of concern.

The velocity through the 36” dia. separator demister was determined to be 46.41 fpm for R-434A with an estimated maximum of 69.11 fpm allowed. Based on these estimates it is concluded that the 36” dia. separator with demister and 3 coalescers will be adequate for R-434A.

1.2.11 Mobil was contacted for comment on the compatibility of SHC-224 for operation with R-434A. Mobil stated, “It (meaning R-434A, my comment) is compatible with mineral and synthetic lubricants but I think EAL Arctic series would be best.” It appears from this statement that Mobil would prefer a different oil, but does not state specifically that the SHC-224 is not recommended. Therefore, some additional consideration for changing the oil should be perhaps considered by discussing the oil choice with Frick and perhaps further discussion with Mobil. Changing oil is not considered a significant change for the system from the standpoint of the findings of this evaluation, but a change is also not specifically required.

2.0 Conclusions

The detailed evaluation found that the performance of the system will be adequate and the system components will have adequate capacity. Existing refrigerant piping is adequate. However, to achieve the performance calculated, the liquid level control valves will have to be increased in size or trim.

The lubricating oil will have to be studied further to confirm using the existing oil after conversion or use an oil suggested by Frick or by Mobil.

To do the conversion, some recommended procedures are presented along with regulatory requirements for recovery and storage of the existing R-22.

2.1 System Performance

The results of the detailed analysis of MR-22 operating on R-434A show the refrigeration capacity available for process operations at -15°F and -22°F and the heat available for recovery for process heating requirements.

Capacity will be essentially the same as for R-22 at the same system operating conditions:

	Capacity, R-434a	Capacity R-22
-15°F	294.4 tons	291.6 tons
-22°F	250.0 tons	248.0 tons

Heat available for recovery will be higher for R-434A than for R-22:

	Available Heat Recovery R-434a	Available Heat Recovery R-22
-15°F	5,163,600 BTUH	4,758,000 BTUH
-22°F	4,832,156 BTUH	4,104,000 BTUH

The bhp requirement will be higher for R-434A:

	Bhp R-434A, Ea. Comp.	Bhp R-22 Ea. Comp.
-15°F	388.1 hp	335.1 hp
-22°F	371.2 hp	318.7 hp

The above results indicate that performance of the system will not be degraded by the conversion.

The results also indicate that the major components all have adequate capacity for operation on R-434A. In fact the existing heat exchangers are larger than actually required.

All system refrigerant piping is adequate. There is a minor concern that the economizer suction line to the compressors is slightly undersized, but the loss associated is small suggesting the existing piping will be adequate.

2.2 Lube Oil Considerations

Mobil, the present supplier for the system, was contacted to determine whether Mobil' Gargoyle SHC-224 would be compatible with R-434A. Mobil better choice would be Mobil Arctic EAL series mineral oil. Frick also stated Frick #13 for R-434A vs. #2A for R-22. The differences in recommendations call for a bit more study before deciding to use the SHC-224 existing oil.

2.3 Conversion Procedures and Recommendations

There are some procedures that are to be followed for converting the system to operation on R-434A to ensure proper removal of the R-22 and existing oil.

2.3.1 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 and Mobil, a small amount if oil left over after recovery should not be a problem (no problem if existing SCH-224 used).

2.3.2 For MR-22 it is recommended that the system should be evacuated using a suitable industrial vacuum pump to a minimum pressure of 1 mm (1,000 microns) HG absolute pressure to ensure complete recovery of R-22.

2.3.3 The existing refrigerant should analyzed by a qualified testing laboratory to check for water or coolant (MeOH) that might be present. Any water found would indicate the need for thorough drying of the system using a dry-nitrogen purge following up with a vacuum-rise test before charging new refrigerant. MeOH found could indicate leakage from heat the heat exchanger tubes of the Chiller and Heat Recovery Condenser (HE-922, HE-923). Water found could indicate leakage in the condenser HE-924 or in the oil coolers, HE-920 and 921. Thorough inspection and repair of the heat exchangers would be then recommended.

2.3.4 After removal of R-22 and oil and checking for MeOH and 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.

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

2.3.6 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.

2.3.7 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 XXXXXXX.

2.3.8 Charge oil into the system, while the system is under vacuum, to the amount as required by XXXXXXX standard operating and maintenance requirements and Frick compressor instructions.

2.3.9 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. The current inventory of R-22 in the system is 14,000 lb. 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 more than 12,000 lb. 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.

2.3.10 After charging refrigerant and oil into the system, follow XXXXXXX standard operating procedures for startup of the system.

2.3.11 Be aware that the operating conditions for the system, particularly the normal operating suction pressure 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.

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APPENDIX

Frick Compressor Rating R-434A at -15.7°F
Frick Compressor Rating R-434A at -22.9°F
201619-PFD-1 Process Flow Diagram
Htbal 1-201619 System Heat and Mass Flow Analyses
Fisher Valve Specifications, LV-7927 and LV-7929