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Design of AC-Split 1 PK with R290 Refrigerant Using Coolpack

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***Abstract* - Global warming is when the world temperature is increasing and many natural disasters happen such as droughts, hurricanes, etc. Using air conditioners can affect to increase of global temperature. Engineers try to find environmentally friendly refrigerants. R290 is chosen by refrigeration engineers because it is one of HC (Hydrocarbon) refrigerants, and has 0 ODP (Ozone Depletion Potential) and 3 GWP (Global Warming Potential). Unfortunately, R290 is flammable so it is necessary to design an air conditioner that can prevent leaks or accidents. AC-Split was designed using R290 refrigerant. In this design, cycle, dimension, and simulation analysis was carried out using CoolPack software and AC-Split design using SOLIDWORKS 2020 software using available catalog data. The analysis and simulation result shows that the design of the Split AC with R290 refrigerant has 0.7 kW of compressor work with 2.91 kW cooling capacity. AC-Split is built with specifications of compressor 2/3 HP with Danfoss brand along with receiver and compressor oil brand ISO VG 32 ESTER, evaporator 2.73 KW with LU-VE brand, and condenser 4.9 kW brand of Thermocoil.**

Keywords: Global Warming, R290, HC, AC-Split, CoolPack.

I. INTRODUCTION

Air Conditioning is the process of changing the properties of the air (especially humidity and temperature) to conditions with which we feel comfortable. On a daily basis, air conditioning can refer to any form of technology humidification, de-humidification, heating, cooling, cleaning, ventilation, or air movement that changes air conditions. In general, an air conditioner is a device that lowers the temperature of the air. Most cooling is done using a simple refrigeration cycle, but sometimes evaporation is used generally for cooling comfort in buildings and motor vehicles. "HVAC" is referring to construction, heating, ventilation, and complete air cooling systems [1].

Refrigerants used in the air conditioning and refrigeration (ACR) industry have evolved a lot since the beginning of industrial revolution. During the early refrigeration development period, natural refrigerants such as ammonia, sulfur dioxide, carbon dioxide (CO_2), etc. Subsequently, CFCs (Chlorofluorocarbons) and HCFCs were introduced (Hydrochlorofluorocarbon) as a natural refrigerant substitute. However, CFC and HCFC refrigerants have problems is to have a high GWP (Global Warming Potential) and also ODP (Ozone Depletion Potential) [2].

GWP number measure how much heat (infrared radiation) will be trapped by one unit of greenhouse gas in the atmosphere relative to what would be trapped by the same amount of carbon dioxide (CO_2) [3]. ODP number refers to the amount of stratospheric ozone depletion caused by a substance relative to the gas R-11[4]. Therefore, the Montreal Protocol emerged which is an international agreement designed to protect the ozone layer by stopping the production of various substances that is responsible for the gradual depletion of ozone [4].

Hydrocarbon is available used on AC with small capacities such as windows and portable air conditioners. R290 has performance characteristics that tend to result in higher energy efficiency and lower cooling and heating capacities than R22. COP with R290 refrigerant increases in many experiments with the value from 5% to 15%. For example, Padalkar et al. [5] showed that the efficiency of R290 was up to 34% higher than that of R22. One of the disadvantages of R290 is its high flammability, which poses safety concerns in the application, installation, and field service [6].

It is necessary to design an AC-Split component that is compatible with the R290 refrigerant. It must be done to prevent unwanted things such as burning or refrigerant leakage. The design process of the Split AC system uses CoolPack and SOLIDWORKS software. CoolPack will calculate parameters on any components and simulate with real conditions and SOLIDWORKS will create 3D geometry and machine drawings for any components.

Theoretics

In a Vapor Compression Refrigeration System, the fluid passes through various components in the refrigeration system so that the refrigeration process occurs. Each refrigeration

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component such as compressor, condenser, evaporator, and capillary tube has its function. This design requires calculating many parameters to decide on components that must be used in this design.

Compressor power can be calculated using thermodynamic properties. Equation (1) shows the formula of the compressor power.

$$\dot{W}_c = \dot{m}(h_2 - h_1) \qquad (1)$$

Where, $\dot{W}_c$ is the compressor power, $\dot{m}$is the mass flow rate of the refrigerant, and h is the enthalpy for each process [10].

The heat dissipation in the condenser can be determined by using thermodynamic properties. Equation (2) shows the formula of condenser heat dissipation rate.

$$\dot{Q}_{cond} = \dot{m}(h_2 - h_3) \qquad (2)$$

Where $\dot{Q}_{cond}$ is the condenser heat transfer rate, $\dot{m}$is the mass flow rate of the refrigerant, and h is the enthalpy for each process.

An expansion valve on the refrigeration system can decrease refrigerant pressure and temperature. In thermodynamics, the refrigerant has the same enthalpy before and after crossing the expansion valve. Equation (3) shows characteristics of refrigerant property on thermodynamics.

$$h_3 = h_4 \qquad (3)$$

Heat transfer in the evaporator can be determined by using thermodynamic properties. Equation (4) shows the formula of evaporator heat absorb rate.

$$\dot{Q}_{evap} = \dot{m}(h_1 - h_4) \qquad (4)$$

Where $\dot{Q}_{evap}$ is the evaporator heat transfer rate, $\dot{m}$is the mass flow rate of the refrigerant, and h is the enthalpy for each process.

II. DESIGN METHOD

This design used CoolPack for Cycle analysis, dimensioning, and adjustment of the auxiliary tool. This design used SOLIDWORK software to make a 3D design of AC-Split with machine drawings for each component.

The cycle analysis process on the refrigeration system does not specify each component in the analysis. At this stage, the pipe connecting each component is not included in the calculation.

The dimensioning stage analyzes the cycle by specifying the performance of each component and including the calculation of the connecting pipe. At this stage, there is also a calculation of catalog data that functions to find components that match the dimensioning of the vapor compression refrigeration cycle.

In the auxiliary tool stage, the initial value is entered according to the catalog product specifications for each component. The specifications for each component are generally found in the technical specifications catalog. The value of the auxiliary tool calculation will then be used in the simulation stage.

In the simulation stage, the refrigeration cycle is simulated with CoolPack software. The values entered into the simulation are based on assumptions, dimensioning calculation results, and also an auxiliary tool. When the simulation does not run properly, CoolPack will notify you that the simulation is not convergent so you have to re-select the components. In addition, the calculation of the connecting pipe influences the simulation of the vapor compression refrigeration system. Figure 1 shows the methodology of this research.

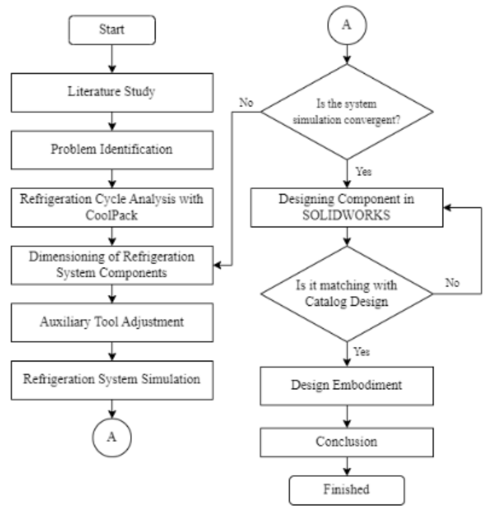

Figure 1: Flow Chart

III. RESULTS AND DISCUSSIONS

Cycle Analysis

In the cycle analysis stage, an analysis of the vapor compression refrigeration cycle is carried out. The cycle does not include the calculation of the connecting pipe to the cycle. Table 1 is the input data to the CoolPack software. In this design, the following is the values entered into the software.

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Table 1: Parameter Input In Cycle Analysis

Parameters	Value
Refrigerant	R290
Cooling Capacity	2638 kW or 1 PK
Evaporating Temp	10°C
Condensing Temp	45
Isentropic Efficiency	70%
Unuseful superheat	10 K
ΔT Superheating	7 K
ΔT Subcooling	2 K

The result from the cycle analysis using CoolPack software is to get 1 PK cooling capacity need compressor which has 0.6163 kW power. The P-h diagram of the cycle is in Figure 2.

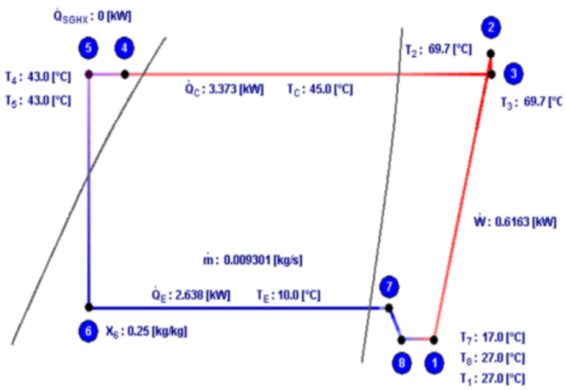

Figure 2: P-h diagram refrigeration cycle analysis

System Refrigeration Dimensioning

Dimensioning is carried out after the refrigeration cycle analysis. Dimensioning included calculation of connecting pipe. Dimensioning included input data on each refrigeration component such as compressor, condenser, evaporator, and connecting pipes. Figure 3 describes dimensioning results on CoolPack software.

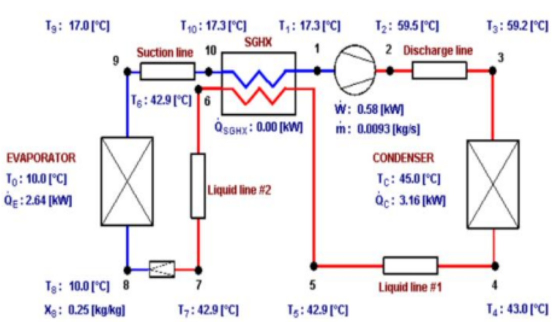

Figure 1: Dimensioning Vapour Compression Cycle

Figure 4 in CoolPack software can calculate state points from each point which show temperature, pressure, enthalpy, and density. Figure 3 describes state points from the cycle.

	STATE POINT	TEMPERATURE [°C] [°C]	PRESSURE [kPa]	ENTHALPY [kJ/kg]	DENSITY [kg/m³]
HIGH PRESSURE	2	59.5	1536.3	557.0	30.2
	3	59.2	1529.7	556.4	30.1
	4	43.0	1529.7	216.9	461.9
	5	42.9	1529.2	216.7	462.0
	6	42.9	1529.2	216.7	462.0
	7	42.9	1528.7	216.5	462.1
LOW PRESSURE	8	10.0	640.7	216.5	-
	9	17.0	640.7	500.5	13.2
	10	17.3	637.1	501.3	13.1
	1	17.3	637.1	501.3	13.1

ADDITIONAL INFORMATION
Pressure ratio (p_2 / p_1): 2.412

Figure 4: State points from the cycle

Compressor Dimensioning

The compressor is being assumed with 70% efficiency and 10% heat loss factor. From catalog data calculation result test condition with DANFOS brand compressor with technical specification on table 2 [7].

Table 2: Result of Test Condition on Compressor

Parameter	Value
$T_{E,CATALOG}$	7.2°C
$T_{c,CATALOG}$	55°C
$T_{s,CATALOG}$	35.3°C
Volumetric Efficiency	0.80

Condensor Dimensioning

Testing condition of condenser catalog to CoolPack software with ΔT 15°C and amount of heat dissipation from condenser equal ± 4.73 kW. Condenser with THERMOCOIL brand is chosen from the catalog of 4.9 kW heat dissipation rate on testing condition with 10°K TD, 45°C condensing temperature, and 10°C environment temperature [8].

Evaporator Dimensioning

Testing condition of evaporator catalog for CoolPack software with $TD_{catalog}$ 10°C. Evaporator with LU-VE brand is chosen from the catalog with 2.73 kW heat absorption rate on testing condition with 10°K TD and 20°C environment temperature [9].

Capillary Pipe Dimensioning

Capillary Pipe Dimensioning is done with Secop Capillary Tube Selector software. The design of AC-Split needs a capillary pipe with 0.83 m long and 0.098 inch internal diameter.

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Compressor Auxiliary Tool

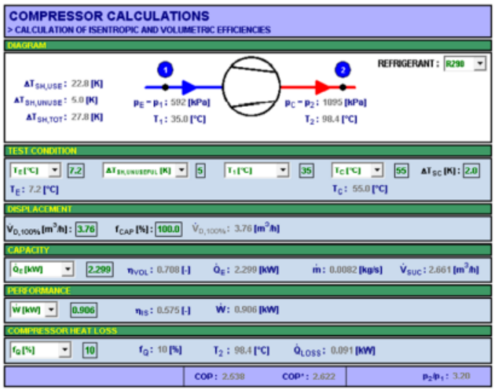

Figure 2 : Compressor Auxiliary Tool

Condenser Auxiliary Tool

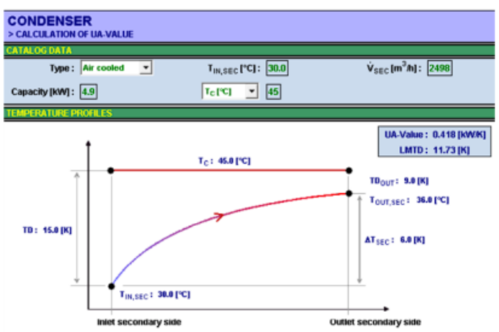

Figure 6: Condenser Auxiliary Tool

Evaporator Auxiliary Tool

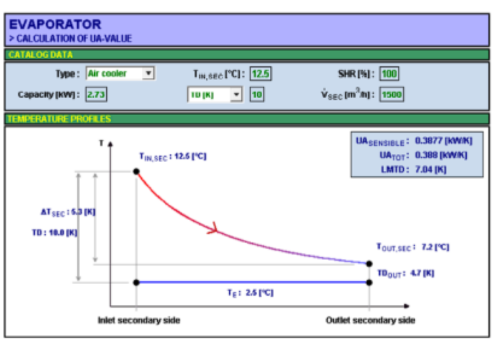

Figure 3: Evaporator Auxiliary Tool

Simulation

Simulation is done with additional parameters which are defined by an auxiliary tool. If the simulation of refrigeration system is not suitable, the CoolPack software will notify if the simulation does not converge, so it mus be re-entered.

IV. CONCLUSION

Design of AC-Split 1PK with R290 refrigerant can be assembled with selected components.

1. Refrigerant Type = R290
2. Evaporator:
   a. Brand = LU-VE FHA 35-80
   b. Cooling Capacity = 2.73 kW
   c. Dimension (ℓ . ω . d) = 1180 mm x 540 mm x 260 mm
3. Condenser:
   a. Brand = Thermocoil 035.1-11-A-N
   b. Capacity = 4.9 kW
   c. Dimension (ℓ . ω . d) = 648 mm x 582 mm x 736 mm
4. Compressor:
   a. Brand = Danfoss NPT16RA
   b. Compressor Power= 2/3 HP
   c. Dimension (ℓ . ω . d) = 192 mm x 162 mm x 210.5 mm
5. Capillary Pipe:
   a. Brand = JB Industries
   b. Length = 0.83 m
   c. Inner Diameter = 0.059 inch
6. Pipes
   a. Discharge line:
      i. Inner Diameter = 7.94 mm
      ii. Length = 1 m
   b. Suction Line
      i. Inner Diameter =12.70 mm
      ii. Length = 5 m
      iii. Insulation = Armaflex
      iv. Insulation Width= 25 mm
   c. Liquid Line
      i. Inner Diameter = 9.53 mm
      ii. Length = 5 m
      iii. Insulation = Armaflex
      iv. Insulation Width= 15 mm

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