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REFRIGERANT CHARGING UNIT FOR RESIDENTIAL AIR CONDITIONERS: EXPERIMENT

Abstract

In the present work, an automatic R410A refrigerant charger for residential air conditioners is fabricated and tested. The charger operates on the throttling principle and uses the suction pressure of the compressor to estimate the refrigerant charge level. This helps to reduce the risk of compressor damage and ensures the correct composition ratio of R410A refrigerant when charged into the machine. The charging process is controlled by the LabVIEW platform, which provides adequate control and visualization of the charging process. The developed charger meets expectations in solving the technical problems encountered when charging R410A refrigerant for residential air conditioners. It is compact, portable and can be directly controlled through the LabVIEW interface, allowing real-time visualization of the charging process. The present work is expected to make a significant practical contribution, serving as a useful reference for the future manufacturing of compact portable equipment in the residential air conditioning field.

1. INTRODUCTION

The automatic control and monitoring of technical processes is significant in production, ensuring reasonable control over these processes and minimizing the direct involvement of operators. The control and monitoring of engineering processes are of interest in actual production and applied research. In the automation field, the MATLAB and LabVIEW platforms are widely used due to their simplicity, intuitiveness, and versatility. Many studies on automatic control have been conducted on these platforms. An automatic battery charger for electric vehicles was studied and tested by (Chellaswamy et al., 2020; Hariharan, 2012). Applications of thermal process control and fluid control were reported in studies by (Simanjuntak et al., 2022; Cao et al., 2023; Niharika et al., 2023; Sabri & Al-mshat, 2015). Applications in robot control were reported in studies by (Ghith & Tolba, 2022; Ramadhan et al., 2022; Sandesh & Venkatesan, 2022), while the control of quadcopter UAVs was

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presented in a study by (Zabidin et al., 2020). Czyż et al. (2023) used LabVIEW to control and regulate the fuselage load of an unmanned aircraft during strength tests. Smart home control applications were reported by (Kocaman & Yiğit, 2022; Kumar, 2017; Zahran et al., 2010). The above studies demonstrate the diversity of control and automation of engineering processes in practical applications of LabVIEW and MATLAB. This has resulted in certain advantages in controlling automatic processes and regarding the quality and efficiency of practical applications.

In the residential air conditioning field, periodic maintenance is a necessary step in machine operation. After a period of operation time, the air conditioner can leak refrigerant. Thus, additional refrigerant charging is required for the machine to operate efficiently and reach the required temperature. This ensures that operating costs are not increased, which is one of the essential requirements for energy efficiency. It is necessary for the goals of sustainable development and environmental protection (Nguyen et al., 2022; Thanh et al., 2024). Several charging techniques were reported in a study by (Houcek & Thedford, 1984). Weighing in the charge is a very accurate charging method; however, information provided by the manufacturer is required. During maintenance, the amount of refrigerant in the system is not always known, so this is not the preferred method of topping up the machine. High- and low-side gauges are valuable methods for refrigerant charging and are widely used by technicians. However, the efficiency and safety of the machine when charging depend significantly on the user's experience level. Manufacturers' charts and tables, along with high- and low-side gauges, provide a very accurate method. However, this method requires complete documentation from the manufacturer, and experience is still a key factor. The Doppler Charging Technique is another charging method that uses ultrasonic sensors. However, this method is costly and requires high user experience to interpret sound signals correctly. A useful charging method using an accumulator–charger device was proposed by (Houcek & Thedford, 1984). The device was reported to simplify the charging process, and the researchers reported that it is highly accurate over a temperature range of 70 to 100 oF. However, the charger requires integration with the machine. Several authors have also studied the use of temperature sensors and algorithms to automate the charging process. Temple and Hanson (2003) proposed a charging method based on data from four temperature sensors–indoor space temperature, condensing temperature, refrigerant temperature after condensing, and compressor discharge temperature–to control the refrigerant charge level. A charging device that uses a virtual refrigerant charge sensor was studied by (Kim & Braun, 2013; Li & Braun, 2006). This device uses data from four temperature sensors, located on the suction line, evaporator, condenser, and liquid line, as the basis for controlling the charging process. From the above studies, it can be seen that two refrigerant charging methods have been applied in practice. Manual charging requires appropriate technical documentation and high experience requirements. Automatic charging is performed through control programs that combine temperature data collected from several locations in the air conditioning system. Automatic control is more convenient than manual charging in terms of use and experience level requirements.

The R410A is one of the refrigerants commonly used in residential air conditioners. The R410A refrigerant is a mixture of R125 and R32, with different boiling points under the same pressure conditions, so the refrigerant must be in liquid phase when charging to the machine (Heredia-Aricapa et al., 2020). During maintenance, the charging process is usually conducted manually using a refrigerant manifold gauge. Suction pressure is used as the basis for charging, with the machine's current helping to control the charging process. However, the refrigeration compressor can be flooded with liquid if the amount of liquid charged into the machine is not sufficiently controlled, which may result in damage to the refrigeration compressor. Therefore, this charging method requires the user to have experience and knowledge of the technique. The aim is to improve the manual charging method to simplify the process and enhance control. An automatic charger has been built and tested based on two principles: using compressor suction pressure to to determine the refrigerant charge level; using the throttling principle to transform the refrigerant from liquid to wet vapor before charging it into system. It ensures the mixing ratio of the refrigerant R410A and prevents flooding of the compressor with the refrigerant. To the best of the author's knowledge, no research has been conducted on chargers using the above two principles. Therefore, an R410A refrigerant charger was fabricated and tested in the present work. Control and monitoring were performed on the LabVIEW platform. The aim was to resolve the following technical problems: (i) providing automatic refrigerant charging for air conditioners; (ii) ensuring that the refrigerant sucked into the refrigeration compressor is in a wet vapor state and there is an adequate mixing ratio; (iii) stabilizing the amount of refrigerant charging per cycle; and (iv) using the compressor suction pressure to estimate the refrigerant charge level. The results of the present study are expected to have practical significance, serving as a useful reference for the future manufacturing of compact portable equipment in the field of residential air conditioning.

2. METHODOLOGY

In the present work, to ensure the mixing ratio of R410A refrigerant and to avoid sucking in of liquid by the compressor during the charging process. For this, the throttling principle was used to reduce pressure and change the refrigerant state. Figure 1 depicts the throttling principle used to change the refrigerant state before charging into the machine. Point A is the liquid state of the refrigerant after leaving the bottle. After passing through the throttling device, the refrigerant changes state and reaches point B.

The dryness of refrigerant at the throttling device outlet (point B) is determined by the formula (Han et al., 2016; Stoecker & Jones, 1981):

$$x_b = \frac{h_b - h_{el}}{h_{eg} - h_{el}} \tag{1}$$

where h_b *(kJ/kg)* is the enthalpy of the refrigerant at state after throttling (point B), h_{el} *(kJ/kg)* and h_{eg} *(kJ/kg)* are the enthalpy of the refrigerant at the saturated liquid and saturated gaseous under pressure after throttling.

The state of the refrigerant after the throttling device is a mixture of vapor and liquid ($0 < x_b < 1$). Therefore, the charging process will limit the sucking of liquid into the compressor. Furthermore, after the throttling device, the mixing ratio of refrigerant is maintained. This solves two technical problems encountered when charging R410A refrigerant to air conditioners. The compressor suction pressure is essential in evaluating whether the air conditioner has a refrigerant leak. A pressure of 125 psi (gauge) was used for reference in the present work, corresponding to the evaporation temperature of 6 ºC for R410A refrigerant for air conditioners.

In air conditioners, the refrigeration compressor is the main energy-consuming device. The correlation between the refrigerant mass flow and the power consumption can be estimated as follows (Han et al., 2016):

$$P = m_r.\frac{v_{ci}}{\eta_i}.p_o.\frac{k}{k-1}\left[\left(\frac{p_o}{p_k}\right)^{(k-1)/k} - 1\right] \quad (2)$$

Where v_{ci} (m^3/kg) is the suction-specific volume of refrigerant in the compressor, *k* is the adiabatic coefficient, η_i is the indicated efficiency, p_k (bar) and p_o (bar) are the condensing pressure and evaporation pressure, m_r (kg/s) is the refrigerant mass flow, P (W) is the power consumption of the refrigeration compressor.

The correlation between the power consumption of the refrigeration compressor (1 phase / AC) and the machine current can be estimated as follows:

$$P = U.I.cos(\varphi) \quad (3)$$

where *U (V)*, *I (A)*, and *cos(φ)* are the input voltage, current, and power factor, respectively.

From eq.2 and eq.3, the relationship between the current of the refrigeration compressor and the refrigerant mass flow can be determined as follows:

$$I = m_r.\frac{v_{ci}}{\eta_i}.p_o.\frac{k}{k-1}\left[\left(\frac{p_o}{p_k}\right)^{(k-1)/k} - 1\right].\frac{1}{U.\cos(\varphi)} \quad (4)$$

From eq. 4, it can be seen that the working current of the machine depends on the refrigerant mass flow. Furthermore, the working current of the machine also depends on the operating mode of the air conditioner (p_o and p_k). Therefore, when charging refrigerant into the air conditioner, the amount of refrigerant and the working current of the compressor need to be considered simultaneously because these two factors affect the power consumption and longevity of the compressor. Figure 2 visually shows the relationship between the refrigerant mass flow and the working current of the machine. Point 1 corresponds to the case where the machine has no refrigerant. The machine runs without load, and the working current is I_A. Point 3 corresponds to the case where the machine has sufficient refrigerant; in this case, the machine runs with the current I_C. Point 2 corresponds to the case where the machine lacks refrigerant; the machine's working current is I_B. This is a case where additional refrigerant is needed. It can be seen that the operating current of the machine is a valuable reference value for controlling the charging process.

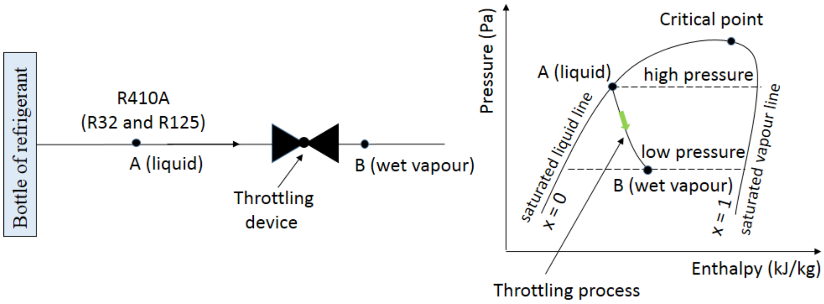

Fig. 1. The transforming refrigerant state by throttling principle

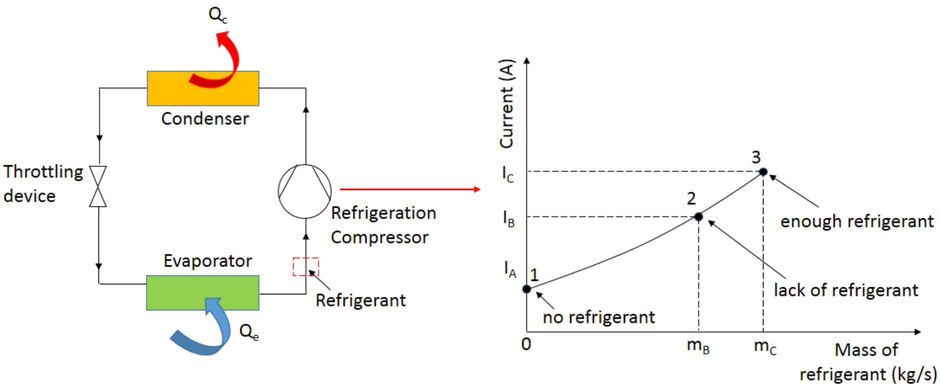

Fig. 2. The correlation between the compressor current and the refrigerant mass flow

Figure 3(a) is a principle diagram of the R410A refrigerant charger. The throttling device (2) was used to transform the refrigerant from liquid to wet vapor after leaving the charger. The solenoid valve (3) was used to control the refrigerant in the charger. Figure 3(b) shows the block diagram of the control section. When the suction pressure is less than 125 psi (gauge), and the machine's current is less than the rated current, the solenoid valve is open to perform the refrigerant filling process. Otherwise, the charging process stops. In each charging cycle, the opening and closing of the intake valve are performed in alternation. The charging cycle time includes the time to open the valve to charge the refrigerant and the time to close the valve to stabilize the machine. The indicator light turns on when charging, and it turns off when charging stops. The charging time is set based on testing to ensure enough time for the refrigerant to leave the charger in a vapor state (no liquid particles remaining) and for the machine to stabilize. In the current work, the charging valve opening time was set to 2 seconds, and the time for the refrigerant to flow through the charger and stabilize the machine was set to 18 seconds.

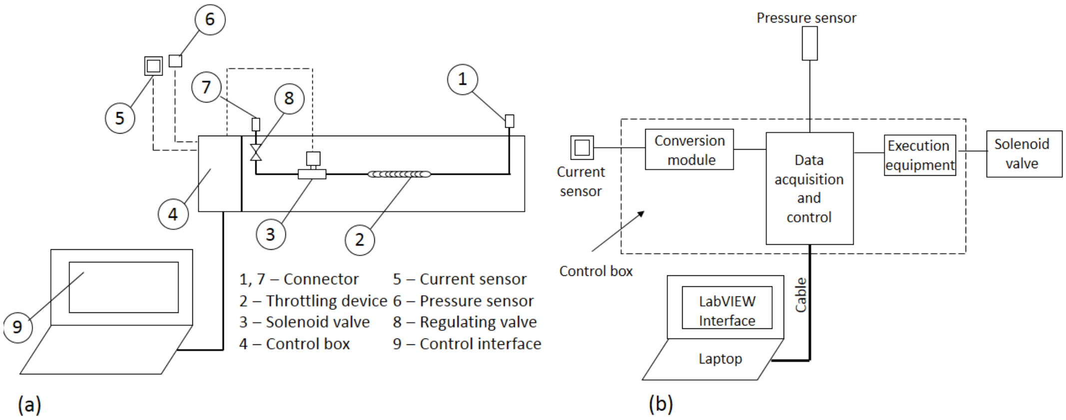

Fig. 3. Principle diagram and block diagram: (a) Schematic diagram of the charger; (b) Block diagram of the control section

3. RESULTS AND DISCUSSION

Based on the principle diagram, the automatic refrigerant charger was fabricated. A control program was built on the LabVIEW platform. After completing the mechanical and control block fabrication, the refrigerant charger is adjusted and calibrated. The regulating valve (see Fig. 3a) has been used to reasonably adjust the amount of refrigerant entering the charger, which ensures that the amount of refrigerant after throttling does not contain liquid particles. A charging experiment was performed on an air conditioner using R410A refrigerant to test the charger's operation. Figure 4(a) shows the experimental setup. The experiment involved charging an air conditioner (1 phase / AC) with a cooling capacity of 3 kW and a rated current of 12.6 A. The charger includes a control section with an NI-USB-6008 data collector, a current sensor with a measuring range of 0–20 A, and a pressure sensor with a measuring range of 0–300 psi. The mechanical and control parts of the charger are housed in a box 16 x 10 x 9 cm in size. Figure 4(b) shows a detailed diagram of the connection between the air conditioner and the charger. It is necessary to ensure that all air in the device and connecting pipes is completely removed before charging and that the machine is set to the correct operating mode. Figure 4(c) shows the data collected during the refrigerant charging process. Throughout the operation, the machine worked stably, and no liquid particles were observed passing through the sight glass on the gauge during the charging process.

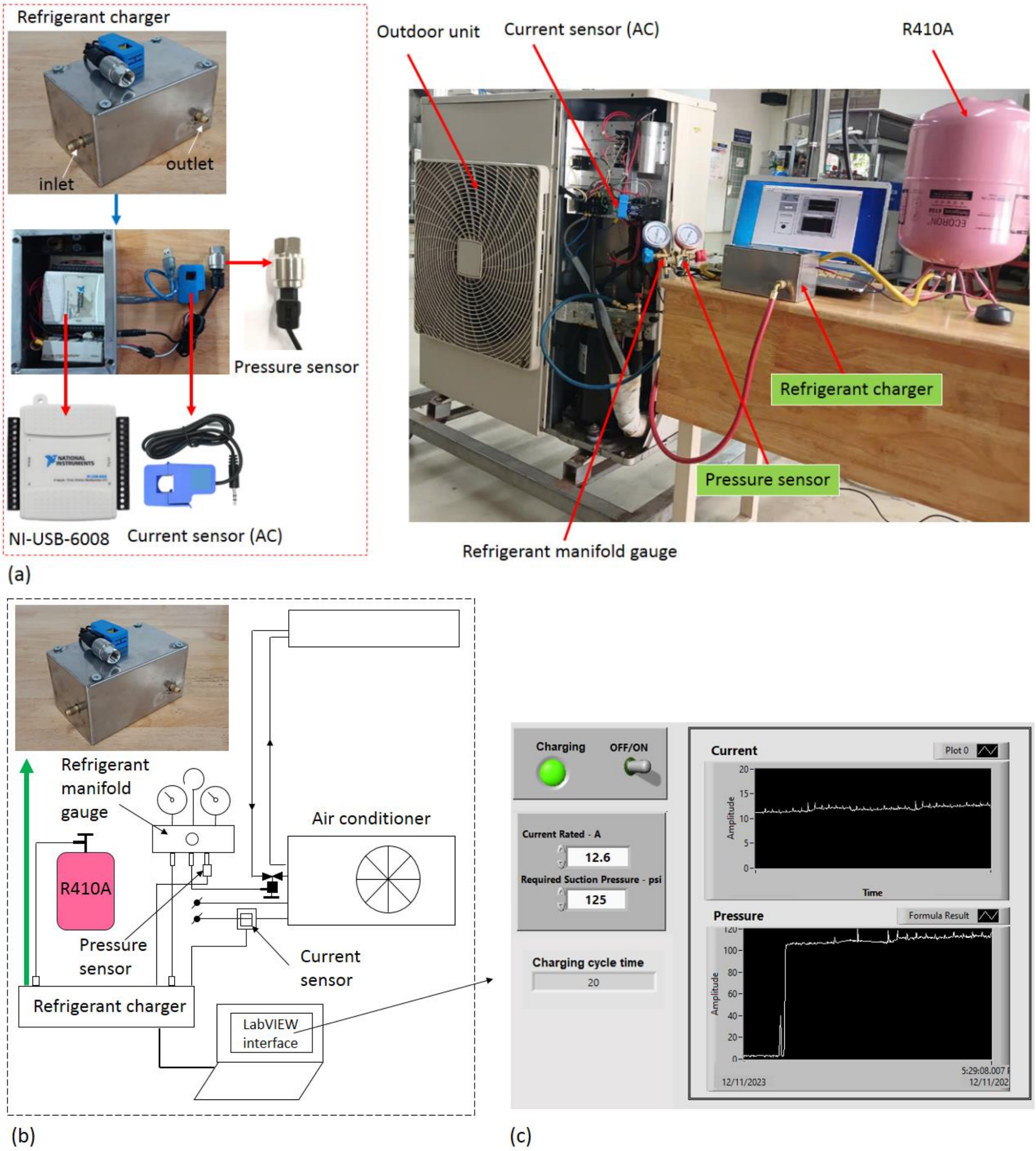

Fig. 4. The experimental model, connection diagram, and LabVIEW Interface: (a) The experimental model; (b) The connection diagram between the air conditioner and the charger; (c) LabVIEW Interface

Figure 5 shows the experimental data corresponding to the charging cycles at steady state. Figure 5(a) shows that the initial suction pressure of the machine was approximately 102 psi, with a current of 10.1 A. After nine charging cycles (180 seconds), the suction pressure reached 125 psi, at which point the charging process stopped and the current reached 11.3 A. Figure 5(b) shows the air temperature leaving the indoor and outdoor units during charging. The air temperature leaving the outdoor unit tended to increase while the air temperature leaving the indoor unit decreased. This is because the increased amount of evaporated refrigerant after each charging cycle leads to improved air cooling. The outdoor unit releases more heat into the air due to increased refrigerant circulation. When the machine stopped charging, the air temperature leaving the indoor unit was approximately 25.4 ^{o}C, and the air temperature leaving the outdoor unit was approximately 49.7 ^{o}C. The charging was approximately 3–3.5 times faster than manual charging due to the large amount of refrigerant charged in each cycle. The experimental results show that the present charger has solved the critical problem of transforming the refrigerant liquid phase into wet vapor before charging into the machine, which limits the risk of compressor damage due to liquid flooding if the charger is inexperienced. This device inherits the manual charging principle of using suction pressure as the basis for charging the machine. The charger simplifies the charging process and does not depend on the user's experience. Moreover, the charging process is faster than manual charging because manual charging requires a longer time to stabilize the machine after each refrigerant manifold gauge is opened. Compared to the charging method reported in previous studies (Kim & Braun, 2013; Li & Braun, 2006; Temple & Hanson, 2003), the present one has fewer sensors, and the sensor arrangement is simple and convenient. In particular, based on the suction pressure signal (corresponding to the evaporation temperature) to determine the refrigerant charge level is suitable when maintaining residential air conditioners. Chargers that use multiple temperature sensors are more suitable for central-type air conditioners than split air conditioners. Such controllers can be integrated directly into the control boards of the machine. The weighing method is more accurate than the current method. However, during maintenance, the amount of refrigerant in the machine cannot be known, making the weighing method impractical. It should only be used when recharging all the refrigerant in the machine. The present method is more convenient than using tables and charts because it does not require documentation. In practice, tables and charts are not always available or fully provided. From the above discussion, the present device represents an evolution of the manual charging method. It is highly mobile and straightforward in structure. However, the main drawback is that the amount of refrigerant charged into the machine cannot be determined, similar to the automatic charging methods mentioned earlier. An electronic scale can be installed if it is necessary to measure the weight of the refrigerant. This solution is helpful for manufacturing compact units.

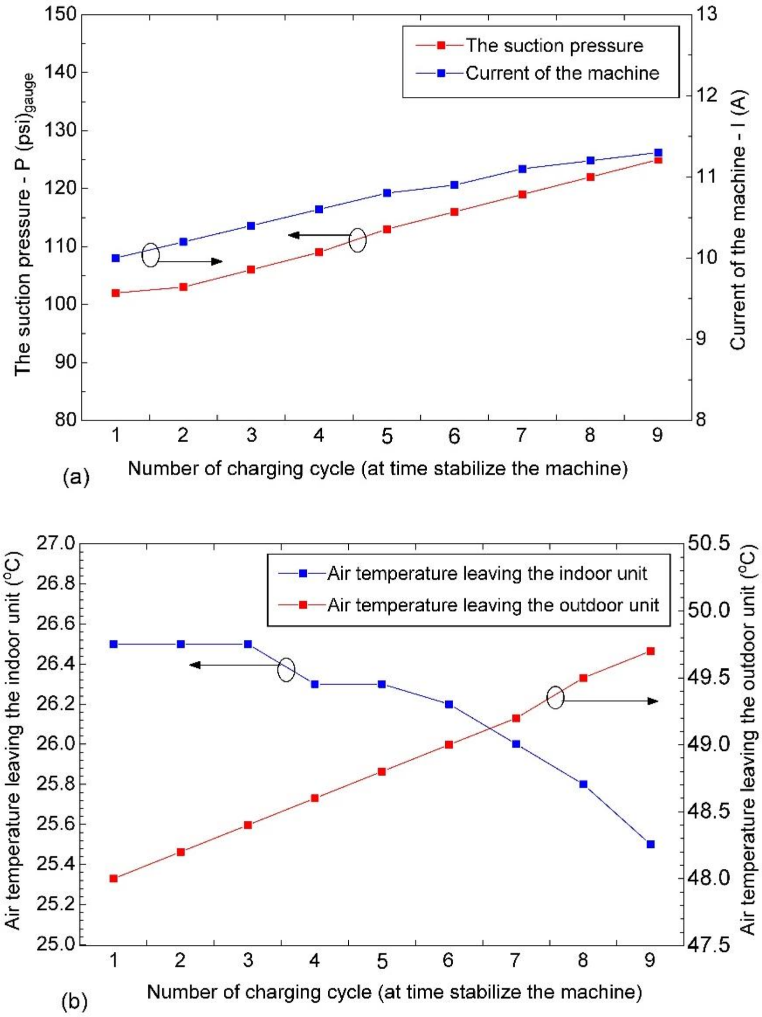

Fig. 5. The experimental data at a stable time: (a) The suction pressure and current of the machine; (b) Air temperature leaving the indoor and outdoor units

4. CONCLUSIONS

This article presents the fabrication and testing of an automatic R410A refrigerant charging unit for residential air conditioners. The charging unit is controlled by the LabVIEW platform. Some key results are as follows:

- The charger was designed to estimate the refrigerant charge level based on suction pressure. It builds and improves upon the manual charging method, simplifying the refrigerant charging process for residential air conditioners while offering high mobility.
- The charger addresses the critical problem in charging R410A refrigerant by converting the liquid phase into wet vapor before charging, which helps minimize the

risk of compressor damage from liquid refrigerant flooding and ensures the correct component ratio of R410A when charging into the machine.

- The charger reduces the charging time by approximately 3–3.5 times compared to the manual method, making the process quicker and more efficient.
- The results provide a valuable reference for the manufacture of compact portable refrigerant charging equipment. Future research will focus on making the device smaller by integrating electronic circuit boards and direct control devices that do not require computer support. Furthermore, the study will be expanded to include sensors to further optimize the charging process.

Author Contributions

Hong Son Le NGUYEN: Writing – original draft, Software; Minh Ha NGUYEN: Writing – original draft, Formal analysis; Luan Nguyen THANH: Writing – review & editing, Supervision.

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Conflicts of Interest

The authors declare that there are no conflicts of interest as applicable to this work.

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