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A Simple Method of Composition Shifting with a Distillation Column for a Heat Pump Employing a Zeotropic Refrigerant Mixture

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ABSTRACT

This work presents a simplified method of controlling heat pump capacity by shifting the composition of a zeotropic refrigerant mix ture with a distillation column. Simplicity is achieved by incorporating the distillation column into the typical suction accumulator used by residential heat pumps. A U.S. patent has been applied for under the title "Accumulator Distillation Insert for Zeotropic Mixtures". An experimental system employing this distillation concept has been evaluated in the laboratory for zeotropic mixtures of R32/134a (30/70) and R32/125/134 a (23/25/52). For the binary mixture the circulating refrigerant composition was shifted t o R32/134a (54/46). For the ternary mixture the circulating refrigerant composition was shifte d to R32/125/134a (36/36/28). Seasonal calculations have shown these composition shifts t o reduce the seasonal resistance heat requirement by up to five percent compared to R22 . Additionally, the instantaneous peak energy requirement of the dwelling has been reduce d relative to R22 by six to nine percent depending on the climate region. The distillation inser t should be capable of producing greater c omposition shifts after further optimization of the insert and improved integration with the heat pump s ystem. For the ternary mixture, it is expected that the insert will be capable of producing a circulating refrigerant composition composed entirely of R32/125.

ACKNOWLEDGEMENTS

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INTRODUCTION

The heating capacity of a single speed air-to-air heat pump is directly proportional to the outside (evaporator) temperature. As the outside temperature falls, the suction pressure and the suction temperature also fall. This causes both the suction vapor specific volume and th e compression ratio to increase. Consequently, the system heating capacity is reduced and th e specific compressor work input is increased. The building heat load, on the other hand, is directly proportional to the temperature difference between the indoor and outdoor air. Therefore, th e building heat load increases as the outside temperature fa lls. For outdoor temperatures below the balance point, the output of the heat pump must be augmented with an auxiliary energy source.

The auxiliary energy required for an entire heating season is the difference between the seasonal building load and the seasonal heat pump output be low the balance point. The auxiliary energy is usually supplied by e lectric resistance heating, which has a coefficient of performance (COP) of one. Since the COP of a heat pump is usually greater than one, the heating seasonal performance factor (HSPF) can be increased by modulating the heat pump capacity to meet the building load thereby reducing the auxiliary heat required. Although the increase in HSPF i s modest (depending on the climatic region), the reduction in peak load to the electric utility can be significant. The benefit of reducing the peak energy demand is magnified if the electric power plant uses a less efficient electric generation system to meet the peak demand.

To reduce the amount of auxiliary heat required, the heat pump capacity mus t be increased to match the building load as the outside temperature falls. Th e only commercially available heat pumps capable of matching system capacity to the building load have been those which vary the volumetric capacity of the compressor. This can be accomplished several ways; the mos t common methods are two-speed compressor motors and frequency inverters for variable- speed compressor motors. The system capacity can also be controlled by varying the composition of a zeotropic refrigerant mixture. Specifically, by controlling the mixture composition th e thermodynamic properties of the refrigerant mixture can be altered to increase system capacity as the outside temperature drops. Basically, composition shifting of a zeotropic mixture can be thought of as a chemical analogue to a variable displacement compressor.

The effects of increasing the heat pump capacity to ma tch the building load are shown for a single-speed system capable of shifting the composition of a zeotropic refrigerant mixture in Figure 1. In this figure, it is assumed that the heat pump would op erate on the original refrigerant
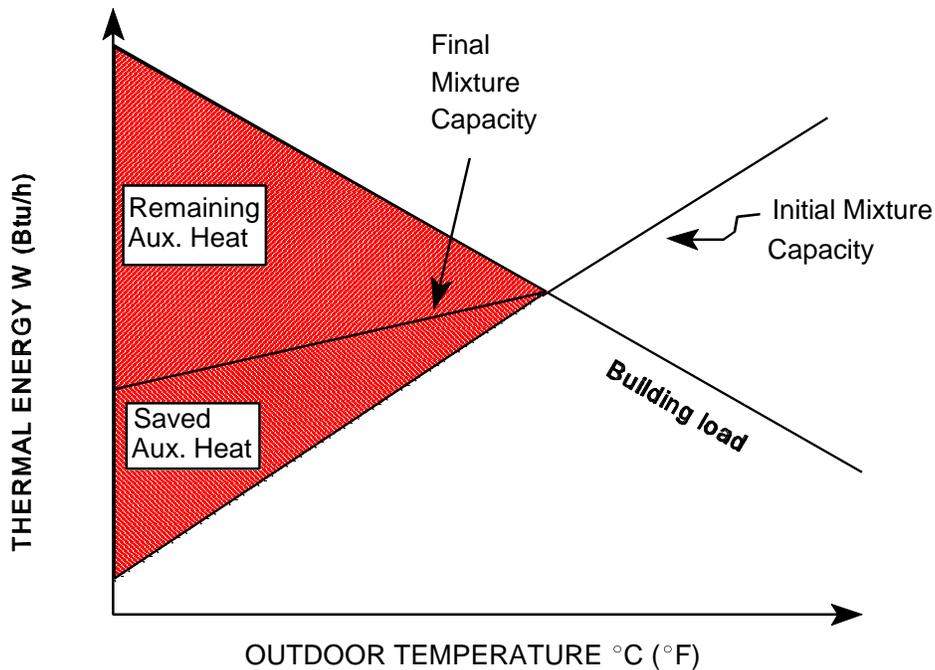
Figure 3 Outdoor Temperature Dependence of Building Load and Heat Pump Output

mixture until the outdoor temperature falls to the balance point. Figure 1 shows that the result of increasing the heat pump cap acity below the balance point will be a reduced auxiliary energy requirement.

The literature (patents and articles) describes many different methods and systems fo r varying the capacity of a heat pump by controlling the composition of a zeotropic mixture. An extensive bibliographical list of pro posed composition shifting systems is contained in reference 3. All of these may be classified into one of the two generic categories of active and passiv e systems. An active system is one that uses a distillation column, whereas a passive system uses an accumulator. Generally, the methods with accumulators are simple to implement but require a large refrigerant charge. Additionally, the magnitude of the refrigerant composition change is theoretically limited to the vapor composition that is in thermal equilibrium with the origina l mixtures bubble point. However, in practice, the magnitude of the refrigerant compositio n change is further limited by the maximum percentage of the total refrigerant charge that may be stored in the accumulator. Conversely, the column methods can achieve much large r composition changes at the cost of increased system complexity in terms of both hardware and control. Many of the proposed active systems have been so complex that they would never be cost effective enough to be applied in the competitive residential heat pump market.

The problems of hardware and control complexity encountered in the previously proposed distillation column systems are largely due to the failure of designers to integrate the distillation

column with the natural tendencies of heat pump operation. This work presents an active distillation column method for shifting the composition that retains the simplicity of a passive system. Simplicity is achieved by integrating the distillation column with the heat pump in a manner that does not change the basic cycle and method of operation.

OPERATING PRINCIPLES OF A PASSIVE SYSTEM

The simplest form for a passive composition shifting system may consist of a typical heat pump with a fixed area expansion device and a suction accumulator. The typical arrangement of these components is shown in Figure 2. In a passive system, the composition shift occurs as a consequence of liquid collecting in the low-pressure accumulator. This occurs naturally in a heat pump with a fixed area expansion device which will progressively flood more liquid into the suction accumulator as the source temperature decreases. The reason that a heat pump naturally floods liquid into the accumulator in response to a drop in source temperature can be explained by considering the mass balance that occurs between the compressor and the expansion device.
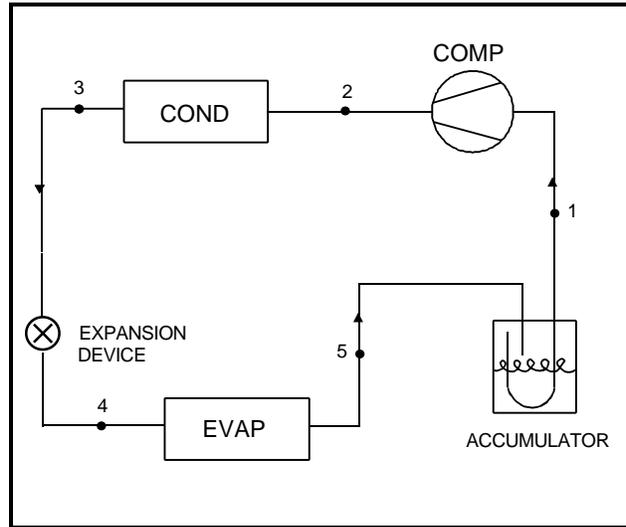
Figure 4 Typical System Components

Consider a pure refrigerant system with a fixed area expansion device operating in the heating mode at steady-state conditions. As the outside temperature falls, the evaporator pressure and temperature will decrease commensurately. Since the indoor temperature remains relatively constant the condenser pressure will also remain relatively constant. Consequently, the compressor will pump less refrigerant due to the lower suction vapor density and the increased compression ratio. However, the expansion device will continue to pass the same amount of refrigerant since it is relatively insensitive to changes in low side conditions [2]. Because the expansion device is now passing more refrigerant than the compressor is pumping, a portion of the refrigerant charge will migrate to the low pressure side of the system where it will collect in the suction accumulator.

As the refrigerant migration proceeds, the condenser will contain progressively less liquid. The migration of refrigerant cannot proceed indefinitely, so the system must adjust itself to achieve a new steady-state refrigerant distribution. Fortunately, the expansion device mass flow rate is directly proportional to the high side pressure and the liquid subcooling. The high side pressure has remained constant, but the amount of subcooling is determined by the amount of liquid in the condenser. Therefore, as the condenser is depleted of liquid the system losses subcooling. Since the amount of refrigerant passed by the expansion device is directly proportional to the amount of subcooling, the gradual loss of subcooling causes a gradual decrease in the expansion device mass flow rate. When the expansion device mass flow rate becomes equal to the compressor mass flow rate, a new steady-state equilibrium condition will have been reached. This new equilibrium condition will be characterized by a greater portion of

the total refrigerant mass in the low side, less subcoolin g (it may even have two-phase refrigerant entering the expansion device) and a lower capacity.

Having examined how a decrease in the outside temperature causes the migration o f refrigerant from the condenser to the suction accumulator, the consequences of this for a zeotropic mixture will now be addressed. Since accumulators normally have a minimal amount of heat transfer at the outside surface, the liquid and vapor inside the vessel will be in a n
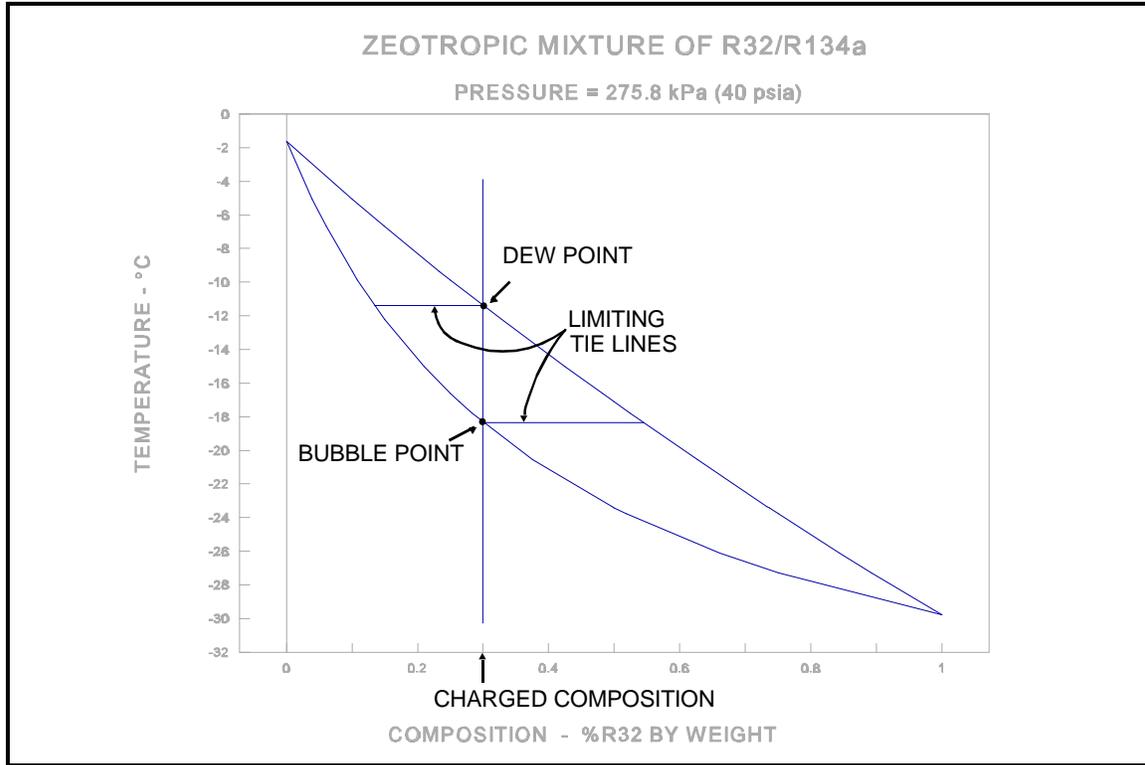
Figure 5 Passive (Equilibrium Stage) Composition Shift Mechanism

approximate state of thermal equilibrium. A Temperature-Composition diagram for a zeotropic mixture of R32/134a is shown in Figure 3. In this figure, thermal equilibrium means that th e vapor leaving the accumulator and the liquid remain ing must lie on a horizontal tie line. In other words, this type of passive system can produce a shift no greater than a single equilibrium stage. Additionally, if the accumulator is in thermal equilibrium then species conservation dictates that one point on the tie line must be concurrent with the vertical line defined by the original charged composition. These constraints define the two limiting tie lines which are shown in Figure 3 . It is theoretically possible for the system to operate so that the state in the accumulator i s represented by any tie line that lies between these two. The max imum system capacity will occur when the circulating fluid, represented by the vapor leaving the accumulator, has the greates t composition of the more volatile component. This vapor composition is defined by the tie line that extends from the original composition bubble point.

Although it is theoretically possible for an ac cumulator storage system to operate so that the circulating composition is that of the vapor in equilibrium with the bubble point, it is no t feasible in practice. Since the liquid remaining in the accumulator and the vapor leaving must lie on the same tie line, as the composition of the more volatile component increases in the vapor it also increases in the stored liquid. Consequently, as the maximum capacity composition i s approached increasingly larger percentages of the refrigerant charge will have to be stored in the

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accumulator. It is impractical to store large percentages of the total refrigerant charge because the excess refrigerant will have to be accommodated in the cooling mode when the accumulator is empty.

OPERATING PRINCIPLES OF THE PROPOSED SYSTEM

The proposed distillation system retains the simplicity of an accumulator storage system, but eliminates the need to store large percentages of the refrigerant charge. Additionally, th e maximum composition shift is not limited to the vapor composition in equilibrium with th e bubble point of the initial composition. This result is made possible by removing the therma l equilibrium constraint. Since the stored liquid and the leaving vapor are not in therma l equilibrium they no longer must lie on the same tie line. Consequently, the stored liquid ma y consist of the less volatile component in a nearly pure composition.

The thermal equilibrium constraint is removed by adding a distillation insert and a low wattage heat source inside the accumulator. The hardware component layout for the proposed system is shown in Figure 4. A patent application for the concept of placing a distillation insert inside a typical suction accumulator is currently pending. The patent application is entitle d "Accumulator Distillation Insert for Zeotropic Mixtures".

The distillation insert is composed of a liquid-barrier and a small diameter packe d distillation column. The insert divides the accumulator into three separate regions of different functions. The volume above the liquid barrier serves as the liquid-vapor separation zone. Its function is identical to the top portion of a standard accumulator. The center region is defined by the liquid-barrier and the volume contained within the distillation column. The liquid-barrier directs all the liquid that leaves the separation zone through the column. The column is fille d with a random distillation packing which provi des the surface area for the heat and mass transfer necessary for column operation. The region below the insert is the liquid storage and vapo r generation volume which also functions exactly as in a standard accumulator except for th e addition of the heat source for vapor generation. The heat source, which is represented in th e figure by the symbol Q_{in}, is obtained from an electric immersion heater. It is important t o mention that the addition of the distillation insert and heat source adds no new moving parts and does not affect the normal accumulator function of providing protection against liquid slugging with positive oil return.

Although the distillation insert was developed to be placed inside a standard suctio n accumulator, for visualization purposes a glass version of the device was used in the experimental program. Additionally, to improve the level of the experimental instrumentation the thre e functional regions of separation, distillation and storage/generation w ere separated into physically separate components. The hardware component layout for the experim ental version of the device is shown in Figure 5.

The random packing utilized in the experimental column consists of 3 mm Teflon Raschig Rings. To develop the theory of a randomly packed continuous contact tower requires a differential analysis. However, a simple qualitative description of the distillation colum n operating principles can be made by considering the random packing to be composed of distinct trays. This type of distillation column, known as a multistage tray tower, is common in th e

chemical industry. The analysis of tray towers is conducted in a manner similar to the passive system by considering each tray to constitut e one equilibrium stage or tie line. Each equilibrium stage or tray is then referred to as a theoretical plate (TP).   The complete multistage tray tower (the analogy for the random packed tower) consists of a series of single stage equilibriu m distillations such as occur in a passive system accumulator.
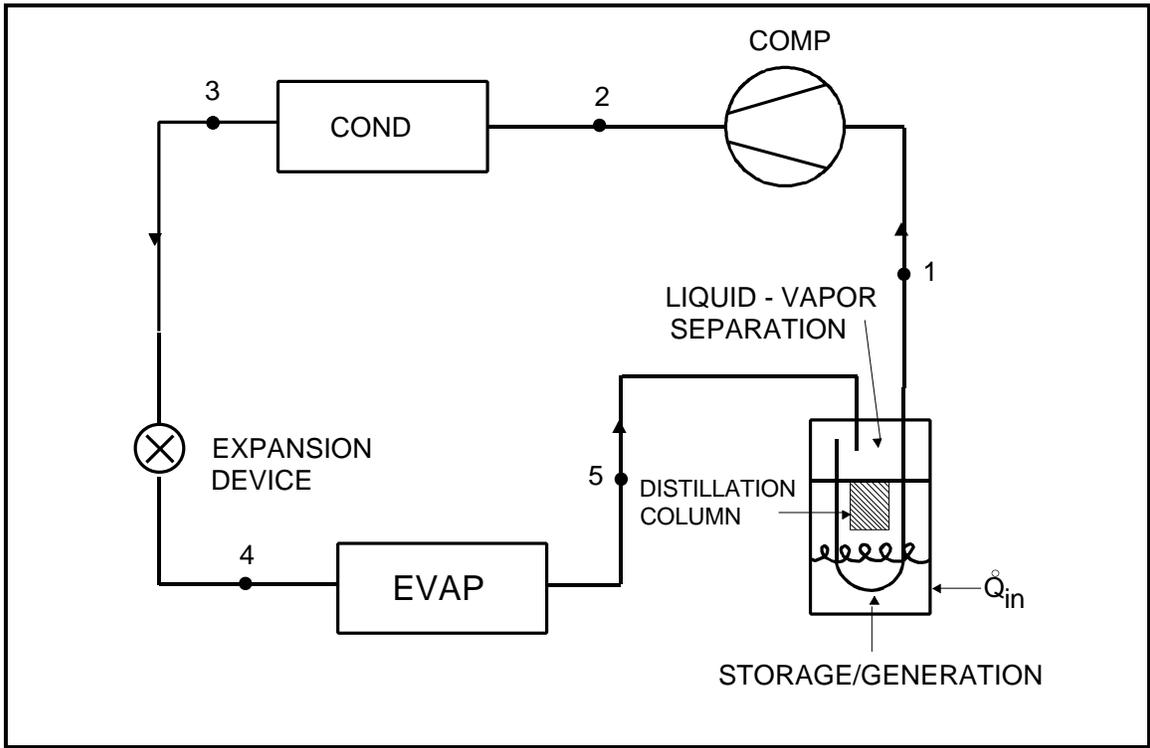
Figure 6 Patent Pending Version
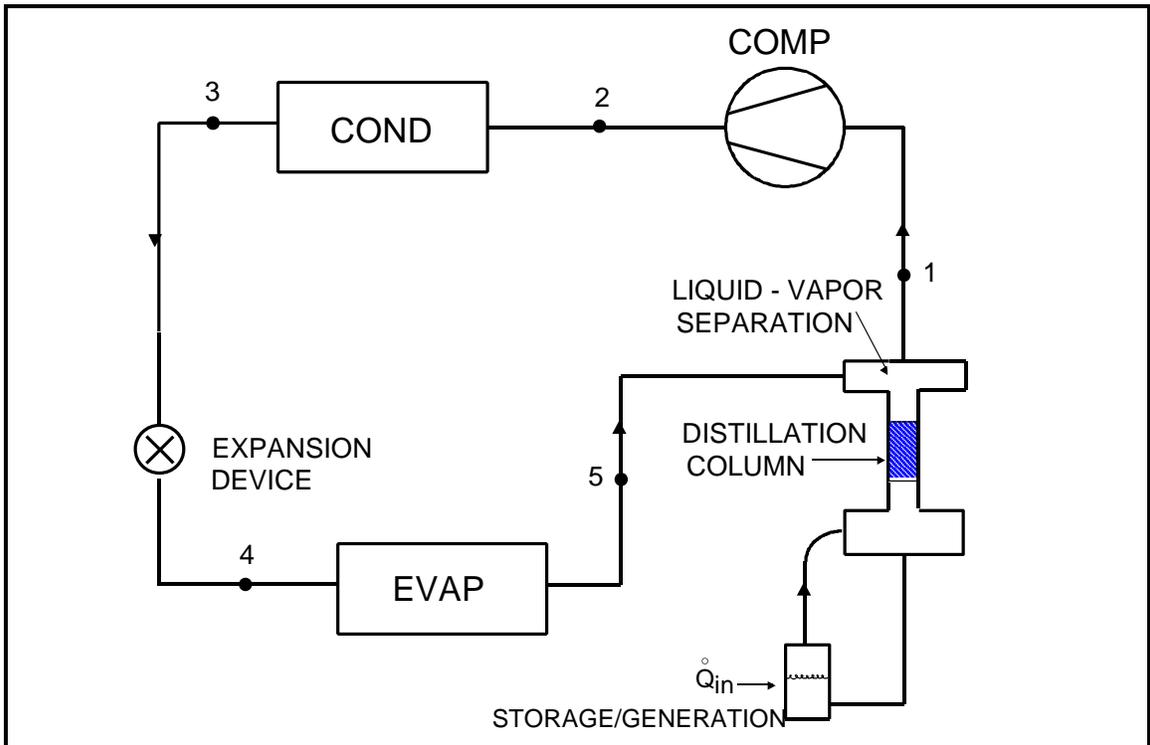
Figure 7 Experimental Version

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This idealized representation of a packed tower distillation column is shown in Figure 6. Figure 6 also shows the functional zones of separation and storage as boundary conditions for the mass flows entering and leaving the column. For illustrativ e purposes, the distillation column of Figure 6 shows four arbitrarily spaced th eoretical plates numbered from the top of the column down (TP1 through TP4). A theoretical plate is to be interpreted as the height of continuou s
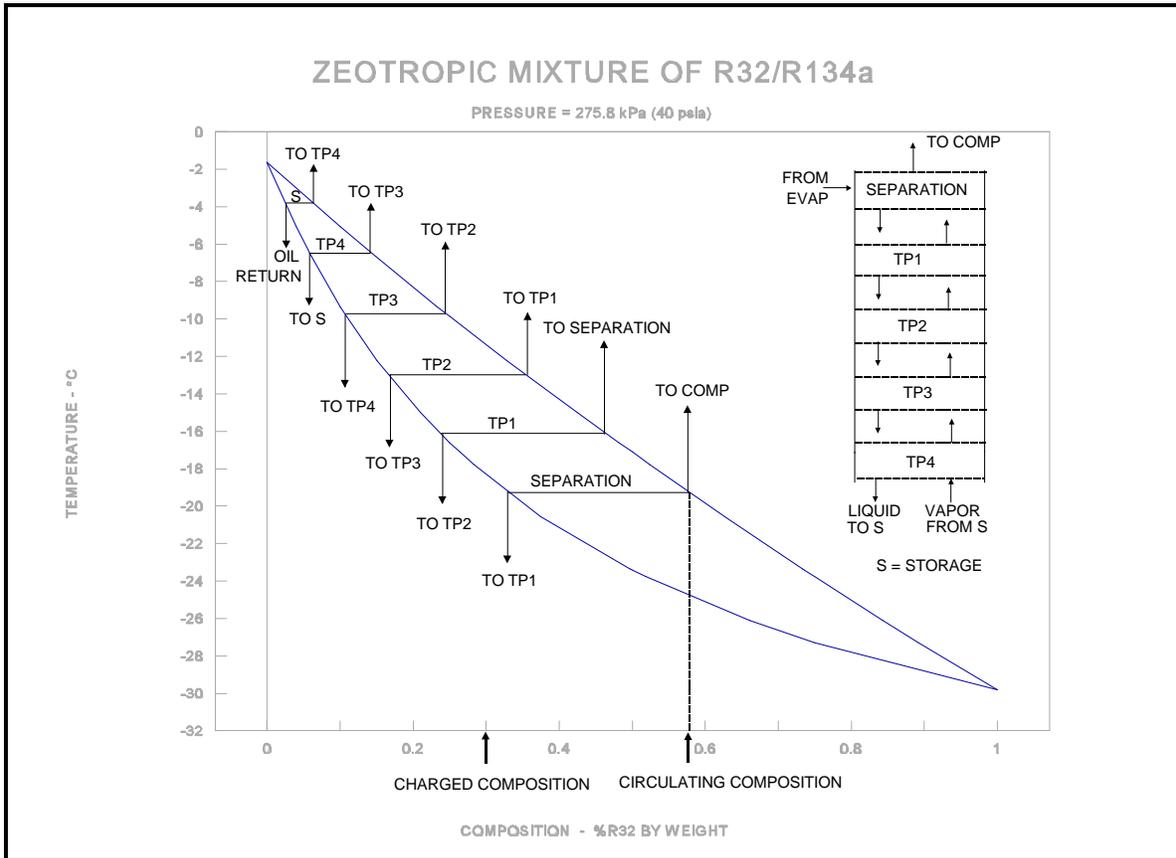
Figure 8 Distillation Column Composition Shift Mechanism

packing that produces one equilibrium stage. Where an equilibrium stage is the compositio n difference between the liquid and vapor in thermal equilibrium at the opposite ends of a tie line. The liquid leaving the storage, shown in Figure 6 as oil return, is the refrigerant that woul d normally be removed from the accumulator sump through the oil return orifice. The oil return mass flow was experimentally contr olled by a valve in a line connecting the storage sump to the suction line at point 1 in Figure 5.

GENERAL COMPOSITION SHIFT RELATIONS

Comparing Figure 6 with Figure 3 shows that the ability of t he distillation column to store nearly pure liquid of the less volatile component has the potential to produce a much greate r composition shift than a passive system. The difference in composition shifting potential can be quantified using conservation of mass and species f or a given percentage of the initial refrigerant charge that is stored in the accumulator. Eq uation 1 shows the resulting binary mixture equation which relates the fraction of the total refrigerant charge stored in the accumulator to the initial composition, the circulating composition and the stored liquid composition.

$$\frac{M_{sl}}{M_T} = \frac{X_c - X_{ic}}{X_c - X_{sl}}$$

(1)

Where M_{sl} is the mass of refrigerant liquid stored in the accumulator, M_T is the total refrigerant charge mass, X_c is the circulating composition, X_{ic} is the initial charge composition, and X_{sl} is the composition of the stored liquid. All compositions in Equation 1 are mass fractions referred to the more vo latile component. For both passive and distillation accumulators M_T and X_{ic} are known quantities and the mass of liquid stored, M_{sl}, can be assumed. For a passive accumulator, X_c and X_{sl} are equilibrium phase compositions on the opposite ends of a tie line. For th e distillation accumulator, X_c and X_{sl} are independent quantities.

In Figure 7, Equation 1 is used to compare the storage requirements necessary to produce a change in the circulating composition of the distillation column system relative to a passiv e system for a zeotropic mixture of 30% R32 and 70% R134a by weight. Clearly, the necessary storage requirements to produce a given composition shift have been considerably reduced. In other words, for a given limitation on the maximum amount of possible refrigerant storage the maximum possible composition of R32 in the circulating refrigerant is increased.

For a ternary refrigerant, applying mass and species conservation results in a set of three equations for the composition shift. This set is labelled as Equation 2. The subscripts T,c,ic and sl have the same meaning as in Eq uation 1 and the additional subscripts A,B and C refer to each component in the mixture. Similar to Equation 1, this set of equations represents the relationship between the fraction of refrigerant stored in the accumulator and the relevant syste m compositions for each component.

$$\frac{M_{sl}}{M_T} = \frac{X_{cA} - X_{icA}}{X_{cA} - X_{slA}}$$

$$\frac{M_{sl}}{M_T} = \frac{X_{cB} - X_{icB}}{X_{cB} - X_{slB}} \tag{2}$$

$$\frac{M_{sl}}{M_T} = \frac{X_{cC} - \left(1 - X_{icA} - X_{icB}\right)}{X_{cC} - \left(1 - X_{slA} - X_{slB}\right)}$$

The result of these equations can be plotted in a manner similar to Figure 7 to show the storage requirements necessary to produce a given composition shift. The results are shown in Figure 8 for a ternary zeotropic mixture of R32/125/134a (23/25/52). In Figure 8, the abscissa is the composition of the R32 plus R125 in the circulating composition. This simplificatio n avoids the necessity of creating a three dimensional graph for the ternary refrigerant . Additionally, because R32 and R125 have almost the same normal boiling point thei r compositions tend to stay in the original ratio to each other. This feature of the ternary mixture can be seen in the summarized experimental data shown in Table 2.
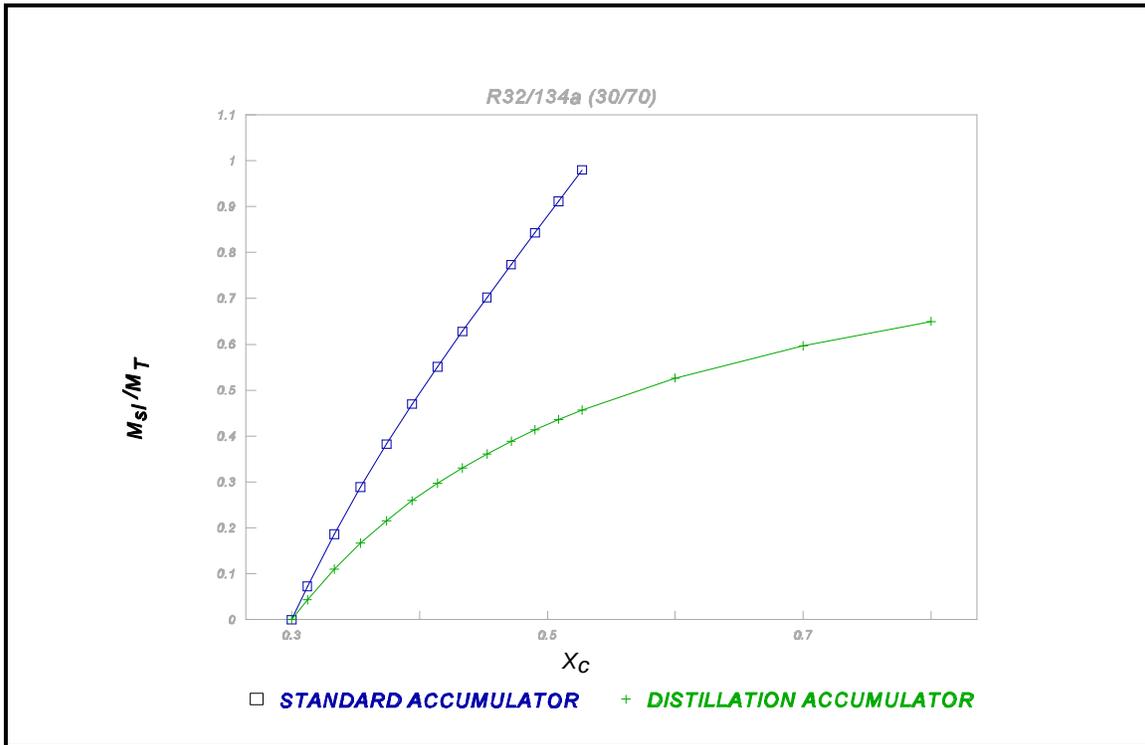
Figure 9 Binary Mixture Storage Requirements
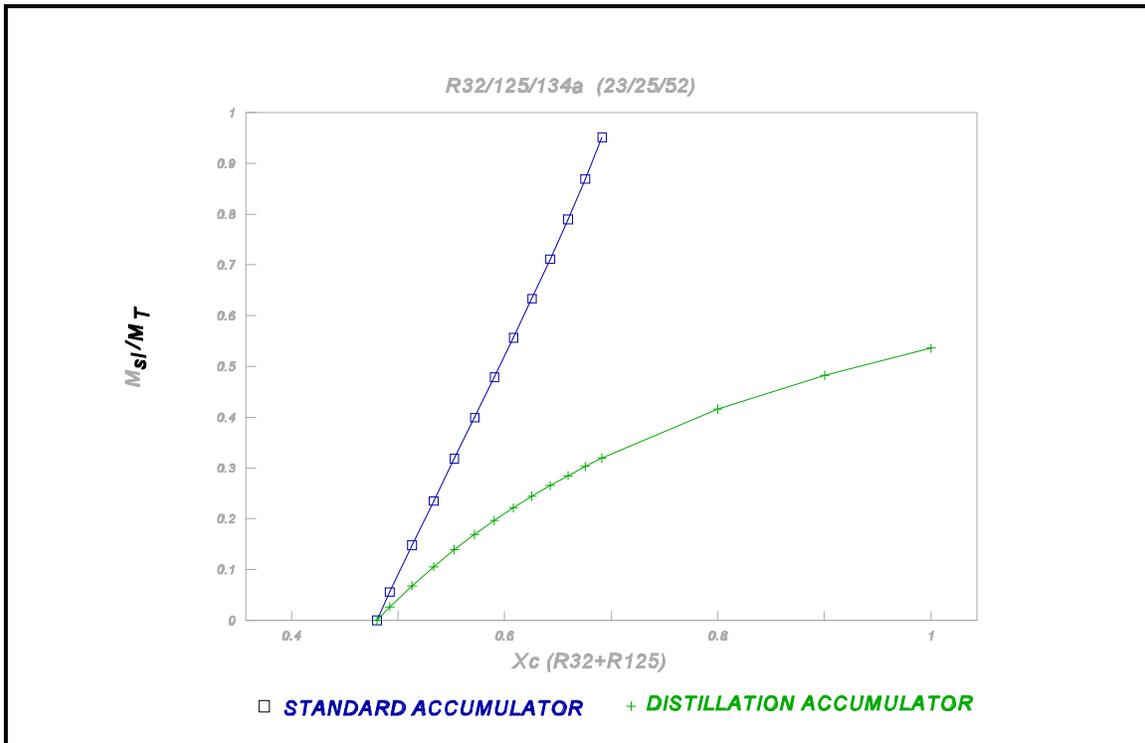
Figure 10 Ternary Mixture Storage Requirements

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TEST METHODOLOGY AND RESULTS

The following test procedure was developed to assess the difference in composition shifting potential between a standard accumulator and an accumulator e quipped with a distillation insert. Equations 1 and 2 show that the circulating composition, X_c, is dependent upon the initial composition X_{ic}, the composition of the stored liquid X_{sl}, the total refrigerant charge mass M_T, and the mass of liquid refrigerant that is stored in the accumulator M_{sl}. For convenience, rearrange Equation 1 by solving for X_c so that it appears as the dependent variable.

$$ X_c = \frac{X_{ic} - \left(\dfrac{M_{sl}}{M_T} \right) X_{sl}}{1 - \dfrac{M_{sl}}{M_T}} \qquad (3) $$

Of the independent variables on the right hand side of Equation 3, X_{ic} defines the mixture to be tested and M_T is a parameter that can be varied through a range for each mixture tested. Th e remaining two variables M_{sl} and X_{sl} are functions of the operating conditions and syste m hardware (i.e., heat exchangers , expansion valve setting, accumulator design, etc.) . Consequently, a test method was required that considers these factors so that the difference in composition shift between the standard and distillation accumulators could be attributed only to the specific accumulator used and not some other systemic factor.

To facilitate the comparison of the two accumulators a test rig was constructed with the standard accumulator of Figure 2 and the experimental distillation accumulator of Figure 5 connected in parallel with isolation valves. This allows the refrigerant flow to be switched from the standard accumulator to the experimental version without changing the total refrigeran t charge mass M_T or the initial composition X_{ic}.

The refrigerant charge was determined at the 8.3 °C (47°F) high temperature heating test by adding enough refrigerant to produce a specified amount of subcooling with the han d expansion valve adjusted to produce approximately 2.8 °C (5°F) of superheat. At this test condition the circulating composition X_c and the initial composition X_{ic} are the same since there is no liquid in the accumulator (M_{sl}=0). To simulate the behavior of a system with a fixed area expansion device the frost accumulation test 1.7 °C (35°F) and the low temperature test -8.3 °C (17°F) were conducted with the same refrigerant charge and expansion valve setting.

After conducting the three required tests (high temperature, frost accumulation, and low temperature) with the standard accumulator, the isolation valves were switched to direct th e refrigerant flow through the experimental distillation accumulator. The same three tests wer e then repeated with the experimental distillation version. To ensure that the total refrigeran t charge mass M_T was still the same, refrigerant was added as necessary to produce the sam e composition, subcooling, superheat, system pressures and capacity as the standard accumulator high temperature heating test. The expansion valve setting was not changed.

The test results for a zeotropic mixture of R32/134a (30/70) are shown in Table 1. The test results for a ternary zeotropic mixture of R32/125/134a (23/25/52) are shown in Table 2. The power inputs shown in these tables is the shaft power consumed by the compressor as measured by in-line torque and RPM transducers. The COP values are not adjusted for fan power. These test results show that the distillation accumulator is capable of producing a much large r composition shift than the standard accumulator. The ternary mixture has the added advantage that as the composition shift progresses the R32 and the R125 tend to stay in their origina l proportions to each other in the circulating composition. This feature of the ternary mixture can prevent the circulating refrigerant from reaching a flammable composition as in the binar y mixture.

A set of tests with the standard accumulator was also conducted with R22. This test will only be used as a comparison baseline for seasonal calculations, so the actual test data will not be reported. A complete uncertainty analysis for the experimental apparatus used in this study has been previously reported in reference 4. This analysis showed that the uncertainty in th e measured heating capacity expressed by nondimensionalizing with the heating capacity itsel f ($\Delta Q_H/Q_H$) was 2.4%.

TABLE 1 TEST RESULTS FOR BINARY MIXTURE OF R32/134a (30/70)

SYSTEM TYPE	OUTDOOR TEMP. °C (°F)	CAPACITY W (Btu/h)	POWER INPUT (W)	COP	COMP PERCENT BY WEIGHT	REFRIG. PRESS. kPa (psia) DISCH. SUCT.		DISCH TEMP °C (°F)
STANDARD ACCUMULATOR	8.3 (47)	1923 (6562)	417.1	4.610	30.17% R32	1628 (236.1)	470 (68.1)	70.9 (159.7)
	1.7 (35)	1632 (5568)	386.0	4.226	34.29% R32	1414 (205.2)	406 (58.9)	61.7 (143.1)
	-8.3 (17)	1098 (3746)	334.5	3.281	40.14% R32	1291 (187.3)	308 (44.7)	68.4 (155.2)
EXPERIMENTAL DISTILLATION ACCUMULATOR	8.3 (47)	1949 (6649)	418.2	4.658	30.08% R32	1628 (236.1)	472 (68.5)	70.1 (158.2)
	1.7 (35)	1664 (5679)	393.0	4.235	35.89% R32	1433 (207.8)	416 (60.4)	61.7 (143.0)
	-8.3 (17)	1242 (4239)	374.9	3.313	53.85% R32	1479 (214.5)	357 (51.8)	74.1 (165.4)

NOTE: The uncertainty in the measured heating capacity expressed by nondimen sionalizing with the heating capacity itself ($\Delta Q_H/Q_H$) was 2.4%.

TABLE 2 TEST RESULTS FOR TERNARY MIXTURE OF R32/125/134a (23/25/52)

SYSTEM TYPE	OUTDOOR TEMP. °C (°F)	CAPACITY W (Btu/h)	POWER INPUT (W)	COP	COMP PERCENT BY WEIGHT	REFRIG. PRESS. kPa (psia) DISCH.	SUCT.	DISCH TEMP °C (°F)
STANDARD ACCUMULATOR	8.3 (47)	2009 (6855)	441.7	4.547	23.06 R32 25.04 R125 51.9 R134a	1727 (250.5)	501 (72.7)	68.1 (154.5)
	1.7 (35)	1718 (5863)	412.0	4.169	25.04 R32 26.68 R125 48.28 R134a	1546 (224.2)	442 (64.1)	59.3 (138.8)
	-8.3 (17)	1189 (4056)	357.4	3.325	28.45 R32 29.38 R125 42.17 R134a	1391 (201.8)	336 (48.7)	63.2 (145.7)
EXPERIMENTAL DISTILLATION ACCUMULATOR	8.3 (47)	2045 (6977)	442.4	4.621	22.96 R32 25.10 R125 51.94 R134a	1721 (249.6)	507 (73.5)	67.1 (152.8)
	1.7 (35)	1722 (5875)	420.5	4.094	25.29 R32 26.76 R125 47.95 R134a	1538 (223.0)	443 (64.3)	56.8 (134.3)
	-8.3 (17)	1337 (4563)	399.4	3.348	35.66 R32 36.20 R125 28.14 R134a	1608 (233.2)	385 (55.8)	66.1 (150.9)

NOTE: The uncertainty in the measured heating capacity expressed by nondimen sionalizing with the heating capacity itself ($\Delta Q_H/Q_H$) was 2.4%.

SEASONAL CALCULATIONS

There are several different measures available to quantify the benefits of employing an accumulator distillation insert. The most familiar of these would be to calculate the Heatin g Seasonal Performance Factor (HSPF). The HSPF is the ratio of the seasonal building loa d expressed in Btu/h to the seasonal energy input to the heating system expressed in Watts. The SI version of HSPF is a dimensionless seasonal COP. The energy input includes the electrical energy input to both the heat pump and the resi stance heat. The results of the HSPF calculations are summarized in Table 3. The effect of the distillation accumulator on HSPF is small except for region 5 where the ternary fluid with the distillation accumulator increases the HSPF b y approximately four percent.

Although the effect on HSPF is small, the distillation accum ulator is capable of producing a reduction in the peak energy demand of the dwelling. This effect is quantified by examining the seasonal resistance heat requirement and t he instantaneous system COP at peak heating load. In Table 4, the percentage of the seasonal building load that is obtained from the resistance heat is shown for the binary and ternary mixtures with a standard a ccumulator and with the distillation accumulator. The tests with R22 in the standard accumulator are shown for comparison. The best performing alternative is the ternary fluid with the distillation accumulator, which reduces the seasonal resistance heat requirement by approximately five percent.

The instantaneous peak energy efficiency for the dwelling is quantified by calculating the overall heating system COP for the -8.3 (17), -11.1 (12), -13.9 (7), and -16.7 °C (2°F) temperature bins. Where the overall heating system COP is the instantaneous building loa d divided by the total electric energy into the heat pump and the resistance heat. The results of this calculation, normalized by the R22 values for each bin, are shown for climate regions 3, 4 and 5 in Tables 5, 6 and 7, respectively. By this measure, the effect of the distillation accumulator is more pronounced. The best performing alternative is again the ternary fluid with th e distillation accumulator, which has a COP higher by 6 to 9% depending o n the climate region and temperature bin.

TABLE 3 HEATING SEASONAL PERFORMANCE FACTOR (HSPF)

	CLIMATE REGION	R22 (Btu/W*h)	BINARY (Btu/W*h)	TERNARY (Btu/W*h)
STANDARD ACCUMULATOR	3	3.339 (11.394)	3.214 (10.966)	3.217 (10.976)
	4	2.485 (8.478)	2.444 (8.340)	2.471 (8.430)
	5	1.986 (6.778)	1.961 (6.690)	1.988 (6.782)
EXPERIMENTAL DISTILLATION ACCUMULATOR	3	---	3.320 (11.328)	3.261 (11.126)
	4	---	2.554 (8.715)	2.538 (8.659)
	5	---	2.056 (7.016)	2.066 (7.050)

TABLE 4 PERCENTAGE OF SEASONAL BUILDING LOAD OBTAINED FROM RESISTANCE HEAT

	CLIMATE REGION	R22	BINARY	TERNARY
STANDARD ACCUMULATOR	3	8.87	8.07	7.62
	4	21.57	20.37	19.53
	5	33.58	32.55	31.50
EXPERIMENTAL DISTILLATION ACCUMULATOR	3	---	6.97	7.01
	4	---	18.11	17.92
	5	---	29.36	28.72

TABLE 5 NORMALIZED HEATING SYSTEM COP FOR PEAK BINS - REGION 3

BIN °C (°F)	R22	BINARY STD ACC	BINARY DIST ACC	TERNARY STD ACC	TERNARY DIST ACC
-8.3 (17)	1.0	0.998	1.054	1.013	1.076
-11.1 (12)	1.0	0.994	1.061	1.018	1.07
-13.9 (7)	1.0	1.0	1.06	1.024	1.066
-16.7 (2)	1.0	1.014	1.033	1.024	1.081

TABLE 6 NORMALIZED HEATING SYSTEM COP FOR PEAK BINS - REGION 4

BIN °C (°F)	R22	BINARY STD ACC	BINARY DIST ACC	TERNARY STD ACC	TERNARY DIST ACC
-8.3 (17)	1.0	0.999	1.06	1.019	1.079
-11.1 (12)	1.0	1.003	1.057	1.022	1.077
-13.9 (7)	1.0	1.003	1.058	1.021	1.077
-16.7 (2)	1.0	1.002	1.053	1.021	1.071

TABLE 7 NORMALIZED HEATING SYSTEM COP FOR PEAK BINS - REGION 5

BIN °C (°F)	R22	BINARY STD ACC	BINARY DIST ACC	TERNARY STD ACC	TERNARY DIST ACC
-8.3 (17)	1.0	0.997	1.072	1.021	1.094
-11.1 (12)	1.0	1.0	1.069	1.025	1.093
-13.9 (7)	1.0	1.003	1.07	1.028	1.091
-16.7 (2)	1.0	1.005	1.069	1.029	1.088

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This study has shown the accumulator distillation insert to be a simple, effective an d inexpensive means to reduce the peak heating energy demand on the electric utility. However, the best performing alternative, the ternary mixture used with the distillation insert, has not yet been utilized to its full potential. If this mixture were to be shifted so that 52% of the refrigerant charge were to be stored in the accumulator as pure R134a, then the system would be running entirely on the more volatile pair of refrigerants. This high pressure circulating composition of 48% R32/52% R125 would further reduce the amount of auxiliary energy required and produce a commensurate reduction in the peak electrical demand.

To reach this maximum composition shift with the distillatio n accumulator, system design must account for the steady state and transient refri gerant mass distribution between the high and low sides of the system. Assuming that the column and storage heater are capable of purifying the stored liquid R134a, then the design problem reduces to the allocation of system volume (i.e., heat exchanger sizing) for a given charge mass and selection of the expansion device.

Additionally, the type of expansion device should also be considered. Although this study utilized a hand valve to simulate a fixed area expansion device such as a short tube restrictor or capillary tube, the application of the distil lation insert is not limited to such an expansion device. Specifically, some sort of stepping motor valve that can be controlled to help regulate the liquid level in the storage sump may be beneficial. Ideally, to accomplish the maximum composition shift requires that all of the less volatile component (R134a in the case of this ternary) be stored in the accumulator. However, the amount of liquid stored should not be so much that a severe loss of subcooling occurs at the condenser outlet because of the detrimental effect o n performance this would impose.

A further refinement to enhance the performance of the distillation accumulator would be to eliminate the parasitic power required for vapor generation. This can be accomplished b y routing the liquid line through the accumulator sump. In this manner, the vapor necessary fo r column operation can be generated wh ile simultaneously obtaining beneficial liquid subcooling. However, the drawback of this refinement is that it will be more difficult to control the amount of heat applied to vapor generation.

In summary, the distillation accumulator requires a system design that is capable o f operating with a dry accumulato r in the cooling mode and an increasing amount of stored liquid in the heating mode as the outside temperature falls. The amount of stored liquid shoul d approach a maximum value as the outdoor temperature approaches the heat pumps minimu m outdoor operating temperature. This maximum should be determined by the amount of stored liquid necessary to produce the desired c omposition shift without overly depriving the system of subcooling.

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