Disposable Container Heel Testing Study Report

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Summary

In 2006, the U.S. Environmental Protection Agency commissioned the Universal Technical Institute in Avondale, Arizona to conduct tests to determine the amount of refrigerant remaining in do-it-yourself (DIY) small cans[1] and professional 30 pound cylinders used to charge motor vehicle air conditioning (MVAC) systems. Industry experts within the Mobile Air Conditioning Aftermarket Parts and Service Equipment Partnership (MACAPSEP) helped develop the testing protocol, proctor the study, and provide peer review of the draft report. Comments from the reviewers were considered in this final report.[2]

Under typical situations, any refrigerant remaining in disposable containers after charging a MVAC system is eventually released to the atmosphere. The releases are referred to as "heel emissions." For small cans, the tests analyzed the heel remaining after various charging times under different scenarios. The tests of 30 pound cylinders quantified the heel remaining in cylinders that had been removed from service as "empty." This report analyzes the results of the disposable container tests, provides a range of annual emission estimates based on those results, and examines potential best practices for DIY and professional charging of MVAC systems to reduce unnecessary MVAC refrigerant emissions.

The testing results provide a few key findings:

- The most important factor regarding the remaining heel of small cans is whether the do-it-yourselfer (DIYer) transfers the refrigerant in a gas or liquid phase when charging the MVAC system. When a DIYer holds a can upright, the refrigerant will transfer as a gas. The test results showed that this transfer is difficult and can take as much as 90 minutes to empty a can and minimize the heel. If the DIYer holds the can upside down, the refrigerant will transfer to the MVAC system as a liquid, and the cans tested under these conditions emptied in five minutes. The tests also analyzed slowly rotating a can from an upright to 90^{o} position repeatedly so that the refrigerant transfers in both the gas and liquid phases. The tests showed that the small cans generally emptied within 5 - 15 minutes under that approach.

- The information and equipment available to DIYers are usually too limited to allow the owner to know how much refrigerant to add or when the system is fully charged. This uncertainty can lead to ineffective use of small cans and increased heel emissions, as well as improper charging of the MVAC system.

- Although the 30 pound cylinders from service shops already have low heel levels, new recovery procedures can reduce the cylinder heels further.

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[1] While sold as a retail product to the general public, service stations also use small cans for some air conditioning servicing. This report refers generally to the use of small cans by DIY consumers, but acknowledges that service station use is also part of the refrigerant market served by small cans.

[2] A separate report summarizes the comments and the response to each substantive issue raised (PQA, 2007).

The small can tests produced a wide range of observed heels based on the different transfer procedures that a DIYer can use. This paper presents a range of small can emission estimates based on different transfer procedure scenarios. For example, based on an informal survey of student technicians, 75% would charge an MVAC system holding the small cans upright for a total system charging time of 5 to 10 minutes. Under that scenario, the estimated average discarded can heel could be as high as 52%, which would result in total national annual emissions of 12.5 million pounds. If DIYers instead used the rotation method or other flow control method to transfer the refrigerant as a mix of gas and liquid or controlled liquid for the same 5 to 10 minute period, the average heel would be about 10 to 12% (with total annual emissions of about 2.2 to 2.9 million pounds). If the DIYer increased the transfer time up to 15 minutes, the heel could be reduced to about 1.6%. The estimated annual emissions from discarded 30 pound cylinders are 0.4 million pounds, based on an average heel of 1.85% in the tested cylinders.

As the test results and emission estimates show, practices to minimize small can heel emissions can have a large impact, especially if a DIYer charges an MVAC system with small can refrigerant in a liquid (or gas/liquid mix) phase. However, liquid charging (or a mix of gas and liquid charging) has the potential to damage an MVAC compressor, if the liquid enters the compressor inlet port. This report recommends that the industry and other MACAPSEP members examine whether they can develop guidelines to provide for the use of a mix of gas and liquid charging, or other liquid flow control method, for DIY small cans. These guidelines must address compressor damage and any other operational or safety concerns. Assuming that those guidelines are feasible, a set of best practices would involve: (1) mixed gas/liquid or flow controlled liquid charging to reduce the heel emissions; (2) charging for up to 15 minutes to empty each can fully; and (3) DIYers (or professionals) limiting small can use to charging already empty systems or professionally evacuated systems, so that they know how much refrigerant they should use.

Service shops currently have the equipment to minimize the heel in empty 30 pound cylinders, so the resulting emissions from this sector are relatively small. A new Society of Automotive Engineers standard (J2788) approved in 2006 may further reduce heel emissions by improving the performance of HFC-134a recovery/recycling equipment and practices.

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1. Background and Report Contents

Government and industry representatives formed the Mobile Air Conditioning Aftermarket Parts and Service Equipment Partnership (MACAPSEP) in May 2004 to reduce unnecessary MVAC refrigerant emissions. Members of MACAPSEP are the U.S. Environmental Protection Agency (EPA), the California Air Resources Board, Automobile Aftermarket Industry Association (AAIA), motor vehicle air conditioning (MVAC) service equipment companies, chemical companies, can manufacturers, can fillers, and can retailers.

Current MVAC systems use HFC-134a (1,1,1,2 Tetrafluoroethane) refrigerant. MVAC refrigerant emissions can come from leaks in the system, from servicing, and from end-of-life disposal. Servicing emissions can occur either at professional repair shops or through do-it-yourself (DIY) servicing. Repair shops generally use 30 pound cylinders and refrigerant recovery/recycling machines that minimize emissions. Do-it-yourselfers (DIYers) use small cans (typically 12 ounces) of refrigerant to recharge or top off an MVAC without the aid of certified service equipment.

As part of MACAPSEP's emission reduction efforts, EPA commissioned the Universal Technical Institute (UTI) in Avondale, Arizona, to conduct testing to produce data on the potential for disposable container heel-related emissions. The small can tests measured the amount of refrigerant remaining in a 12 ounce container after directly charging the container contents to an MVAC system. The 30 pound cylinder tests measured the amount of refrigerant remaining in the cylinder after a service shop had determined it was empty and had removed it from the charging equipment. Ward Atkinson of Sun Testing Engineering and Ken Adams of the Technical Chemical Company proctored the tests.

Section 2 of this report outlines the test procedures in detail. Section 3 provides a summary of the test results. Sections 4 and 5 then examine what the potential heel-related emissions may be and how DIYers and professional service stations can improve their practices to reduce heel emissions.

2. Test Procedures

2.1 Small Can Testing

2.1.1 Equipment

The small can study used two vehicle front end clips with production MVAC systems and engine components representative of current orifice tube (OT) and thermal expansion valve (TXV) MVAC systems. Figure 1 shows a 2004 Ford Focus front end clip that had an OT system. The TXV system was tested using a 2004 Hyundai front end clip.

Figure 1: Ford Focus Front End Clip with Recovery/Recycling Machine and Shop Fan

The UTI technicians used the same brand of commercially available 12 ounce can and charge kit throughout the tests. The kit included a can tap and recharge hose with pressure gauge. The can and kit were used with a low side service port adapter that provided continuous system pressure readings. The can, kit, and adapter appear in Figure 2.

The technicians used the same recovery/recycling machine to remove and evacuate refrigerant in the MVAC before each can test (shown in Figure 1). Then, if necessary to establish the appropriate test conditions, they used the machine to charge the system with a specific amount of refrigerant to represent different levels of a partially full system. After determining that a can was empty, the technicians recovered the final refrigerant heel using the recovery/recycling machine. The tests also used a calibrated high side and low side pressure gauge and hose to measure high and low side pressure during the testing, and a calibrated scale with a readability of 0.1 grams (0.001 ounces) and a range of 2,000 grams to weigh the cans before, during, and after the test runs.

Figure 2: Small Can with Charge Kit and Adapter Installed on the Ford Focus Accumulator Service Port

2.1.2 Test Conditions

The tests involved both controlled and variable conditions. During the tests, the MVAC system controls were set to operate at the maximum cool and highest fan settings, with outside air and the compressor operating. The test proctors maintained the work area temperature at approximately 70 to 75^{o} F. The UTI technicians tested at least four cans under each scenario.

Table 1 summarizes the variable test conditions under each test scenario. The most important variable is can orientation because it affects whether a DIYer transfers the refrigerant in the liquid or gas phase. The can contents will transfer more quickly as a liquid than as a gas. A can held upside down (can opening pointed down) will transfer liquid refrigerant, and a can held upright will transfer the refrigerant as a gas. The tests used three different can orientations: (1) upright can (gas phase charging, and the position generally recommended by suppliers); (2) upside down can (liquid phase charging); and (3) slowly rotated can (from 0^{o} upright to 90^{o} from vertical), which provides a mix of gas and liquid phase charging. The technicians did not follow any specific procedures with respect to the rate of motion and number of can rotations per five minutes of charging time.

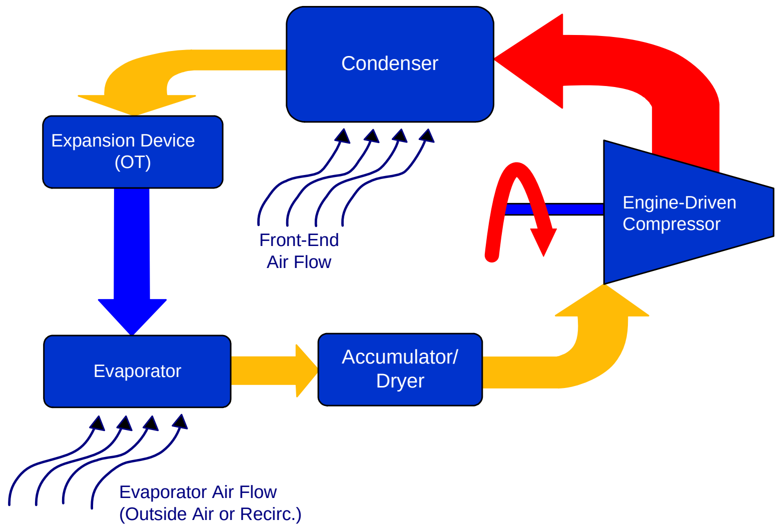
The technicians did not conduct tests of TXV systems with cans in the upside down position because liquid entering the TXV system compressor inlet could damage the compressor. Figure 3 shows the layout of components and refrigerant flow in the OT and TXV systems. In an OT system, the low pressure port is on or upstream of the accumulator, which separates liquid refrigerant before the compressor. A similar reservoir is not present in the TXV system. The technicians did conduct tests on TXV systems with the rotated can orientation. The rotation method relies on the liquid refrigerant portion of the charge flashing off in the system before the inlet of the operating compressor.

Table 1: Small Can Test Scenarios

MVAC System(s) Tested[1]	Can Orientation (Charge Phase)	System Start State	Shop Fan[2]	Engine Speed[3]	Can Agitation[4]
OT and TXV	Upright (gas phase charging)	Empty system 0 in. Hg	Off	Idle	No
OT and TXV	Upright (gas phase charging)	Partial charge (1/2 full) - 12 oz.	Off	Idle	No
OT	Upside down (liquid phase charging)	Empty system 0 in. Hg	Off	Idle	No
OT	Upside down (liquid phase charging)	Partial charge (1/2 full) - 12 oz.	Off	Idle	No
OT and TXV	Rotate 0 - 90^o (mixed phase charging)	Empty system 0 in. Hg	Off	Idle	Yes
OT and TXV	Rotate 0 - 90^o (mixed phase charging)	Partial charge (1/4 full) - 6 oz.	Off	Idle	Yes
OT and TXV	Rotate 0 - 90^o (mixed phase charging)	Partial charge (1/4 full) - 6 oz.	On	1,500 rpm	Yes
OT and TXV	Rotate 0 - 90^o (mixed phase charging)	System evacuated - 29 in. Hg	On	Idle	Yes
OT and TXV	Rotate 0 - 90^o (mixed phase charging)	System evacuated - 29 in. Hg	On	1,500 rpm	Yes

Notes:
[1] The upside down can orientation with liquid phase charging was done only with the OT system because of risk of compressor damage from liquid slugging.
[2] AAIA suggested adding a fan to the test scenarios to simulate air blowing through the car grille.
[3] AAIA recommended the 1,500 rpm scenario, because the engine speed affects the compressor operation. The compressor operating time is a direct result of the MVAC system evaporator freeze protection device. The compressor operating at a higher speed changes the cycle rate. For example, at idle the compressor may not cycle or have a very long period of operating time and a short off time. At higher speeds the compressor on and off times can change greatly due to the evaporator freeze protection control.
[4] At least some DIY instructions direct the user to shake the cans to mix the can contents before and/or during charging. The only can agitation provided during the test scenarios was the slow 0 to 90^o rotation.

(a) Orifice Tube (OT) System



(b) Thermo-Expansion Valve (TXV) System

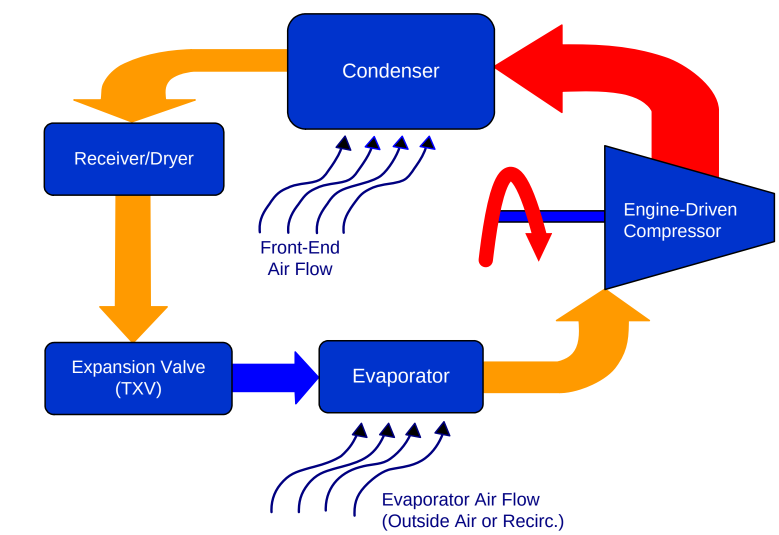


Figure 3: Diagram of MVAC Systems
(Adapted from Hendricks, 2001)

2.1.3 Heel Test Procedure

The UTI technicians preheated each MVAC system for 15 minutes by idling the engine with the hood open. Preheating took place at the start of the test day and after lunch breaks. Before each can run, the recovery/recycling machine evacuated the MVAC system to remove any refrigerant and hold a vacuum of 29 in. Hg for 30 minutes. After the evacuation, depending on the test scenario, the technicians either (1) charged the system with 6 or 12 oz. of refrigerant using the charging feature of the recovery/recycling machine; (2) opened the system and allowed it to reach atmospheric pressure; or (3) used the service equipment to obtain a vacuum level in the system.

The technicians weighed full cans and cans connected to the charge kit hose and gauge. To start the run, they connected the high side pressure hose and calibrated pressure gauge to the high side port, and then connected the special low side adaptor and charge kit/can to the low side of the MVAC system. The low side adaptor was connected to a calibrated pressure gauge. After connecting the low and high side hoses, they turned on the engine and ran the engine either at normal idle speed or at 1,500 rpm, with the shop fan on or off. The hood was open and the air conditioner was turned on to high settings/outside air.

To initiate charging, the technicians turned the valve handle of the charging hose can tapper to puncture the can, and then opened it to begin charging in the appropriate can orientation. Every five minutes, they disconnected the can and recharge hose from the system, and weighed the small can apparatus. They removed any moisture on the outside of the can with a dry cloth before weighing. If the can was not empty, they reconnected the can to the MVAC system to charge for another five minutes (the time to disconnect, weigh, and reconnect was about one to three minutes). This was repeated until the can was empty, or for up to 30 minutes. The technicians determined an empty can by the weight difference and can temperature (a warm can indicating an empty can). Then, they recovered the remaining contents from the can with the recovery/recycling machine before the final weight measurement. They also collected additional parameters described in Table 2 at five minute intervals during each can test.

Table 2: Small Can Test Data Collection
(Recorded Every Five Minutes)

Parameter Recorded	Location Measured or Description
Temperature	Shop and vehicle ambient
	Vehicle grille inlet air
	Evaporator inlet air
	Panel outlet vent air (left, center left, center right, and right)
	Compressor inlet pipe surface
Pressure	Low side system service port
	High side system service port
Voltage	Blower
Engine speed	Engine

(cont.)

Table 2: Small Can Test Data Collection (Recorded Every Five Minutes) (cont.)

Parameter Recorded	Location Measured or Description
Kit gauge color	Recorded gauge color
Compressor cycling	Yes/no
Can temperature	Cold/warm
Shop fan operation	Yes/no
Air selection	Always OSA (outside air)

2.2 Thirty Pound Cylinder Testing

2.2.1 Equipment

The UTI Training Facility conducted heel tests of six 30 pound HFC-134a cylinders from the facility's training shops. The tested cylinders (Figure 4) had been removed as "empty" from equipment used in MVAC system service activity. Test equipment included a recovery/recycling machine certified to the Society of Automotive Engineers (SAE) J2210 standard, a calibrated scale, a pressure gauge, a thermometer, and a heat blanket.

Figure 4: Thirty Pound Cylinder on Scale

2.2.2 Heel Test Procedure

The technicians conducted the tests at standard room temperatures. They weighed each cylinder before recovery of the cylinder contents, and measured and recorded the initial cylinder pressure. With the recovery/recycling machine, they performed two recovery cycles on each cylinder and measured the cylinder weights after each recovery cycle. The technicians pulled a vacuum (10 to 15 in. Hg) during the first recovery cycle. The recovery was completed after the pressure stabilized. They used a different procedure during the second recovery cycle to examine the effects of pulling a deeper vacuum (29 in. Hg). They also applied a heat blanket during the second recovery and oriented the cylinders upside down to transfer the refrigerant in the liquid phase.

3. Results and Observations

3.1 Small Cans

3.1.1 Heel and Charging Time

The charge time required to empty the cans varied significantly based on can orientation, which determines whether the DIYer transfers the refrigerant in the liquid or gas phase (see Figure 5). The cans held upside down (charging in the liquid phase) were emptied in the shortest time, all within five minutes. The average overall charging time to empty a rotated can (mix of gas and liquid phase charging) was 12 minutes for the TXV system, with a range of 10 to 15 minutes, and 14 minutes for the OT system, with a range of 10 to 20 minutes. About 80% of the can contents were transferred into both systems in the first five minutes.

The cans held upright (charging in the gas phase) did not empty within 15 minutes, or even within the full 30-minute test period (see Figure 6). In these tests, over half of the can contents were still in the can after 15 minutes, and 26 to 43% of the contents remained after 30 minutes. These results demonstrate how difficult it is to transfer refrigerant in the gas phase. During gas phase charging, the can will get colder, and the colder temperature decreases the can pressure, which in turn reduces the pressure differential that transfers the refrigerant from the can into the MVAC. The reduced pressure differential inhibits the transfer of the gas from the can to the system.

The UTI technicians performed a longer test with one can to determine how long it would take to empty the can in the upright position. They performed the test with the OT system initially empty at atmospheric conditions. It took 90 minutes of upright charging to empty the can contents.

In most cases, other factors (such as system beginning state, engine speed, or use of a shop fan) did not appear to have a significant impact on the charge time required to empty a small can. For example, in the upside down can test scenarios, all the cans emptied within five minutes under all conditions. In addition, for tests on the TXV system that used the rotated can scenarios, all the cans emptied within 10 to 15 minutes.

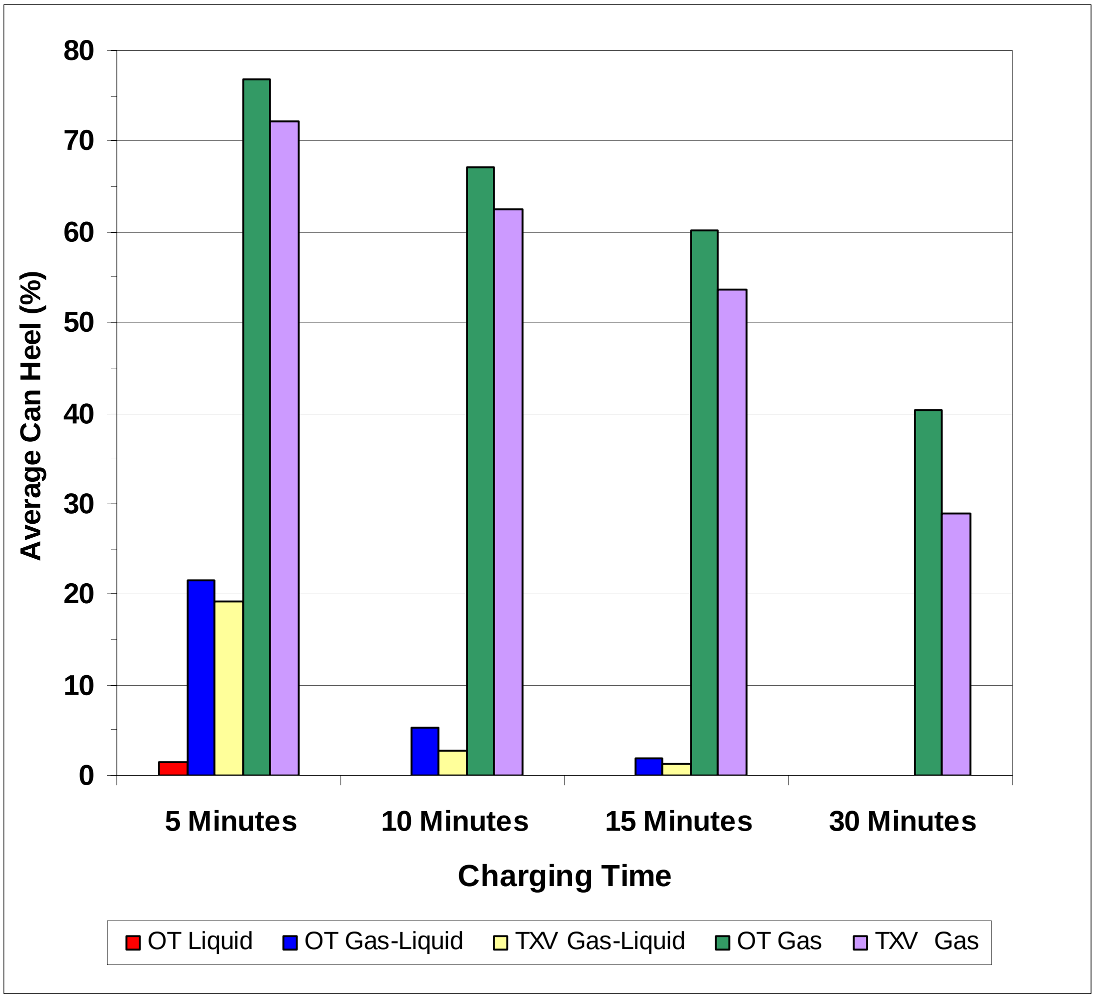


Figure 5: Comparison of Can Heels by Charging Method and MVAC Type

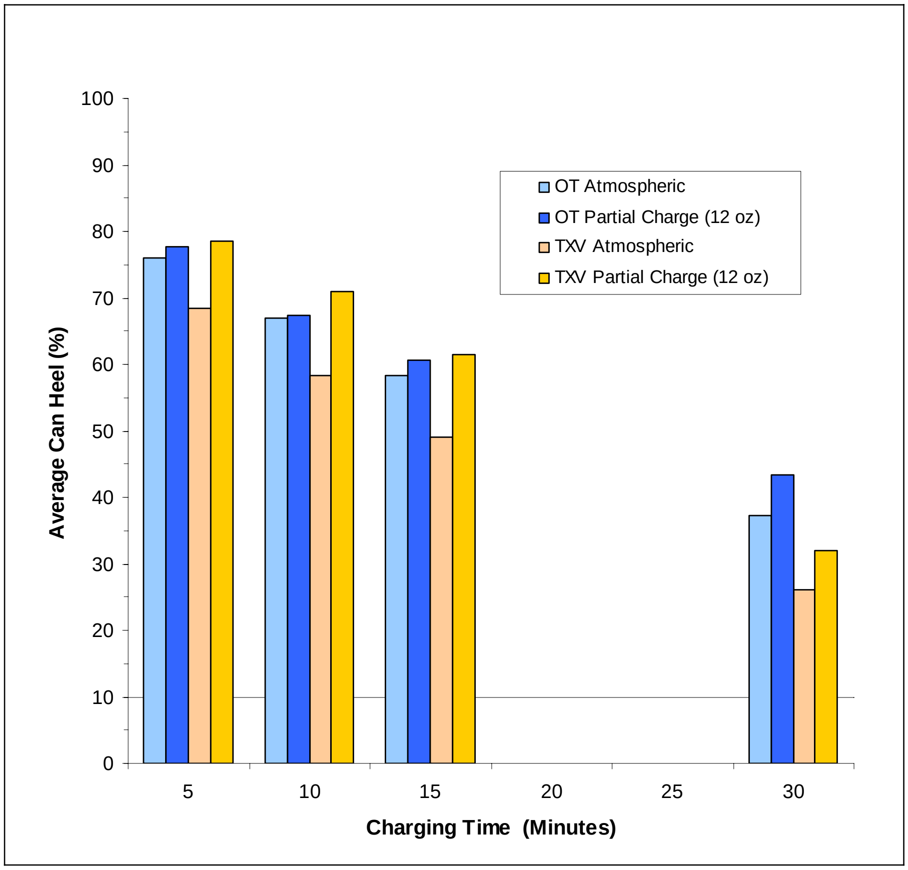


Figure 6: Percent Can Heels Based on Upright Scenario (Gas Phase Charging)

The test results did show increased variability in some situations, although this variability was not as significant as the differences observed based on can orientation. For example, Figures 5 and 6 show that the TXV system tends to charge slightly faster than the OT system. Also, charging an empty TXV system resulted in a substantially lower heel than all other conditions in the upright can scenarios (see Figure 6). This result most likely occurs because of the larger pressure difference between the low side port and the can. Also, the OT system showed some variability in the charging time needed to empty a can under the rotated can scenarios (see Figure 7). This variability may be related to differences in how often and how quickly an individual can was rotated, given the critical influence of liquid versus gas phase charging. However, the number and speed of can rotations were not controlled during the testing. Additional testing with controls on can rotation would be necessary to explore this observed variability further.

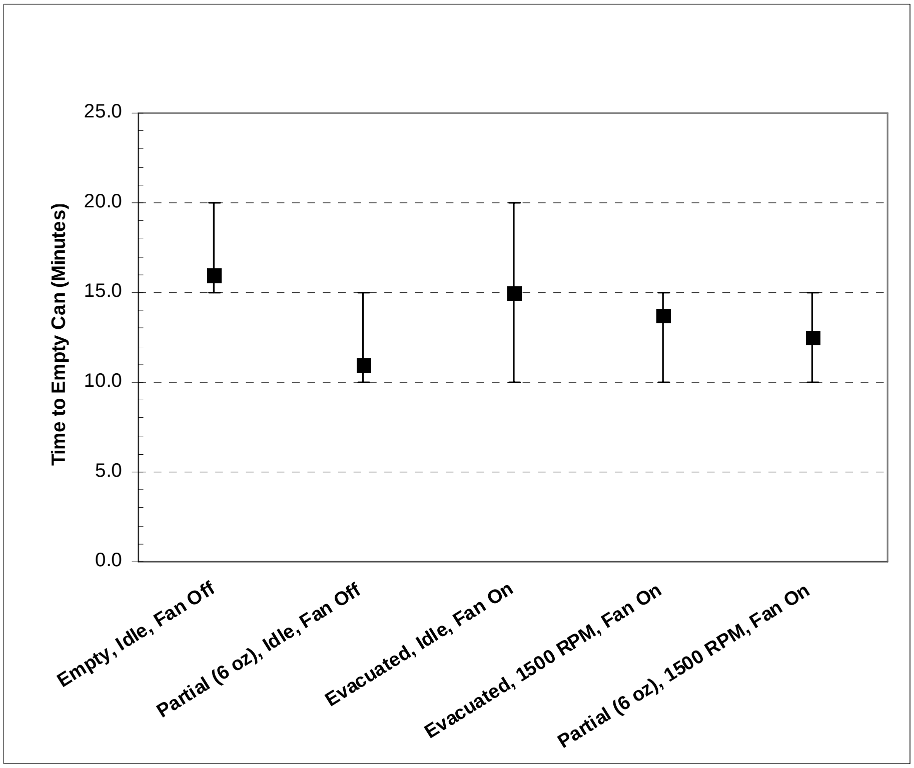


Figure 7: OT Systems: Charge Time Comparison with Can Rotated 0 to 90 Degrees (Mean and Range)

3.1.2 Charge Kit Observations

The charge kit in this study included a pressure gauge to measure low side pressure, with color shading to show when the system was undercharged, full, or overcharged with refrigerant (Figure 8). The gauge indicates only the low side system pressure for any given system condition. The system condition is dependent on more than just the amount of refrigerant in the MVAC system. Therefore, the kit gauge reading does not provide the information needed to determine the amount of refrigerant in an operating MVAC system.

Records of the kit gauge readings during charging demonstrate this limitation. For example, during the empty system scenario for upright can testing, the gauge readings showed that the MVAC system was fully charged for all 30 readings over the 30 minute charge period for the OT system, and for 12 of 30 readings for the TXV system. In both cases, the readings were from operating MVAC systems that were less than half full of refrigerant. If a DIYer stopped charging based on the kit gauge readings, he/she would not have a properly charged system and might also discard a can with a large heel. Do-it-yourselfers, however, can use the low side pressure gauge to determine if refrigerant is present in the MVAC system. A low side gauge pressure of zero would indicate an empty system.

Figure 8: Example of Charge Kit Pressure Gauge with System Charge Ranges

The UTI technicians also observed leaks from the hose and coupling of all charge kits used during the tests. The leaks were more evident when the assembly became cold during the charging procedure. The rotation of the can during the 0 to 90^o rotation scenarios may have contributed to the observed leaks. The technicians did not measure or estimate the amount of leakage. Figure 9 shows the observed leak locations.

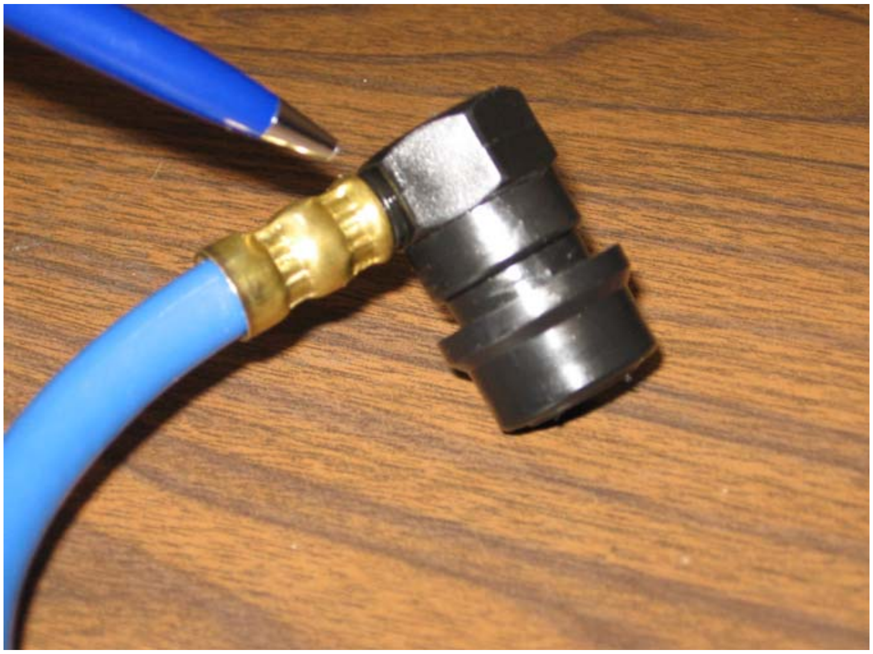


Figure 9: Charge Kit Leak Locations
a. Hose Leak at Service Port Adaptor

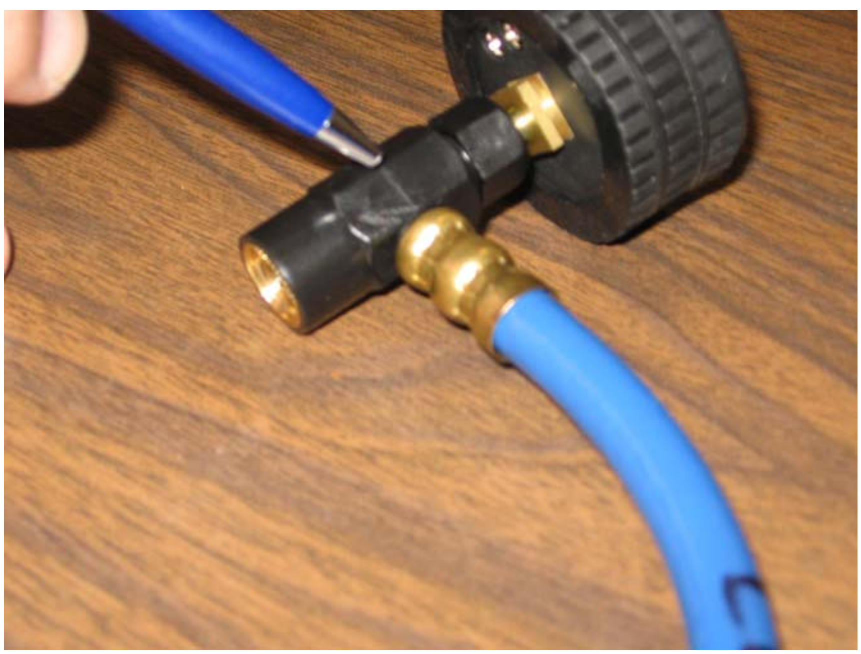


Figure 9: Charge Kit Leak Locations
b. Hose Leak at Can Tap

3.1.3 Observations of System Conditions at Full Charge versus Partial Charge

Instructions for DIYers sometimes point to the panel vent temperature as a useful indicator of a fully charged system for topping off purposes. Instead of using the pressure gauge described in the previous section, the DIYer measures the temperature from one or more panel vents during charging, and stops charging either when the temperature is within a certain range or when it becomes stable as the charging progresses.

The UTI technicians recorded panel vent temperatures of both partially and fully charged OT systems during the tests. These results provide some data on the use of panel vent temperature as an indicator of a full system. After at least five minutes of charging, systems at 60 to 80% of capacity had one vent with temperatures at least as low as those recorded for a fully charged system. Thus, the temperature at a single vent is not a good indicator of a fully charged system.

The undercharged systems also showed increased variation in temperatures between vents (see scatter plots of the recorded temperature data in Figure 10). These results suggest that charge kits could recommend that DIYers check more than one vent to determine the system charge. If one vent's temperature is in the proper range, and all other vent temperatures are within 10° F of that vent, the test data indicate that the system most likely is fully charged.

However, the test data do not provide information on vent temperatures for a system that is overcharged. An overcharged system can provide cooling similar to a full system under the load conditions typical of DIY charging conditions. At hotter weather conditions and operating at road speeds, the system may have elevated high side pressure due to the overcharging, and can reach levels where the compressor will disengage due to a system pressure control, reducing system performance and cooling. Also, at high temperatures an overcharged system may vent excess refrigerant. Thus, further tests with overcharged systems may be necessary to ensure that the charge kit recommendations on vent temperature do not suggest procedures that could harm MVAC performance or lead to excess refrigerant venting.

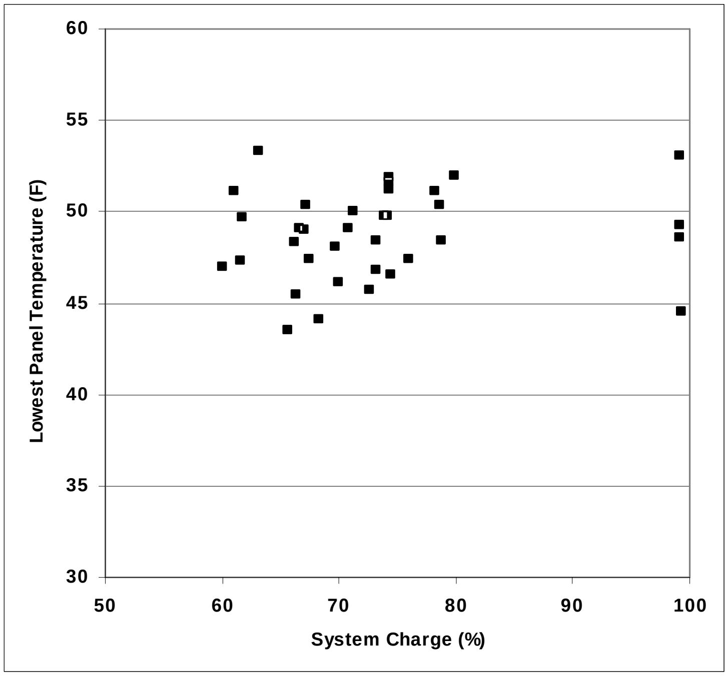


Figure 10: Panel Vent Temperature Readings -- At Least Five Minutes of Charging
a. Lowest Vent Temperature at Different System Charges

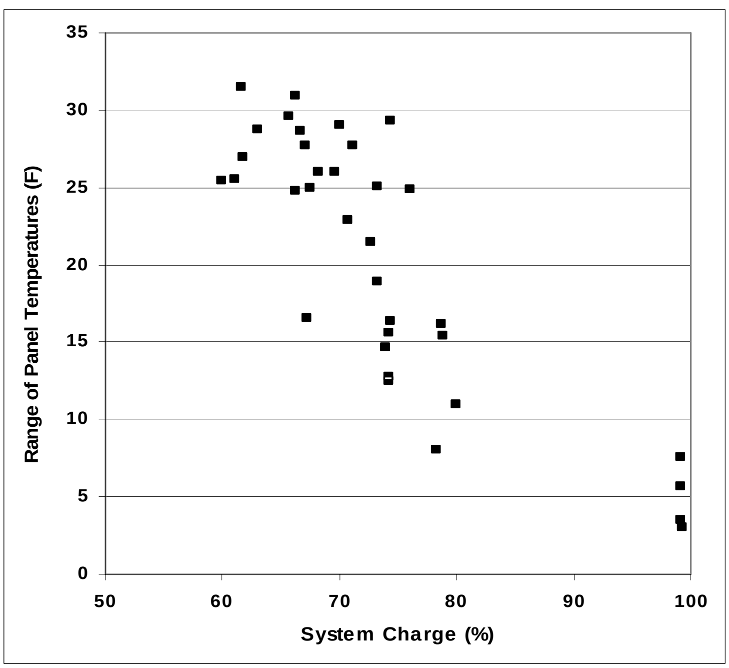


Figure 10: Panel Vent Temperature Readings -- At Least Five Minutes of Charging
b. Range of Vent Temperatures at Different System Charges

3.2 Thirty Pound Cylinder Heel Results

Table 3 shows the heel testing results for each of the six 30 pound cylinders in the UTI test study. The average heel was 1.85%, with a range from 0.302 to 4.46%. The results show that service facilities leave very little refrigerant in discarded 30 pound cylinders. The heels were similar to those found in the small can tests with liquid phase charging, and significantly below the levels found in the small can tests that involved only gas phase charging.

Table 3 also shows the heel remaining after both the first and second recovery processes. As noted in the procedures section, the first and second recovery procedures were different, with the first recovery performed in the gas phase, and the second recovery performed upside down in the liquid phase, with a heat blanket and higher vacuum. A separate 30 pound cylinder refrigerant transfer study, also performed at UTI, demonstrates the improved refrigerant transfer by the higher vacuum/upside down/heat blanket recovery process used in the second recovery for each 30 pound cylinder. See Appendix A for a brief summary of that separate refrigerant transfer study.

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Table 3: Empty 30 Pound Heels

Cylinder	Initial Tank Pressure (psig)	Heel % After First Recovery	Heel % After Second Recovery
UTI1	53	1.92	1.97
UTI3	25	0.99	1.17
UTI4	Yes	0	4.46
UTI5	Yes	0	1.25
UTI6	0	0	0.302
UTI7	49	1.40	1.98
		30 Pound Cylinder Average Heel:	**1.85**

4. Heel Emission Estimates

4.1 Small Cans

The estimated national annual emissions from discarding small cans with HFC-134a heels are a product of two variables: average percent heel per discarded can and total annual small can sales. The following section first examines scenarios for determining average percent heel per discarded can, and then combines these scenarios with annual sales data to provide a range of heel emission estimates.

Key factors in determining the average can heel are the charging time and whether the average DIYer transfers refrigerant to an MVAC system in the liquid or gas phase (upright, upside down, or rotated can orientation).

Table 4 shows average heels for different can orientations and charging times. The heels were calculated by aggregating the results of all the test scenarios by only can orientation. OT and TXV system data were also combined to simplify the calculation, even though the TXV system tended to charge faster than the OT system. This simplification is balanced by the larger market share for OT systems (approximately 55 to 60%) compared to TXV systems.

Table 4: Average Small Can Heel Based on Time and Can Orientation

Can Orientation	Average Charging Time (Minutes)	Average Heel (%)	Standard Error (%)
Upright	5	74.7	1.04
Upright	10	65.1	1.31
Upright	15	57.3	1.43
Rotated	5	20.4	1.80
Rotated	10	3.94	5.13
Rotated	15	1.63	1.56
Upside down	5	1.40	0.09

With a potential heel that ranges from 1.40 to 74.7% based on the can orientation and charging time, the choice of "typical" DIY practices will have a large impact on potential emissions. To establish an estimate that reflects relatively poor practices in terms of minimizing heel emissions, this report examines one DIY practice scenario based on small can charge kit directions and a survey of auto technician students. Directions with small can kits from three out of four suppliers instruct the user to hold the can upright, and one instructs the user to hold the can upside down. Two of the instructions with upright can use include directions to shake the can before and/or during charging. None of the instructions directs the DIYer to rotate the can. For charge times, the directions refer to the pressure gauge reading or vent temperature. The test proctors conducted a student survey of UTI auto technician students in the classroom. Fifty-seven students from three classes completed the survey, although not all participants responded to all questions. Of the students, 20 said that they had used small cans to charge MVAC systems. The survey and results are in Appendix B.

When asked how to hold the can (upright, upside down, rotate side to side), 28 students said upright, nine said upside down (an approximate 75/25% split). None of the students said to rotate side to side. Fourteen students said they would shake the can during charging, and 25 said they would not. As to how long they would charge a system with one can, 13 said for less than 5 minutes, 19 said for 5 to 10 minutes, and none said that they would charge for longer than 10 minutes. There was no indication of whether the students who had used small cans answered differently than the other students.

Given the survey results and kit instructions, the first estimate scenario assumes DIYers use only the upright and upside down can orientations, with time intervals of 5 to 10 minutes. The survey suggests that about 25% of DIYers will charge systems holding the cans upside down and 75% will charge systems holding the cans upright. These survey results are consistent with the kit instructions, where only one of four kits reviewed directed the DIYer to charge a system holding the can upside down. This is Scenario 1 in Table 5, which results in about 50% of small can refrigerant usage emitted per year due to the can heel.

As noted before, some of the charge kits direct users to shake the cans in an upright position, and a number of the students surveyed also said that they would shake the can when charging an MVAC system. None of the test scenarios, however, included upright can shaking. The 0 to 90^o can rotation scenarios did provide agitation, but the can agitation caused by the can rotation to 90^o from vertical resulted in a mix of gas and liquid phase charging. An upright shaken can with a tighter angle of rotation would still result in gas phase charging, similar to the tested upright can scenario without agitation. Therefore, the upright can assumption in Scenario 1, and not a rotated can assumption, is the closest representation of the likely heel from a shaken upright can.

Two other scenarios investigate how emissions might change if DIYers rotated cans from 0 to 90^o, as was done in the test scenarios. The Scenario 2 estimate in Table 5 assumes that DIYers charge MVACs by holding cans in an upside down position for 25% of all cans and by rotating cans from 0 to 90^o for the remaining 75% of cans. The estimate maintains the assumption of an average time of 5 to 10 minutes. Scenario 3 assumes that all charging occurs by rotating the cans for an average time of 5 to 10 minutes. The assumptions in Scenarios 2 and 3 result in similar emission estimates of 10 and 12% of small can refrigerant use per year. These scenarios reduce heel emissions by about 80% from the estimates in Scenario 1.

Table 5: Annual Emission Estimate Scenarios

DIYer Charging Assumptions	Annual Emission Estimates (pounds/year)
Scenario 1 - All liquid and all gas charging: 25% of refrigerant charged upside down for 5 minutes, 75% charged upright for an average of 5 to 10 minutes	$[1.40\% \times 0.25]_{\text{upside down}} + [0.75 \times (74.7\% + 65.1\%)/2]_{\text{upright}} = 52.8\%$ average heel 52.8/100 x 11,833 tons x 2,000 pounds/ton = 12,496,000 pounds emitted
Scenario 2 - All liquid and mixed gas-liquid charging: 25% of refrigerant charged upside down for 5 minutes, 75% rotated 0 to 90^{o} for an average of 5 to 10 minutes	$[1.40\% \times 0.25]_{\text{upside down}} + [0.75 \times (20.4\% + 3.94\%)/2]_{\text{rotated}} = 9.5\%$ average heel 9.5/100 x 11,833 tons x 2,000 pounds/ton = 2,248,000 pounds emitted
Scenario 3 - Mixed gas-liquid charging: 100% rotated for an average of 5 to 10 minutes	$[(20.4\% + 3.94\%)/2]_{\text{rotated}} = 12.2\%$ average heel. 12.2/100 x 11,833 tons x 2,000 pounds/ton = 2,887,000 pounds emitted

Note: The annual 11,833 tons/year HFC-134a sales figure for the DIY market is from 2004 sales data from AAIA (Thundiyil, 2005).

The accuracy of the estimated heel emissions in Table 5 is limited by the relatively small survey of charging practices. However, the student technicians surveyed could be viewed as representing, at minimum, a well-informed segment of the general population regarding small can charging practices. A randomized internet survey of MVAC DIYers performed by Frost and Sullivan for the Automotive Refrigerant Products Institute (ARPI) also examined DIY practices. Summary results on DIY charging practices have been made available in PowerPoint form (ARPI, 2006). It is difficult to evaluate those results at this time in the context of this study without further detailed information on the questions or on the survey instrument. However, the findings of that report would suggest lower emission estimates than shown in Table 5. To refine the estimates in Table 5, EPA and others could conduct a follow-up, scientific survey of DIYers to identify specific common practices. Absent that data, the estimates in Table 5 indicate the potential for significant emission reductions if DIYers follow best practices to minimize heels.

Another important consideration is that the annual emission estimates in Table 5 are only for small can heel emissions and do not include emissions from refrigerant charged into a leaking system, refrigerant released by improper opening of the system, releases due to overcharging, and leaks from charge kit hoses and connections. Estimates for those emissions are outside the scope of this report.

4.2 Thirty Pound Cylinders

The development of emission estimates from 30 pound cylinders relies on the average heel in a cylinder and the total number of pounds of refrigerant sold annually in cylinders. The estimated heel emissions from discarded cylinders are about 0.4 million pounds per year, based on the overall 1.85% average heel for the 15 tested cylinders and annual 30 pound cylinder sales of 23.3 million pounds of refrigerant per year (Hoffpauir, 2005).

5. Practices to Minimize Disposable Container Heel Emissions

5.1 Small Cans

Given the potential for significant heel emissions from small cans, this study raises an important question: other than taking a car in for professional MVAC servicing, how can a DIYer minimize can heel emissions? The results indicate a set of three practices that could significantly reduce these emissions:

(1) Evaluate adoption of the can rotation orientation or other flow control methods. In the small can tests, can orientation (liquid, gas, or a mix of gas and liquid phase charging) had a significant effect on the amount of time required to empty a can while charging. The other test factors (such as system state, higher engine speed, and cooling with a shop fan) did not show a significant effect. Liquid phase charging (can upside down) is the fastest method, but can damage the compressor. Thus, individuals should not conduct upside down charging while the compressor is operating. As demonstrated by the upright can tests, gas phase charging takes much longer, approximately 90 minutes, to empty the can.

The alternative orientation of rotating the can from 0 to 90^{o}, with a mix of gas and liquid phase charging that in effect controls the flow of refrigerant, is reasonably fast and reduces the can heel significantly compared to charging only in the gas phase. The rotated can testing showed an average final charging time of 12 minutes for the TXV system and 14 minutes for the OT system. The can rotation method could reduce the average heel to about 1.6% if done for up to 15 minutes (see Table 4).

The rotation method relies on the liquid refrigerant portion of the charge flashing off in the system before the inlet of the operating compressor. Although this method was tested on both TXV and OT systems, there may be the potential for liquid reaching the operating compressor. Three out of the four charge kit instructions reviewed for this report recommend only upright charging, so suppliers may be reluctant to recommend the 0 to 90^{o} rotation practice. However, if the industry and others working in the MACAPSEP framework can develop detailed guidelines to protect against possible compressor damage from liquid refrigerant, the rotation method would offer an approach for DIYers to minimize small can heel emissions. The industry also may need to consider kit equipment changes to reduce leaks from the DIYer rotating the can, as well as other operational and safety issues outside the scope of this study.

A possible alternative to the 0 to 90^o rotation practice for industry consideration would be to develop a method that incorporates a flow limiter in the charging kit that would allow upside down liquid charging without compressor damage (PQA, 2007). The flow limiter would provide the same flow control as the 0 to 90^o rotation practice, and would be designed to empty the can while held upside down at a rate that would protect the compressor. This would offer a more straightforward and less variable approach than the 0 to 90^o rotation practice.

(2) Set a minimum charge time. The second recommended practice is to prescribe a minimum charging time of up to 15 minutes, assuming that the DIYer is using the rotated can method or other flow control method and is servicing an empty or evacuated system. The tests showed that, after 15 minutes, all small cans used to charge the TXV system were empty under the rotated can scenarios. For the OT system, under most conditions, all rotated cans were empty after 15 minutes, whereas it took up to 20 minutes to remove a slight percentage of additional refrigerant from a few of the cans tested. The effectiveness of this recommendation, however, will depend on the willingness of a DIYer to rotate or hold a can for 15 minutes over or near a hot running engine.

(3) Charge empty or evacuated systems only. As demonstrated by the charge kit pressure gauge readings, there is no way to tell how much refrigerant is in the system (except that the DIYer can tell that the system is empty if the gauge static pressure is zero). An alternative approach, relying on the panel vent temperatures, may result in improperly charging the system.

Thus, the best approach is to limit DIY or professional charging activities to an empty system. A zero static pressure reading can determine whether or not the system is empty. If there is a positive static pressure reading, then the best way to add the proper amount of refrigerant is to recover refrigerant and evacuate the system with a recovery/recycling machine, and then charge the amount specified by the manufacturer. Venting the MVAC refrigerant without capture is a violation of EPA regulations that prohibit the knowing release of refrigerants. To be in compliance, a DIYer could have a professional repair shop recover and evacuate the system, and then charge the system by himself or herself. It may be difficult to obtain acceptance of this practice. Continued industry testing to develop a reliable means of using pressure and vent temperatures, while avoiding overcharging, may be needed to address this issue.

Implementing all of these new practices in combination not only would reduce emissions but could also reduce a DIYer's long-term costs by avoiding MVAC system damage from improper charging. At a minimum, the practices would help avoid reduced system performance associated with undercharging or overcharging a system. This study did not evaluate these potential non-emission benefits. Further work in this area could assist DIYers in understanding the MVAC impacts of improper charging, as well as how the practices designed to reduce emissions could help to reduce those impacts.

If an MVAC system is already empty, the recommended practices would not affect the DIYer's cost to conduct the service. If the system is not empty, the recommendation that the system be professionally evacuated before DIY servicing would increase the overall servicing costs and discourage this approach. However, the DIYer also may avoid significant additional costs from improper MVAC system charging. These practices also ensure that the DIYer uses all the refrigerant in a can rather than discarding a can with significant levels of purchased refrigerant still available for use.

It is important to note that these practices are solely from the viewpoint of minimizing heel emissions. Further work with industry stakeholders and DIYers will be necessary to tailor these concepts into workable guidelines that gain acceptance by DIYers. In addition, these practices are not meant to reduce emissions from other aspects of DIY servicing, especially the potential emissions from charging a leaking system without fixing the underlying leaks. That said, the average small can heel can be reduced to about 1.6% of the original can contents if DIYers follow practices that use a mix of gas and liquid phase charging and charge each can for about 15 minutes. Implementing these practices would reduce annual heel emissions by as much as 97% from the potential heel emissions based on alternative practices that involve primarily gas phase charging for shorter time periods.

5.2 Thirty Pound Cylinders

On the professional side, the heel tests found that service shops currently have the equipment to minimize the heel in empty 30 pound cylinders. In addition, SAE has approved a new standard J2788 for recovery/recycling equipment and recovery/recycling/recharging of MVAC systems. This new standard has the potential for further heel reductions. The SAE J2788 standard supersedes the requirements of SAE's prior J2210 standard. The new, tighter standard requires that the recovery/recycling equipment recover 95% of a system refrigerant charge in 30 minutes or less. This requirement will result in new recovery/recycling machines that can pull a deeper vacuum on empty cylinders prior to disposal than do the current J2210 machines.

References

Atkinson, W., Data spreadsheet from December 2005 empty 30 pound cylinder heel tests performed at the Mobile Air Conditioning Society (MACS) Technical Center, August 29, 2006.

Automotive Refrigerant Products Institute (ARPI), Prepared for ARPI by Frost and Sullivan, U.S. Consumer Buying Buying Behaviors of R-134a Refrigerant for Light Vehicle Applications, Draft Report, September 2006.

Hendricks, T., Vehicle Transient Air Conditioning Analysis: Model Development and System Optimization Investigations. NREL/7P-540-30715. National Renewable Energy Laboratory, Golden, Colorado, June 2001.

Hoffpauir, E.T., Reducing Refrigerant Emissions at Service and Vehicle End of Life, Presentation to the Mobile Air Conditioning Summit, Sacramento, California, March 15 - 16, 2005.

Perrin Quarles Associates, Inc. (PQA), Summary of External Review of Disposable Container Heel Testing Study Report, Prepared for the Stratospheric Protection Division, U.S. Environmental Protection Agency, March 21, 2007.

SAE J2788 - HFC-134a (R-134a) Recovery/Recycling Equipment and Recovery/ Recycling/Recharging for Mobile Air Conditioning Systems, 2006.

Thundiyil, K., Mobile Air Conditioning Aftermarket Parts and Service Equipment Partnership (MACAPSEP), Presentation to the Mobile Air Conditioning Summit, Sacramento, California, March 15 - 16, 2005.

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Appendix A
Thirty Pound Cylinder Transfer Study

A.1 Introduction

The Universal Technical Institute (UTI) conducted a cylinder heel test program that evaluated refrigerant transfer from a 30 pound disposable cylinder that contained about 10% of its original charge. The test program recovered refrigerant from cylinders with low refrigerant levels to evaluate the effectiveness of recovery/recycling machines in transferring the refrigerant under different transfer conditions.

A.2 Methods

The test program was structured in the same manner as the 30 pound cylinder heel study. UTI weighed each cylinder before and after recovery with a recovery/recycling machine. The weight difference determined the amount of refrigerant transferred. UTI tested five cylinders with each transfer method.

For the gas transfer evaluation, UTI made three consecutive transfer runs with each cylinder in the upright position, followed by a final liquid transfer run. UTI performed the liquid phase transfer with the cylinders in the upside down position, and with a heat blanket heating the lower portion of the cylinder. The liquid transfer evaluation consisted of three consecutive transfer runs with the cylinder upside down and a heat blanket. The technicians added the heat blanket after observing frost on the bottom of the cylinders.

Table A-1 outlines the target vacuums and recovery cycle times for each recovery run. At the beginning and end of each recovery run, technicians recorded measurements of the time, shop temperature, gauge tank pressure, vacuum, qualitative tank temperature (touch), and before and after weight measurements. They also recorded the amount of material transferred, as measured by the recovery/recycling machine, for the first gas and liquid phase runs.

A.3 Results

A.3.1 Refrigerant Transfer

Table A-1 compiles the average amount of the original cylinder refrigerant that was recovered after each run, and the average cylinder heel with the 95% confidence intervals for the averages. The results confirm that it is much easier to transfer the refrigerant out of the container in the liquid phase. The average percentage recovered in the first liquid phase run is greater than the total material recovered after three runs in the gas phase (97.7% versus 93.8%).

Table A-1:
Transfer Run Cycle Parameter and Recovery Results

Recovery Test	Transfer Phase	Target Vacuum (in. Hg)	Target Cycle Time (minutes)	Mean of Refrigerant Recovered (% of Original Contents)	95% Confidence Interval of Mean Recovered (%)	Mean Cylinder Heel (%)	95% Confidence Interval of Mean Heel (%)
Gas Phase Transfer							
Gas 1	Gas	10	15	43.6	42.3 to 44.8	6.04	4.95 to 7.12
Gas 2	Gas	29	30	74.4	67.1 to 81.8	4.18	3.82 to 4.54
Gas 3	Gas	29	30	93.8	88.5 to 99.1	2.70	2.02 to 3.39
Gas 4	Liquid	29	10	100	-	0.913	0.116 to 1.71
Liquid Phase Transfer							
Liquid 1	Liquid	29	15	97.7	95.9 to 99.5	2.33	0.53 to 4.12
Liquid 2	Liquid	29	15	100	99.9 to 100	0.032	-0.031 to 0.096
Liquid 3	Liquid	29	10	-	-	0	-

A.3.2 Recovery/Recycling Machine Measurement Accuracy

The testing identified significant discrepancies between the recovery/recycling machine measurement of material transferred during a recovery cycle and the amount of material transferred based on the before and after weights. Table A-2 lists the relative accuracy for the 10 cylinders in the study, and Figure A-1 presents a scatter plot of relative accuracy versus the weight of material transferred. Both the table and plot show a negative bias in the machine measurements.

Table A-2:
Recovery/Recycling Machine Relative Accuracy

Cylinder	Weigh Scale Refrigerant Measurement (oz.)	R/R Machine Refrigerant Measurement (oz.)	Measurement Difference (oz.)	Relative Accuracy (%)
F1	21.745	6	15.745	-72
F3	30.370	8	22.370	-74
F9	29.815	23	6.815	-23

(cont.)

Table A-2:
Recovery/Recycling Machine Relative Accuracy (cont.)

Cylinder	Weigh Scale Refrigerant Measurement (oz.)	R/R Machine Refrigerant Measurement (oz.)	Measurement Difference (oz.)	Relative Accuracy (%)
F5	30.485	14	16.785	-55
F8	32.480	31	1.480	-5
F2	66.380	58	8.380	-13
F4	62.925	51	11.925	-19
F6	43.745	50	-6.255	14
F7	52.745	36	16.725	-32
F10	56.310	60	6.310	-10

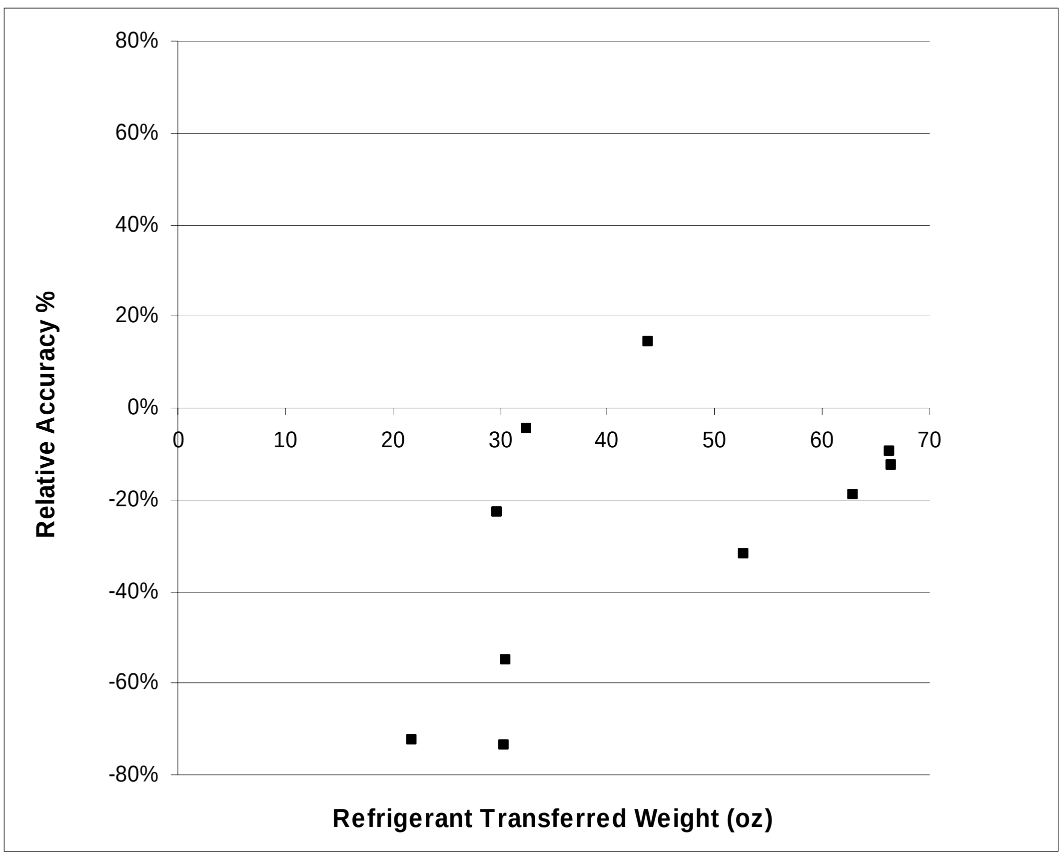

Figure A-1: Scatter Plot of Relative Accuracy and Weight Transferred

A.4 Conclusions

This testing program showed that a liquid transfer, with the 30 pound cylinder upside down and a heat blanket wrapped around the bottom portion of the cylinder, could greatly improve refrigerant recovery from cylinders with low refrigerant levels. Transferring this amount of refrigerant from a 30 pound cylinder, however, is not typical of normal usage.

The tests also indicated problems with the machine's accuracy in measuring recovered refrigerant amounts. The SAE has recently modified the recovery/recycling machine standards to include accuracy specifications. Implementation of the new J2788 standard should ensure an appropriate degree of machine measurement accuracy for new equipment when it takes effect.

Appendix B
Student Survey Results

Table B-1:
Student Survey Results: May 2006 Classes

Responses	Class 1	Class 2	Class 3
Question 1	**Have you used small cans to charge A/C systems?**		
Yes	10	5	5
No	15	22	2
Question 2	**What is the condition of the system requiring change?**		
No pressure	8	1	3
Pressure	0	5	4
Question 3	**If there is no pressure in the system, how do you prepare for charging?**		
Just add	1	5	3
Evacuate/add	0	22	3
Question 4	**When charging with cans, what position do you hold can?**		
Upright	2	22	4
Upside down	8	0	1
Rotate side to side	0	0	0
Question 5	**When charging with cans, do you:**		
Agitate (shake) can	6	4	4
No can movement	0	22	3
Question 6	**How do you determine if all refrigerant has been removed from can?**		
Feel liquid movement	0	0	0
Can feels cold	0	5	2
Can feels warm	1	9	5
Can feels empty	4	2	0
Other	0	0	5*

(cont.)

Table B-1:
Student Survey Results: May 2006 Classes (cont.)

Responses	Class 1	Class 2	Class 3
Question 7	**How much time will you spend charging one can?**		
Less than 5 minutes	4	8	1
5 - 10 minutes	2	11	6
10 - 15 minutes	0	0	0
More than 15 minutes	0	0	0
Question 8	**How do you determine if charge amount is correct?**		
Weight	0	N/A**	0
Gauge pressure	0	N/A**	2
Cold air out panel vent	0	N/A**	1
Gauge and panel vent	0	N/A**	5
Cannot	19	N/A**	0
Question 9	**If refrigerant remains in can, what do you do with the extra refrigerant?**		
Saved refrigerant in can	N/A***	N/A***	4
Vent	N/A***	N/A***	3
Question 10	**When charging system with cans, what engine speed?**		
Low speed/idle	3	0	7
High engine RPM	2	17	0
Question 11	**When diagnosing A/C system performance, what engine speed do you use?**		
Idle	N/A	0	2
High engine RPM	N/A	22	5

* Weight and can temperature combination.
** Not available. This question was not asked in this class.
*** Not available. There was no count of responses, but listed responses included vent, dispose in trash, evacuate, recover, and save.