





# Design and Fabrication of a Refrigeration Demonstration Unit for Studying Condensation and Evaporation on Tube Surfaces

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| Abstract   | Article History  |
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| <p>Refrigeration plants in the food industry have a key role, yet are very energy-intensive, which poses a serious problem given the current steep rise of energy prices. In this framework, energy consumption minimization represents a paramount goal for plant managers, yet most are loathing to test new control strategies in real-life plants, lest normal operation be disrupted and food be spoiled as a consequence. It is now essential to look inward and design functional refrigeration trainers for production using locally sourced materials and technology because of the significance of refrigeration trainers in the applied thermodynamics laboratory, or the refrigeration and air-conditioning laboratory, as the case may be, and the extremely high cost of laboratory equipment imported from overseas. The design, construction, and testing of a refrigeration demonstration apparatus for use in the mechanical engineering department's refrigeration and air-conditioning laboratory was motivated by the necessity to provide instructional aids and laboratory refrigeration trainers, as well as the prohibitive cost of importing laboratory equipment. Transparent windows allow pupils to observe the condensation and evaporation processes in the condenser and evaporator. R600A is the refrigerant chosen for vapour compression refrigeration because, when compared to other competing refrigerants, it has the lowest condenser pressure, which is less than 5 bar at 30 degrees Celsius. It is highly recommended that more work be done in the design, production, and performance analysis of a Refrigeration Demonstration Apparatus – condensation and evaporation in inside of tubes to compliment this study.</p> <p><b>Keywords:</b> Refrigeration system, Energy efficiency, Laboratory trainer, Vapour compression cycle, R600A refrigerant.</p> | <p>Received: 25 Sept 2025<br/>Accepted: 10 Oct 2025<br/>Published: 13 Oct 2025</p>  <p>Scan the QR code to view*</p> <p>License: CC BY 4.0*</p>  <p>Open Access article</p> |
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## 1. Introduction

Some of the known methods of refrigeration include vapour compression refrigeration, vapour absorption or diffusion absorption refrigeration, air power cycle refrigeration (also known as Bell Coleman's refrigeration system mainly used in aircraft air-conditioning), steam ejection refrigeration, thermoelectric refrigeration, and vortex tube refrigeration to mention but a few [1]. However, the most widely used in both domestic and commercial refrigeration application is the vapour compression refrigeration system [2, 3, 4]. The simple vapour compression refrigeration cycle basically consists of the compressor, condenser, expansion valve and the evaporator.

The types of compressors in use in refrigeration and air-conditioning industry are the reciprocating compressors, rotary compressors, scroll compressors, screw compressors and centrifugal compressors [5]. The type of compressor used in a given application depends on the size of the unit, amount of cooling required, serviceability and noise requirements [6]. For domestic refrigerators, the size of the compressor must be small enough as to fit under the refrigerator cabinet. It must be quiet and not require servicing for many years [7]. In this case, the compressor is sealed in a metal casing and such compressors are described as hermetic compressors.

In larger installations, the compressor is coupled to an external electric motor by belt, chain or gear drives [8]. The electric

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motor drives the compressor which compresses the refrigerant to superheated conditions of high pressure and temperature [9]. The superheated refrigerant is then discharged into the condenser. The function of the condenser in the refrigerating system is to remove heat from the refrigerant vapour leaving the compressor so that the refrigerant ultimately condenses to the liquid state [10]. The liquid refrigerant under the condenser pressure is now throttled to the evaporator pressure to produce refrigeration by Joule-Thompson's effect [11, 12, 13]. The condenser is a heat exchanger in the refrigerating system, it rejects the heat absorbed by the evaporator and the heat energy input by the compressor [14]. The condensed refrigerant liquid in the condenser is passed through a refrigerant control device (any type of expansion valve) to the evaporator. Due to the importance of refrigeration trainers in the applied thermodynamics laboratory or the refrigeration and air-conditioning laboratory as the case may be, coupled with the very high cost laboratory equipment imported from overseas, it has become imperative to look inwards and design functional refrigeration trainers for production with locally sourced materials and technology [15]. The laboratory equipment in view is the refrigeration demonstration apparatus- condensation and evaporation on outside of tubes. This will be used in the refrigeration and air-conditioning laboratory of the department of Mechanical Engineering Department of Chukwuemeka Odumegwu Ojukwu University, Uli.

## 2. Materials and Method

### 2.1 Methodology

The refrigeration demonstration apparatus consists of such major components as the refrigerant compressor, the condenser, the thermostatic expansion valve, the evaporator, the ballistic cylinder, the heat transfer fluid control valves, the water pump, the reservoir and the electrical control and monitoring devices [16]. The vapour compression refrigerating system consisting of the hermetic compressor, the condenser, the expansion valve, the evaporator is evacuated and charged with Refrigerant R600A. The condenser and evaporator are heat exchangers with transparent windows for viewing the processes of condensation and evaporation in real time [17]. Heat transfer fluid, which in this project is water doped with ethylene glycol, is circulated through the condenser, evaporator and ballistic cylinder in a particular sequence. The electrical control and monitoring devices consisting of mains switch, pump control, ammeter, voltmeter, digital multi-station thermometer and indicator lamps [18]. Pressure gauges are positioned as indicated in the diagram, to read the condensing and evaporating pressures.

#### 2.1.1 Conceptualization of the design of a refrigeration demonstration apparatus

The conceptualization of the design of a refrigeration demonstration apparatus (condensation and evaporation on outside of tubes) is based on the thermodynamics of the vapour compression refrigeration cycle [19]. Using the Temperature versus entropy (T-s) diagram depicted in Fig.1, at point 1 in the diagram, the circulating refrigerant enters the compressor as a low temperature low pressure superheated vapour.

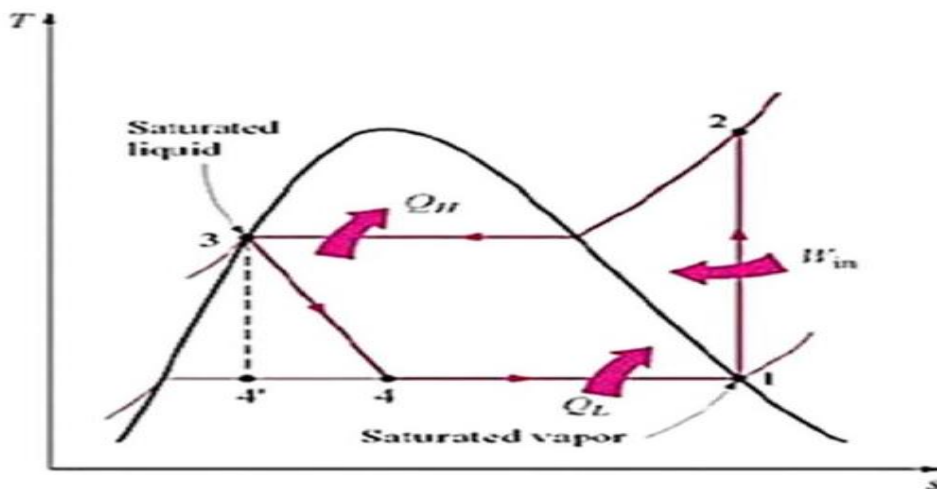


Figure 1: Temperature versus entropy (T-s) diagram.

From state point 1 to state point 2, the vapour is compressed isentropically and exits the compressor as a high temperature high pressure superheated vapour [20]. From state point 2 to state point 3, the superheated vapour passes through the condenser and is finally condensed into a high temperature, high pressure sub-cooled liquid. The condensation process occurs essentially at constant pressure.

Between state point 3 and state point 4, the sub-cooled liquid refrigerant passes through the expansion valve, in this case a Thermostatic Expansion Valve (TEV), and undergoes an abrupt decrease in pressure. The process results in the adiabatic flash

evaporation and auto-refrigeration of a portion of the liquid. The adiabatic flash evaporation process is isenthalpic [21, 22].

Between point 4 and point 1, the cold and partially vaporized refrigerant travels through the evaporator coils where it is totally vaporized by the heat from the space being refrigerated.

The condenser and evaporator are designed and constructed with transparent windows to show the processes of condensation and evaporation. The transparent windows are constructed with a ply of perspex glass each measuring about 10 mm in thickness to give an overall thickness of 30 mm. This is to provide enough

shear strength to withstand the high pressure in the condenser [23].

### 2.1.2 Plumbing Design.

The circulation of the heat transfer fluid through the evaporator, condenser, and the ballistic cylinder, used in measuring flow rate through the various components of the demonstration

apparatus, is controlled by a system of valves [24]. A single phase, 220V, 0.5 Hp water pump draws the heat transfer fluid from a reservoir and sends it through system of control valves to the condenser, evaporator and ballistic cylinder. The plumbing diagram for the circulation of the heat transfer fluid is shown in Figure 2.

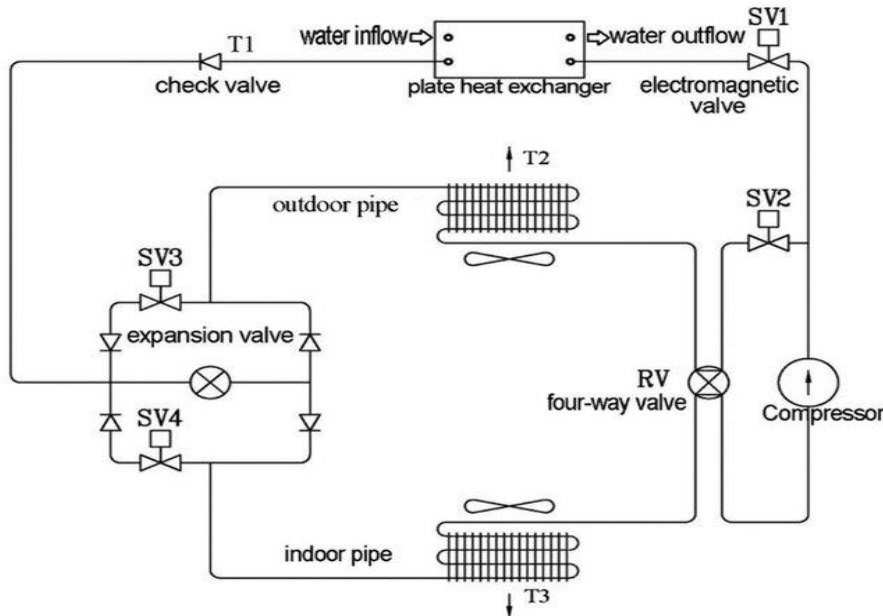


Figure 2: plumbing diagram for the circulation of the heat transfer fluid

## 3. Results and Discussion

### 3.1 Effect of varying refrigeration parameters on performance characteristics

The refrigeration parameters that may affect the performance of the vapour compression refrigeration system include, change of the evaporation pressure, (ii) change of the condenser pressure, (iii) increase of the degree of sub-cooling (iv) increase of the degree of superheat at the entrance to the compressor and (v) change of mass flow rate.

#### (i) Change of the evaporation pressure.

If the evaporator pressure is lowered, the Refrigerating Effect, RE, decreases as  $(h_1 - h_4)$  reduces but Compressor Work,  $W_c$ , increases. Hence, the Coefficient of Performance,  $COP = RE/W_c$  reduces. The volumetric efficiency,  $\eta_{vol} = 1 + c - c(P_2/P_1)^{(\gamma-1/\gamma)}$ , decreases as  $P_2/P_1$  increases.

If, however, the evaporating pressure is increased, the RE increases as  $(h_1 - h_4)$  reduces. Compressor work reduces and hence the  $COP = RE/W_c$  increases. The volumetric efficiency,  $\eta_{vol} = 1 + c - c(P_2/P_1)^{(\gamma-1/\gamma)}$  increases as  $P_2/P_1$  reduces.

#### (ii) Change of the condenser pressure,

If the condenser pressure is lowered, RE remains the same, compressor work decreases and the COP increases. The volumetric efficiency  $\eta_{vol} = 1 + c - c(P_2/P_1)^{(\gamma-1/\gamma)}$  increases as  $P_2/P_1$  is reduced. If the condenser pressure is increased, RE still remains the same but the compressor work is increased causing the COP to decrease. The volumetric efficiency  $\eta_{vol} = 1 + c - c(P_2/P_1)^{(\gamma-1/\gamma)}$  decreases as  $P_2/P_1$  is increased.

#### (iii) Increase of the degree of sub-cooling

When the condenser sub-cools the refrigerant at constant pressure,  $(h_1 - h_4)$  and therefore RE is increased while the compressor work remains the same. The  $COP = RE/W_c$  therefore increases. The Volumetric Efficiency  $\eta_{vol} = 1 + c - c(P_2/P_1)^{(\gamma-1/\gamma)}$  remains the same as  $P_2/P_1$  is unchanged.

#### (iv) Effect of the degree of super-heating.

When the degree of superheating is increased, RE is increased and also  $W_c$  increases. COP may increase or decrease depending on the refrigerant used. Since  $P_2$  and  $P_1$  are unchanged, the volumetric efficiency remains the same.

#### (v) Effect of increase in mass flow rate

Refrigeration Effect, RE and Compressor Work,  $W_c$  are directly proportional to Mass flow rate. An increase in mass flow rate will result in proportional increases in RE and  $W_c$ . COP is independent of mass flow rate and is unaffected by any change in mass flow rate. Also, the volumetric efficiency remains unchanged.

## 4. Conclusions

This study sets out to conceptualize, design, produce, operate and evaluate the performance of a refrigeration demonstration apparatus, visualizing condensation and evaporation on outside of tubes. The key components of condenser and evaporator were designed and produced with local materials and indigenous technology. The focus was to demonstrate visually the processes of condensation and evaporation on outside of tubes. Measurement and monitoring instruments were incorporated to collect data for performance evaluation. The outcome of this project is the production of a laboratory equipment in-house.

Based on the need to provide teaching aids and laboratory refrigeration trainers, and considering the prohibitive cost of importing laboratory equipment, a refrigeration demonstration apparatus was designed, built and tested for use in the mechanical engineering department's refrigeration and air-conditioning laboratory. The condenser and evaporator so designed are equipped with transparent windows for students to view the process of condensation and evaporation. The refrigerant selected for the vapour compression refrigeration is R600A because it has the lowest condenser pressure of below 5 bar at 30°C compared to other competing refrigerants. It also has an ozone layer depletion potential (ODP) of zero being a HFC refrigerant. The relatively low discharge pressure of R600A (Iso-butane) to the condenser ensures that the acrylic transparent glass (Perspex glass) does not deform and explode under high condenser pressure. Even then, the transparent windows in the condenser and evaporator are made of 3-ply composite sheet of 10mm thick acrylic material (30mm effective thickness) as a safety precaution.

The heat transfer fluid flows inside the copper tube passes engaged in steel shells, while the refrigerant R600A is contained in the shells. The processes of condensation and evaporation of the refrigerant are viewed through the transparent windows, hence the name refrigeration demonstration apparatus.

During operation, measurements of pressure, temperature, flow rates, voltage, and current are taken at various locations. These data are used to determine the performance of the refrigeration system. The cost of production of this laboratory equipment is about 2% of the cost of imported refrigeration trainer on account of the prohibitive foreign exchange rate. It therefore made a lot of sense to look inwards to produce our own laboratory equipment and save lot of money that will be channeled to other areas of educational development. This project, in addition, exposes the student to basic engineering design, workshop processes and finding solutions to our engineering problems.

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**Competing interests:** The authors declare no competing interests.

**Data Availability** The authors confirm that the data supporting the findings of this study are available within the article.

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