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Experimental Analysis of Air Conditioner Performance Improvement: Enhancing COP and Reducing Power Consumption via Sub cooling

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ABSTRACT:

This paper presents experimental investigation of increase in COP and reduction in power consumption of a conventional air conditioning by implementing sub-cooling techniques. The cooled refrigerant is by passed partially after the evaporator circulated through tubing in the condenser and then passed through coolant sump. The coolant is also circulated to cool the condenser using a pump separately. This results in the cooling of refrigerant in the condenser and simultaneously availability of saturated vapor in the compressor, which improves the compressor's lifespan, and overall system efficiency. Due to sub-cooling of the saturated liquid at the outlet of condenser which will results in increase in the refrigerating effect. The COP of the Modified AC is almost double and compressor power consumption of modified AC is almost half as compared of conventional AC. Implementing a coolant for condenser cooling in the conventional air conditioning system along with bypass cooling system, have a positive impact. These types of modifications can increase the coefficient of performance and can improve the energy efficiency of the system. The Glycerin and water solution as a coolant is an effective approach for cooling.

Key word: sub cooling, air conditioning, glycerin, COP

1. INTRODUCTION

Window air conditioning is a self-contained cooling system designed for installation on the wall or window of a room, providing cooling and humidity control for a single room or small area. Unlike central air conditioning systems, which cool entire buildings, window air conditioning units typically come in a metal box containing cooling components such as the compressor, evaporator, and condenser. They also feature a front-facing vent and a control panel for adjusting temperature and other settings. To operate, these units draw warm air from the room and circulate it over a cold evaporator coil, cooling the air. The cooled air is then blown back into the room while the warm air is expelled outside through the back of the unit. Easy to install and cost-effective, window air conditioning units are a popular choice for cooling a single room or small area, while larger buildings typically use central air conditioning systems to regulate temperature, humidity, air movement, and air cleanliness for the entire building .

The air conditioning systems has various types , including:

- Window Air Conditioners - self-contained units that are installed on a window or through a wall opening, designed to cool a single room or space.
- Central Air Conditioning - a whole-home system that distributes cooled air through ductwork and registers in each room.

- Split Systems - consist of an outdoor unit that contains the compressor and condenser, and an indoor unit that contains the evaporator. They can be used to cool one room or multiple rooms.
- Portable Air Conditioners - stand-alone units that can be moved from room to room and vent hot air through a window or wall opening.
- Packaged Terminal Air Conditioners (PTACs) - often used in commercial settings, PTACs are installed through the wall and feature both heating and cooling capabilities.
- Ductless Mini-Split Air Conditioners - similar to a split system, but do not require ductwork and can be used to cool individual rooms or zones.
- Geothermal Air Conditioning - uses the stable temperature of the ground to provide heating and cooling. It is energy-efficient but requires a significant investment for installation.

The purpose of air conditioning systems is to regulate temperature, humidity, air flow, and air quality inside a building to ensure a comfortable and healthy environment for its occupants. These systems, whether standalone or integrated, provide cooling and humidity control to all or part of a building. Air conditioned buildings typically have sealed windows to maintain constant indoor air conditions, as open windows would work against the system.
Fresh air is drawn into the indoor heat exchanger section from outside through a vent, creating positive air pressure. The amount of fresh air intake can be controlled by adjusting the opening of this vent, with the typical intake being around 10%. Heat is removed from the building through radiation, convection, or conduction. Refrigerants such as water, air, ice, and chemicals are used to conduct refrigeration.

A refrigerant is employed in either a heat pump system, where a compressor drives a thermodynamic refrigeration cycle, or a free cooling system that circulates a cool refrigerant (usually water or a glycol mix) using pumps.

2. BASIC REFRIGERATION CYCLE

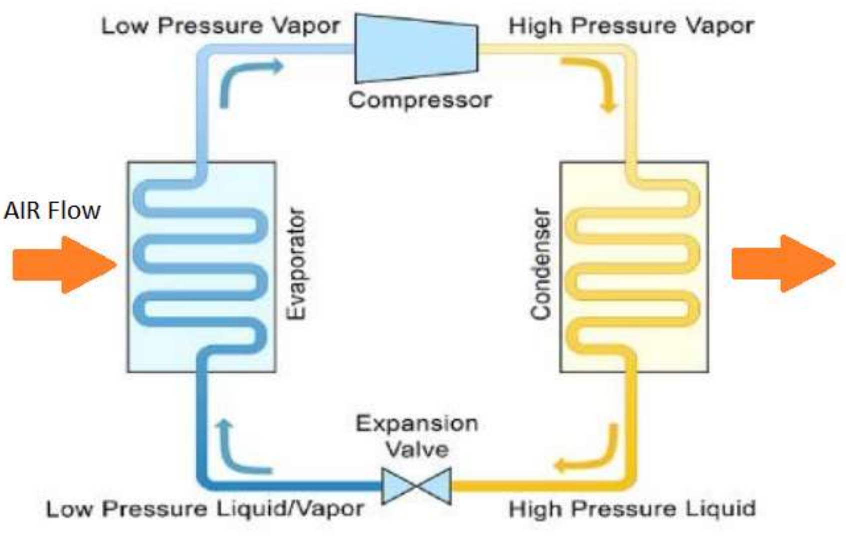

Figure 1 Basic Refrigeration Cycle

The fundamental refrigeration cycle explains the operation of refrigeration systems, and it consists of four primary components: the compressor, condenser, expansion valve, and evaporator (Nishant Dhanore 2014). Here's how the cycle operates:

- Compression: The compressor intakes low-pressure refrigerant gas from the evaporator and compresses it, raising its temperature and pressure.
- Condensation: The high-pressure, high-temperature refrigerant gas then moves into the condenser, where it releases heat to the surrounding environment and transforms into a high-pressure liquid.
- Expansion: The high-pressure liquid refrigerant then flows through a metering device or expansion valve, reducing its pressure and temperature.
- Evaporation: The low-pressure, low-temperature liquid refrigerant moves into the evaporator, absorbs heat from the surrounding environment, and vaporizes into a low-pressure gas.

Once the refrigerant evaporates in the evaporator, it returns to the compressor, and the cycle starts again. This procedure continuously transports heat from one location to another, allowing refrigeration systems to deliver cooling. The fundamental refrigeration cycle can be used in various applications, including air conditioning and refrigeration systems, as well as industrial processes that necessitate temperature control. The Figure 1 illustrates the basic refrigeration cycle.

3. SUB COOLING IN REFRIGERATION PROCESS

Sub cooling is the heat removed from a liquid below its condensing point prior to expansion in a capillary tube, depicted in figure 2, to improve the COP of the cycle.

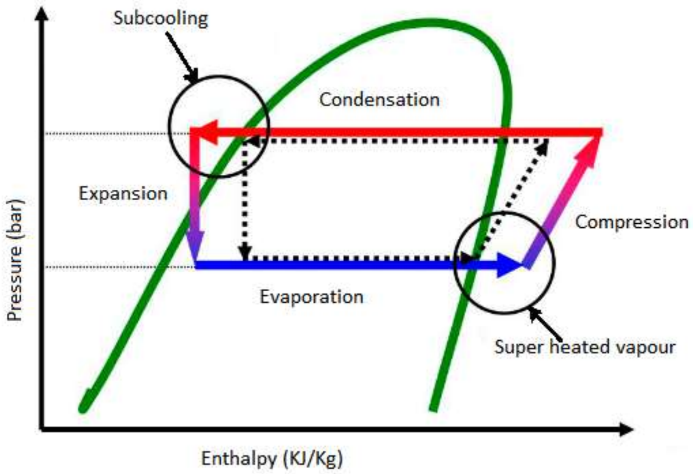

Figure 2 Sub cooling in Refrigeration Cycle

4. LITERATURE REVIEW

In conventional vapor compression cycles, it is commonly assumed that the refrigerant state at the expansion device inlet is a saturated liquid. Nonetheless, cooling the liquid below saturation can enhance the refrigeration effect and potentially boost the coefficient of performance (COP). As per the second law of thermodynamics, sub cooling also reduces throttling losses during an isenthalpic expansion (Gustavo Pottker 2015). There are various methods to obtain sub cooled liquid before the expansion process. One of the ways is by adding additional components to sub cool the refrigerant between the condenser outlet and the expansion device inlet. Internal heat exchangers are examples of such components in both single-stage (P.A Domanski 1994) and two-stage cycles. Additionally, other cooling sources like evaporator condensate water (G.E. 1997) can be used to sub cool the liquid that exits the condenser. When refrigerant is charged, condenser sub cooling is typically accomplished. However, Gosney (Gosney 1982) poses a query on whether it would be more beneficial to use the sub cooling heat transfer surface, either inside the condenser or in a separate sub cooler, to lower the condensing pressure and hence the compression work.
The impact of condenser liquid sub cooling on refrigeration system performance was experimentally explored by Linton et al. (Linton 1992). It is found that all three refrigerants - R134a, R12, and R152a - experienced improved cooling COP and refrigeration capacity with an increase in subcooling (from 6°C to 18°C), while the condensing temperature remained constant. Specifically, R134a showed a 12.5% improvement, R12 showed a 10.5% improvement, and R152a showed a 10% improvement. Selbas et al. (Reşat Selbaş 2006) developed a combination of exergy and economic concepts to perform a thermo economic optimization of de-superheating, condensing, sub cooling, evaporating, and superheating heat transfer areas. They reported that a sub cooling of about 5°C would result in maximum COP. The (Y. Yamanaka 1997) has proposed a sub cooler system that features a liquid receiver placed before the last pass of a parallel-flow micro channel condenser, as opposed to at the condenser exit. The increase in enthalpy difference across the evaporator due to sub cooling would enhance the COP. Such condensers with an integrated receiver and sub cooler pass have now become the norm in advanced automotive air conditioning systems. Pomme (Pomme 1999) presented a similar study, in which sub cooling was generated by a pre-expansion valve between the condenser exit and a liquid receiver.

Pomme 1999, conducted a study that utilized a pre-expansion valve placed between the condenser exit and a liquid receiver to produce sub cooling, similar to the approach adopted by (Jose M. Corberán 2008)

investigated the impact of refrigerant charge variation on COP in an R290 heat pump with a thermostatic expansion valve, where no receiver was installed. They observed that the system's response to an increasing charge was an increase in condenser sub cooling, and the COP-maximizing charge was linked to a corresponding sub cooling (F. Poggi 2008) in the condenser. The antifreeze composition used for cooling an internal combustion engine, with a composition water and glycerin is one of the low cost solutions (Azeem Anzar 2016). Glycerin is a by-product while manufacturing biodiesel and biodiesel fuel is gaining importance and expected market share will in next few years, hence glycerin can be used as coolant (Hudgens R. 2007).

5. METHODOLOGY

The Refrigerant after condensation process is cooled below saturation temperature before expansion from throttling such process is called sub cooling of refrigerant. This project aims to improve the coefficient of performance (COP) of conventional air conditioning. The low temperature refrigerant is extracted just after the evaporator circulated through the condenser as shown by light brown line lines in the figure 3. The cooled refrigerant is by passed and circulated through the condenser to cool it, further the cooled refrigerant is then passed through a coolant sump, which contains a mixture of glycerin and water that has good heat absorption and release properties. The low-temperature refrigerant cools the mixture in the coolant sump. The low temperature refrigerant that was bypassed, sometimes in wet phase get converted into gaseous phase after circulation through condenser and coolant sump as it absorbs the latent het of vaporization. It is reintroduced into the inlet pipe of the compressor as illustrated in the figure 3. The cooled mixture (water + Glycerine) in the coolant sump circulated through the condenser to cools it as shown by blue line. The compressed refrigerant gets cooled in the condenser is called sub cooling. The Actual working model is shown in figure 4.

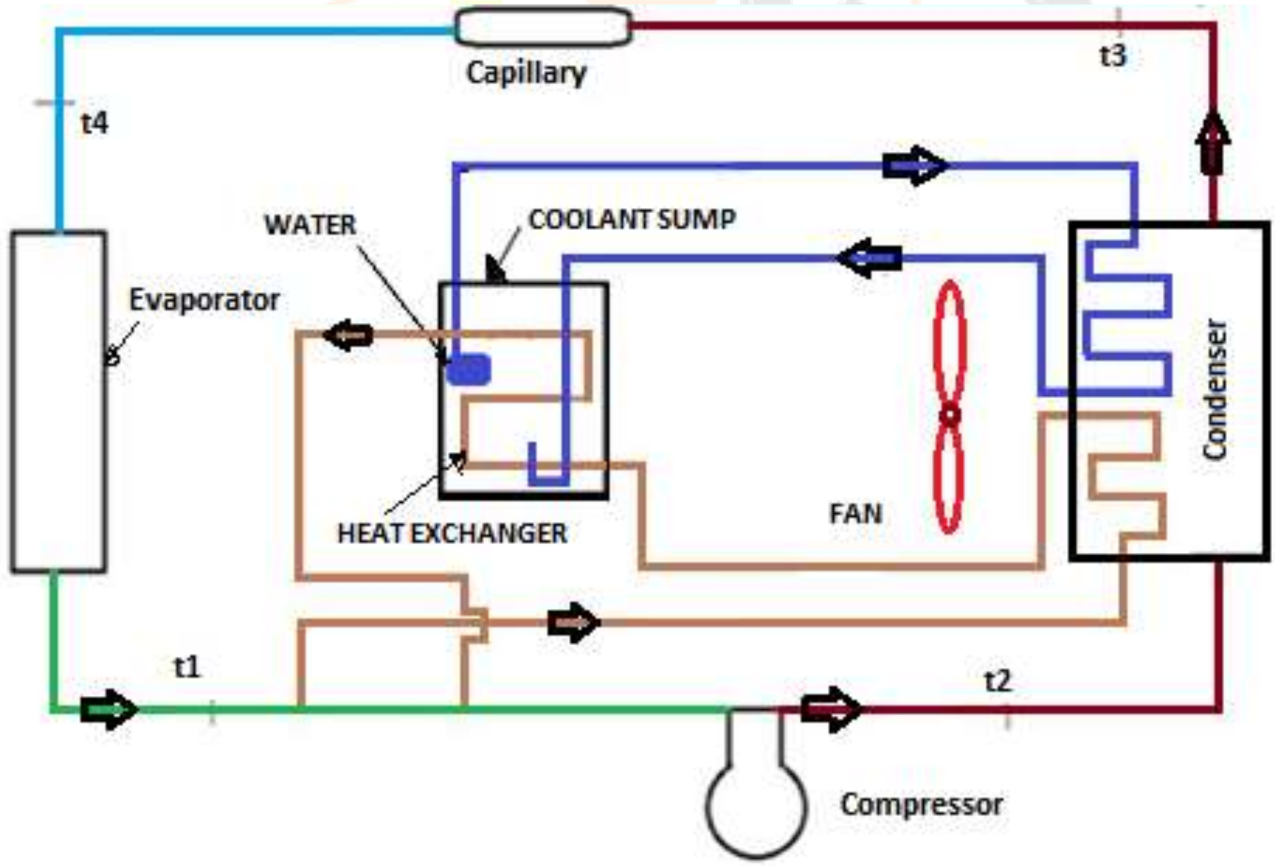

Figure 3 Schematic diagram of modifies AC cycle

Figure 4 Modified Wndow AC

6. COMPARE CONVENTIONAL & MODIFIED REFRIGERATION CYCLE

The basic refrigeration cycle involves four main processes: compression, condensation, expansion, and evaporation. These processes can be described in terms of changes in enthalpy of the refrigerant, which is a measure of the energy contained within the refrigerant. The figure 5 illustrates the conventional and modified refrigeration cycle.

Process 1-2 (compression): The vapor that has reached saturation after passing through the evaporator undergoes adiabatic compression within a hermetically sealed compressor. This compression results in an increase of pressure to the desired level. As the refrigerant is compressed, work is done by the compressor, causing a rise in temperature and an increase in the enthalpy of the refrigerant.

Work done by compressor = $(h_2 - h_1)$ – Conventional AC
Work done by compressor = $(h_{2'} - h_{1'})$ – Modified AC

Process 2-3 (condensation): The refrigerant is compressed in the compressor at high temperature and pressure; it is further cooled at constant pressure in the condenser by forced convection with ambient air. That results to decrease the enthalpy of the refrigerant.

Heat loss in condenser = $h_2 - h_3$ – Conventional AC
Heat loss in condenser = $h_{2'} - h_{3'}$ – Modified AC

Process 3-4 (expansion): The refrigerant is expanded at constant enthalpy through capillary tube $h_3 = h_4$ or $h_{3'} = h_{4'}$. Hence the pressure of refrigerant gets decreased.

Process 4-1 (evaporation): The low pressure and low temperature refrigerant absorbs the latent heat of vaporization at constant pressure in the evaporator. Hence the enthalpy of the refrigerant gets increased. This process is also called refrigerating effect.
The **Refrigerating effect = $h_1 - h_{4'}$** (modified cycle) > **$h_1 - h_4$** (conventional cycle) as shown in figure 5.

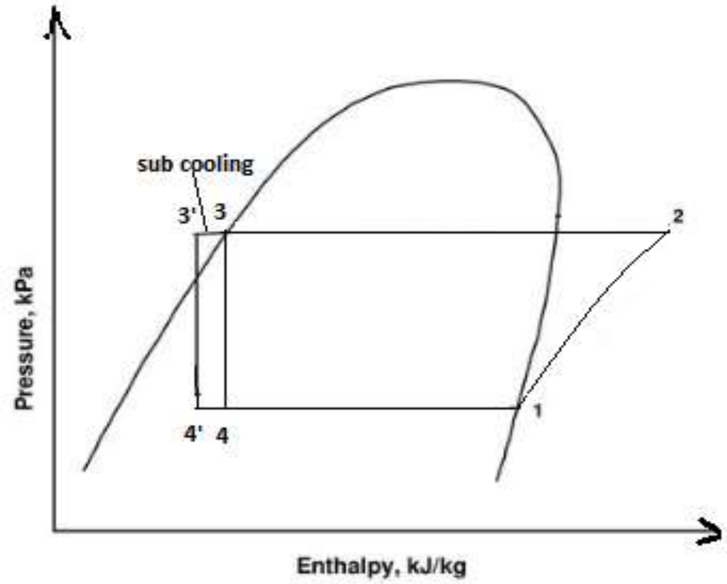

Figure 5 Schematic diagram of sub-cooling on P-h Graph

7. THEORETICAL ANALYSIS

Refrigerant Effect: During evaporation the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium which is to be cooled. The heat absorbed by the refrigerant is called refrigeration effect (Shrivastava 2014).

Q = R + W

Where,
Q = heat removed at condenser, kJ/Kg
R = refrigerating effect produced, kJ/Kg
W = work of compression, kJ/Kg

$$R.E. = h_1 - h_4 = h_1 - h_{f3}$$

$$\text{C.O.P.(coefficient of performance)} = \frac{\text{Refrigerating effect (RE)}}{\text{Work done (W)}}$$

8. RESULTS AND DISCUSSIONS

The readings were collected on conventional AC and Modified AC as mentioned in Table 1 and Table 2 respectively.

Table 1 Observations on Conventional AC

Pressure (bar)		Temper-ature (°C)		Enthalpy (KJ/Kg)		COP
P_1	6	t_1	27	h_1	420	2.37
P_2	20	t_2	70	h_2	487.5	
		t_3	50	h_3	260	
		t_4	6	h_4	260	

Table 2 Observations on Modified AC

Pressure (bar)		Temper-ature (°C)		Enthalpy (KJ/Kg)		COP
P_1	5	$t_{1'}$	20	$h_{1'}$	415	5.5
P_2	18	$t_{2'}$	65	$h_{2'}$	445	
		$t_{3'}$	40	$h_{3'}$	250	
		$t_{4'}$	0	$h_{4'}$	250	

Where: P_1 and P_2 are the higher and lower pressure line in the cycle

t_1 - Temperature of refrigerant at inlet of compressor

t_2 - Temperature of refrigerant at exit of compressor

t_3 - Temperature of refrigerant at inlet of capillary tube

t_4 - Temperature of refrigerant at exit of capillary tube (the suffix ' is used for modified AC)

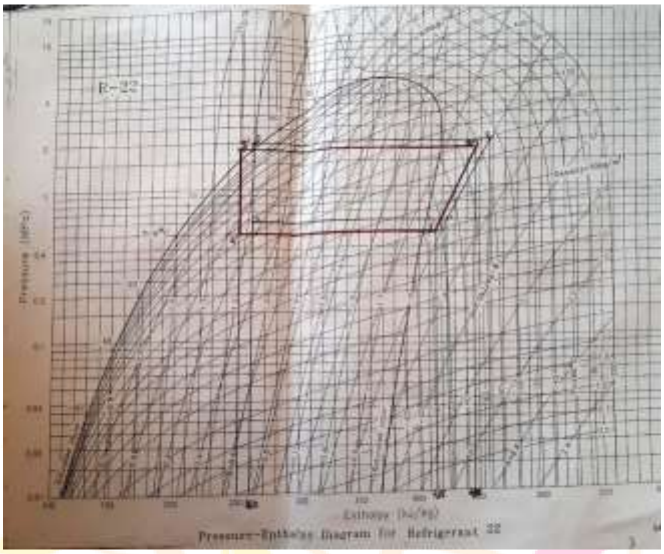

Figure 6 Representation of pressure and enthalpy on P-H chart (R22)

The R22 refrigerant was used in the AC for testing purpose; the results were sketched on R22 PH chart to establish the results as illustrated in figure 6.

The experimental investigation illustrates that the COP of Modified AC is almost double than the conventional AC. It is also observed that the compressor work of the modified AC is decreased as compared to conventional AC as shown in figure 6.

9. CONCLUSION

After analyzing both the conventional and modified air conditioning systems, the following conclusions are drawn:

- Implementing a coolant for condenser cooling in the conventional air conditioning system along with bypass cooling system, have a positive impact. These types of modifications can increase the coefficient of performance and improve the energy efficiency of the system.
- The Glycerin and water solution as a coolant is an effective approach for cooling.
- The use of only bypass refrigerant cooling system did not produce the desired results.
- The use of green scale inhibitors can be an effective way to prevent the formation of scale on the condenser coils and coolant tubes.

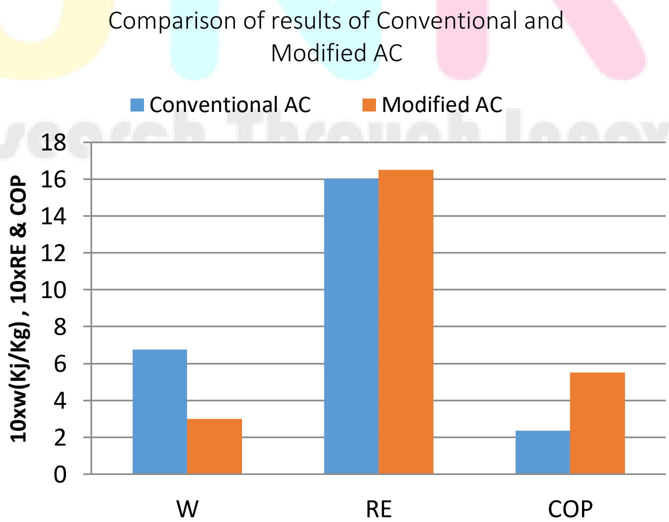

Figure 7 Comparison of results of Conventional and Modified AC

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