

**EQUILIBRIUM POINT DRYNESS AND WATER CAPACITY
OF DESICCANTS WITH ALTERNATIVE REFRIGERANTS**

Final Report

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ABSTRACT

The purpose of this project was to construct equilibrium point dryness (hereinafter EPD) curves using data collected in this research for HFC refrigerants and HFC refrigerant blends in equilibrium conditions with a variety of desiccants at two temperatures, 24°C (75°F) and 52°C (125°F). Four HFC refrigerants (R-32, R-125, R-134a, and R-143a) and three HFC refrigerant blends (R407C, R410A, and R507A) were studied in combination with six commonly used desiccants: UOP 4AXH-6 molecular sieve, UOP XH-11 molecular sieve, Grace 511 molecular sieve, Bayer Scale/SA-40 alumina, Lonza alumina, and Alcoa F-200 alumina.

EPD curves were based on total water content of the refrigerant and total water content found in the desiccant after equilibrium. Each curve consists of six to twelve points of varying moisture content aliquots of a given desiccant. Each desiccant aliquot was placed one at a time in an environmentally controlled, closed, flow-through, circulating system (hereinafter EPD test system) for 16 hours to establish water equilibrium between the desiccant and refrigerant. Isotherm curves were made for each refrigerant/desiccant equilibrium combination at 24°C (75°F) and 52°C (125°F). To maintain uniformity in this project, the amount of desiccant (35g), the amount of refrigerant (500g), and the temperature (24°C (75°F) and 52°C (125°F)) remained constant. The desiccant and refrigerant amounts were selected to mimic a typical operating refrigeration system.

In this project, three moisture determinations were made for each refrigerant/desiccant equilibrium test point to determine refrigerant water content. The triplicate refrigerant-moisture determinations, in parts per million (ppm), were made using a Karl Fischer coulometer. A sample of the refrigerant/water mixture was isolated in the sample loop with a valve and vented under the controlled conditions of a needle valve into the coulometer.

Total water content (%) of each desiccant sample was determined using a dry nitrogen-purged tube furnace and a Karl Fischer titrator. One measurement was made for desiccant moisture content along with blanks and duplicates for quality assurance purposes.

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INTRODUCTION

Desiccants play the vital role of maintaining hermetic refrigerant systems in an acceptably dry state, free of circulating contaminants (Cavestri and Schooley 1998). Historically, refrigerant systems have used CFC and HCFC chemicals with mineral or alkylbenzene lubricants. However, the latest systems are quite different; HFC refrigerants generally use polyolester lubricants, which are polar, oxygen-bearing lubricants. The thermodynamics of equilibrium water retention on the desiccant with refrigerant can be quite different and require measurement. The circulating water equilibrium conditions are desiccant-temperature dependent.

Hermetic systems use desiccants either in a loose form or as molded solid blocks with screens or filter pads housed in metal shells known as filter driers. Filter driers are generally installed in the liquid line of refrigerant systems in order to provide continuous filtration and drying of the circulating medium. Although moisture can be one of the major contaminants found in refrigeration systems, the filter driers presently being used have the added advantage of removing some amount of inorganic acids and organic carboxylic acids (Cavestri and Schooley 1998, Schooley 1999). Another benefit is the filtration of many solid contaminants including dirt, metal particles, waxes, sludge, and varnishes.

Filter drier packages containing desiccants are usually placed in the fluid pulsations of the liquid line of refrigerant systems and are exposed to a variety of mechanical vibrations. Therefore, the beaded materials need to be physically strong and show low attrition rates. Desiccant beads and crushed granules can be used as manufactured, held in a mechanical chamber with screens and springs. Desiccants can also be bonded into a solid core or block. The construction of a solid core produces a rigid assembly that also acts as a controlled pass filter.

Regardless of the refrigerant or lubricant used, moisture can cause problems in refrigeration and air-conditioning systems. These problems can be ameliorated when new, field-service refrigerant reclaim/recycle equipment uses loose or solid filter driers. For maximum life and reliability, it is essential for the system to be maintained at a minimum circulating water content to minimize corrosion and polyolester hydrolysis. A properly desiccated system will normally have a water content below 50ppm.

In the newer HFC operating systems that use polyolester lubricants, larger desiccant drier loads may be necessary so that refrigerant and lubricant systems are at a nominal circulating level

of 10 to 30ppm moisture. Unlike mineral oil lubricants, polyolesters tend to be hygroscopic and need to be safeguarded from atmospheric moisture. Hydrolysis of polyolesters is temperature and moisture level dependent, occurring slower at lower temperatures and moisture levels (10-30ppm).

Retained system moisture must be a consideration when manufacturing and repairing HVAC systems. Some amount of moisture is present regardless of refrigerant and desiccant selection. Since trace amounts of water are present, it may be necessary to use over-sized driers so that polyolester hydrolysis is not a concern. Both activated molecular sieve and activated alumina driers have an excellent history of maintaining dry and acid-free hermetic systems.

Desiccant materials are typically 3Å and 4Å pore size molecular sieves, activated crystalline alumina, or silica gel beads. Desiccants in a molded core use combinations of molecular sieves, alumina, silica gel, and sometimes carbon, with a suitable binder. The binder used with inorganic desiccants is either an organic polymer or an inorganic phosphate salt complex. This research study was designed to ascertain the water capacity of two prominent desiccant types: molecular sieve beads and activated crystalline alumina beads.

The equilibrium water capacity of various desiccants in the presence of alternate refrigerant and lubricant mixtures is important information. New equipment manufacturers need isothermal curves of water equilibrium with various desiccants to install the proper size and type of desiccant into refrigeration and HVAC systems. Since equipment manufacturers are currently investigating several HFC blends containing R-32, R-125, R-134a, and R-143a, data on the performance of desiccants with individual component refrigerants provides useful information for predicting desiccant performance in HFC blends.

BACKGROUND

Desiccants are generally inorganic materials that are insoluble in circulating organic media. Desiccants can be made anhydrous, or nearly so, by activation (drying) at elevated temperatures for a specified period. Desiccant materials, whether zeolites or alumina, when placed in a circulating refrigerant environment, extract water by either an adsorption process or by water becoming part of the chemical structure (absorption). The amount of water removed from the refrigerant/lubricant medium depends on the refrigerant type, the temperature of the environment, the type of desiccant, and the amount of water in the desiccant. Pure refrigerant is

more effectively dehydrated when compared with refrigerant containing a lubricant because the lubricant may impact the rate of desiccation and its equilibrium level dryness point (Cavestri and Schafer 1999).

Desiccants differ in their ability to adsorb and retain water of hydration. The equilibrium amount of water circulating in the refrigerant/lubricant mixture is highly dependent on the chemistry and structure of the desiccant, the competition of adsorbed refrigerant for water sites, the action, if any, of the lubricant on the desiccant surface, and the temperature of the mixture. Typically, increased circulating water levels in refrigerant are seen with increased temperatures and increased water content in the desiccant.

Depending on the structure and type of desiccant, R-32 uptake could have been an issue in this research because the desiccant package was removed and replaced with each new desiccant sample to form the isothermal curve. The composition change (content) of the R-32 remaining in liquid refrigerant blends was not addressed as part of this research project.

Molecular Sieve

Available information suggests that refrigerant R-32, contained in alternate refrigerant blends, is selectively adsorbed and retained by some desiccants (Cohen 1996). The amount of composition change could affect the moisture isotherm curve and provide misleading results of desiccant moisture capacity. Theoretically, some types of molecular sieve beads may be more prone to competition by R-32 than water at the water adsorption site. Pore size in the zeolite is the principal factor in its capacity for adsorbing and retaining water from refrigerant/lubricant mixtures. Inorganic and organic binders are used to form solid core filter driers containing molecular sieve products. These binders may also have some impact on reducing the effectiveness of water entering the bonded core.

Alumina Beads

Crushed or beaded activated alumina is an important ingredient in both loose fill and bonded filter drier cores. Depending on the chemistry, manufacturing, and construction of the alumina beads, alumina can be made more attractive to polar compounds, acids, and/or other chemistries. The structure of some alumina types may not be affected by the R-32 competition for water and organic acid absorption sites.

In neutral, dry, non-polar refrigerant systems that use mineral oil, alumina has an affinity for oil polymers and retains large amounts of system acids (Cavestri and Schooley 1998). The absorptive qualities of alumina seem to remain the same regardless of the pH value when measured in a water slurry. Some types of alumina have very selective retentive qualities for carboxylic acids, a prime benefit with polyolester lubricants. Alumina bead can be acidic, neutral, or alkaline. These qualities of alumina can be determined by measuring the pH of a slurry of the powder in distilled water. In refrigerant media, the *alkalinity* of alumina is diminished to very low levels. The pH characteristics of alumina are determined during the manufacturing process. Alumina also has several absorption activity ranges, the highest being Brockmann I (very dry) to the lowest activity Brockmann V (least dry, nearly saturated). The activity range depends on the amount of water of hydration, the refrigerant media, and other crystalline surface characteristics. Acid washed alumina is best for refrigerant service because of regulated pore size and its neutrality to polyolester systems using HFCs.

ANALYTICAL PROTOCOL

The purpose of this project was to construct equilibrium point dryness (hereinafter EPD) curves using data collected in this research for HFC refrigerants and HFC refrigerant blends in equilibrium conditions with a variety of desiccants at two temperatures, 24°C (75°F) and 52°C (125°F). Four HFC refrigerants, three HFC refrigerant blends, and six commonly used desiccants were examined (Table 1). Table 2 displays the combinations studied.

Table 1
Nomenclature and Description of HFC Refrigerants,
HFC Refrigerant Blends, and Desiccants Examined

Refrigerant	Manufacturer/ Vendor	Description
R-32	ICI & National Refrigerants, Inc.	HFC
R-125	Allied Signal	
R-134a		
R-143a		
R407C		HFC Blend
R410A		
R507A		
Desiccant		
4AXH-6	UOP	type 3A
XH-11		3Å molecular sieve
511	Grace	type 4A 4Å molecular sieve
Bayer Scale	Sporlan	scale alumina
Lonza	Lonza	trihydrate alumina
F-200	Alcoa	

Table 2
Test Matrix

HFC Refrigerant or Blend	Desiccant							
	4AXH- 6	XH-11	511	Bayer Scale (BS)	4AXH- 6/BS (50:50)	XH- 11/BS (50:50)	Lonza	F-200
R-134a	√		√	√	√		√	√
R-32	√	√	√	√		√		
R-125	√		√	√	√			
R-143a	√		√	√	√			
R507A	√		√	√	√			
R407C		√	√	√		√		
R410A		√	√	√		√		

√ = combination tested

Introduction to the EPD Test System

The EPD test system, designed and built by Imagination Resources, Inc., is an environmentally controlled, closed, flow-through, circulating system designed to optimize the water equilibrium process between refrigerant and hydrated desiccant at specified temperatures between 24°C (75°F) and 52°C (125°F) (Figures 1-4, Pictures 1-2). Equilibrium was accomplished in the following manner. Refrigerant/water mixture was pumped with an in-line, hermetically sealed pump from the refrigerant holding cylinder through the open side of crossover valve #1 (COV1) (Figure 1) into the sample loop that accommodates 24-30g of refrigerant. The amount of refrigerant contained in the sample loop varies with each refrigerant and its density. When COV1 is closed (not in the flow-through position) the sample loop is isolated from the rest of the EPD system (Figure 2). This was useful for measuring the water content of a representative sample in the EPD system. From the sample loop, the refrigerant/water mixture travels through COV1 and into the open side of crossover valve #2 (COV2) (Figure 1). The flow of refrigerant/water mixture exits COV2 and enters valve #1 (V1). When V1 is in the flow-through position (Figure 1), refrigerant/water mixture is permitted to enter the desiccant chamber. Switching COV2 out of the flow-through position isolates the desiccant loop from the rest of the EPD system (Figure 3) and placing V1 in the alternative (not flow-through) position permits venting of refrigerant in the desiccant loop (Figure 4). This was necessary for changing the desiccant sample without losing the system's refrigerant load. The refrigerant/water mixture flows through V1 and enters the desiccant chamber, thereby allowing contact between refrigerant and hydrated desiccant (Figure 1). The refrigerant/water mixture leaves the desiccant chamber and flows through the other open side of COV2 continuing on to the refrigerant holding cylinder. This circulating pattern repeats itself for 16 hours. The pumping ability of this hermetic pump was measured at two liters/minute.

Charging the EPD System with Refrigerant

Before charging the EPD system with 500g of refrigerant, a vacuum must be applied to the entire system, with the exception of the desiccant loop, for 30-45 minutes using the Schrader valve at the top of the refrigerant holding cylinder. The system is capable of holding at least one

Figure 1
EPD Test System with Flow-Through Positioning

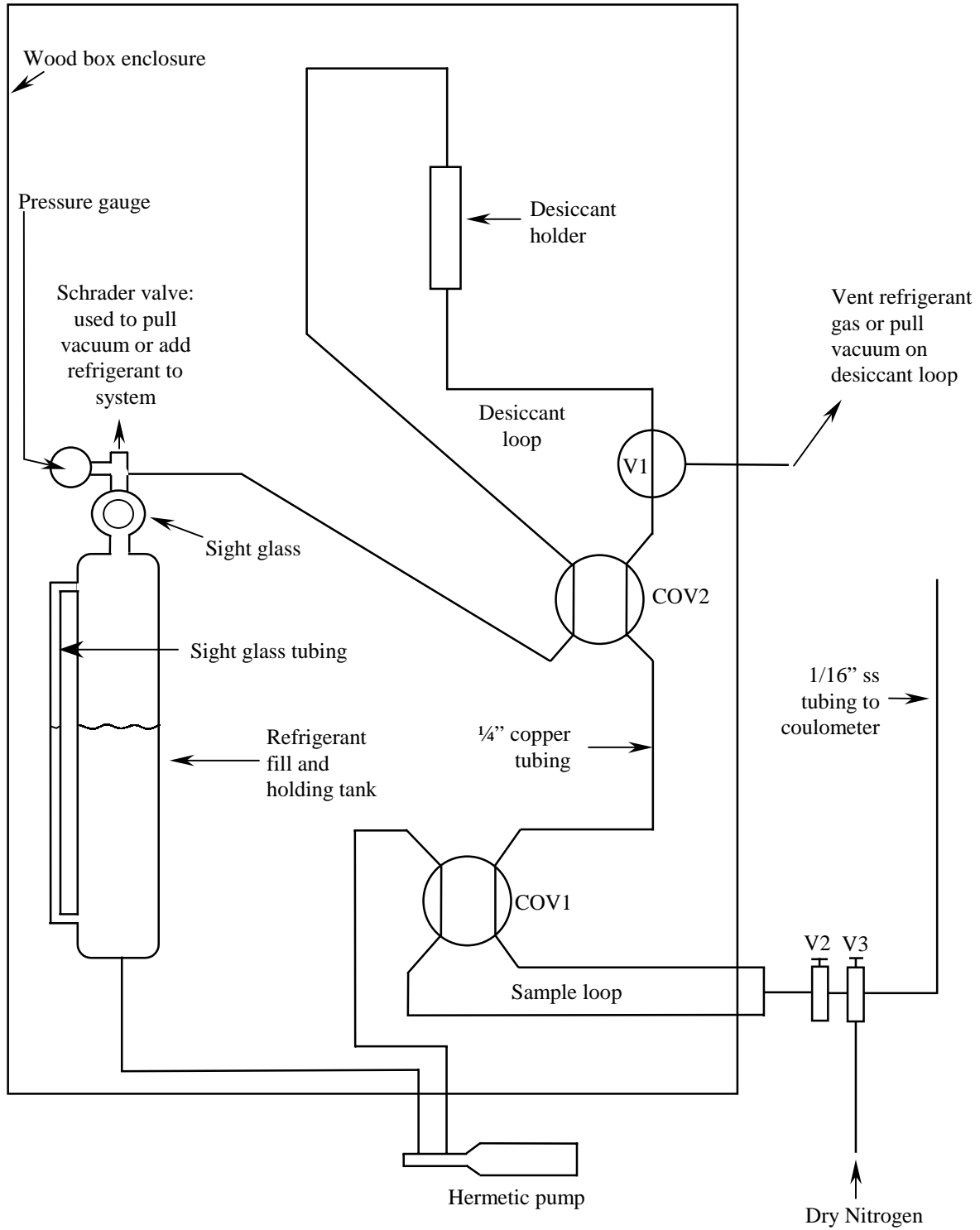


Figure 2
EPD Test System with Sample Loop Isolated

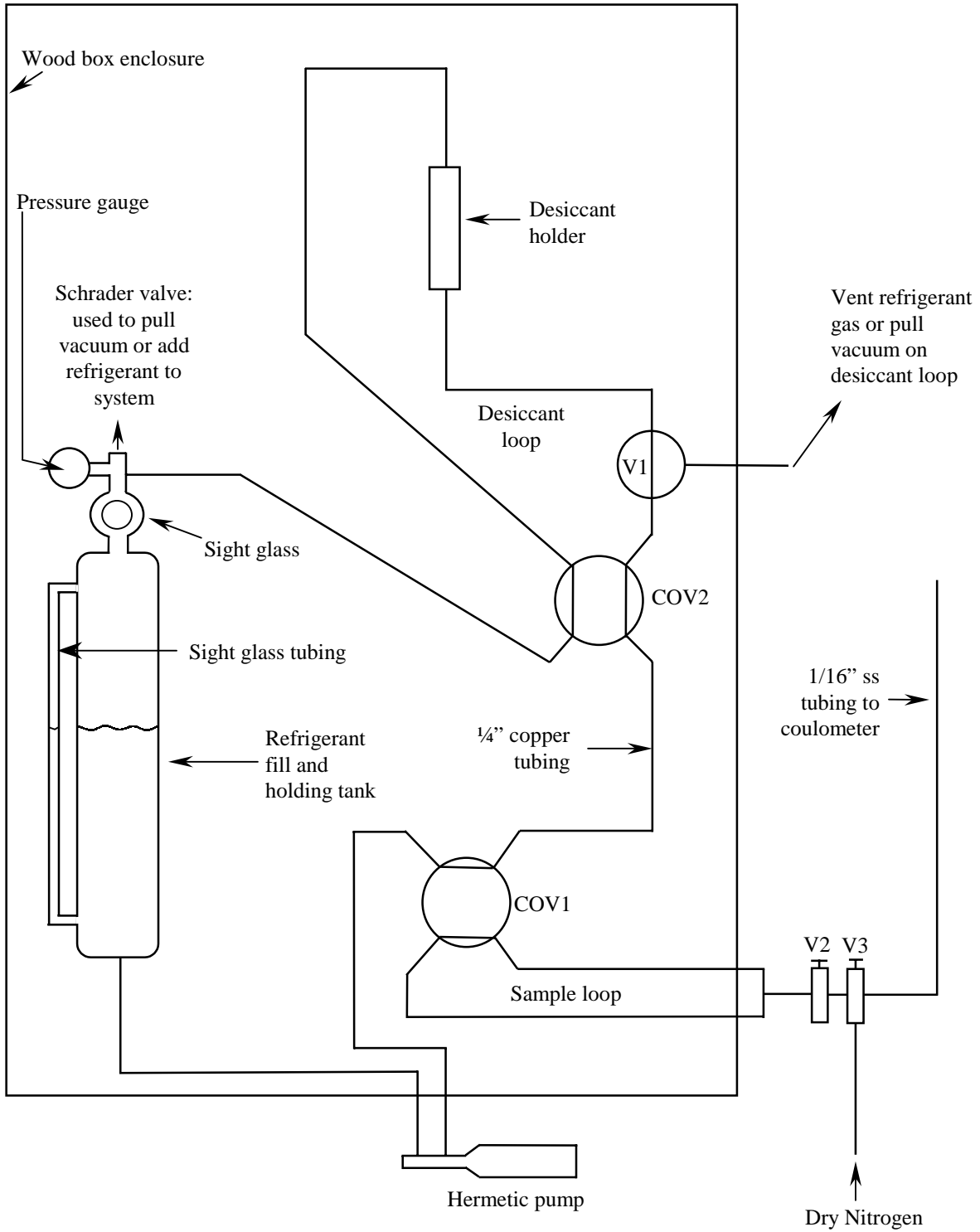


Figure 3
EPD Test System with Desiccant Loop Isolated

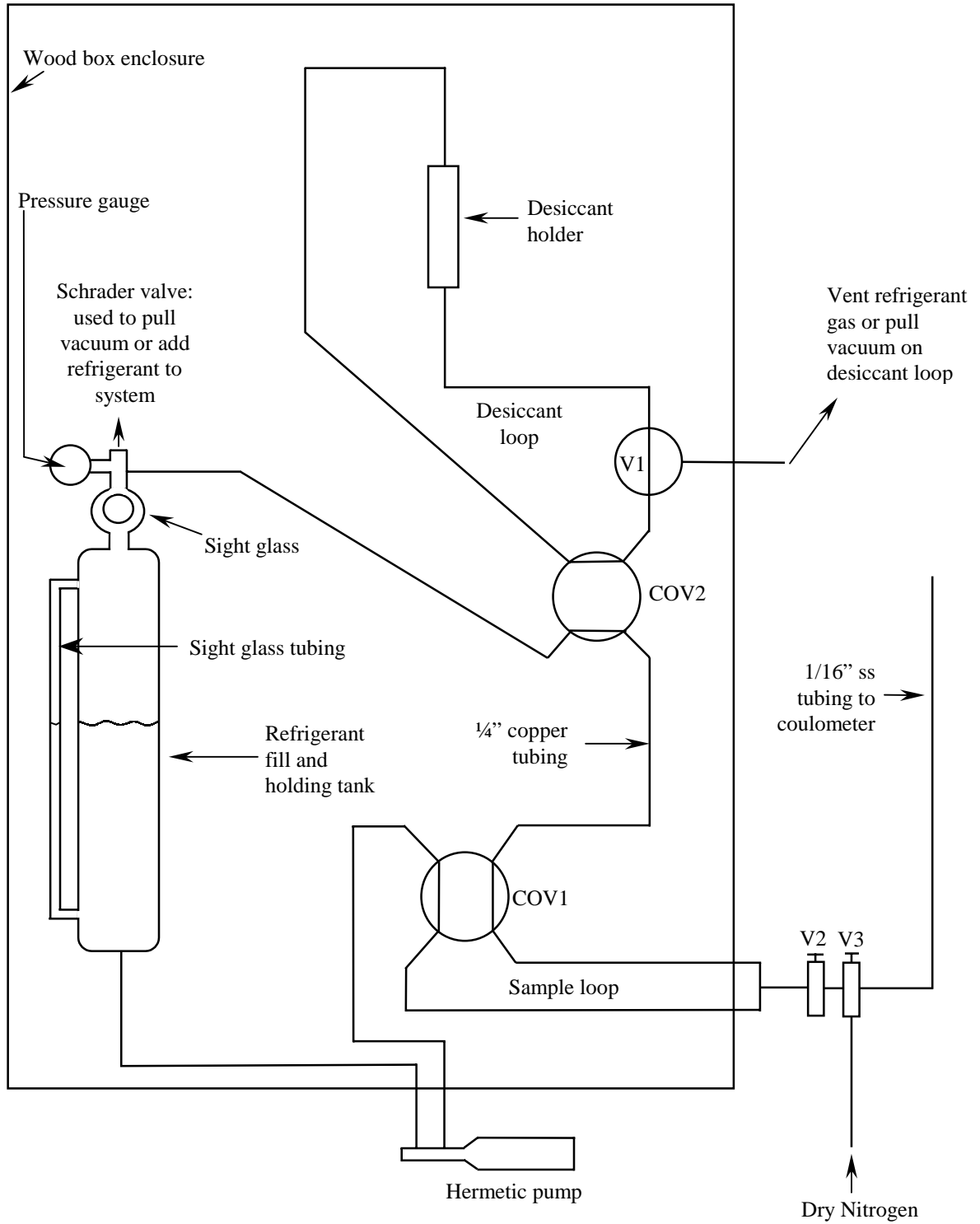
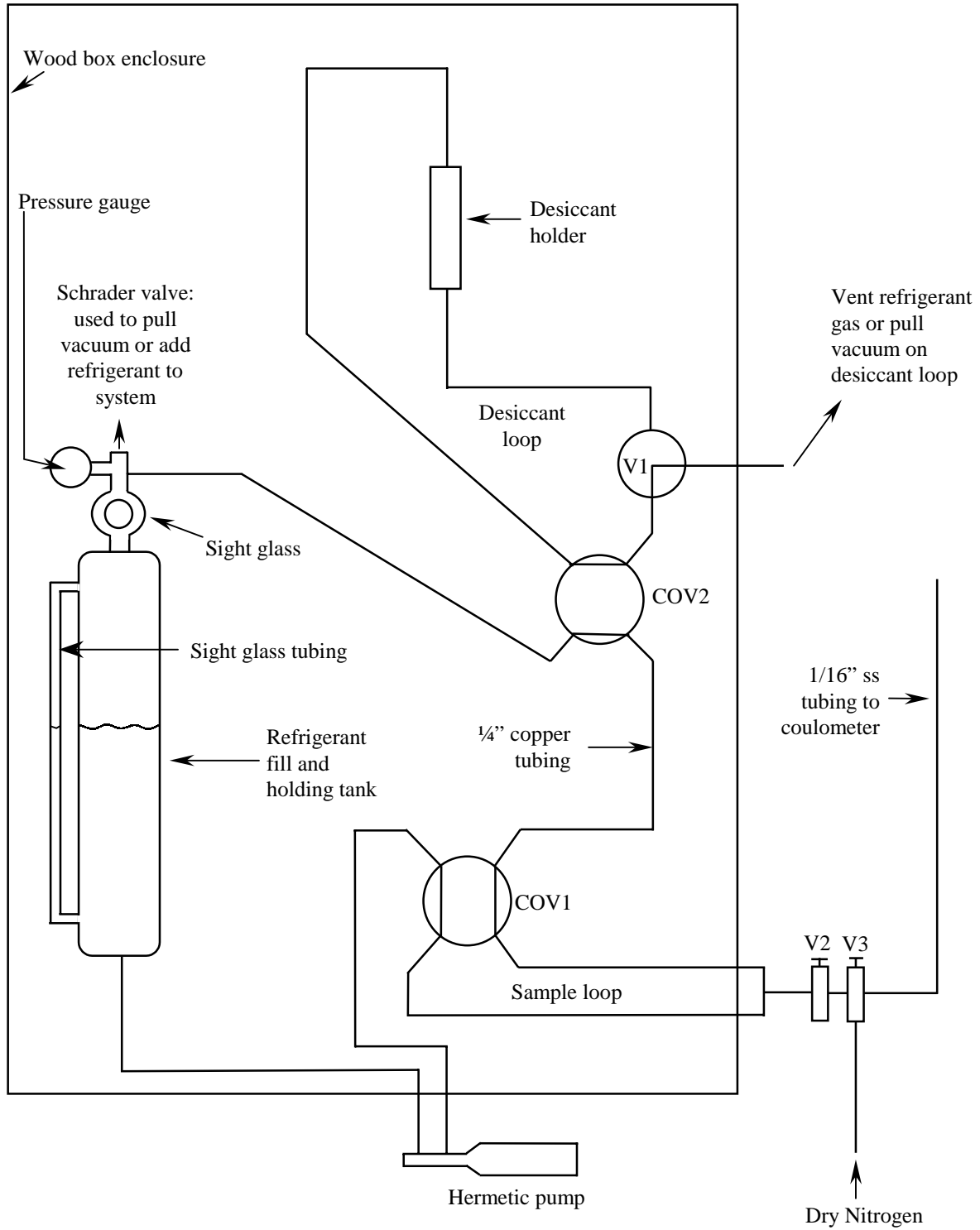
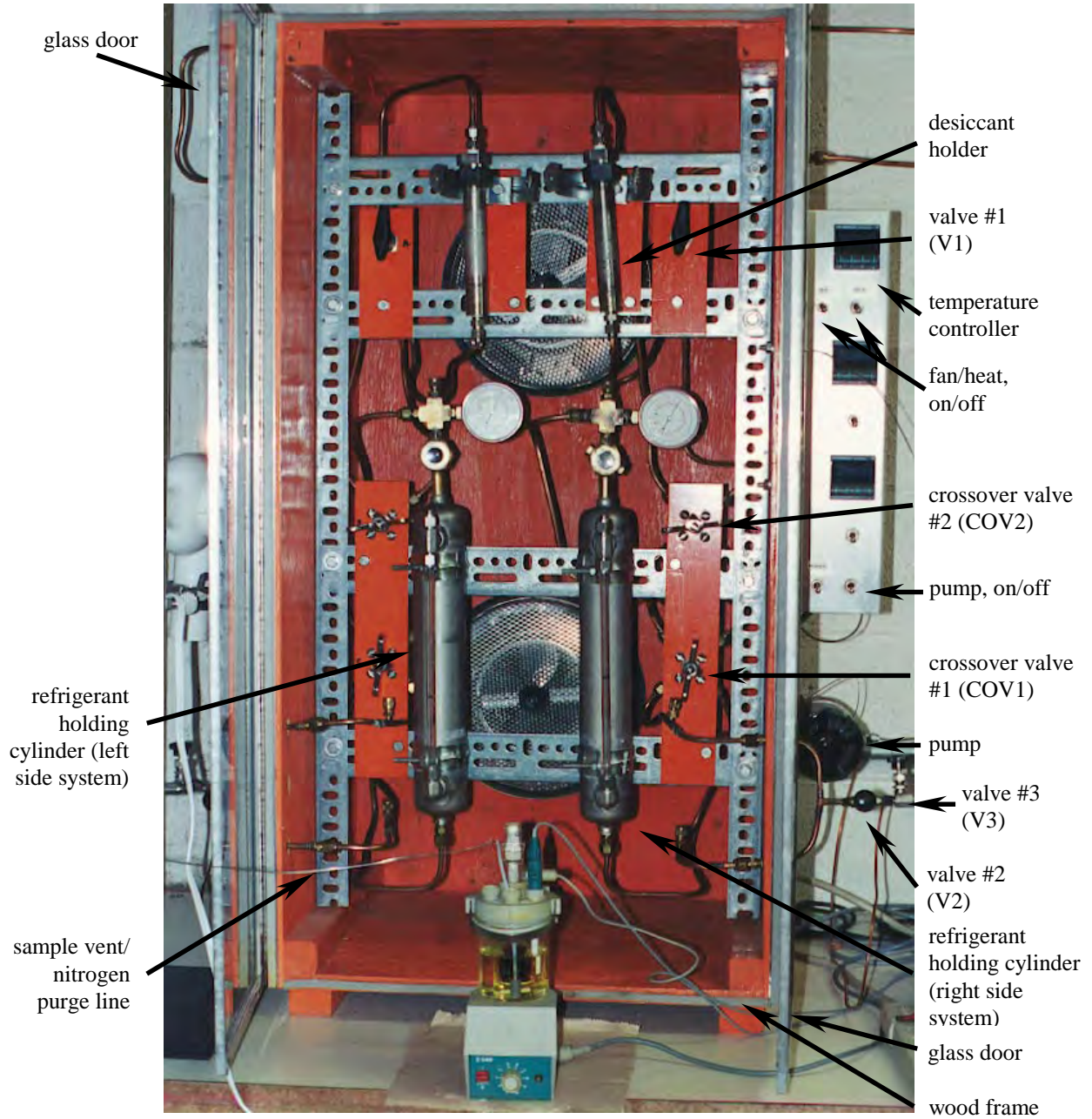


Figure 4
EPD Test System with V1 in Vent Position

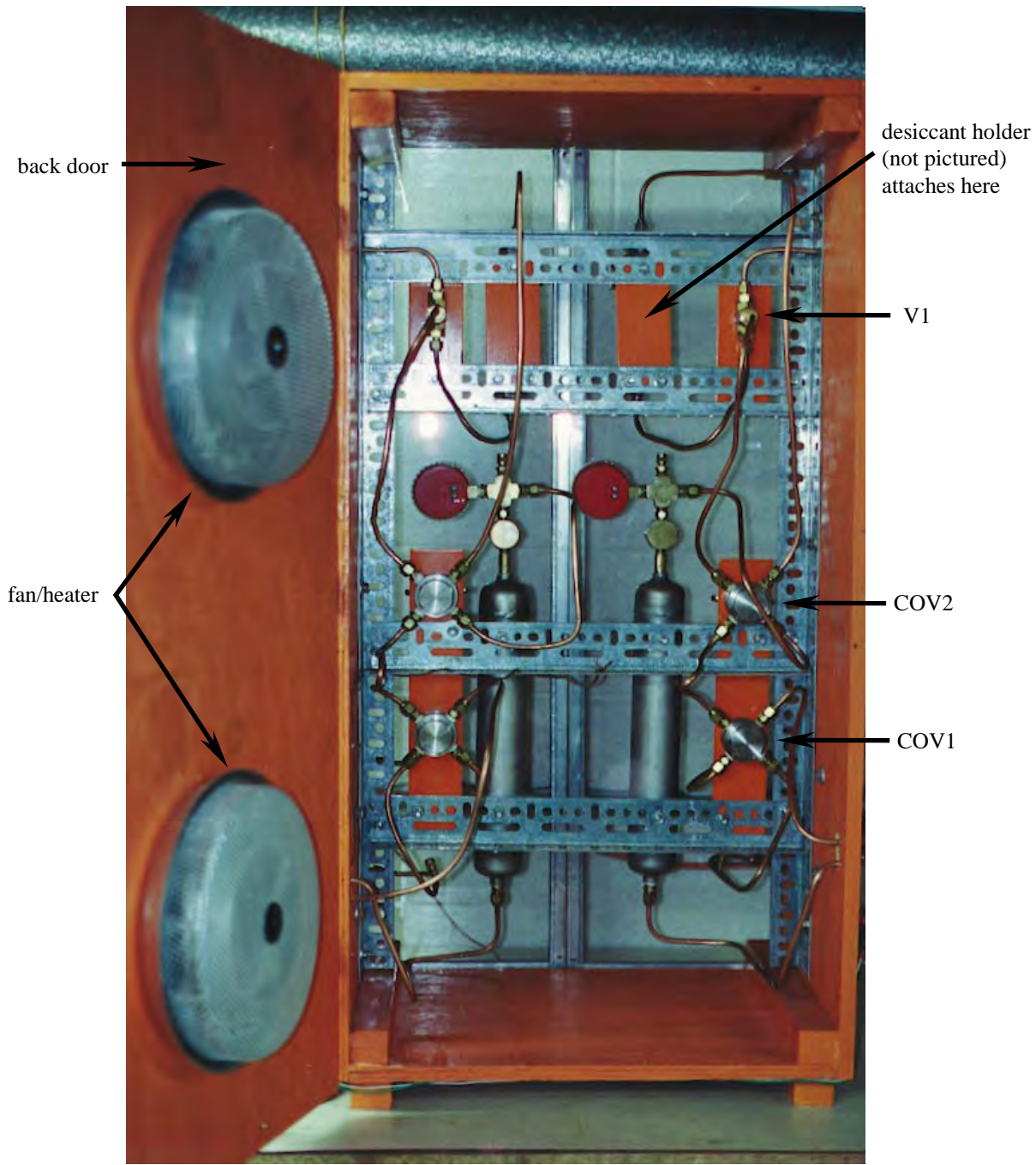


Picture 1
EPD Test System: Front View



Note: There are two separate EPD (equilibrium point dryness) systems inside one box.

Picture 2
EPD Test System: Back View



kilogram of refrigerant. The desiccant loop was isolated from the vacuum since later it will briefly be exposed to the atmosphere when changing the desiccant load (Figure 3). Using a charging meter, 500g of refrigerant were discharged into the EPD system using the Schrader valve at the top of the refrigerant holding cylinder. A marking pen was used to notate the liquid level of 500g of refrigerant on the sight glass tubing. This mark will change between refrigerants as their densities change. This mark is significant since lost refrigerant needs to be replaced before testing the next moisture-containing desiccant aliquot in order to maintain the 500g refrigerant load. Refrigerant is lost from the system from multiple sample analysis (each analysis uses 24-30g of refrigerant) and from the desiccant loop when the desiccant load is changed.

To facilitate refrigerant transfer from the cylinder to the refrigerant-containing test system, the refrigerant cylinder may need to be heated safely, just enough to permit refrigerant transfer (increase temperature 2.8-5.5°C (5-10°F) over room temperature). This task was conducted with the desiccant loop isolated (Figure 3) as it was when the initial refrigerant charge was added to the EPD system.

Desiccant Preparation

Activation

This project used three types of molecular sieve desiccant (4AXH-6, XH-11, and 511), three types of alumina desiccant (Bayer Scale, Lonza, and F-200), and 50:50 combinations of 4AXH-6 with Bayer Scale and XH-11 with Bayer Scale. Each EPD curve incorporates test measurement points from equilibrium of a specific refrigerant with different moisture-containing aliquots of a selected desiccant. Glass bottles (two to three kilogram capacity) were dried at 110°C (230°F) overnight and then filled with alumina desiccant that was activated in a programmable oven using the programmable temperature ramping method (hereinafter PTRM) (Table 3). The molecular sieve desiccants were used as received without any activation process (Table 3).

Table 3
Baseline H₂O Content of Desiccants

H ₂ O content (% by wt.) of molecular sieves as received		H ₂ O Content (% by wt.) of aluminas after activation by the PTRM	
4AXH-6	0.57	Bayer Scale	1.1
XH-11	0.64	Lonza	2.6
511	2.0	F-200	3.7

Using the PTRM, alumina desiccant was activated as follows:

- a 2.54cm (1in) bed-depth pan of desiccant was charged at room temperature,
- the sample was heated at 5°C/min (9°F/min) to 110°C (230°F) and held for ½ hour,
- the sample was heated at 3°C/min (5.4°F/min) from 110°C (230°F) to 250°C (482°F) and held for ½ hour,
- the sample was heated at 2°C/min (3.6°F/min) from 250°C (482°F) to 425°C (797°F) and held for ½ hour,
- the sample was cooled at 10°C/min (18°F/min) to 100°C (212°F),
- the sample was removed from the oven, placed in a desiccator, allowed to cool to room temperature, and
- the desiccant sample was transferred to a dried glass bottle.

Desiccant Hydration

Each glass bottle of activated alumina or a molecular sieve aliquot was emptied into its own large aluminum pan (30.48cm x 26.67cm x 3.81cm (12in x 10.5in x 1.5in)) and allowed to absorb different amounts of atmospheric moisture, monitored by weighing. The intention was to hydrate desiccant aliquots in approximately 2% moisture increments from activation or initial moisture determination up to approximately 20% moisture. Once the desiccant samples were thought to have absorbed the appropriate amount of moisture, a representative 0.5 to 1.0g sample was tested in the tube oven for moisture content (see *Measuring Desiccant Moisture Content*). The remainder of the desiccant sample was returned to its bottle, capped, sealed, and labeled with the percent moisture found. The desiccant was then ready for use.

Some experimentation was done with another activation method to determine whether the PTRM showed any benefits (Table 4). Three alumina desiccants were activated by two different methods. The water content was measured after exposure at 425°C (797°F) for 45 min. (normal tube oven temperature and time), 1100°C (2012°F) for 1 hour, and 1100°C (2012°F) for 2 hours. In all cases, the PTRM-activated desiccant yielded less water than the other method, indicating it to be a more thorough activation method. Of course, desiccant heated to 1100°C (2012°F) will have its integrity compromised by the high temperature and if used will have a lower drying capacity. However, the exposure to high temperature still demonstrates better desiccant activation by PTRM.

Table 4
Moisture Content Results of Three Alumina Desiccants Using Two Activation Methods

Desiccant	H ₂ O Content* (% by wt.)		LOI ⁺ (% by wt.)		LOI ^x (% by wt.)	
	Activation Method		Activation Method		Activation Method	
	PTRM	375°C (707°F)/ 1 hour [#]	PTRM	375°C (707°F)/ 1 hour [#]	PTRM	375°C (707°F)/ 1 hour [#]
Bayer Scale	1.1	3.2	3.9	7.4	4.0	8.8
Lonza	3.7	4.1	6.6	7.3	6.6	7.2
F-200	2.6	3.7	4.9	6.1	4.9	6.1

* Tube furnace at 425°C (797°F) purged with dry nitrogen into KF titrator.

⁺ Muffle furnace heated to 1100°C (2012°F) desiccant sample put in furnace, furnace allowed to reach 1100°C (2012°F) again, samples held at 1100°C (2012°F) for one hour.

^x Muffle furnace heated to 1100°C (2012°F), desiccant sample put in furnace, furnace allowed to reach 1100°C (2012°F) again, samples held at 1100°C (2012°F) for two hours.

Activation Methods:

PTRM: see previous page

[#] 2.54cm (1in) bed depth pan of desiccant placed in convection oven at 375°C (707°F), oven allowed to reach 375°C (707°F) again, sample held at 375°C (707°F) for 1 hour, sample cooled to approximately 100°C (212°F).

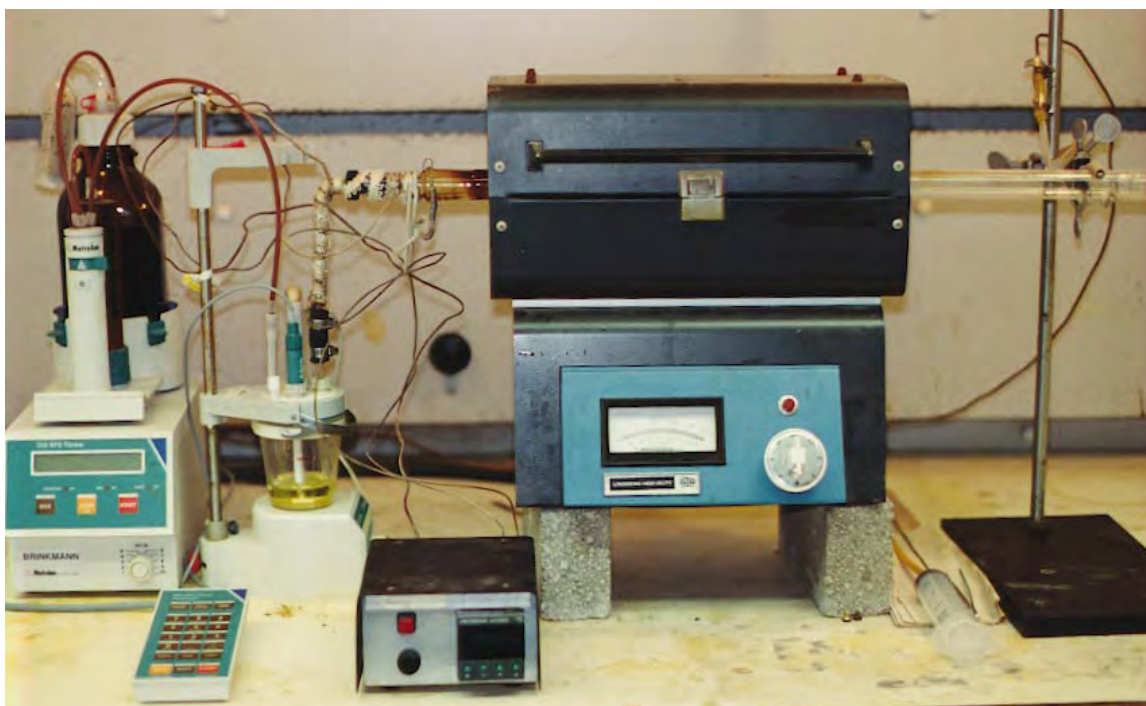
Measuring Desiccant Moisture Content

Desiccant moisture content was determined using a tube oven and a Karl Fischer titrator, useful for moisture determinations greater than 1% (by wt.) (Picture 3). 0.5 to 1.0g of desiccant was placed in a dry weigh boat. The boat containing the desiccant sample was pushed into the tube oven for a minimum of 45 minutes with a constant, controlled stream of dry nitrogen sweeping the moisture from the desiccant into the Karl Fischer titration vessel. The furnace was maintained at 425°C (797°F) and a temperature controller was used to heat thermal tape around

the glass bend between the oven and the titration vessel to 105°C (221°F) to prevent condensation. Water content was re-measured on every tenth desiccant sample for quality control purposes. Duplicate measurements were within 5% of the original measurement.

Moisture determinations were performed on the hydrated desiccant samples to insure that initial target moisture contents were met. Moisture content of the desiccants in equilibrium with refrigerant was determined for the equilibrium point dryness graphs (Appendices A-G).

Picture 3
Tube Oven and Titrator



Charging the EPD System with Desiccant

The desiccant loop of the EPD system was isolated in order to avoid losing the refrigerant in the system and V1 was placed in the position to vent the small amount of refrigerant gas in the desiccant loop (Figure 4). V1 was returned to the flow-through position (Figure 1). The desiccant holder was removed by unscrewing the two finger-tightened, SSP fitting, type 316 stainless steel nuts at the top and bottom of the holder. Once separated from the system, the desiccant holder was easily opened. 35g aliquots of desiccant were used in this project. After adding the desiccant sample to the holder and placing the holder back in the system, a quick

vacuum was pulled from V1 on the desiccant loop to remove any air (COV2 must be in the isolated position and V1 in the vent position (Figure 4)).

Testing Procedure

The system was charged with the specific refrigerant and desiccant as described previously. All valves were placed in the flow-through position (Figure 1). The pump and the internally mounted fan/heater were turned on and the microprocessor controlled temperature controller was set at 24°C (75°F) or 52°C (125°F). Two internally mounted fan/heaters were used for temperature uniformity. The refrigerant/water mixture circulated through the desiccant for 16 hours to establish equilibrium. After 16 hours, the heater and pump were turned off and the desiccant loop was isolated to prevent further contact of the refrigerant/water mixture with the desiccant (Figure 3). The pump was turned back on to continue mixing, cooling the mixture to room temperature (21°C (70°F)) by circulating the mixture through the sample loop. While the mixture cooled to room temperature, the Karl Fischer coulometer was turned on and dry nitrogen was passed through the tubing connecting the sampling valve (V2) with the Karl Fischer coulometer vessel for moisture removal purposes. A hot air gun was aimed at the nitrogen-control flow-valve (V3) to heat the dry nitrogen to further its drying capabilities. The hot air gun was also aimed at the sampling valve to prevent internal icing during sample expulsion. Once the refrigerant/water mixture cooled to room temperature, which was necessary for determining the weight of refrigerant in the sample loop, the sample loop was isolated, capturing a representative sample of the equilibrium (Figure 2). The pump was turned off, the nitrogen flow was turned off (V3), and the refrigerant/water mixture was expelled with the control of a needle valve (V2) into a Karl Fischer coulometer. After the sample (24-30g, depending on the refrigerant) was expelled, V2 was closed, COV1 was put in the flow-through position, and the pump was turned on in preparation for subsequent sample measurement. At the same time, heated dry nitrogen was channeled for 20 min. through the sample tubing connecting the sample valve (V2) and the Karl Fischer coulometer vessel for purposes of picking up any moisture left in the tubing. 30-40 min. was needed to expel the sample into the coulometer vessel. The desiccant sample was removed from the desiccant loop as previously described and placed in a dry, labeled bottle for moisture content analysis using the aforementioned tube oven. The cap was placed on loosely for approximately one hour before tightening so that any refrigerant in the desiccant

would escape, thereby avoiding pressure build-up in the sample bottle. At this point, another refrigerant equilibrium sample was measured for water content or the system was prepared for the next equilibrium point. Triplicate measurements were averaged to determine each equilibrium test point.

Equilibrium Time

We found 16 hours to be ample contact time between refrigerant and hydrated desiccant to achieve water equilibrium. To determine adequate contact time, two 4AXH-6 and two 511 samples were tested with R-32 for refrigerant water content after 6, 18, and 42 hours of circulation (Table 5). Additionally, the desiccant was tested for water content after 42 hours. For the most part, there was an increase in refrigerant water content between six and 18 hours. However, there was little change in refrigerant water content after 18 hours; thus supporting the fact that 16 hours of circulating time was adequate to achieve equilibrium.

Table 5
Comparison of Equilibrium R-32 Water Content after 6, 18, and 42 Hours

Desiccant	Desiccant H ₂ O Content* (% by wt.)	6 hours		18 hours		42 hours			
		24°C (75°F)	52°C (125°F)	24°C (75°F)	52°C (125°F)	24°C (75°F)		52°C (125°F)	
		R-32 H ₂ O Content (ppm)	R-32 H ₂ O Content (ppm)	R-32 H ₂ O Content (ppm)	R-32 H ₂ O Content (ppm)	Desiccant H ₂ O Content ⁺ (% by wt.)	R-32 H ₂ O Content (ppm)	Desiccant H ₂ O Content ⁺ (% by wt.)	R-32 H ₂ O Content (ppm)
4AXH-6	0.570	3.3	3.6	15	1.7	2.20	2.6	1.99	1.6
	5.85	23	49	31	49	7.01	28	7.17	59
511	2.00	1.4	0.94	6.5	1.9	2.64	1.4	2.59	4.5
	4.56	0.76	3.0	4.9	2.1	5.17	6.8	5.46	4.8

* Desiccant water load before R-32 exposure (initial).

⁺ Final water content of desiccant.

DISCUSSION OF RESULTS

R-134a with 4AXH-6, 511, Bayer Scale, 4AXH-6/Bayer Scale (50:50), Lonza, and F-200

511, a molecular sieve desiccant, demonstrates the largest capability for water retention with R-134a, followed by 4AXH-6, 4AXH-6/Bayer Scale (50:50), Bayer Scale, Lonza, and F-200 (see Appendix A). 4AXH-6 reaches water retention capacity slower than Bayer Scale at the area on the equilibrium curve where water begins to distribute itself between desiccant and refrigerant. This is evidenced by the prominent bend on the 4AXH-6/ Bayer Scale (50:50) EPD

curve displaying characteristics of both the 4AXH-6 and Bayer Scale graphs. Clearly, Lonza and F-200 do not possess comparable R-134a drying capabilities to the other desiccant or desiccant combinations. Lonza and F-200, unlike the Bayer Scale alumina, and much more so than 4AXH-6, show a slow, exaggerated EPD curve with a continued distribution of water in the system between desiccant and refrigerant until water retention capacity has been reached. Desiccant temperature affects the ability of the 4AXH-6/Bayer Scale (50:50) combination and Lonza. As is often seen, an increase in desiccant temperature results in a decrease in water retention and, therefore, drying capacity.

Evaluating the desiccants tested, molecular sieves are better at moisture containment in R-134a than the aluminas. The 50:50 4AXH-6/ Bayer Scale mixture shows hybrid signs of the parent components. [Table 6](#) shows the water content of desiccants at 50ppm measured water in R-134a.

Table 6
Percent Water (by wt.) in Desiccant at 50ppm Water in R-134a

Desiccant	24°C (75°F)	52°C (125°F)
4AXH-6	17.0	17.0
511	19.5	19.5
Bayer Scale	16.5	16.5
4AXH-6/Bayer Scale (50:50)	17.0	17.0
Lonza	8.50	7.50
F-200	6.50	6.50

R-32 with 4AXH-6, XH-11, 511, Bayer Scale, and XH-11/Bayer Scale (50:50)

As seen previously, 511 displays the largest water retentive capabilities of the group of desiccants tested with R-32 (see Appendix B). 4AXH-6 and 511 behave differently with R-32 than they do with other refrigerants. Instead of a small, concise bend spanning less than 5% desiccant water content and 50ppm refrigerant content on the EPD curve where water distributes itself between refrigerant and desiccant, as is seen with R-134a, R-125, and R-143a, 4AXH-6 and 511 data reflect a large sweeping curve leading to moisture capacity. This may be a result of R-32 competing with water for *adsorption* sites on 4AXH-6 and 511 desiccants. Desiccant temperature, as noted, influenced water retention ability. Elevated 4AXH-6 temperature resulted in lower water capacity. Surprisingly, the Bayer Scale 52°C (125°F) isotherm shows an ability to

retain more water than the 24°C (75°F) isotherm until its capacity is reached. However, the Bayer Scale 24°C (75°F) isotherm capacity is greater than the 52°C (125°F) isotherm. The 50:50 XH-11/Bayer Scale combination upon close inspection has characteristics of both component desiccants. The shape of the combination EPD curve resembles that of XH-11. The lower water capacity can be attributed to greater water distribution between Bayer Scale and R-32 as seen in the 24°C (75°F) Bayer Scale isotherm. It is probable that R-32 competes with water for *absorption* on Bayer Scale. The water in equilibrium between Bayer Scale and R-32 provides more water for *adsorption* on XH-11 sites, therefore water retention capacity is reached sooner.

After 511, water retentive capabilities for R-32 from largest to least are Bayer Scale, 4AXH-6, XH-11, and the 50:50 combination of XH-11/Bayer Scale. [Table 7](#) reflects the water content of desiccants at equilibrium with R-32 at 50ppm water in refrigerant.

Table 7
Percent Water (by wt.) in Desiccant at 50ppm Water in R-32

Desiccant	24°C (75°F)	52°C (125°F)
4AXH-6	11.0	8.50
XH-11	15.0	15.0
511	13.5	13.5
Bayer Scale	16.0	12.0
XH-11/Bayer Scale (50:50)	12.5	12.5

R-125 with 4AXH-6, 511, Bayer Scale, and 4AXH-6, /Bayer Scale (50:50)

The R-125/4AXH-6 EPD curve demonstrates equilibrium performance similar to the R-134a/4AXH-6 curve; there is a small area of water distribution between desiccant and refrigerant before water retention capacity is reached. 511 displays the most water retentive ability, followed by Bayer Scale, 4AXH-6, and the 50:50 mix of 4AXH-6/Bayer Scale (see Appendix C). The 50:50 4AXH-6/Bayer Scale curve resembles the 4AXH-6 EPD curve and displays similar water equilibrium capacity. R-125 and Bayer Scale show more equilibrium distribution than the other desiccants. Desiccant temperature shows affects on 511 and Bayer Scale; increased desiccant temperature results in decreased water retention. [Table 8](#) demonstrates desiccant water content at 50ppm water in R-125.

Table 8
Percent Water (by wt.) in Desiccant at 50ppm Water in R-125

Desiccant	24°C (75°F)	52°C (125°F)
4AXH-6	17.5	17.5
511	21.5	20.5
Bayer Scale	18.0	16.5
4AXH-6/Bayer Scale (50:50)	17.0	17.0

R-143a with 4AXH-6, 511, Bayer Scale, and 4AXH-6/Bayer Scale (50:50)

511 holds the most water with R-143a at maximum equilibrium, followed by 4AXH-6, Bayer Scale, and the 50:50 4AXH-6/Bayer Scale mixture (see Appendix D). R-143a water equilibrium results are similar to R-125. Desiccant temperature plays a role in water retention for 511 and Bayer Scale; in both cases, an increase in temperature results in a decrease in water equilibrium capacity. The water retention capacity of the 50:50 4AXH-6/Bayer Scale mixture resembles that of Bayer Scale. [Table 9](#) demonstrates desiccant water content at 50ppm water in R-125.

Table 9
Percent Water (by wt.) in Desiccant at 50ppm Water in R-143a

Desiccant	24°C (75°F)	52°C (125°F)
4AXH-6	17.0	17.0
511	20.0	19.0
Bayer Scale	16.0	15.0
4AXH-6/Bayer Scale (50:50)	15.5	15.5

R507A with 4AXH-6, 511, Bayer Scale, and 4AXH-6/Bayer Scale (50:50)

Evaluating equilibrium point dryness of R507A with the above desiccants shows 511 as having the best water removing capabilities followed by 4AHX-6, 4AHX-6/Bayer Scale (50:50), and Bayer Scale (see Appendix E). All four graphs display similar bends in the EPD curve where water begins to distribute itself between refrigerant and desiccant. 4AHX-6 was the only desiccant/combination that showed signs of being affected by temperature. The 50:50 combination of 4AHX-6 and Bayer Scale graphically appeared to display characteristics of both parent components, specifically curve appearance of 4AHX-6 and the data point scatter of Bayer Scale.

The component refrigerants of R507A, R-125 and R-143a, show remarkably similar EPD graphs to R507A for each desiccant tested. The 4AHX-6 graphs are similar in shape, water distribution bend, and water capacity. Desiccant temperature influences R507A/4AHX-6 equilibrium, but not R-125/4AXH-6 or R-143a/4AXH-6 equilibrium. 511 graphs are similar in water retention with temperature-affecting R-125 and R-143a. R507A and R-143a Bayer Scale EPD graphs show similar characteristics with temperature-affecting component refrigerant R-125 and R-143a. R507A, R-125, and R-143a graphs for EPD with the 50:50 4AHX-6/Bayer Scale mixture are similar in shape and water distribution bend. However, R-143a with 4AHX-6/Bayer Scale (50:50) shows a smaller water equilibrium capacity than the other two. [Table 10](#) shows the water content of desiccants at 50ppm measured water in R507A.

Table 10
Percent Water (by wt.) in Desiccant at 50ppm Water in R507A

Desiccant	24°C (75°F)	52°C (125°F)
4AHX-6	18.0	17.0
511	20.5	20.5
Bayer Scale	16.5	16.5
4AHX-6/Bayer Scale (50:50)	17.5	17.5

R407C with XH-11, 511, Bayer Scale, and XH-11/Bayer Scale (50:50)

511 has the most water retention capacity in equilibrium of the four desiccants/mixtures tested with R407C followed by XH-11, XH-11/Bayer Scale (50:50), and Bayer Scale (see Appendix F). The 511 EPD curve bend covers a large area of water distribution between refrigerant and desiccant before equilibrium capacity is reached. The Bayer Scale EPD graph has no distinct bend where equilibrium capacity has been reached. A small change in desiccant water content yields a much bigger change in refrigerant water content over the entire curve. The 50:50 XH-11/Bayer Scale graph is characteristic of both desiccant component R407C plots with respect to shape, bend, and equilibrium capacity. An increase in desiccant temperature (52°C (125°F)) resulting in a decrease in water equilibrium capacity is noted with 511, Bayer Scale, and 50:50 XH-11/Bayer Scale when used with R407C.

A comparison of R407C EPD graphs with that of its refrigerant component (R-134a, R-32, and R-125) graphs highlight a few notable observations. The only R407C component tested with XH-11 was R-32 and both graphs (R-32/XH-11 and R407C/XH-11) are nearly identical.

R407C/511 has some similarities with its components. R-32/511 and R407C/511 produce curves with a large area under the curve depicting water distribution between phases before equilibrium capacity is reached. This happens because R-32 competes with water for attachment on 511 desiccant. The 511 graphs with R-134a, R-32, R-125, and R407C show similar EPD and water capacity. The Bayer Scale graphs are different in shape and water capacity, reflecting a blended curve shape and desiccating ability of R407C. The desiccant combination of XH-11/Bayer Scale (50:50) was tested with R-32 and R407C. Both curves are similar in shape and desiccant temperature influence, but slightly different in equilibrium water capacity. Table 11 shows the water content of desiccants at 50ppm measured water in R407C.

Table 11
Percent Water (by wt.) in Desiccant at 50ppm Water in R407C

Desiccant	24°C (75°F)	52°C (125°F)
XH-11	15.0	15.0
511	18.0	16.5
Bayer Scale	9.5	9.0
XH-11/Bayer Scale (50:50)	14.0	13.0

R410A with XH-11, 511, Bayer Scale, and XH-11/Bayer Scale (50:50)

The desiccant with the most drying capacity is 511, followed by XH-11, XH-11/Bayer Scale (50:50), and Bayer Scale (see Appendix G). The 50:50 XH-11/Bayer Scale mixture’s drying capacity is lower than XH-11, showing the influence of Bayer Scale. Desiccant temperature affected the 511, Bayer Scale, and XH-11/Bater Scale (50:50) EPD curves by reducing water equilibrium capacity at elevated temperatures. The R410A/511 EPD curve, like the R407C/511 curve, has substantial area under the bend reflecting water distribution between phases before equilibrium capacity has been reached. This is due to R-32, a component common to both blends, and previously discussed with the R-32 EPD and water capacity test results.

There are some noteworthy comparisons between R410A and its component refrigerant (R-32 and R-125) EPD graphs. R-32/XH-11 and R410A/XH-11 have very similar graphs with respect to curve shape, bend, and water equilibrium retention capacity. The R410A/511 curve is a blend of components R-32/511 and R-125/511; R-125/511 exerts a moderating influence on the water distribution portion of the R-32/511 graph as reflected in the R410A/511 curve. This is because R410A is 50% R-32 and 50% R-125. Therefore, one half the amount of R-32 is

competing with water for 511 *adsorption* sites. R-32 and R-125 Bayer Scale plots are curiously different and not at all similar to the more predictable looking graph of R410A/Bayer Scale. The R410A/Bayer Scale results show less water capacity than the components' Bayer Scale graphs. A small change in desiccant (Bayer Scale) water content results in a larger change in refrigerant (R410A) water content. Desiccant temperature is a factor in water retention for R-32, R-125, and R410A tested with Bayer Scale, with temperature affects reversed for R410A. R-32/XH-11 and Bayer Scale (50:50) and R410A/XH-11 and Bayer Scale (50:50) graphs compare favorably with respect to EPD water capacity. R-125 was not tested with XH-11/Bayer Scale (50:50). Desiccant temperature affected R410A/XH-11 and Bayer Scale (50:50) retention capacity. R-32/XH-11 and Bayer Scale (50:50) shows reverse temperature affects (increase in temperature causes an increase in water capacity) as the curve approaches equilibrium capacity. This is a possible link to the other situation where temperature affects are reversed (R410A/Bayer Scale). [Table 12](#) shows the water content of desiccants at 50ppm measured water in R507A.

Table 12
Percent Water (by wt.) in Desiccant at 50ppm Water in R410A

Desiccant	24°C (75°F)	52°C (125°F)
XH-11	14.5	14.5
511	17.0	15.0
Bayer Scale	10.0	10.5
XH-11/Bayer Scale (50:50)	14.0	12.0

CONCLUSION

The type 3A molecular sieve desiccant is designed to exclude R-32. However, it was found that a type 4A molecular sieve desiccant had an equal to or better capacity for water with the R-32 containing blends, R407C and R410A. In every other instance, the type 4A molecular sieve desiccant yielded water capacity values in excess of other type 3A molecular sieve products ([Table 13](#)). This data also suggests that type 3A and type 4A desiccants are equally suitable for water removal when used with HFC refrigerants. Keep in mind that this work only evaluates dryness equilibrium conditions and does not address any material compatibility issues. Hence, certain desiccants may not necessarily be immune to refrigerant decomposition.

This study took into account the activity of several aluminas. Generally, it is known that aluminas retain less water than molecular sieves. Furthermore, this research reveals that different

alumina products have different water capacities. One remarkable discovery is that different activation procedures with regard to time and temperature result in unequal amounts of water remaining on the activated desiccant (Table 4). Clearly, when aluminas are activated under identical conditions, Bayer Scale has the lowest water content (Table 3). Bayer Scale also has the best desiccating qualities over the other aluminas tested (Figures A.3, A.5, and A.6).

Conceivably, the primary reason why Bayer Scale in many cases produces an isothermal curve similar to molecular sieve is its lower initial water load. Although its larger pore size allows water and refrigerant to compete for water-retaining sites, Bayer Scale does *not* trap refrigerant in the void volume of the crystalline structure, thereby resulting in a larger equilibrium capacity.

Table 13
Summary of Desiccant Water Content (% by wt.) at 50ppm Refrigerant Water Content
at Desiccant Temperatures of 24°C (75°F) and 52°C (125°F)

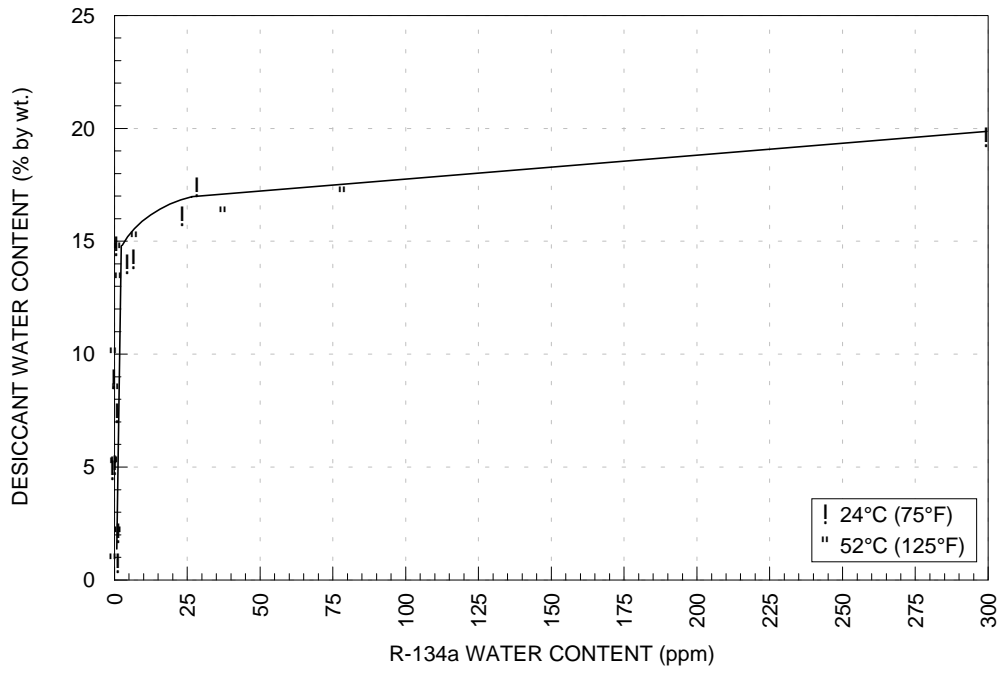
Desiccant Type/Mixture	Temp (°C/°F)	R-134a	R-32	R-125	R-143a	R507A	R407C	R410A
4AXH-6	24/75	17.0	11.0	17.5	17.0	18.0		
	52/125	17.0	8.50	17.5	17.0	17.0		
XH-11	24/75		15.0				15.0	14.5
	52/125		15.0				15.0	14.5
511	24/75	19.5	13.5	21.5	20.0	20.5	18.0	17.0
	52/125	19.5	13.5	20.5	19.0	20.5	16.5	15.0
Bayer Scale	24/75	16.5	16.0	18.0	16.0	16.5	9.50	10.0
	52/125	16.5	12.0	16.5	15.0	16.5	9.00	10.5
4AXH-6/Bayer Scale (50:50)	24/75	17.0		17.0	15.5	17.5		
	52/125	17.0		17.0	15.5	17.5		
XH-11/Bayer Scale (50:50)	24/75		12.5				14.0	14.2
	52/125		12.5				13.0	12.0
Lonza	24/75	8.50						
	52/125	7.50						
F-200	24/75	6.50						
	52/125	6.50						

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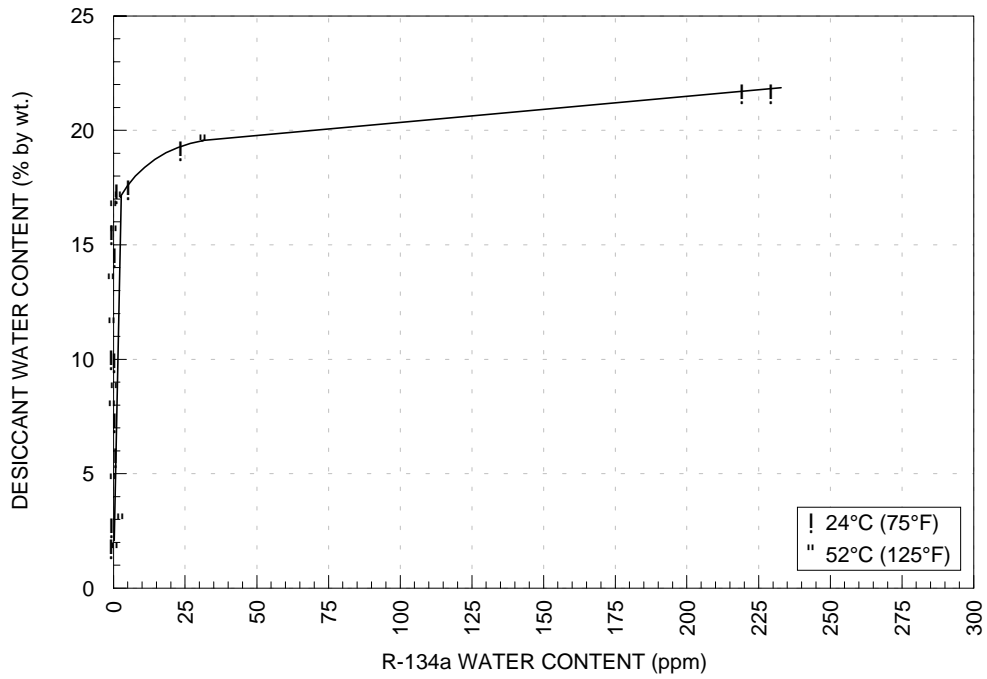
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Appendix A
Graphs and Raw Data for R-134a

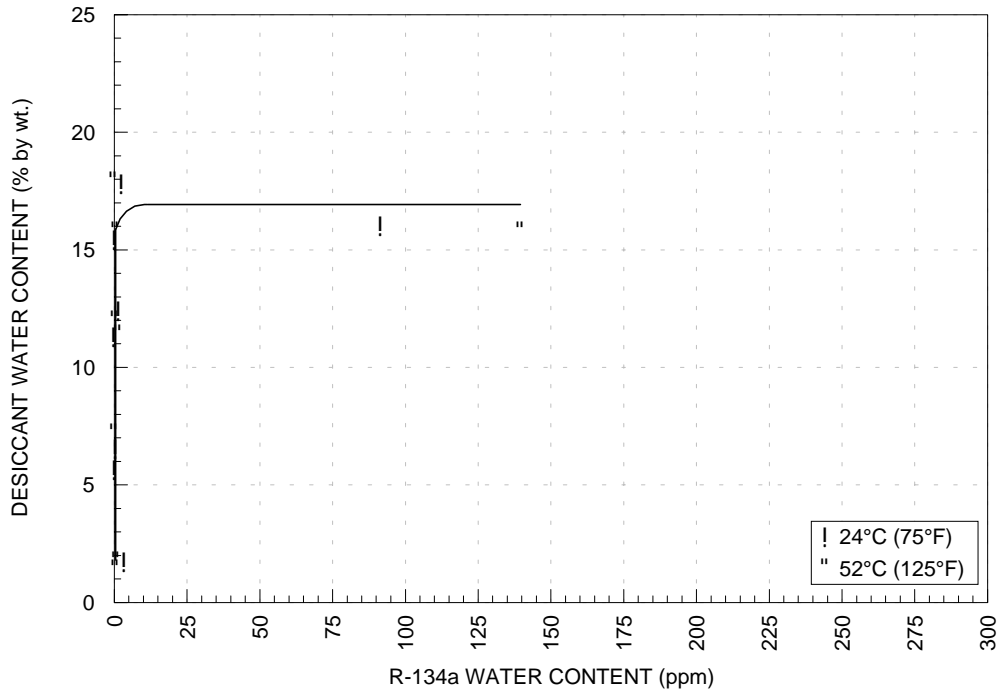
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-134a / UOP 4AXH-6 (3Å) MOLECULAR SIEVE
Figure A.1



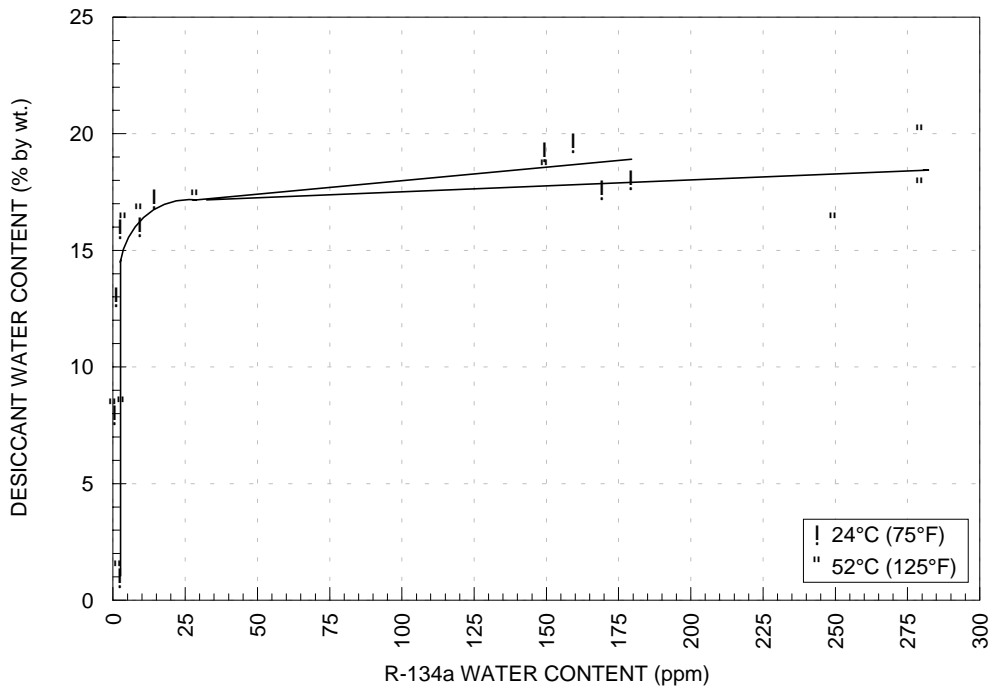
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-134a / GRACE 511 (4Å) MOLECULAR SIEVE
Figure A.2



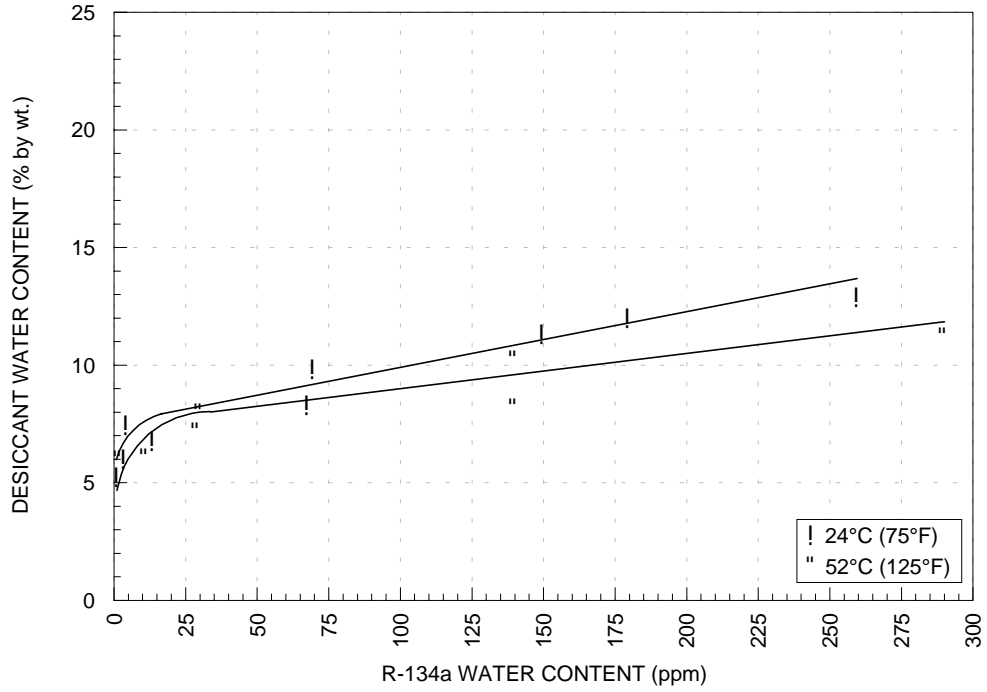
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-134a / BAYER SCALE ALUMINA
Figure A.3



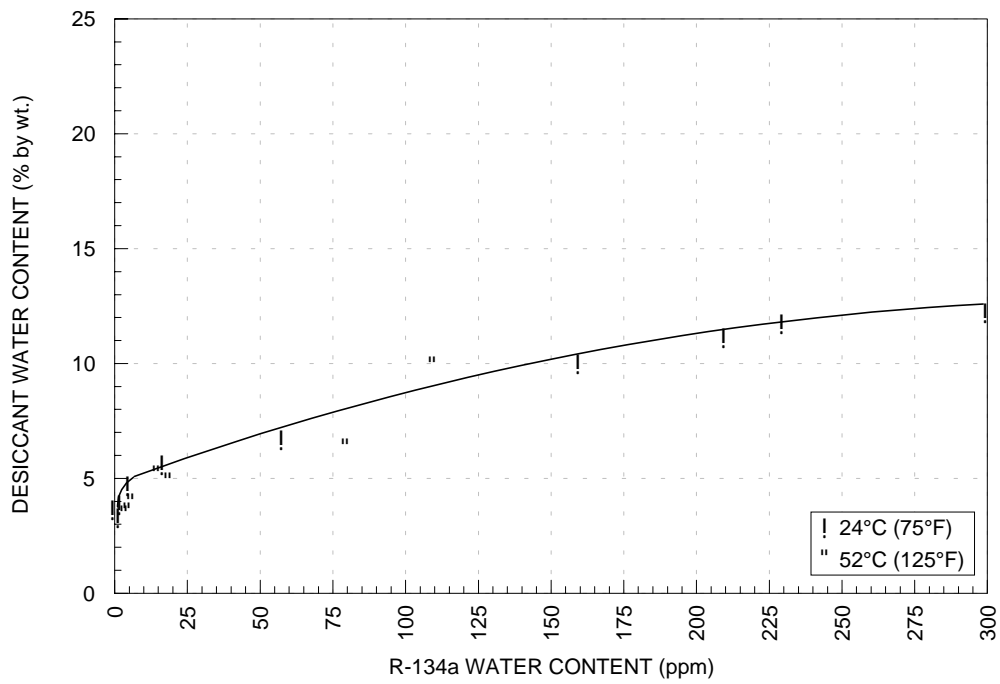
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F):
R-134a / UOP 4AXH-6 (3Å) MOLECULAR SIEVE & BAYER SCALE ALUMINA (50:50 % BY WT)
Figure A.4



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-134a / LONZA ALUMINA
Figure A.5

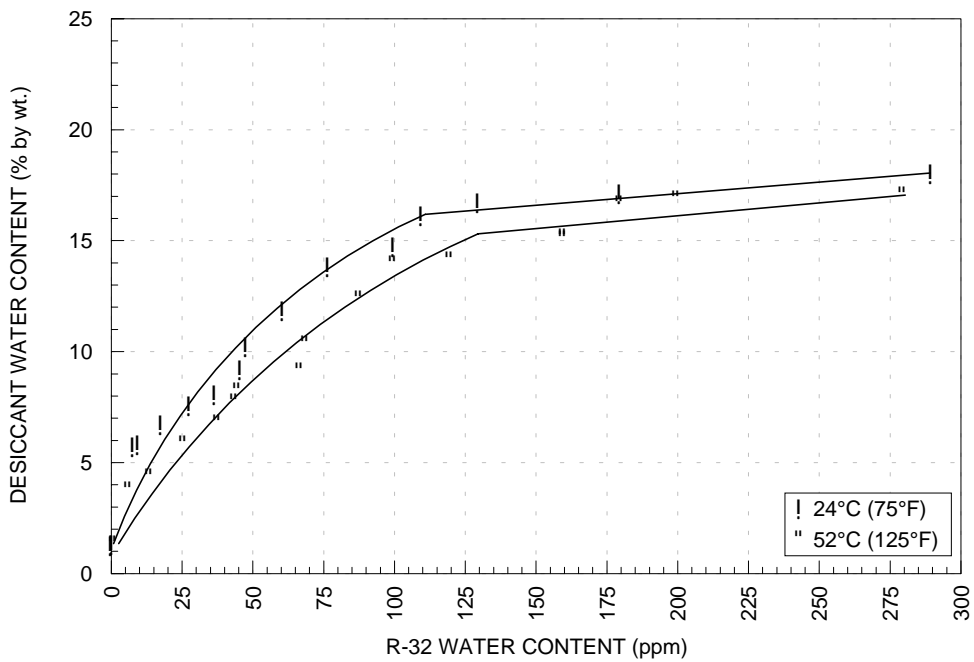


WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°C): R-134a / F-200 ALUMINA
Figure A.6

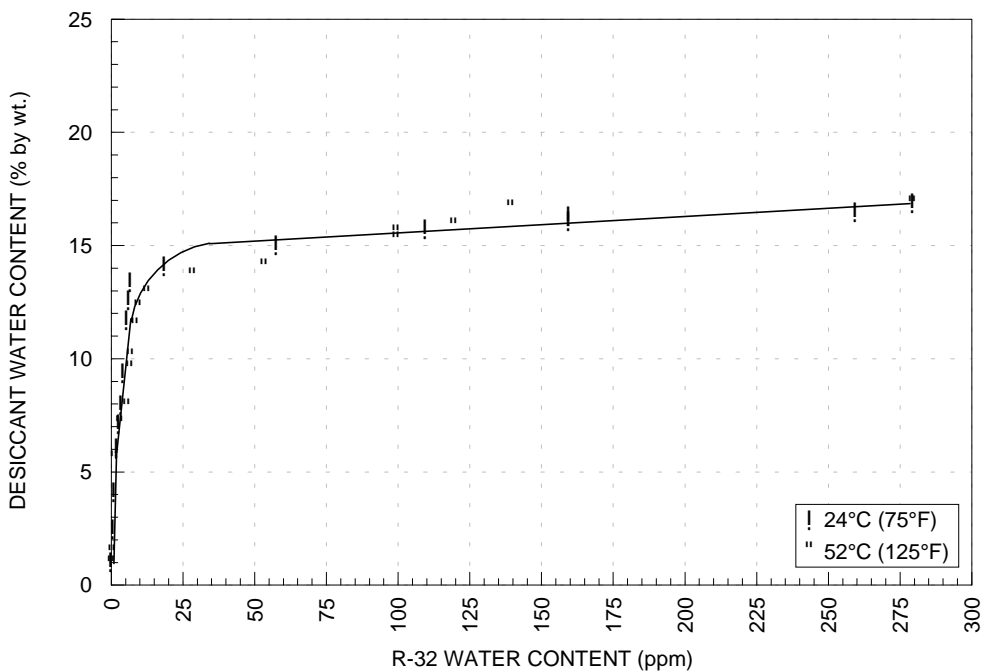


Appendix B
Graphs and Raw Data for R-32

WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-32 / UOP 4AXH-6 (3Å) MOLECULAR SIEVE
Figure B.1

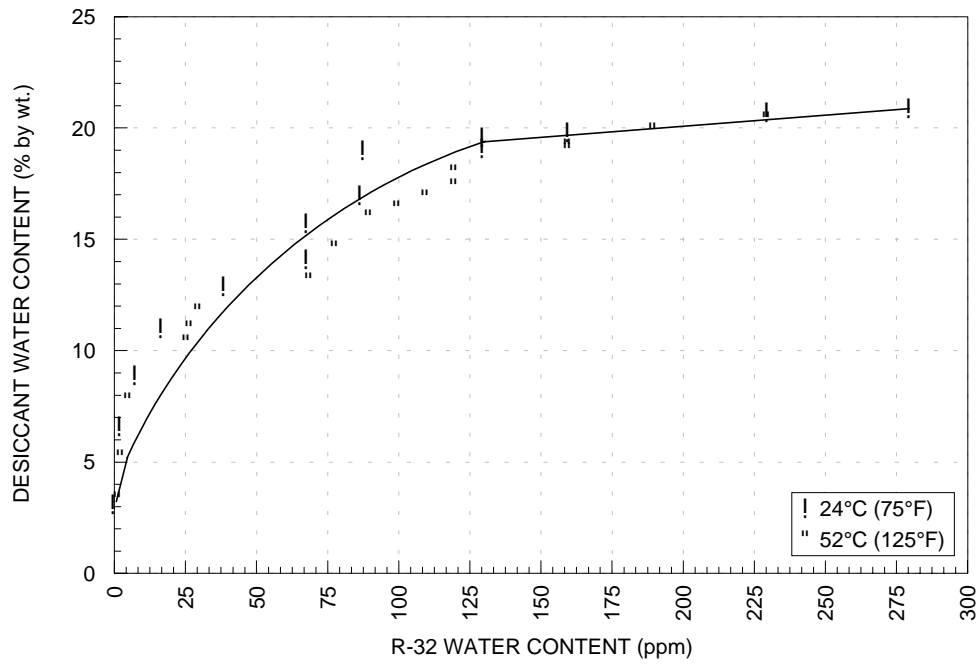


WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-32 / UOP XH-11 (3Å) MOLECULAR SIEVE
Figure B.2



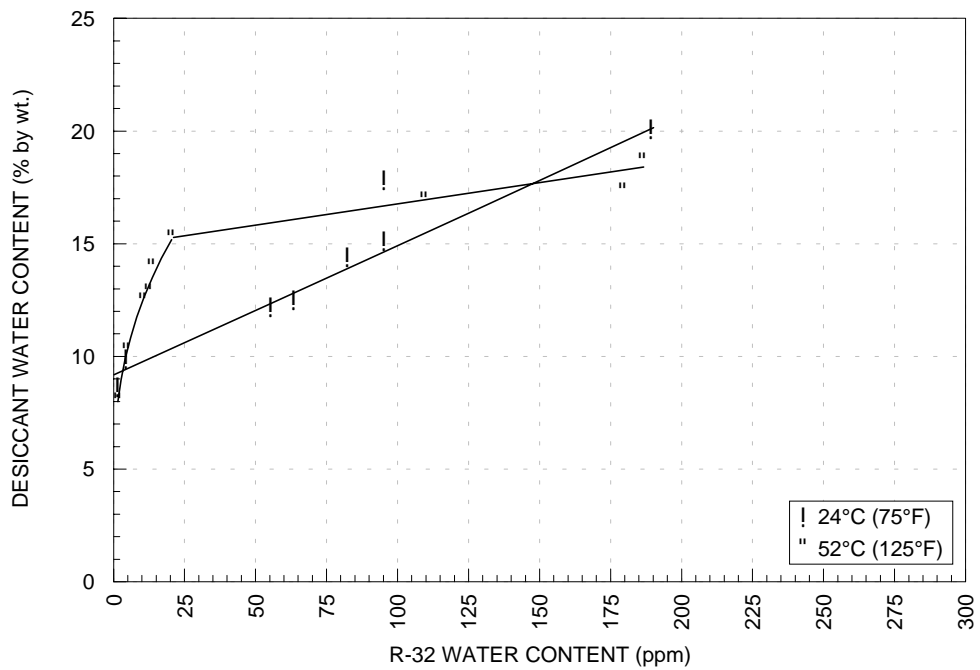
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-32 / GRACE 511 (4Å) MOLECULAR SIEVE

Figure B.3

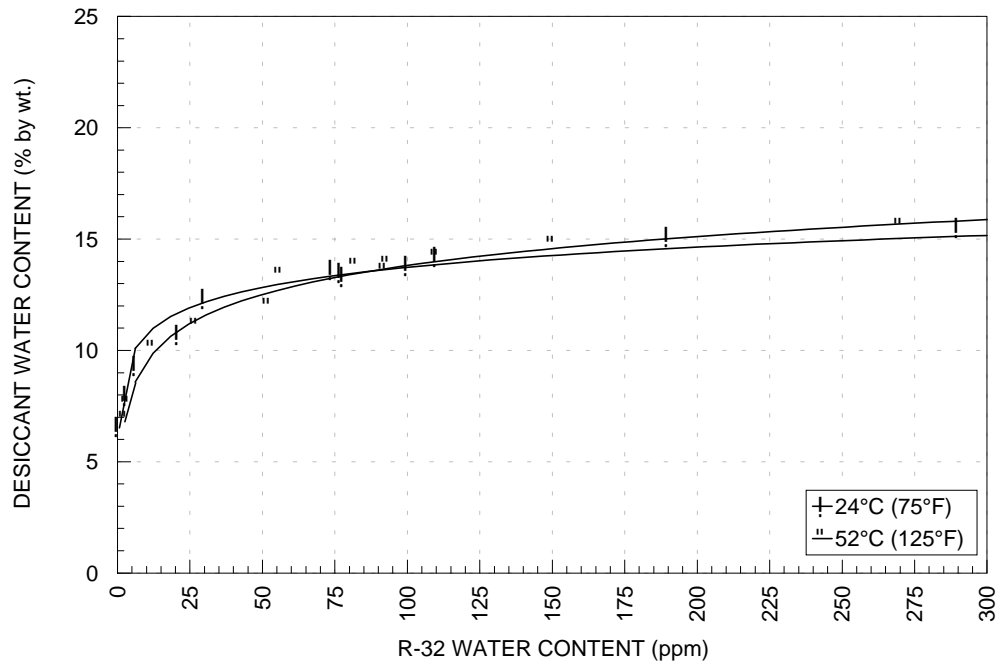


WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-32 / BAYER SCALE ALUMINA

Figure B.4



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F)
R-32 / UOP XH-11 (3Å) MOLECULAR SIEVE & BAYER SCALE ALUMINA (50:50 % BY WT)
Figure B.5



Water Equilibrium at 24°C (75°F) and 52°C (125°F) with R-32 and Desiccants
Table B.1

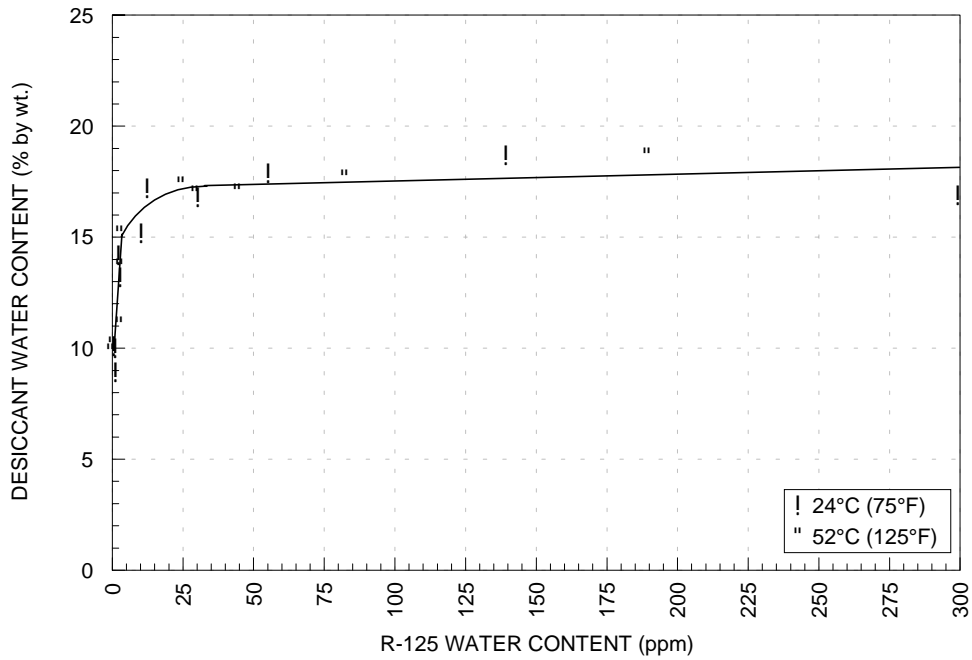
4AXH-6		511		Bayer Scale Alumina (BS)		XH-11		XH-11/BS (50:50)	
R-32 H ₂ O Content (ppm)	4AXH-6 H ₂ O Content (% by wt.)	R-32 H ₂ O Content (ppm)	511 H ₂ O Content (% by wt.)	R-32 H ₂ O Content (ppm)	BS H ₂ O Content (% by wt.)	R-32 H ₂ O Content (ppm)	XH-11 H ₂ O Content (% by wt.)	R-32 H ₂ O Content (ppm)	Mixture H ₂ O Content (% by wt.)
24°C (75°F)									
0.34	1.23	0.17	3.10	2.1	8.64	0.50	1.00	0.15	6.58
0.67	1.28	7.8	8.92	5.0	9.89	1.1	2.49	3.0	7.95
8.1	5.70	17	11.0	56	12.2	1.5	4.10	6.3	9.29
9.9	5.80	39	12.9	64	12.5	2.4	6.03	21	10.7
18	6.68	68	14.1	83	14.4	3.1	7.12	30	12.3
28	7.53	68	15.7	96	15.1	3.9	7.96	78	13.3
37	8.03	87	17.0	96	17.8	4.6	9.38	77	13.5
46	9.17	88	19.0	190	20.1	5.9	11.7	74	13.6
48	10.2	130	19.1			6.6	12.6	100	13.8
61	11.8	130	19.6			7.1	13.4	110	14.2
77	13.8	160	19.8			19	14.1	190	15.1
100	14.7	230	20.8			58	15.0	290	15.5
110	16.1	280	20.9			110	15.7	330*	16.1*
130	16.7					160	16.1		
180	17.1					160	16.3		
290	18.0					260	16.5		
						280	16.9		
52°C (125°F)									
1.3	1.29	1.7	3.23	2.2	7.96	0.82	0.86	2.5	6.83
6.5	3.73	2.9	5.15	5.2	10.2	1.0	1.35	3.3	7.50
14	4.29	5.4	7.70	11	12.4	1.8	5.51	12	10.0
26	5.80	26	10.3	13	12.8	3.7	7.05	27	11.0
38	6.75	27	10.9	14	13.9	6.1	7.81	52	11.9
44	7.67	30	11.7	21	15.2	7.1	9.48	56	13.3
45	8.15	69	13.1	110	16.9	7.4	10.0	92	13.5
67	9.07	78	14.5	180	17.3	9.0	11.4	82	13.7
69	10.3	90	15.9	190	18.6	10	12.2	93	13.8
88	12.3	100	16.3			13	12.8	110	14.1
100	13.9	110	16.8			29	13.6	150	14.7
120	14.1	120	17.3			54	14.0	270	15.5
160	15.0	120	17.9			100	15.2		
160	15.1	160	18.9			100	15.5		
180	16.6	160	19.1			120	15.8		
200	16.8	190	19.8			140	16.6		
280	17.0	230	20.3			280	16.8		
						340*	16.9*		

* not plotted on graph

Appendix C
Graphs and Raw Data for R-125

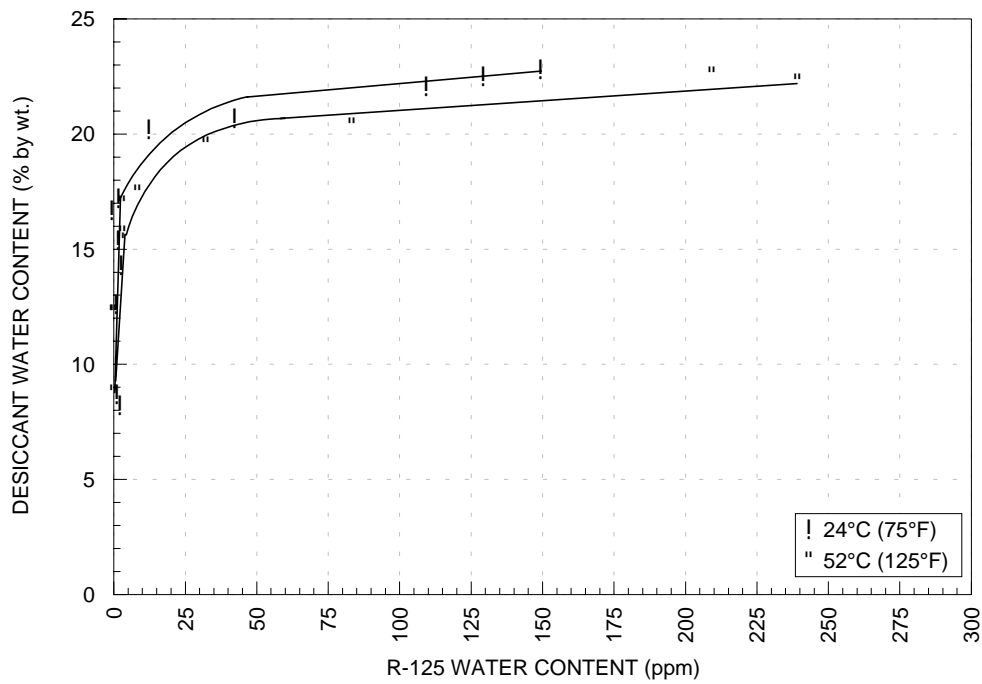
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-125 / UOP 4AXH-6 (3Å) MOLECULAR SIEVE

Figure C.1

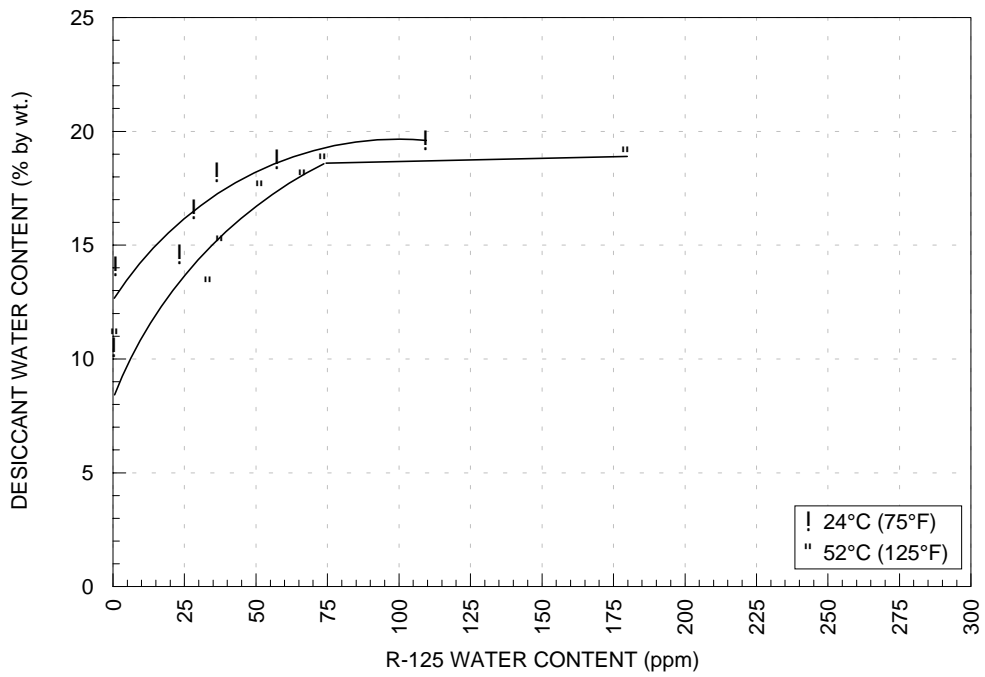


WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-125 / GRACE 511 (4Å) MOLECULAR SIEVE

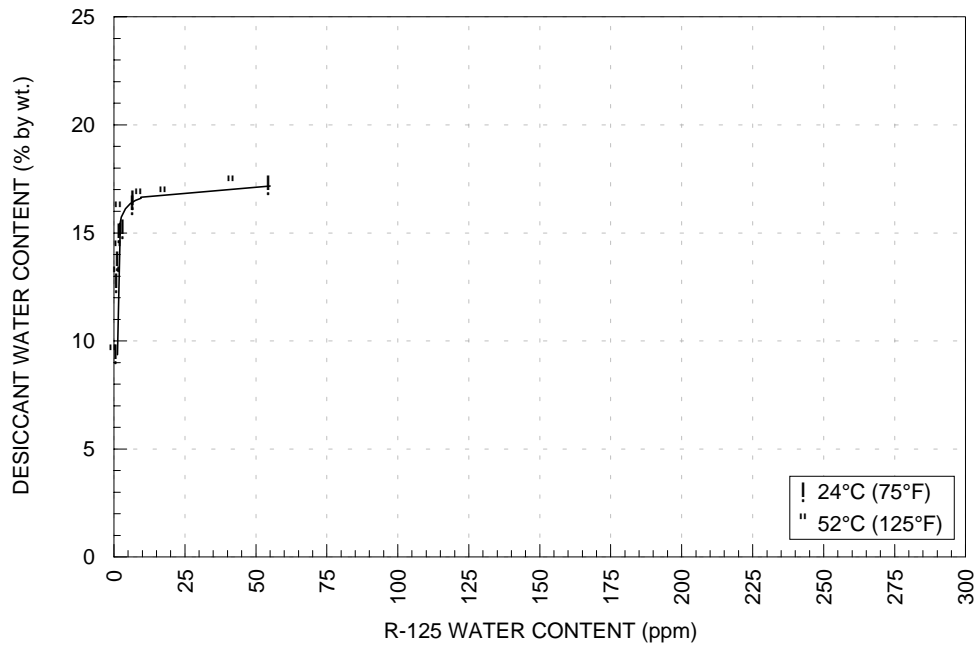
Figure C.2



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-125 / BAYER SCALE ALUMINA
Figure C.3



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F):
R-125 / UOP 4AXH-6 (3Å) MOLECULAR SIEVE & BAYER SCALE ALUMINA (50:50 % BY WT)
Figure C.4



Water Equilibrium at 24°C (75°F) and 52°C (125°F) with R-125 and Desiccants

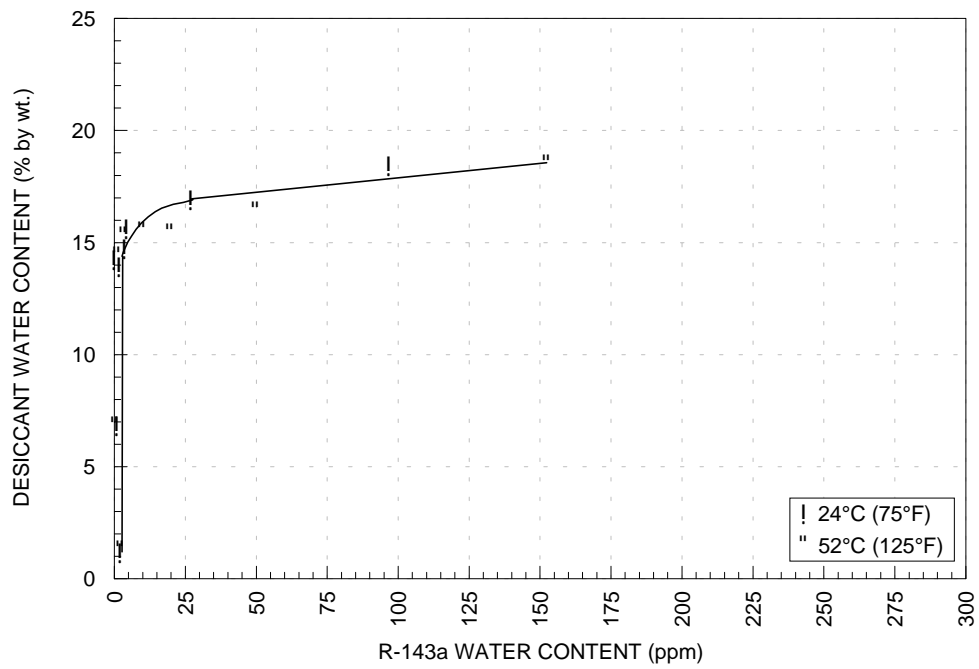
Table C.1

4AXH-6		511		Bayer Scale Alumina (BS)		4AXH-6/BS (50:50)	
R-125 H ₂ O Content (ppm)	4AXH-6 H ₂ O Content (% by wt.)	R-125 H ₂ O Content (ppm)	511 H ₂ O Content (% by wt.)	R-125 H ₂ O Content (ppm)	BS H ₂ O Content (% by wt.)	R-125 H ₂ O Content (ppm)	Mixture H ₂ O Content (% by wt.)
24°C (75°F)							
1.8	8.90	2.9	8.20	0.98	10.5	1.3	9.40
1.7	10.0	1.8	8.70	16	14.1	1.6	12.7
1.3	10.1	1.6	12.6	24	14.6	2.0	13.7
3.5	13.2	3.4	14.3	29	16.6	2.5	15.0
3.0	14.2	2.2	15.4	37	18.2	3.7	15.2
11	15.2	0.0	16.7	58	18.8	7.1	16.3
31	16.8	2.3	17.2	110	19.6	7.4	16.5
300	16.9	13	20.2			55	17.2
13	17.2	43	20.7				
56	17.9	110	22.1				
140	18.7	130	22.5				
		150	22.8				
52°C (125°F)							
0.20	9.80	0.63	8.70	1.3	10.9	0.48	9.40
0.76	10.1	0.53	12.2	34	13.2	1.7	13.0
3.3	11.0	0.92	12.2	38	15.0	2.2	14.2
3.4	13.6	3.3	15.3	52	17.4	2.4	16.0
3.4	15.1	3.9	15.6	67	17.9	9.4	16.6
30	16.9	3.7	16.9	74	18.6	18	16.7
45	17.0	9.0	17.4	180	18.9	42	17.2
25	17.3	33	19.5				
83	17.6	84	20.3				
320*	17.6*	240	22.2				
190	18.6	210	22.5				

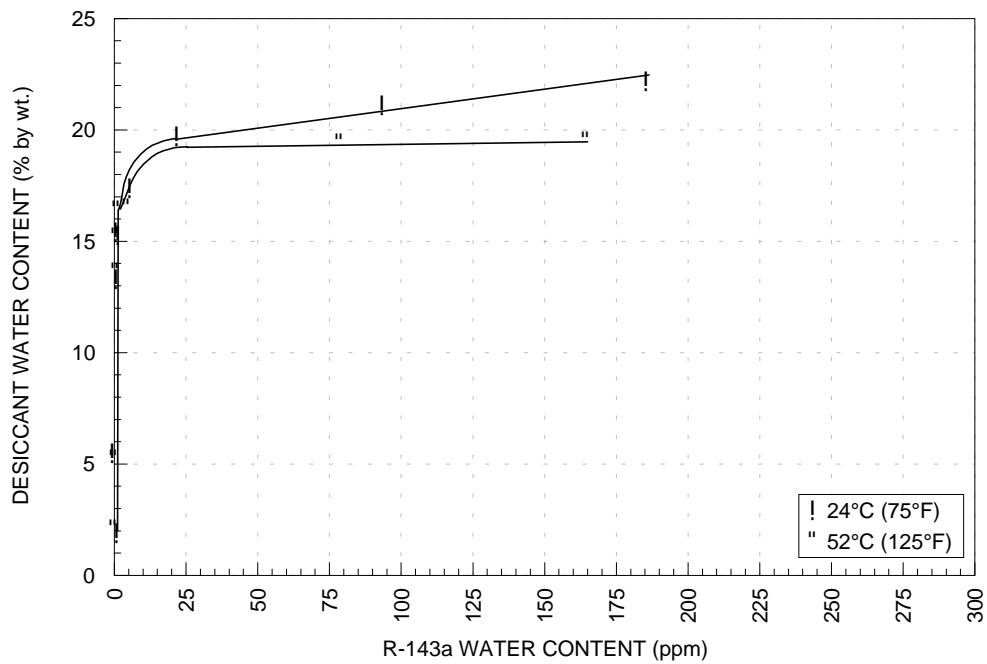
* not plotted on graph

Appendix D
Graphs and Raw Data for R-143a

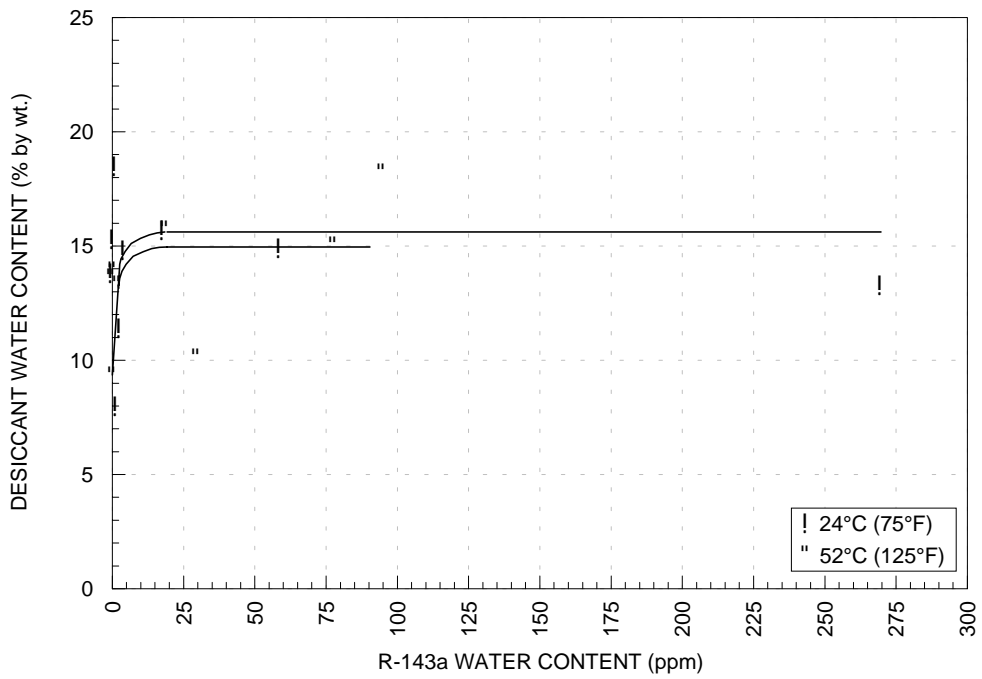
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-143a / UOP 4AXH-6 (3Å) MOLECULAR SIEVE
Figure D.1



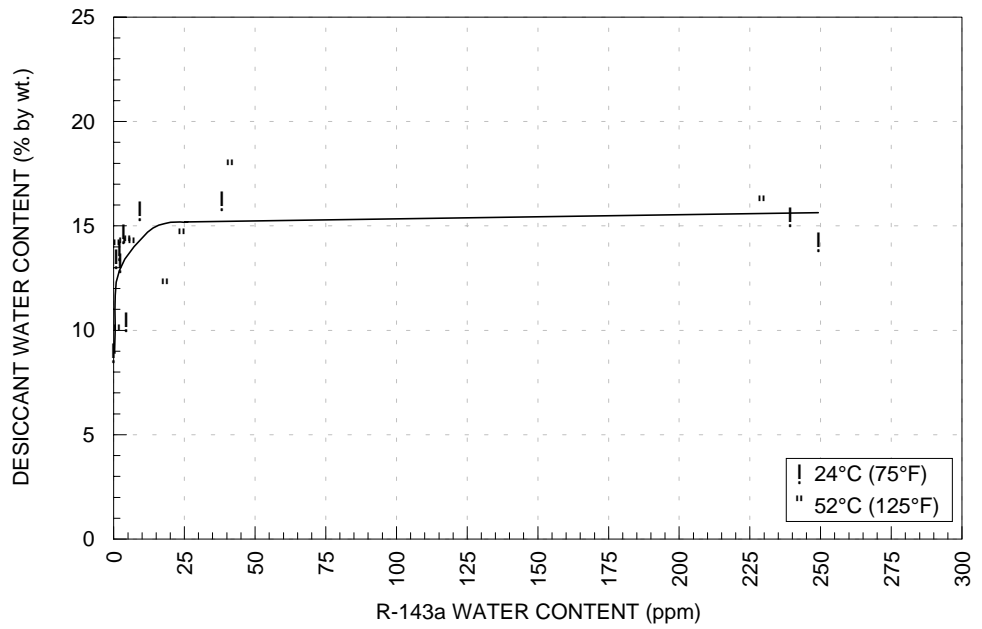
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-143a / GRACE 511 (4Å) MOLECULAR SIEVE
Figure D.2



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R-143a / BAYER SCALE ALUMINA
Figure D.3



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F):
R-143a / UOP 4AXH-6(3Å) MOLECULAR SIEVE & BAYER SCALE ALUMINA (50:50 % BY WT)
Figure D.4



Water Equilibrium at 24°C (75°F) and 52°C (125°F) with R-143a and Desiccants

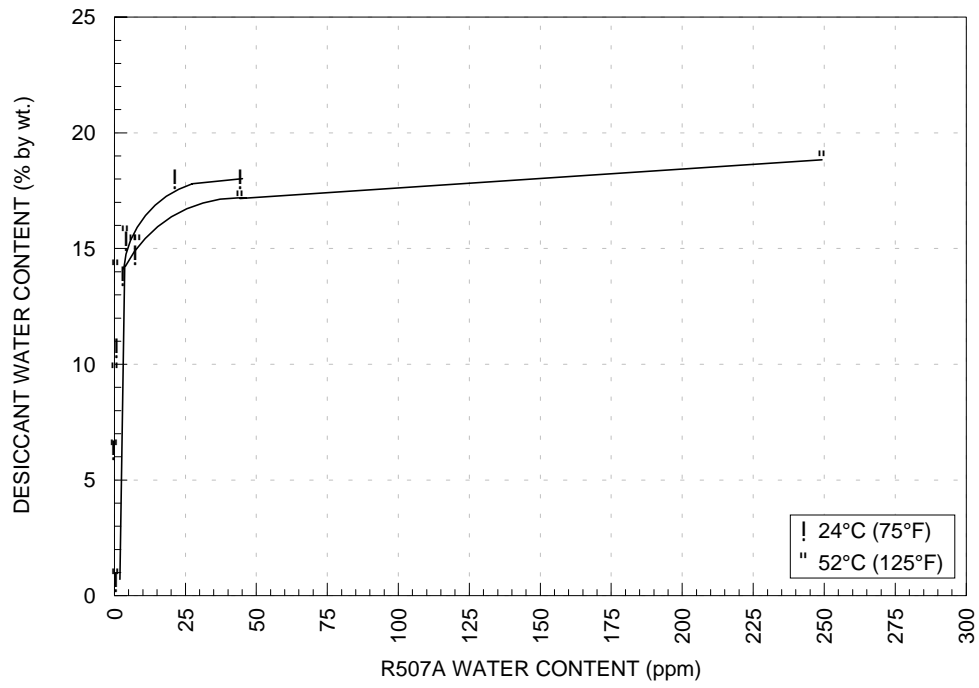
Table D.1

4AXH-6		511		Bayer Scale Alumina (BS)		4AXH-6/BS (50:50)	
R-143a H ₂ O Content (ppm)	4AXH-6 H ₂ O Content (% by wt.)	R-143a H ₂ O Content (ppm)	511 H ₂ O Content (% by wt.)	R-143a H ₂ O Content (ppm)	BS H ₂ O Content (% by wt.)	R-143a H ₂ O Content (ppm)	Mixture H ₂ O Content (% by wt.)
24°C (75°F)							
2.7	1.20	4.4	1.90	1.6	8.00	0.68	8.90
1.5	6.80	0.0	5.50	2.9	11.4	5.2	10.4
2.4	13.9	1.2	13.3	270	13.3	3.0	13.2
0.55	14.2	2.0	15.3	0.0	13.8	1.7	13.4
4.2	14.7	1.2	15.4	4.3	14.8	2.8	13.8
5.0	15.6	6.1	17.4	59	14.9	250	14.2
28	16.9	22	19.7	0.50	15.3	4.2	14.6
97	18.4	94	21.1	18	15.7	240	15.4
520*	20.4*	190	22.2	390*	16.3*	10	15.7
				1.2	18.5	39	16.2
52°C (125°F)							
2.7	1.30	0.27	2.10	0.61	9.30	2.0	9.80
0.85	6.80	0.44	5.20	30	10.1	19	12.0
1.6	14.4	0.99	13.6	2.2	13.3	1.9	13.9
3.9	15.3	1.0	15.2	0.19	13.6	3.9	14.0
20	15.4	1.4	16.4	0.73	13.9	7.2	14.0
10	15.5	4.8	16.5	78	15.0	5.7	14.1
51	16.4	79	19.4	19	15.7	25	14.4
150	18.5	170	19.5	330*	16.7*	230	16.0
740*	20.8*	370*	22.5*	95	18.2	330*	16.5*
				330*	18.7*	42	17.7

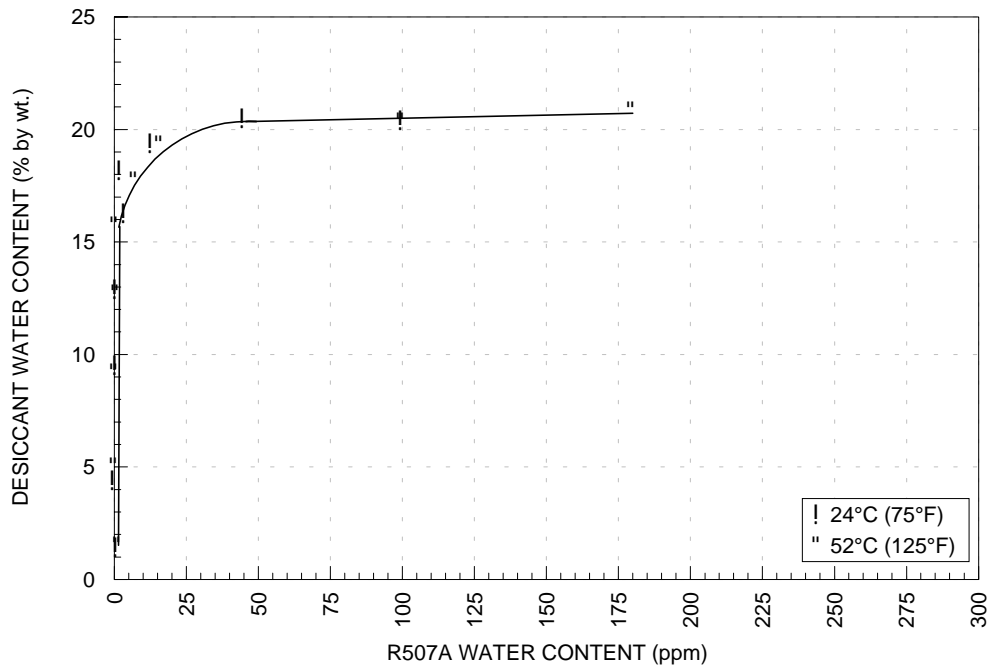
* not plotted on graph

Appendix E
Graphs and Raw Data for R507A

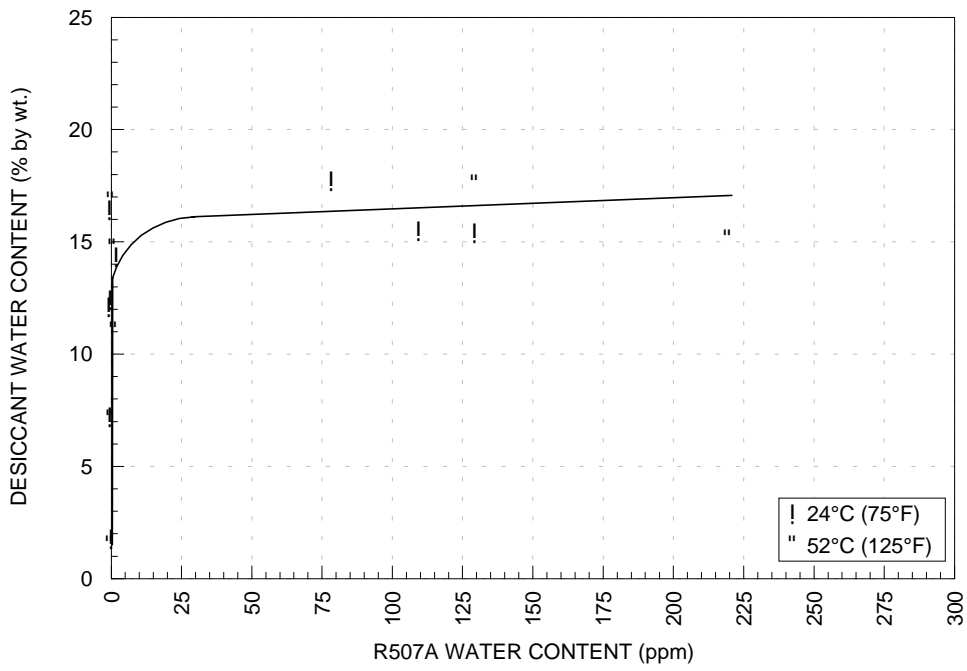
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R507A / UOP 4AXH-6 (3Å) MOLECULAR SIEVE
Figure E.1



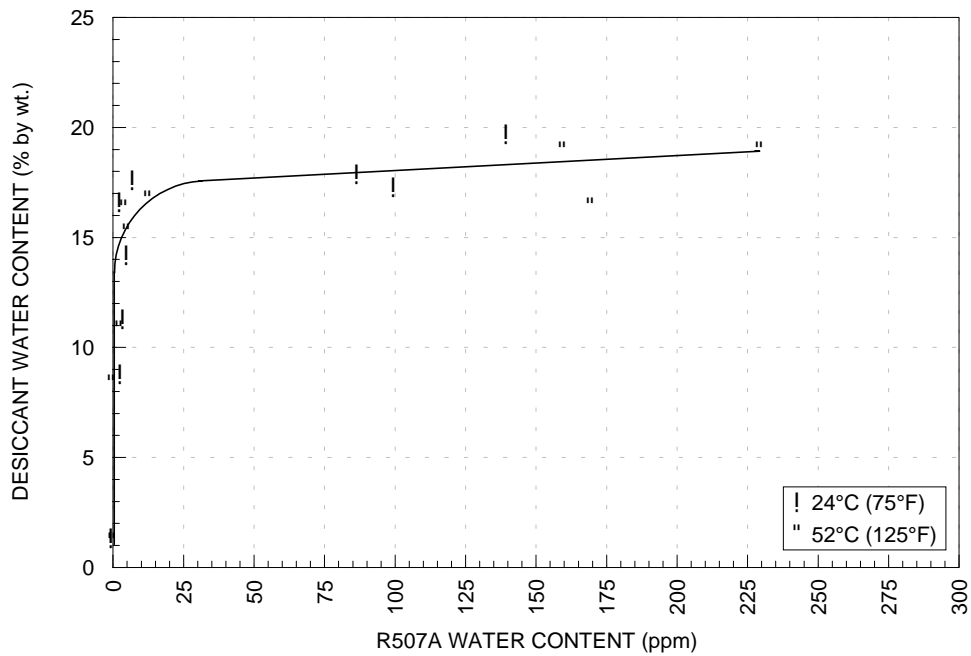
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R507A / GRACE 511 (4Å) MOLECULAR SIEVE
Figure E.2



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R507A / BAYER SCALE ALUMINA
Figure E.3



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F):
R507A/ UOP 4AXH-6 (3Å) MOLECULAR SIEVE & BAYER SCALE ALUMINA (50:50 % BY WT)
Figure E.4



Water Equilibrium at 24°C (75°F) and 52°C (125°F) with R507A and Desiccants

Table E.1

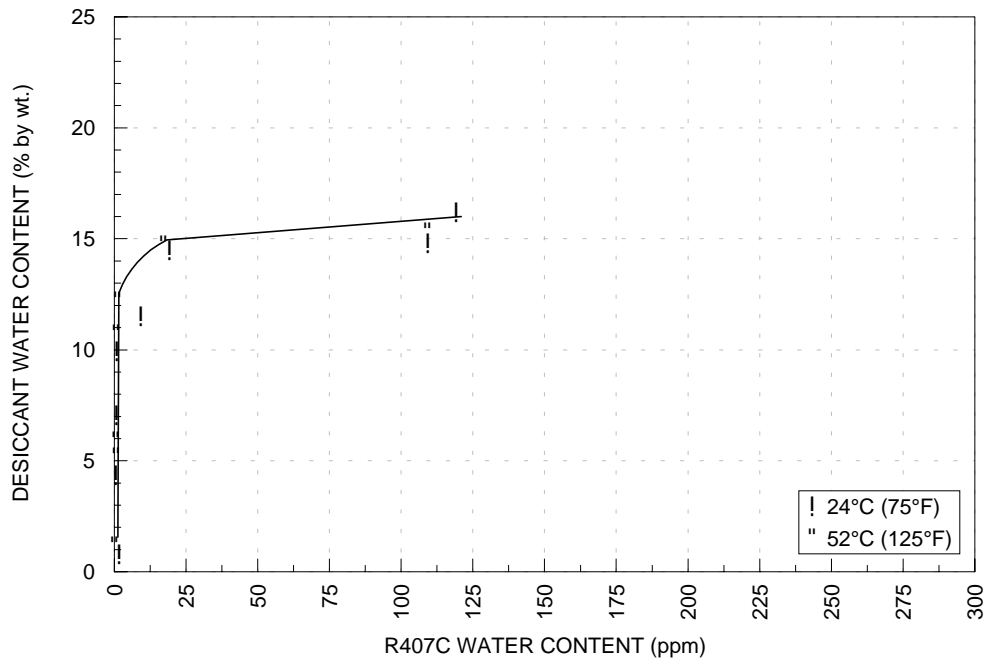
4AXH-6		511		Bayer Scale Alumina (BS)		4AXH-6/BS (50:50)	
R507A H ₂ O Content (ppm)	4AXH-6 H ₂ O Content (% by wt.)	R507A H ₂ O Content (ppm)	511 H ₂ O Content (% by wt.)	R507A H ₂ O Content (ppm)	BS H ₂ O Content (% by wt.)	R507A H ₂ O Content (ppm)	Mixture H ₂ O Content (% by wt.)
24°C (75°F)							
1.3	0.59	0.99	1.43	0.71	1.76	0.0	1.33
0.36	6.31	0.0	4.43	0.27	7.19	3.2	8.80
1.5	10.7	0.78	9.51	0.0	12.1	4.0	11.3
3.8	13.8	0.81	12.9	0.46	12.4	5.4	14.2
8.0	14.7	3.8	16.3	2.5	14.3	2.9	16.6
4.9	15.3	2.2	18.2	130	15.4	100	17.3
22	18.0	13	19.4	110	15.5	7.6	17.6
45	18.0	100	20.4	0.23	16.4	87	17.9
560*	20.2*	45	20.5	79	17.7	340*	18.3*
		410*	22.6*			140	19.7
52°C (125°F)							
1.3	0.76	1.5	1.48	0.07	1.50	0.35	1.14
0.69	6.35	0.37	4.97	0.33	7.11	0.17	8.31
0.89	9.66	0.54	9.15	1.5	11.0	2.9	10.8
1.2	14.1	1.0	12.7	1.1	14.7	5.5	15.2
7.4	15.2	0.61	15.7	220	15.1	4.4	16.3
8.9	15.2	7.3	17.7	0.40	16.8	170	16.4
4.6	15.6	16	19.3	130	17.6	13	16.7
45	17.1	100	20.3			230	18.9
250	18.8	180	20.8			160	18.9
740*	19.8*	510*	22.5*				

* not plotted on graph

Appendix F
Graphs and Raw Data for R407C

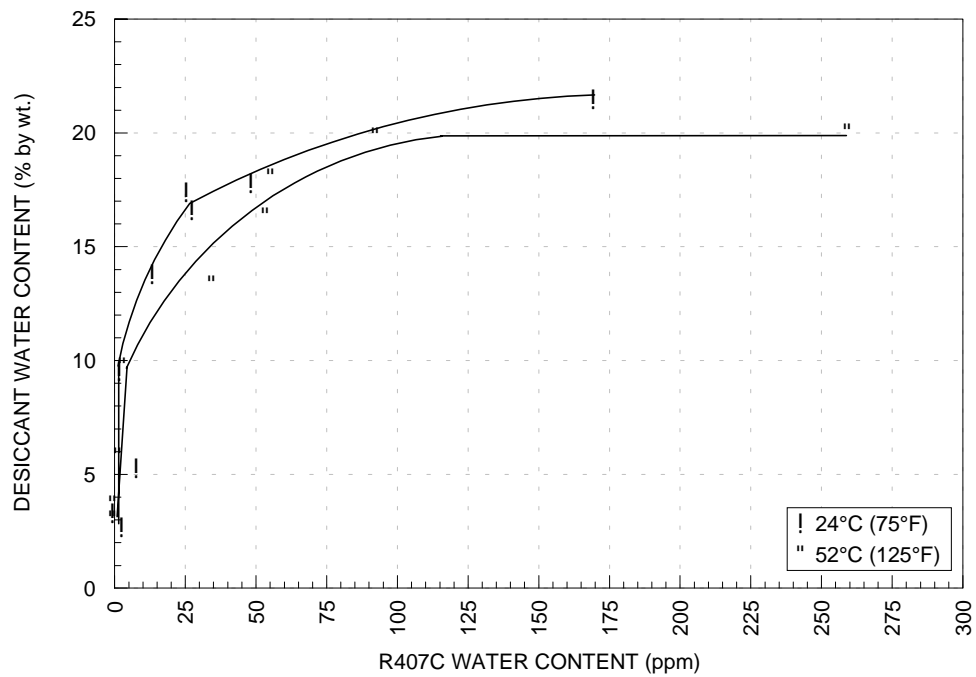
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R407C / UOP XH-11 (3Å) MOLECULAR SIEVE

Figure F.1

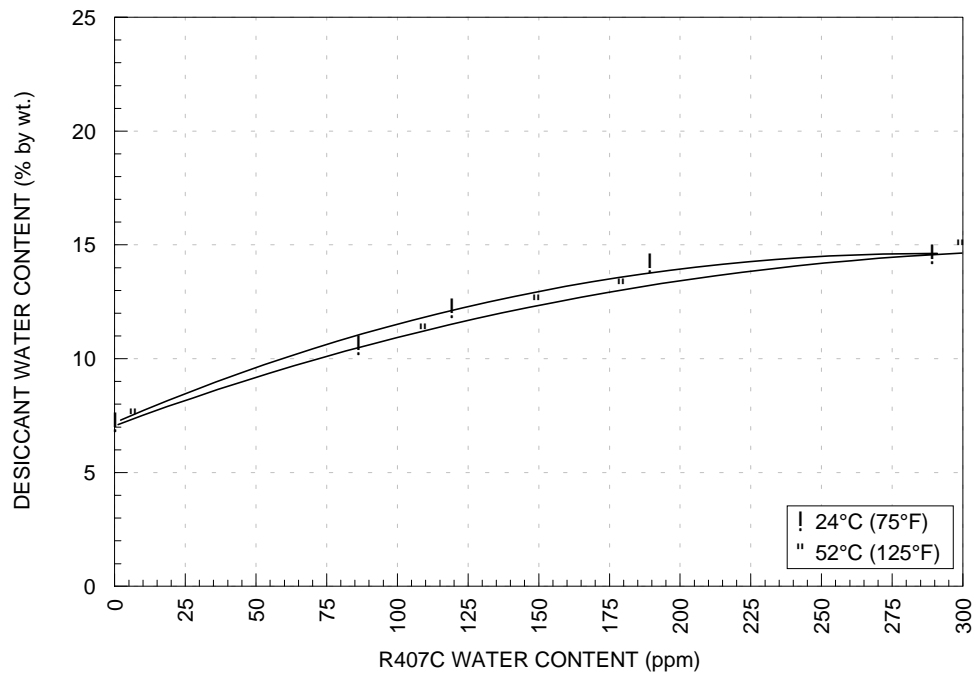


WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R407C / GRACE 511 (4Å) MOLECULAR SIEVE

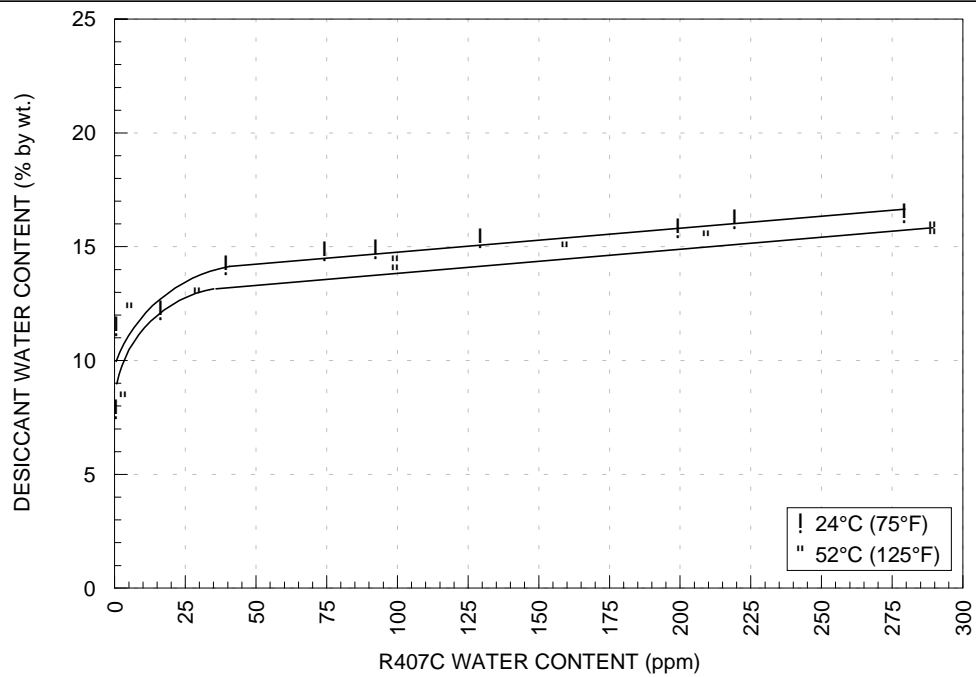
Figure F.2



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R407C / BAYER SCALE ALUMINA
Figure F.3



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F):
R407C / UOP XH-11 (3Å) MOLECULAR SIEVE & BAYER SCALE ALUMINA (50:50 % BY WT)
Figure F.4



Water Equilibrium at 24°C (75°F) and 52°C (125°F) with R407C and Desiccants

Table F.1

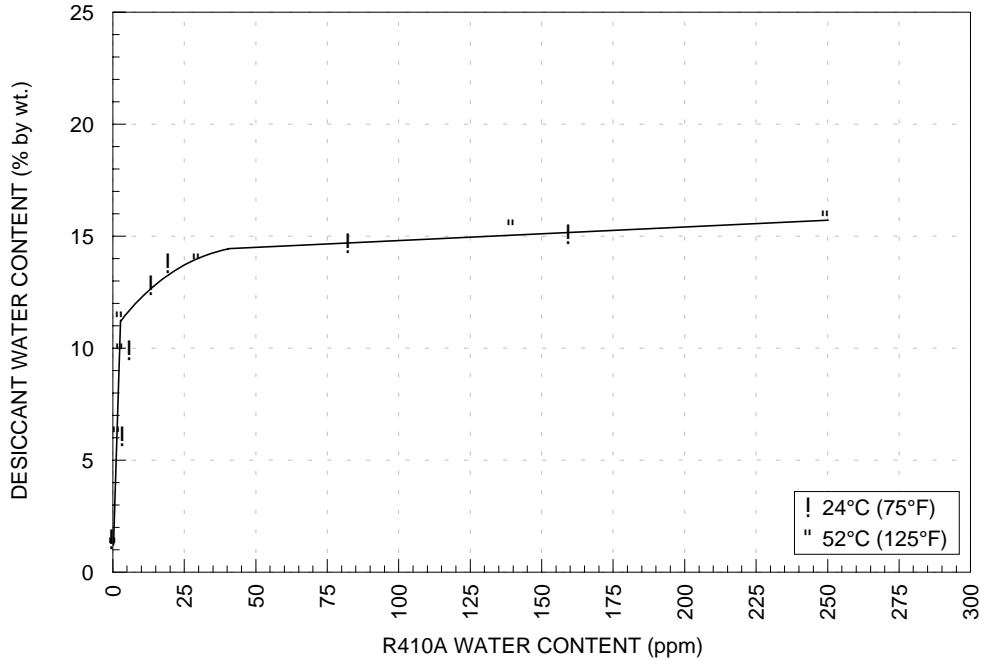
XH-11		511		Bayer Scale Alumina (BS)		XH-11/BS (50:50)	
R407C H ₂ O Content (ppm)	XH-11 H ₂ O Content (% by wt.)	R407C H ₂ O Content (ppm)	511 H ₂ O Content (% by wt.)	R407C H ₂ O Content (ppm)	BS H ₂ O Content (% by wt.)	R407C H ₂ O Content (ppm)	Mixture H ₂ O Content (% by wt.)
24°C (75°F)							
2.5	0.77	3.1	2.67	1.0	7.20	1.2	7.86
1.2	4.33	0.0	3.28	87	10.6	1.3	11.5
1.5	7.04	8.4	5.27	120	12.2	17	12.2
1.6	9.92	2.4	9.53	190	14.2	40	14.2
10	11.5	14	13.8	290	14.6	75	14.8
20	14.5	28	16.6			93	14.9
110	14.8	26	17.4			130	15.4
120	16.2	49	17.8			200	15.8
330*	17.4*	170	21.5			220	16.2
		660*	21.6*			280	16.5
52°C (125°F)							
0.86	1.16	0.07	3.00	7.4	7.39	3.8	8.23
1.4	5.17	0.08	3.65	110	11.1	6.1	12.1
1.3	5.88	1.9	5.75	150	12.4	30	12.8
1.4	10.7	3.5	9.72	180	13.1	100	13.8
1.9	12.2	35	13.3	300	14.8	100	14.2
18	14.7	54	16.3			160	14.8
110	15.3	56	18.0			210	15.3
340*	15.7*	93	19.8			290	15.4
		260	20.0			290	15.7
						410*	16.0*

* not plotted on graph

Appendix G
Graphs and Raw Data for R410A

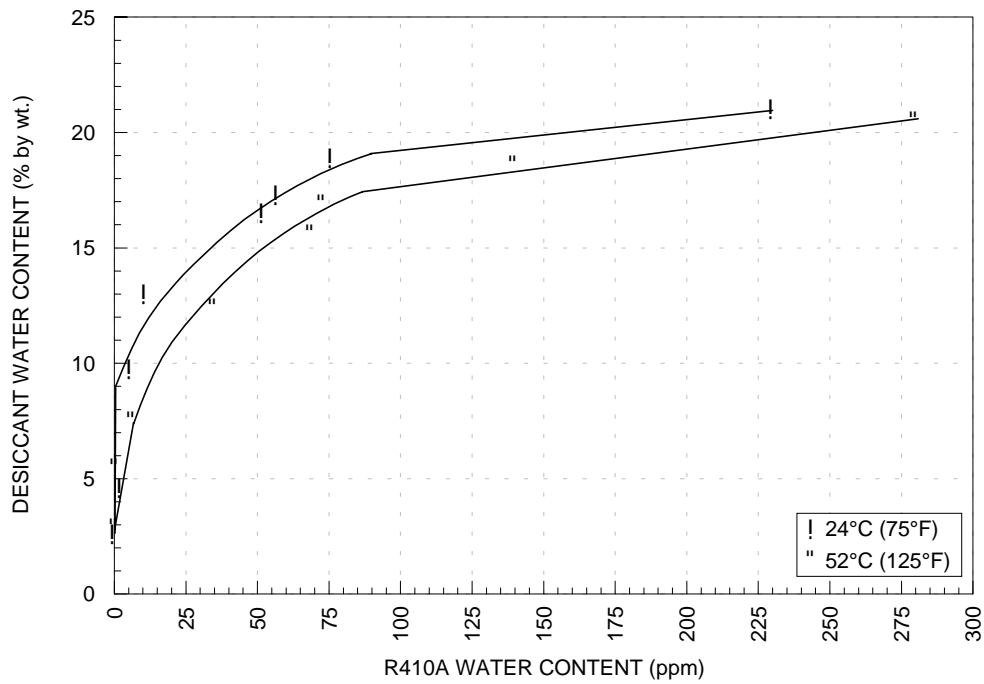
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R410A / UOP XH-11 (3Å) MOLECULAR SIEVE

Figure G.1



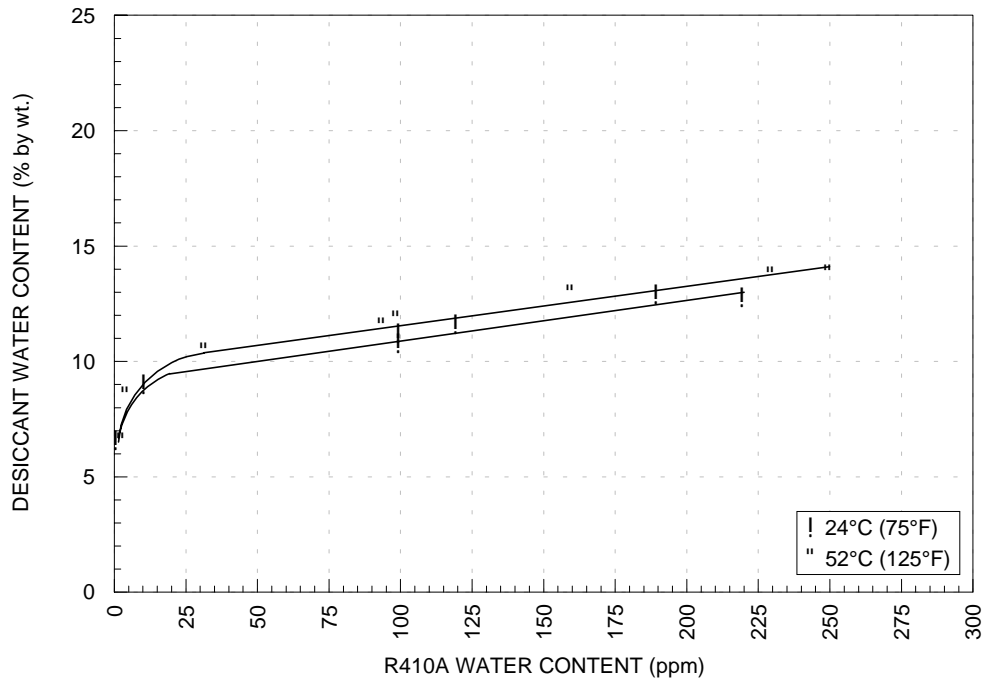
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R410A / GRACE 511 (4Å) MOLECULAR SIEVE

Figure G.2



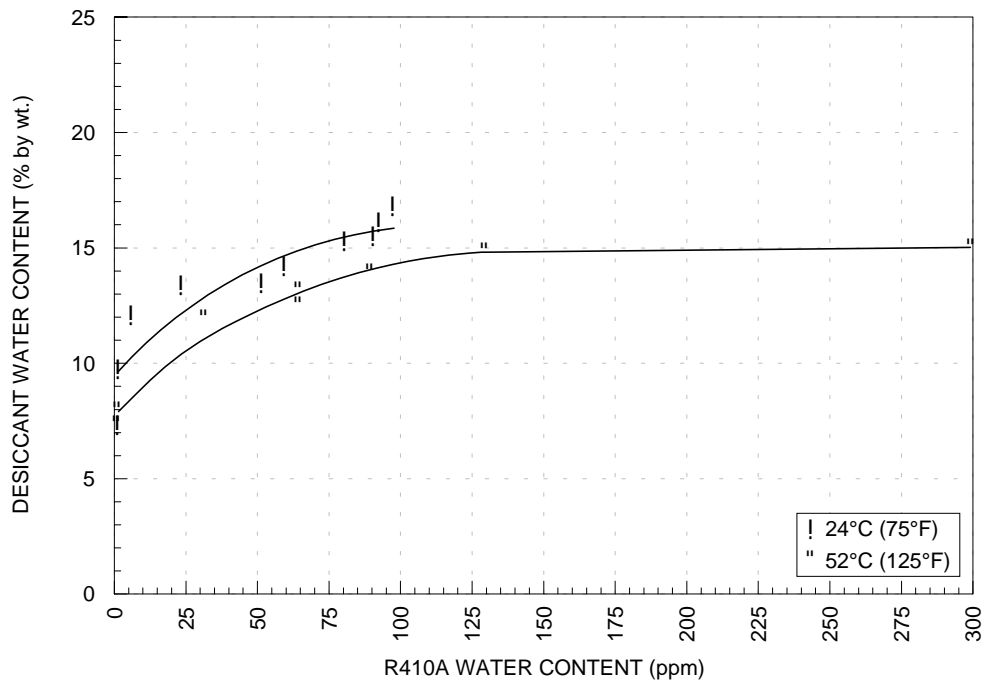
WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F): R410A / BAYER SCALE ALUMINA

Figure G.3



WATER EQUILIBRIUM AT 24°C (75°F) AND 52°C (125°F):
R410A / UOP XH-11 (3Å) MOLECULAR SIEVE & BAYER SCALE ALUMINA (50:50 % BY WT)

Figure G.4



Water Equilibrium at 24°C (75°F) and 52°C (125°F) with R410A and Desiccants

Table G.1

XH-11		511		Bayer Scale Alumina (BS)		XH-11/BS (50:50)	
R410A H ₂ O Content (ppm)	XH-11 H ₂ O Content (% by wt.)	R410A H ₂ O Content (ppm)	511 H ₂ O Content (% by wt.)	R410A H ₂ O Content (ppm)	BS H ₂ O Content (% by wt.)	R410A H ₂ O Content (ppm)	Mixture H ₂ O Content (% by wt.)
24°C (75°F)							
0.20	1.46	0.0	2.61	1.1	6.60	1.7	7.33
4.0	6.06	2.4	4.60	11	9.00	1.9	9.73
6.5	9.93	5.8	9.76	100	10.8	6.5	12.1
14	12.8	11	13.0	100	11.2	24	13.4
20	13.8	52	16.5	120	11.6	52	13.5
83	14.7	57	17.3	220	12.8	60	14.2
160	15.1	76	18.9	190	12.9	81	15.3
330*	16.4*	230	21.0	330*	15.2*	91	15.5
						93	16.1
						98	16.8
						440*	17.5*
						440*	17.7*
52°C (125°F)							
0.69	1.12	0.41	2.85	3.0	6.49	1.4	7.33
2.0	6.07	0.65	5.47	4.5	8.51	1.7	7.90
3.1	9.76	6.5	7.49	32	10.4	32	11.9
3.0	11.2	35	12.4	94	11.5	65	12.5
30	13.8	69	15.6	99	11.8	65	13.1
140	15.3	73	16.9	160	12.9	90	13.9
250	15.7	140	18.6	230	13.7	130	14.8
530*	16.1*	280	20.5	250	13.8	300	15.0
				350*	14.1*	310*	15.6*

* not plotted on graph