A Performance Based Method to Determine Refrigerant Charge Level For Commissioning Unitary AC and HP Systems

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ABSTRACT

A method is presented for determining the refrigerant charge level in a unitary air conditioning (AC) or heat pump (HP) system. The method is based on performance characteristics of the system and applies to systems with either an expansion valve or a fixed expansion device (orifice or capillary tube). Application of the method requires initial laboratory testing of a system to determine the performance characteristics as a function of refrigerant charge level. The performance characteristics are primarily a function of the outdoor components (outdoor coil and compressor) and expansion device. A correlation for refrigerant charge level is developed from the laboratory test data. With this correlation, field evaluation of refrigerant charge level only requires measurements at the outdoor unit during near steady operation of the system. Measurement of indoor or outdoor ambient conditions is not required. The method is particularly suited for split systems because it does not require adjustment for refrigerant line length. Data are presented for two systems to demonstrate the application of the method and agreement between the predicted and actual charge levels is ±10% over the range from 70% to 130% of the base charge level. The proposed method is shown to have potential for determining the refrigerant charge level in field-installed systems and further investigation is recommended to verify the applicability of the method to other systems.

Introduction

The need for proper refrigerant charge in AC and HP systems is documented in the literature, including publications by Farzad and O'Neal (1993, 1994), Robinson and O'Neal (1994), and Davis (2001). Undercharge or overcharge results in a reduction in both capacity and efficiency of a system. Methods are available to determine refrigerant charge level in systems; however, implementation can be problematic due to the required measurements. An improved method of refrigerant charge determination could contribute to improved system servicing and operation.

A new method is presented for determining the refrigerant charge level in a unitary air conditioning or heat pump system. The proposed method requires measurements only at the outdoor unit and can be applied to systems with either an expansion valve or a fixed expansion device. The method is illustrated using test data for two systems.

Background

There are a number of methods that have been suggested for determining the charge level in AC and HP systems. The most common methods, charge weight, subcooling, and superheat, are reviewed by Wray et al. (2002) and the Consortium for Energy Efficiency (2000). Holder (2000) also discusses the subcooling and superheat methods.

Charge determination based on refrigerant weight can be applied to any system, but the refrigerant must be removed from the system to be weighed. Additionally, the target charge value provided by the equipment manufacturer must be adjusted for refrigerant line length and possibly indoor coil volume. Weighing charge is an effective method for installing the proper charge in system that has been evacuated, but since it requires removal of the refrigerant charge it is usually not an effective method for verifying charge level in an existing system.

The subcooling method is recommended for systems with an expansion valve. The method is relatively straightforward to implement and requires only measurement of the liquid line pressure and liquid line temperature during steady system operation. The calculated subcooling value is then compared to the target value. Equipment manufacturers typically provide a single target subcooling value (independent of ambient conditions). In contrast to the single target value, Holder (2000) presents a table of target subcooling values for different outdoor temperatures and indoor wet-bulb temperatures. An adjustment is not required for refrigerant line length. The subcooling method is effective in verifying the charge level in a system and providing a relative indication of the charge level (high or low), but the author is not aware of any references where the method is used to provide a quantitative prediction of charge level in an installed system.

The superheat method is recommended for systems with a fixed expansion device (orifice or capillary tube). The method requires measurement of the suction pressure and suction temperature during steady system operation. Additionally, the outdoor air temperature (dry-bulb) entering the condenser and the indoor return air wet-bulb temperature are required to determine the target superheat value. The equipment manufacturer typically provides a superheat table or chart to determine the target superheat value based on the ambient temperature conditions. An adjustment is not required for refrigerant line length. Siegel and Wray (2002) conducted an evaluation of refrigerant charge diagnostics that are based on superheat measurement and identified problems with the three methods that were evaluated. Several potential measurement issues were identified including obtaining adequate thermal contact between sensor and pipe for refrigerant line temperature measurements, impact of thermal mass of sensors, and the need for accurate condenser entering air temperature measurement. They also recommended the development of an improved charge determination method. Wurts (2003) also identified problems associated with the three temperature measurements required to apply the superheat method for evaluating refrigerant charge level. The potential problems include outdoor air temperature variations around the outdoor unit, maintaining good “wetting” material for wet-bulb measurements, and obtaining good thermal contact between the sensor and pipe for suction line temperature measurement. Wray and Sherman (2001) also listed potential problems with applying the superheat method including measuring the indoor wet-bulb temperature within the house rather than within the return plenum downstream of return duct leaks, measuring outdoor air temperature remotely from the condensing unit in direct sunlight with an unshielded sensor, and measuring refrigerant line temperature downstream of a line restriction or with an uninsulated sensor that has poor surface contact. The superheat method is effective in verifying the charge level in a system and providing a relative indication of the charge level (high or low), but the author is not aware of any references where the method is used to provide a quantitative prediction of charge level in an installed system.

Refrigerant Charge Determination Method

A new method for determining the refrigerant charge level in a unitary air AC or HP system is presented. The method was developed based on experimental observations of system performance variations with charge level and ambient conditions. The basic concept of the method will be discussed and then the method will be illustrated for two systems: a system with an expansion valve and a system with a fixed expansion device.

Subcooling and superheat are the two main performance parameters that are frequently used for evaluating charge level in AC and HP systems. Subcooling is typically used for a system with an expansion valve and superheat is used for a system with a fixed expansion device. Subcooling, evaluated at the condenser outlet, is defined as

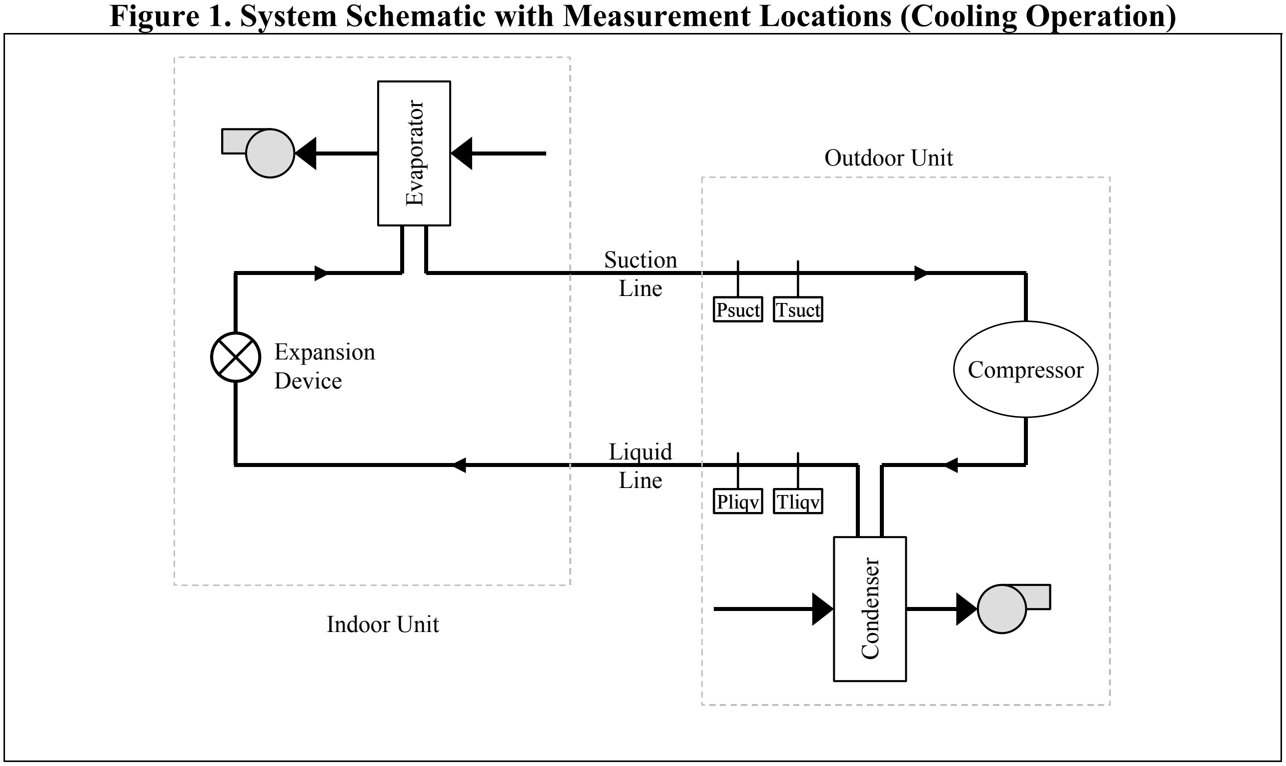
$$\Delta T_{sc} = T_{satl} - T_{liqv} \quad (1)$$

where T_{liqv} is the refrigerant temperature in the liquid line and T_{satl} is the saturated liquid temperature at the liquid pressure P_{liqv}. Superheat, evaluated at the compressor inlet (total superheat according to Holder, 2000), is defined as

$$\Delta T_{sh} = T_{suct} - T_{satv} \quad (2)$$

where T_{suct} is the refrigerant temperature in the suction line and T_{satv} is the saturated vapor temperature at the suction pressure P_{suct}. A system schematic is presented in Figure 1 and the measurement locations are identified. The parameters of subcooling and superheat are normally used independently of each other; however, they can be used together to provide an improved indicator of the system performance.

Figure 1. System Schematic with Measurement Locations (Cooling Operation)



In the following paragraphs and figures, data are presented from laboratory tests conducted in accordance with ARI Standard 210/240. An air conditioning system with an expansion valve and a system with an orifice were tested and the system characteristics are summarized in Table 1. The same outdoor unit and indoor coil were used for both systems. Tests were conducted at eleven sets of ambient conditions and five charge levels. The ambient conditions are presented in Table 2 and the charge levels were 70%, 85%, 100%, 115%, and 130% of the base charge level. The data were all recorded with the system operating at steady conditions.

Table 1. Test Unit Data

Expansion Device	**Expansion Valve (TXV)**	**Orifice**
System Type	split system AC	split system AC
Nominal Total Cooling Capacity (Btu/h)	48,000	48,000
Refrigerant	R-22	R-22
Base Refrigerant Charge (lb)	6.7	6.7
Evaporator Airflow Rate (cfm)	1400	1600
Refrigerant line length (ft)	25	25
Total Cooling Capacity (Btu/h) at base charge and 80/67/95	41,900	45,200
Energy Efficiency Ratio (Btu/Wh) at base charge and 80/67/95	8.9	9.3

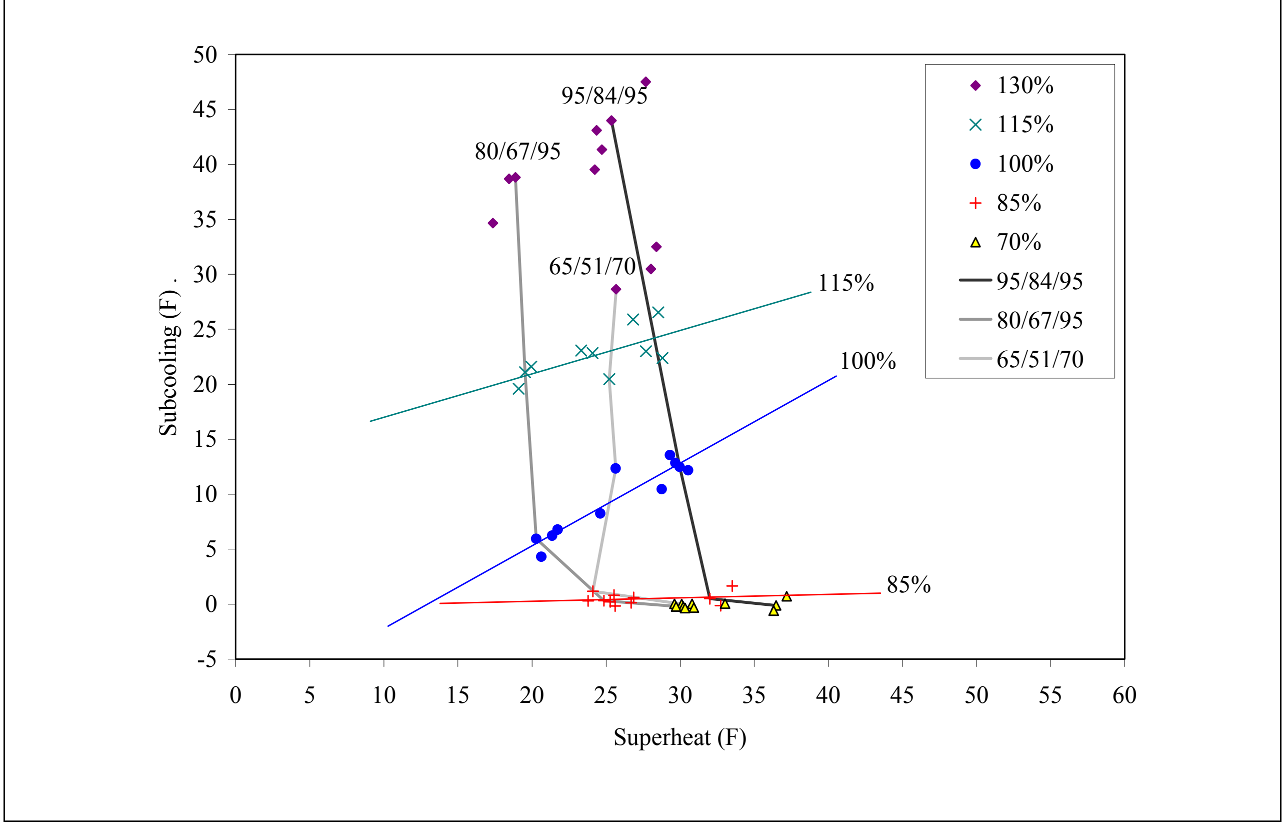
Table 2. Test Conditions

Test Number	**Indoor Dry-Bulb Temperature (F)**	**Indoor Wet-Bulb Temperature (F)**	**Outdoor Dry-Bulb Temperature (F)**	**Indoor Relative Humidity (%)**
1	65	51	70	35
2	65	51	95	35
3	65	51	115	35
4	80	62	95	35
5	80	67	70	50
6	80	67	95	50
7	80	67	115	50
8	80	71	95	65
9	95	84	70	60
10	95	84	95	60
11	95	84	115	60

short notation for ambient test conditions: xx/yy/zz
where xx is the indoor dry-bulb, yy is the indoor wet-bulb, and zz is the outdoor dry-bulb

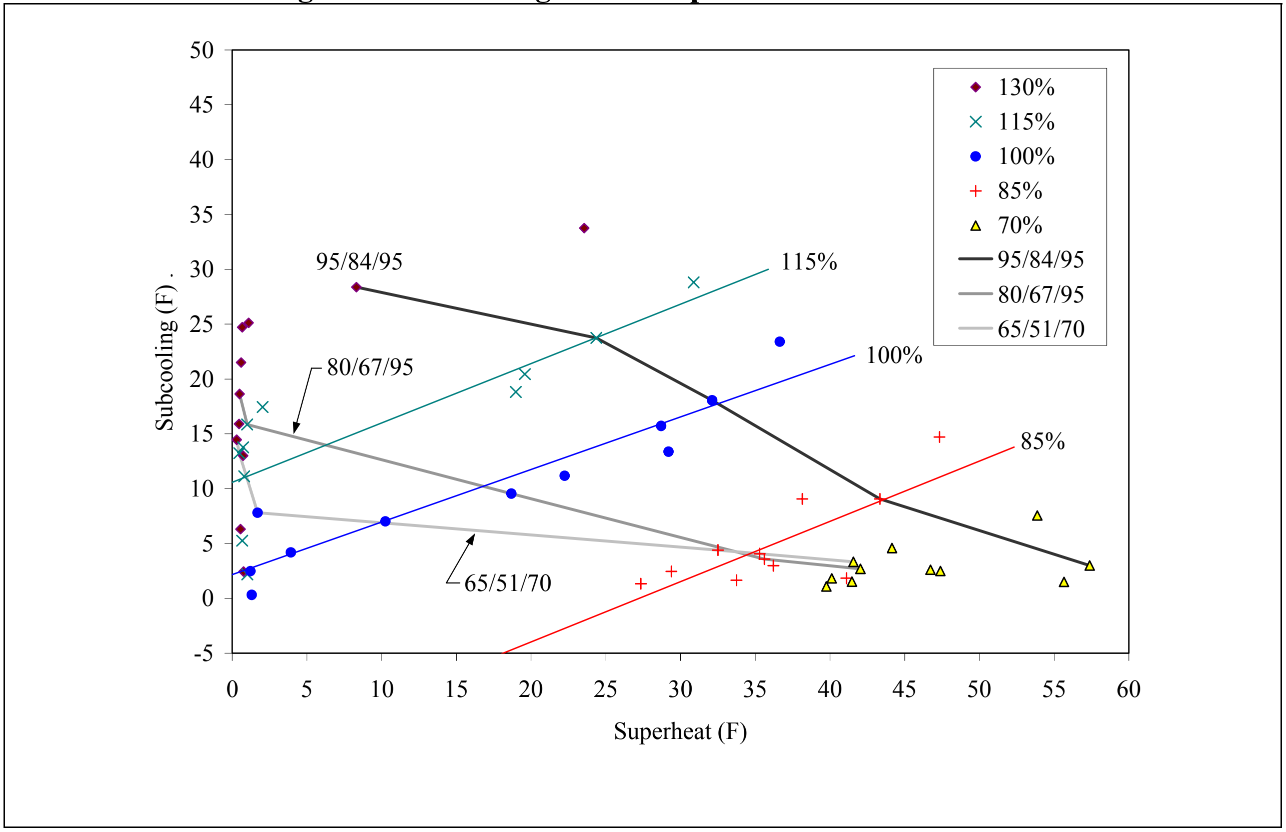
Application of both subcooling and superheat will first be considered for a system with an expansion valve. Experimental data for the test system are presented in Figure 2 as subcooling versus superheat. Data are presented for all the test conditions and trend-lines are included for 85%, 100%, and 115% charge levels. It can be observed that there is some variation of subcooling with ambient conditions. At the 100% charge level the subcooling varies from 4.3° to 13.6°F. This indicates potential error associated with charging an expansion valve system to a fixed subcooling value and supports the varying target subcooling values presented by Holder (2000). Additionally, as charge level decreases and subcooling approaches zero, there can be no further variation of this parameter with charge level. There is, however, a corresponding increase in superheat as can be observed by following the line for a fixed set of ambient conditions such as 80/67/95. The data for 100% charge level have limited scatter about the plotted trend-line and have good differentiation with the 85% and 115% data. This provides an indication that subcooling combined with superheat may provide an improved indicator of charge level for a system with an expansion valve. The data scatter increases as the charge level increases (115% and 130%) and there is little differentiation between the 85% and 70% data, indicating that the method is probably not valid beyond 85% or 130% charge levels.

Figure 2. Subcooling versus Superheat for Expansion Valve Unit



Application of both subcooling and superheat will now be considered for a system with an orifice expansion device. Experimental data for the test system are presented in Figure 3 as subcooling versus superheat. Data are presented for all the test conditions and trend-lines are included for 85%, 100%, and 115% charge levels. From this figure it can be observed that superheat increases and subcooling decreases as charge is reduced. The relatively parallel and separated trend-lines at the three different charge levels indicate that subcooling can potentially be used as an additional parameter to account for performance variations with ambient temperature. This would eliminate the need to measure ambient conditions to determine a target superheat value, indicating that superheat combined with subcooling may provide an improved indicator of charge level for a system with a fixed expansion device. There is little differentiation between operating points with low or no superheat; however, these are not desirable operating points due to the potential for liquid refrigerant at the compressor inlet.

Figure 3. Subcooling versus Superheat for Orifice Unit



Based on the experimental observations, a simple correlation was developed to predict charge level from the experimental measurements. The proposed method can then be evaluated by comparing the predicted charge level to the actual charge level. The correlation for predicted charge level, CL, is defined as

$$CL = a \cdot \Delta T_{sc} + b \cdot \Delta T_{sh} + c + d \cdot P_{liqv} + e \cdot P_{suct} \qquad (3)$$

where a, b, c, d and e are correlation coefficients. The correlation coefficients presented in the remainder of this section are based on temperature differences with units of degrees F and pressures with units of psig. The key variables of the correlation are the subcooling and superheat terms; however, the correlation is further improved by including terms for the pressures. The measurements required for the proposed method are summarized in Table 3 and compared to the requirements for the subcooling and superheat methods.

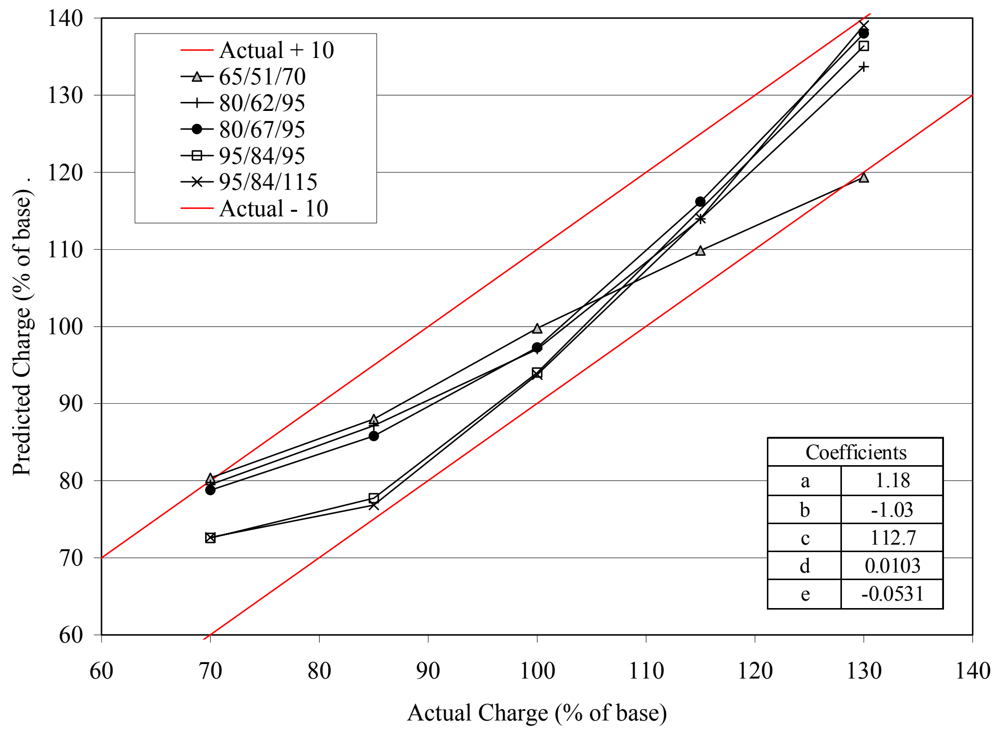
Table 3. Method Summary

	Method	Weigh Charge	Subcooling	Superheat	Subcooling and Superheat
System	TXV	yes	yes	no	yes
	Orifice	yes	no	yes	yes
Measurements	Charge weight	x			
	Liquid pressure		x		x
	Liquid temperature		x		x
	Suction pressure			x	x
	Suction temperature			x	x
	Outdoor air temperature			x	
	Indoor wet-bulb temperature			x	
Method Application	Charging	yes	yes	yes	yes
	In place charge level determination	no, requires removal of charge	?	?	yes

Because the method is based on the performance parameters of subcooling and superheat, the target performance characteristics are primarily a function of the outdoor components (outdoor coil and compressor) and expansion device. A change in refrigerant line length will change the required refrigerant charge but will not change the target performance characteristics. An increase in refrigerant line length increases the volume of the system. In order to obtain the same system performance the refrigerant charge must be increased to account for the refrigerant that will occupy the additional volume. If the refrigerant charge is not increased, the performance will be similar to a system with low charge. This will be a shift in performance along a curve (refer to Figure 2 or Figure 3) for a given set of ambient conditions. For a system with an expansion valve the subcooling will be low. A reduction in line length has the opposite effect. This is the reason that the subcooling and superheat methods do not require adjustment for line lengths. Since the proposed method is essentially an improvement of these methods, it also does not require an adjustment for refrigerant line length variation.

Correlation coefficients were determined for the expansion valve system using the entire data set and the predicted charge level is presented as a function of actual charge level in Figure 4. Data are included for 5 sets of ambient conditions that adequately represent the complete set of data. In the charge level range from 85% to 115% the agreement between predicted and actual charge level is approximately ±6%. Over the charge level range from 70% to 130% the agreement is approximately ±10% as indicated by the straight lines at +10% charge and –10% charge.

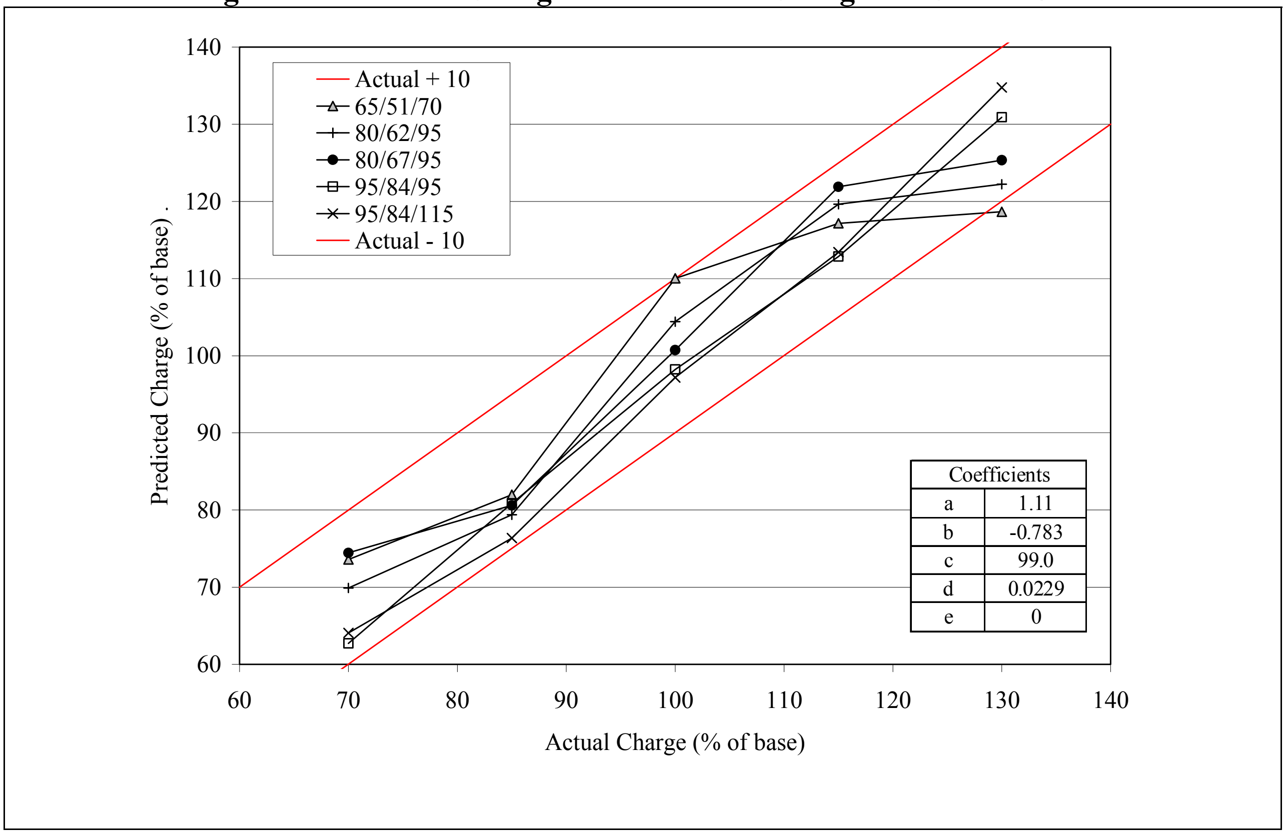
Figure 4. Predicted Charge versus Actual Charge for Expansion Valve Unit



Correlation coefficients were also determined for the orifice system using the entire data set and the predicted charge level is presented as a function of actual charge level in Figure 5. Data are included for 5 sets of ambient conditions. In the charge level range from 85% to 115% the agreement between predicted and actual charge level is approximately ±9%. Over the charge level range from 70% to 130% the agreement is approximately ±10%.

An analysis was conducted to compare the estimated accuracy of the proposed method, the subcooling method for the TXV system, and the superheat method for the orifice system. Since the methods of subcooling and superheat are not typically used to provide a quantitative prediction of charge level, an evaluation of the accuracy of these methods could not be located in the literature. The estimated accuracy of each method was assessed by comparing predicted charge levels to actual charge levels. The analysis of each method was completed using the measured temperatures and pressures for the suction and liquid lines. The analysis does not explicitly address measurement uncertainties. The proposed method was compared to the subcooling method for the system with an expansion valve by determining correlation coefficients for the limited data set of 85%, 100% and 115% charge levels. For the subcooling method, the coefficients b, d, and e in Equation 3 were fixed at zero. The results are presented in Figure 6 and the equation coefficients are indicated in the figure. For the proposed method, over the charge level range from 85% to 115%, the agreement is ±5% compared to ±7% for the subcooling method. A similar analysis was performed for the superheat method. Coefficients for the superheat method were determined for each set of ambient conditions. The coefficients a, d, and e in Equation 3 were fixed at zero. The results are presented in Figure 7. For the proposed method, over the charge level range from 85% to 115%, the agreement is ±5% compared to ±7% for the superheat method. The results, for the units tested, indicate a slight improvement in the accuracy of the proposed method compared to the subcooling and superheat methods. There is potential to further improve the agreement at the 100% charge level by tuning the correlation coefficients.

Figure 5. Predicted Charge versus Actual Charge for Orifice Unit



The analysis presented considers the impact of a range of ambient conditions (Table 2) on the predicted charge level, but has not addressed a number of other factors. The ambient conditions tested cover a fairly wide range of operating conditions, but it may be desirable to expand or reduce the set of conditions. The analysis has not explicitly included the impact of measurement uncertainty on the predicted charge level. The analysis also does not include the impact of simultaneous faults such as those associated with reduced evaporator airflow (dirty coil, etc.), reduced condenser airflow (blocked coil, etc.), and refrigerant line restrictions. Additional testing is recommended to further evaluate the proposed method.

Application of the proposed method requires initial testing of the outdoor unit in a system and effective field measurements and analysis. If the method were to be applied as a charging method, only data at the 100% charge level (and various ambient conditions) would be required. Testing would be similar to that required to generate a superheat table or chart. The data could be presented in the form of a table or a chart or included in a device that is capable of performing calculations when provided with the measured temperatures and pressures. A device has been suggested by Temple and Hanson (2003) that would include sensors, an input module, and computational capabilities to determine superheat and subcooling. If the method were to be applied to predict the charge level in existing systems, then further testing at other charge levels is required (85%, 115%, etc.). Temperature sensors must be selected to provide good thermal contact with the refrigerant lines. Additional analysis should also be conducted to evaluate the impact of measurement uncertainties on the overall accuracy of the method.

Figure 6. Comparison of Subcooling and Proposed Method for Expansion Valve Unit

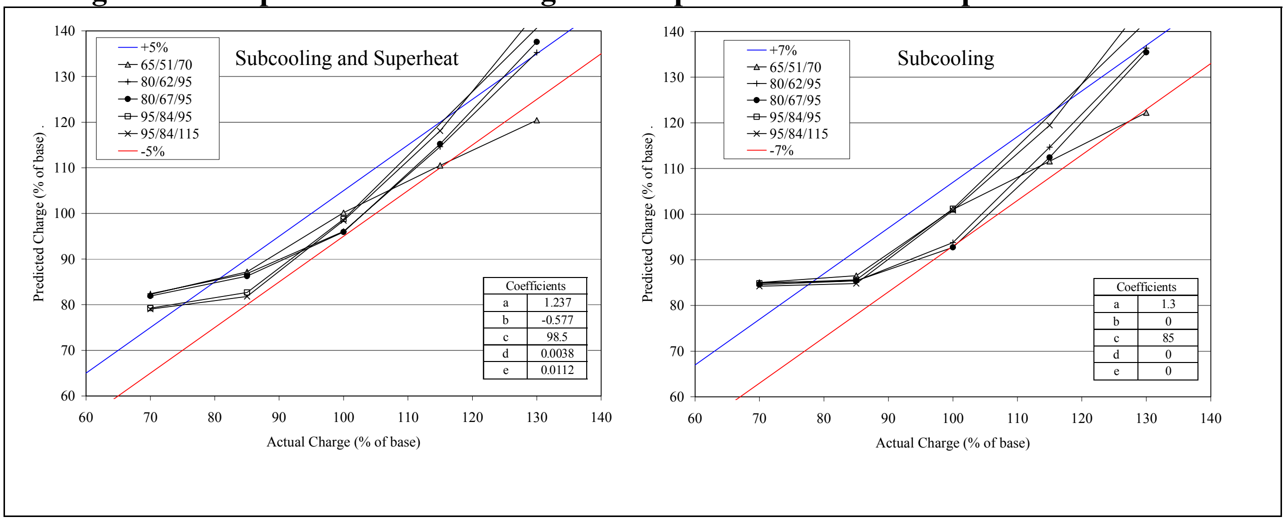
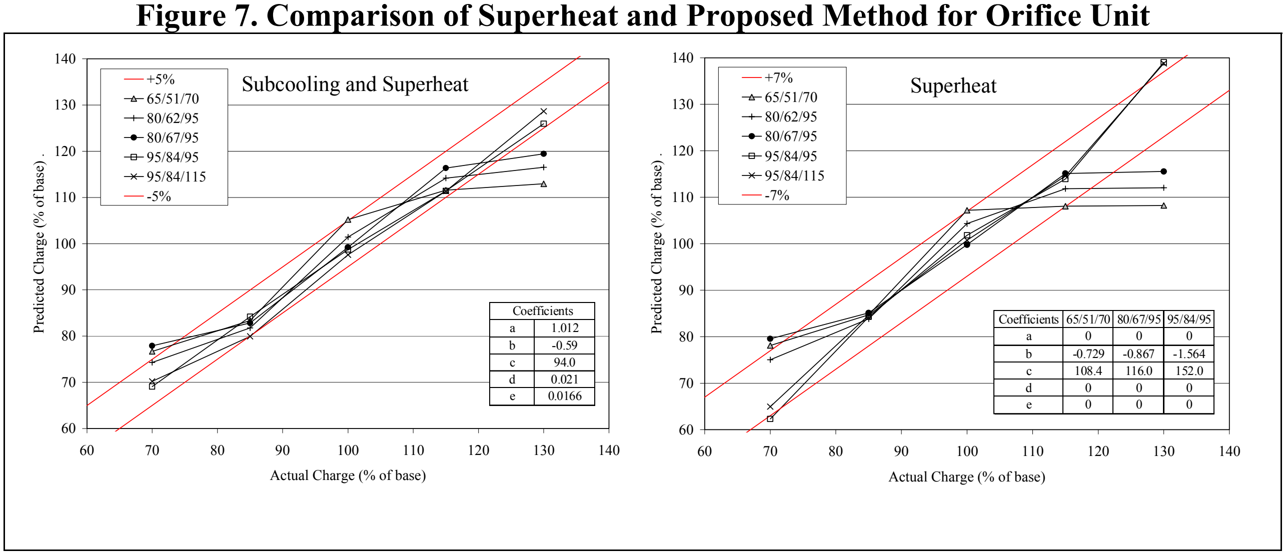


Figure 7. Comparison of Superheat and Proposed Method for Orifice Unit



Conclusions

A new method is presented for determining the refrigerant charge level in a unitary AC or HP system. The method is based on performance characteristics of superheat and subcooling and application in the field requires only four measurements made at the outdoor unit during near steady operation. The method can be applied to systems with either an expansion valve or a fixed expansion device (orifice or capillary tube). Application of the method requires initial laboratory testing of a system to determine the performance characteristics as a function of refrigerant charge level. The target performance characteristics are primarily a function of the outdoor components (outdoor coil and compressor) and expansion device. The results for the two systems tested indicate that the proposed method can be used to predict refrigerant charge to within ±10% over the range from 70% to 130% charge level. The agreement can be improved over a narrower range of charge levels by tuning the coefficients. The analysis does not explicitly include the uncertainty associated with field measurement of the temperatures and pressures.

The proposed refrigerant charge identification method has the following advantages:

1. The method is applicable to systems with an expansion valve or a fixed expansion device. One method can be used for all systems.
2. All measurements are made at the outdoor unit and can be made at the same time. Measurements are not required at the indoor unit as with the superheat method.
3. The method can be used to provide a quantitative prediction of the charge in the system as opposed to only a qualitative evaluation (when charge is low or high). This can be used to provide guidance on the amount of charge to add or remove from a system.
4. The method does not require an adjustment for refrigerant line length variation. This is similar to the subcooling and superheat methods.
5. The method has potentially improved accuracy compared to subcooling or superheat. This requires further evaluation.

The proposed method does not eliminate the need for good measurements. The method does limit the type of measurements to refrigerant pressures and refrigerant line temperatures. Additionally, all measurements are made at the same location, the outdoor unit, and can easily be made at the same time with multiple sensors. The primary measurement challenge is selecting temperature sensors that make good thermal contact with the refrigerant lines.

The investigation did not include an evaluation of sensitivity to other system faults and further investigation is recommended to determine the impact of low evaporator airflow and other system faults on the proposed charge determination method.

The results of the investigation indicate that the proposed method has potential as a diagnostic method for refrigerant charge level. The results are dependent on the two air conditioning systems tested. Further investigation of the method is recommended to determine its applicability to other systems and also to explore possible improvements and address the issues identified.

Acknowledgement

The technical concept was developed by the author and Oved Hanson at the Lennox Industries Product Development and Research Facility in Carrollton, Texas. Some applications of the proposed charge determination method are covered by United States Patent Number 6,571,566 (Temple and Hanson, 2003).

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