A New Air Conditioning Trainer for a Technology Laboratory

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Abstract

This paper describes the features and usage of a self-contained mobile air conditioning trainer. This device resulted from a senior project carried out in the Mechanical Engineering Technology department at Indiana University-Purdue University, Indianapolis. Two students created the specifications and experiments for the equipment which was fabricated at the Carrier Corporation in Indianapolis, Indiana. The trainer includes a condenser, evaporator, compressor, expansion valve and fan coil unit. All the components as well as a control bank with pressure, temperature and flow measurement devices are mounted on a 6 feet by 3 feet wheeled cart. The system is charged with refrigerant 22 (R-22) and permits a complete analysis of the vapor compression refrigeration cycle. The system is being used in a basic thermodynamics course as well as an HVAC elective.

I. Introduction

All mechanical engineering technology (MET) students, and many electrical engineering technology (EET) students, take one or more courses in thermodynamics, the study of energy and its various forms. Part of any thermodynamics curriculum is the study of refrigeration and air conditioning (RAC) whereby heat is transferred from a cooler to a warmer region by the addition of mechanical work. Students at our institution find thermodynamics one of the most difficult subjects. The concepts are difficult to grasp and the problems are hard to solve. By the time the topic of RAC is introduced, the student may be adrift in a sea of enthalpy, entropy, Mollier charts, and the Carnot cycle. Even though the student is exposed to RAC equipment in everyday life, it is difficult to apply thermodynamic principles that were not well-understood to begin with. Thus it was felt that the development of laboratory equipment that was easy to use, provided the necessary data, and permitted the student to see how the components operated would be of significant benefit to students of RAC.

As part of our required capstone course in MET, two senior students developed a test bed for air conditioning with the desired features noted above and with appropriate laboratory experiments. They, with this author as advisor and a team of engineers from Carrier Corporation in Indianapolis, designed and built a self-contained mobile air conditioning system which is now in use in our MET laboratories.

II. System Description

The Air Conditioning Trainer is mounted on a 6 feet by 3 feet wheeled cart. The major components of the system are shown in Figure 1. Room air is taken in at the base of the fan coil unit (position 3). The fan is visible through a window in this unit. The air is cooled as it passes over the evaporator coil (C) and exits through louvers at position 4. The air conditioning unit contains R-22 passing through the evaporator coil. The refrigerant then flows through the suction line G into the compressor D located in the “outdoor” unit on the right (F). The compressed gas exits the compressor and enters the condenser (A) where it gives off heat to the “outdoor” air, actually room air, circulating through it from point 1 to point 2. A window in the air conditioning unit permits visualization of the compressor and the condenser. The condensed liquid flows out at K to the expansion valve B where it drops in pressure and enters the evaporator. Sight windows (H) allow the student to see the flow of R-22. A condensate trap J collects moisture condensed from the conditioned air.

Pressure taps and thermocouples are strategically located to provide correlation with a pressure-enthalpy (p-h) diagram so that the student can analyze the performance of the system according to the vapor compression cycle. All temperature and pressure readouts are conveniently located on an instrument panel (I) located in the center of the system. The following R-22 pressures are available:

1. Entrance to the expansion valve.
2. Exit of the expansion valve.
3. Entrance to the compressor.
4. Exit of the compressor.

The following temperatures are available:

1. Room ambient air before conditioning.
2. Air over the evaporator coil.
3. Conditioned air at the exit.
4. Room air entering the condenser coil.
5. Air discharged from the condenser.
6. R-22 entering the compressor.
7. R-22 leaving the compressor.
8. R-22 entering the expansion valve.
9. R-22 leaving the expansion valve.

In addition, flowmeters are provided to read the flow rate of R-22 leaving the compressor and the velocity of the conditioned air moving through the fan coil unit.

The instrument panel includes a switchbox to permit a digital readout of whichever pressure or temperature is desired. The system is powered by a 220v power supply for the air conditioner and a 120v input for the instrumentation.

This Trainer has advantages over other commercial systems such as those produced by Hampden[1]. In our system actual industrial components are used including air plenum chambers, louvers, heat exchangers and fans. This system actually looks like an air conditioning unit (see photograph in Figure 2) rather than a table top assembly of components. This Trainer was custom built by Carrier Corporation for about $7,000. Inquiries from parties interested in obtaining a similar system should contact the Corporation[2].

III. Experimental Procedures

The student may now use this system to understand the vapor compression cycle using the p-h diagram. The pressure-enthalpy diagram and a table of R-22 properties are included with the equipment. The teaching of refrigeration and air conditioning typically is built around the ideal vapor compression cycle, shown as A'B'C'D in the p-h diagram of Figure 3. In the ideal cycle, the refrigerant exits the condenser as saturated liquid and enters the compressor as saturated vapor. This cycle which can be analyzed for its coefficient of performance, the measure of the efficiency of this cycle, using enthalpy values. However, real RAC systems utilize a modified vapor compression cycle which includes superheat of the gas leaving the evaporator and subcooling of the liquid leaving the condenser (ABCD in Figure 3). In our system, the pressure and temperature of the R-22 entering the compressor are available to determine its degree of superheat. Superheating is required to insure that no moisture enters the compressor. Measurements of pressure and temperature leaving the condenser permits the determination of the amount of subcooling that takes place.

The measurements of pressure and temperature at all key points in the cycle are available with this system. The refrigeration effect per pound of refrigerant may be found from the difference of the enthalpies leaving and entering the evaporator. These are obtained from the pressure and temperature data using the R-22 diagram and tables. The compressor work per pound is the difference of the enthalpies entering and leaving the compressor, available from the pressure and temperature data and the R-22 chart. The coefficient of performance may then be calculated as[3]:

$$COP = \frac{refrigeration\ effect}{compressor\ \ work}$$

The student may now compare this result with that for the ideal cycle where the enthalpy entering the evaporator is that of saturated liquid at condenser saturation conditions, the enthalpy leaving the evaporator is saturated vapor, and the enthalpy leaving the compressor assumes an adiabatic compressor.

The student can also use this equipment to examine other concepts in the vapor compression cycle. Using pressure and temperature data at the entrance and exit of the expansion valve, the concept of throttling as a constant enthalpy process can be verified. Also the efficiency of the compressor can be examined by comparing the enthalpy increase through it to an isentropic process with the same entrance enthalpy. The rate of air cooling can be found by evaluating the mass flowrate of the air using the air velocity indicator and the average air temperature measurement to determine its density. The air temperature rise is available from the temperature-measuring thermocouples. The rate of heat transfer from the R-22 in the evaporator is found using the refrigeration rate times the R-22 mass flow rate. Mass flow rate is available from the R-22 turbine flowmeter and the density of the refrigerant. Comparing the rate of air cooling with the rate of heat transfer from the R-22 gives the student an idea of the efficiency of the entire heat transfer process. The position of the exit louver in the air flow line can be varied to simulate air flow restriction such as would be caused by a dirty filter. Finally, psychrometric analysis can be done by measuring the rate of water condensate produced.

IV. Summary and Conclusion

A new laboratory trainer has been developed to help teach students the basics of refrigeration and air conditioning. It is a self-contained mobile unit with all industrial components including condenser, evaporator, compressor and expansion valve. It is fully instrumented to provide pressure and temperature measurements at key points in the vapor compression cycle plus outputs of air and refrigerant flow rates. The system was built at the Carrier Corporation plant in Indianapolis and is charged with R-22. A series of experiments have been developed to evaluate the refrigeration effect, compressor work, coefficient of performance, heat flow rates, the amount of superheating and subcooling, and various efficiencies. This unique system has been installed in the mechanical engineering technology laboratories of Indiana University-Purdue University Indianapolis.

V. Acknowledgement

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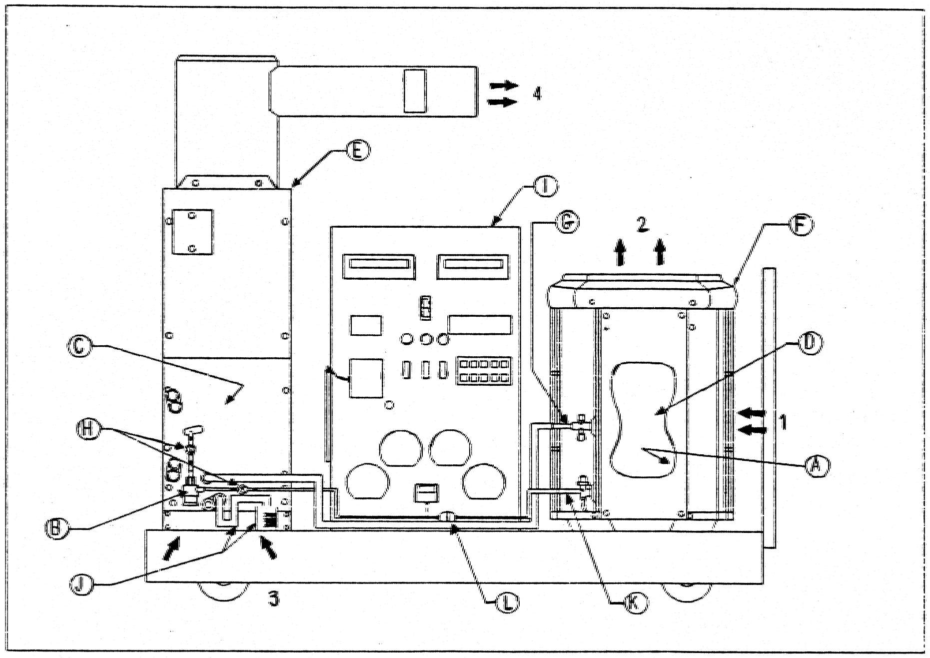

Figure 1. Air Conditioning System Components

Figure 2. Photograph of the Trainer

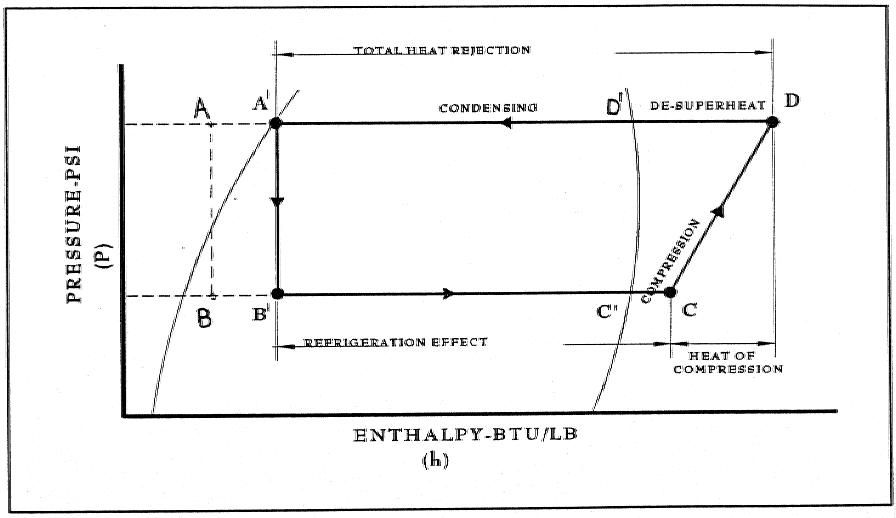

Figure 3. Pressure-Enthalpy Diagram