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Feasibility of Testing Electrical Components at Low Temperature through Cascade Refrigeration System

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Abstract: Testing department of many automobile and electrical industries requires test rig for checking feasibility of the critical components at the very low temperature about -40℃ to -50℃. Automobile's electrical equipment's operating in cold weather regions are subjected to change their properties so their functions may not be desirable. There are always two factors for products used in cold weather- safety and function. Functionality of the electrical components can also be altered or negatively affected by cold temperatures. In military vehicles, due to low temperature electrical components may fail or may not work properly, hence safety will be in dangerous zone. Failure or functionality damage occurs in low temperature regions because water will condense on the circuit boards and cause problems. Therefore, testing at -50℃ is very essential to check feasibility of operation with temperatures because components change with temperatures, to the point where they may no longer operate reliably, may not start up or may quit entirely. Hence, verification of reliability of electrical, electronic and mechanical components for operating at low temperature region has become a necessity. This paper discusses the component design and readings obtained from cascade refrigeration system operating at -50℃, which is designed for the temperature of -60℃. Further, it is shown how COP of actual system is differ from design COP.
Keywords: COP (Coefficient of Performance), VCR (Vapour Compression Refrigeration), Cascade Refrigeration System, Flare Connection.

I. INTRODUCTION

In North Region of India, the ambient temperature is a lower. As we know that, places like Ladakh, Kargil, North Sikkim (Kanchenjunga) where ambient temperature in winter season is around -22℃, -48℃, -40℃ respectively. Regular Vapour Compression Refrigeration (VCR) have certain limitations to achieve such lower temperature around -50°C. Cascade Refrigeration System is more suitable as compared to single stage VCR system and Multistage VCR system to achieve much lower temperature than atmospheric temperature. This paper is deals with results obtained from Cascade Refrigeration System having selected refrigerant as R-404A for first stage and R-508B for second stage. The selection of refrigerants is done on the basis of safety, environmental effects and requirements of system. The developed cascade refrigeration system is based on selection and design of economical, efficient and effective components to satisfy the requirements of system.

II. BASICS OF CASCADE REFRIGERATION SYSTEM

A. Basic Working Principle of Cascade Refrigeration System

To condense refrigerants that are capable of achieving ultralow temperatures that would not be able to condense at room temperature. This condensation is achieved by using an evaporator of first refrigeration system.[1]

B. Cascade Refrigeration System Description

The cascade refrigeration cycle is a combination of two vapor compression cycles which utilizes two different refrigerants. The primary refrigerant flows from low temperature circuit evaporator to low stage compressor and condensed in cascade condenser which also acts as evaporator for high temperature circuit. The heat rejected from condenser of low temperature circuit is extracted by evaporator of high temperature circuit containing secondary refrigerant then, this secondary refrigerant gets compressed in high stage compressor and finally condensed to outer atmosphere. The desired refrigerating effect is occurred from evaporator of low temperature circuit. The temperature difference in cascade condenser is an important design parameter that decides the COP of the entire refrigeration system.[1]

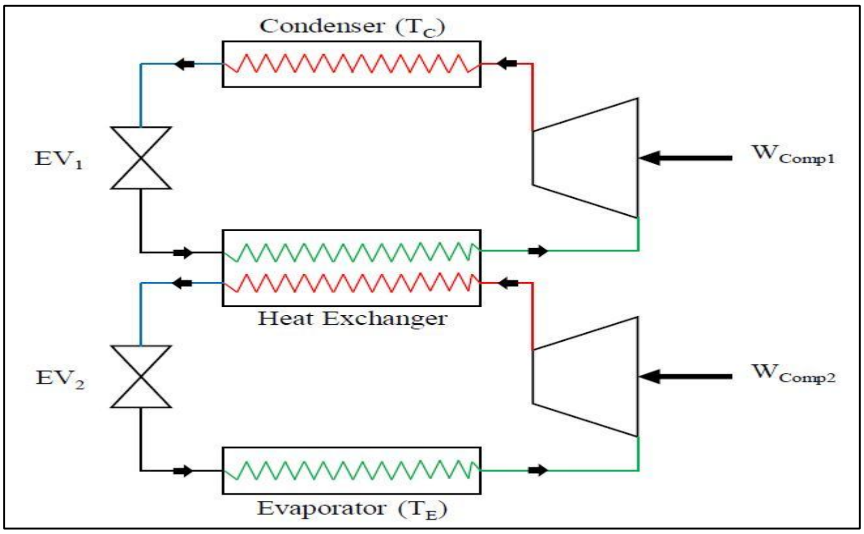

Fig. 1: Schematic View of Cascade Refrigeration System

III. DESIGN & SELECTION OF SYSTEM COMPONENTS

A. First Stage

1) Compressor selection- KCJ450LAL (Emerson)
2) Condenser Designed-
a) Length of tube (L) = 24 m
b) No. of Tubes = 10
c) No. of Row = 4
3) Capillary Designed-
a) Inner Diameter (D) = 0.7874 mm
b) Length of Tube (L) = 1.365 m
4) Filter Drier -
a) Model: DCL 053 (Flare Connection)
5) Solenoid Valve -
a) Model: EVR3
6) Cascade Evaporator -
a) Length of Tube (L) = 7 m

B. Second Stage

1) Compressor selection- KCJ450LAL (Emerson)
2) Evaporator Designed-
a) Length of tube (L) = 10.17 m
b) No. of Tubes = 5
c) No. of Row = 3
3) Capillary Designed-
a) Inner Diameter (D) = 1.27 mm
b) Length of Tube (L) = 0.9786 m
4) Cascade Condenser -
a) Length of Tube (L) = 7 m
5) Filter Drier -
a) Model: DCL 053 (Flare Connection)
6) Solenoid Valve -
a) Model: EVR3

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IV. TESTING PARAMETERS

Evaporating Temperature

A. when only first compressor is running about -36°C.
B. when both compressors are running about -50°C.

TABLE: I
Observation Table

Parameters	First Stage	Second Stage
Suction Pressure (bar)	1.7	6
Discharge Pressure (bar)	29.5	15.5
Condenser outlet Temperature (°C)	47.06	-27.43
Compressor inlet Temperature (°C)	11.43	10.92

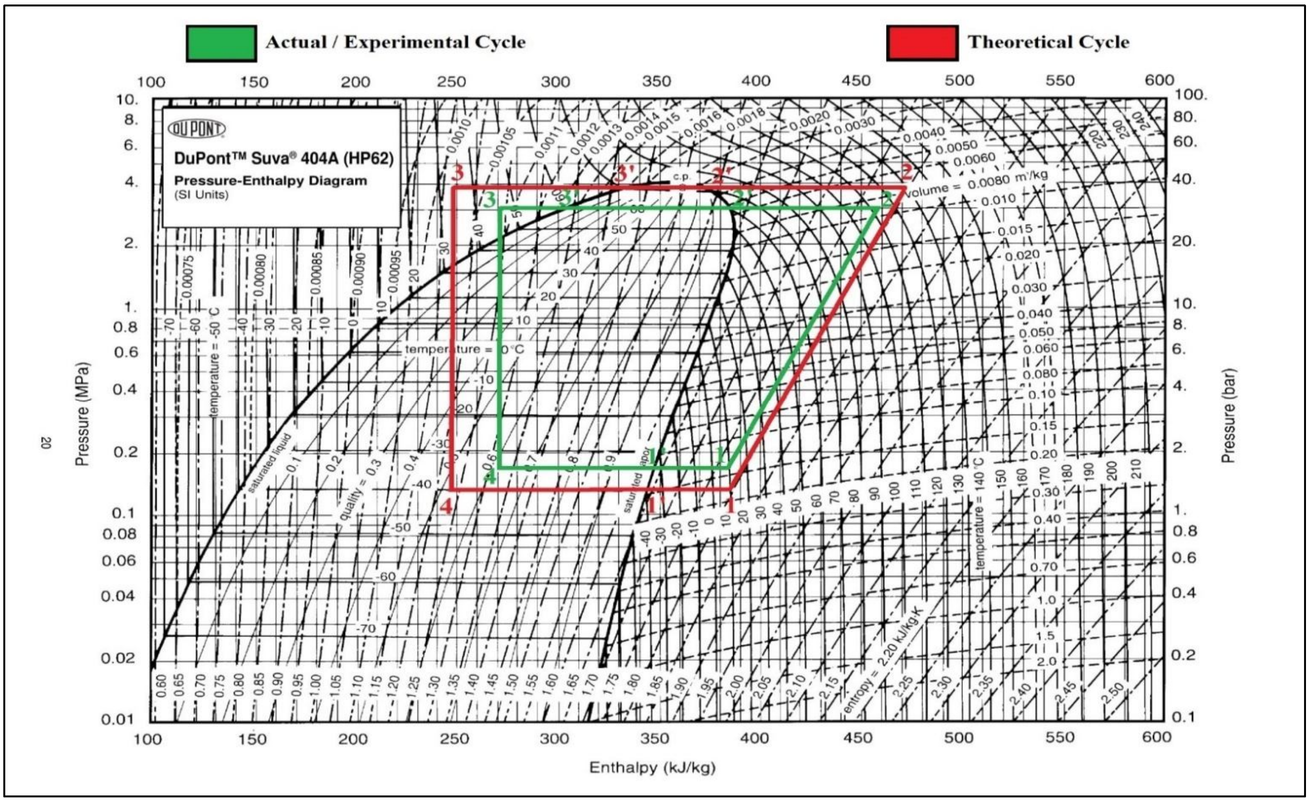

Fig. 2: P-h Chart for R-404A Refrigeration Cycle [2]

TABLE: II
Refrigeration Properties For Design Pressure (R-404A)

Point	P (Bar)	T (^{0}C)	h (kJ/kg)	h_f (kJ/kg)	h_{fg} (kJ/kg)	h_g (kJ/kg)
1	1.33	13.092	386.772	142	200	342
2	36.887	133.969	473.573	332	41	373
3	36.887	32	249.573	332	41	373
4	1.33	-40	249.573	142	200	342

TABLE: III
Refrigeration Properties For Actual Pressure (R-404A)

Point	P (Bar)	T (^{0}C)	h (kJ/kg)	h_f (kJ/kg)	h_{fg} (kJ/kg)	h_g (kJ/kg)
1	1.7	11.43	385	146	200	346
2	29.5	117	462	302	81	383
3	29.5	47.06	275	302	81	383
4	1.7	-35.51	275	146	200	346

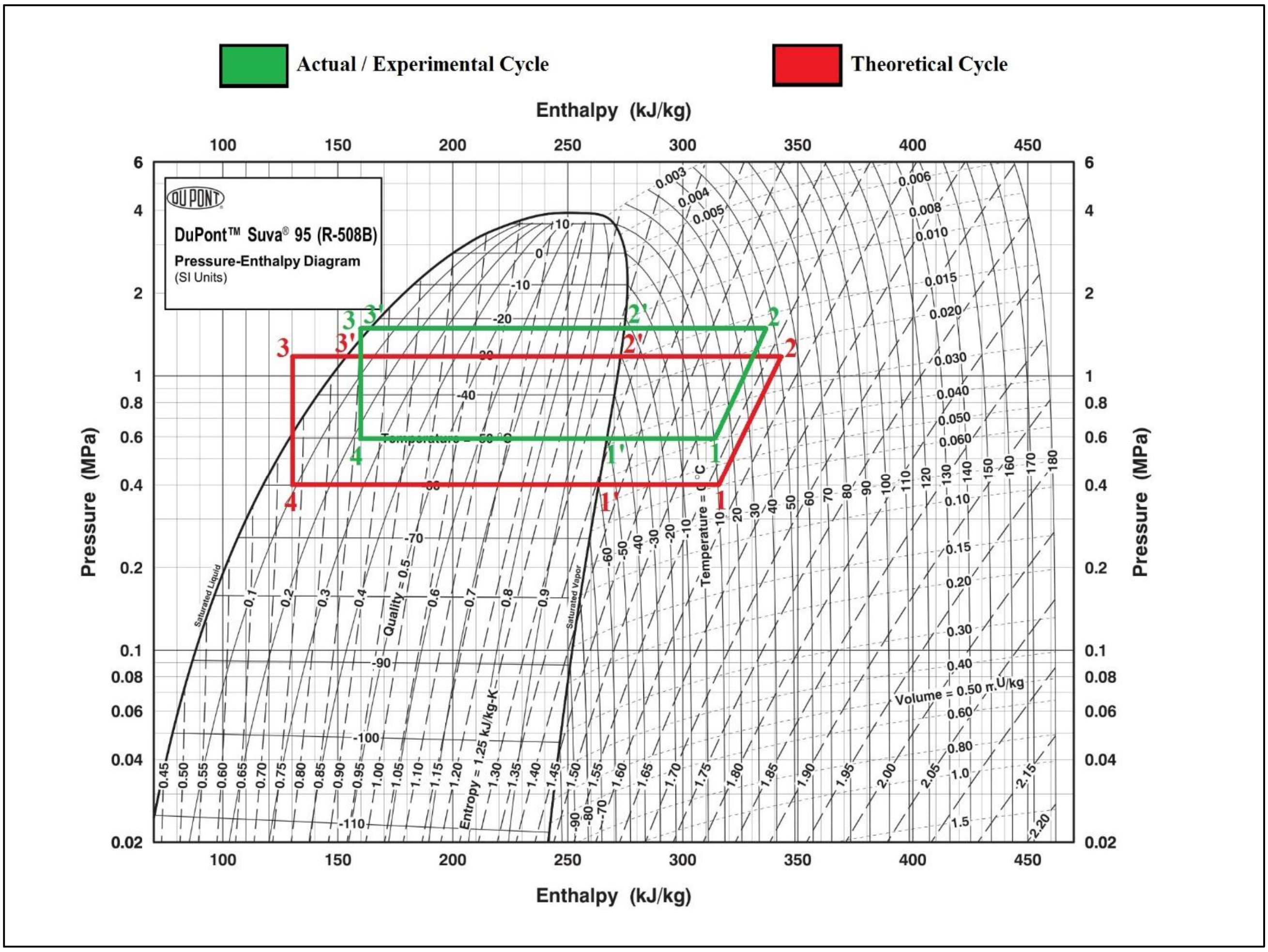

Fig. 3: P-h Chart for R-508B Refrigeration Cycle [2]

TABLE: IV
Refrigeration Properties For Design Pressure (R-508B)

Point	P (Bar)	T (^{0}C)	h (kJ/kg)	h_f (kJ/kg)	h_{fg} (kJ/kg)	h_g (kJ/kg)
1	4	10	317	118	145	263
2	12.5	50	343	165	108	273
3	12.5	-50	130	165	108	273
4	4	-60	130	118	145	263

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TABLE: V
Refrigeration Properties for Actual Pressure (R-508B)

Point	P (Bar)	T (^{0}C)	h (kJ/kg)	h_f (kJ/kg)	h_{fg} (kJ/kg)	h_g (kJ/kg)
1	6	10.92	313	130	137	267
2	15.5	42	337	162	112	274
3	15.5	-27.43	160	162	112	274
4	6	-49.87	160	130	130	267

V. COP CALCULATIONS

A. Design Pressure COP

$$COP_{Combined} = \frac{[\dot{m}_2(h_1 - h_4)]_{II}}{[\dot{m}_1(h_2 - h_1)]_I + [\ \dot{m}_2(h_2 - h_1)]_{II}} = 3.6643$$

B. Actual Pressure COP

$$COP_{Combined} = \frac{[\dot{m}_2(h_1 - h_4)]_{II}}{[\dot{m}_1(h_2 - h_1)]_I + [\ \dot{m}_2(h_2 - h_1)]_{II}} = 3.3113$$

VI. RESULT ANALYSIS

Parameters	First Stage (R-404A)	Second Stage (R-508B)	Combined COP
Design Pressure COP	1.5772	7.1923	3.6643
Actual Pressure COP	1.4285	6.375	3.3113

VII. CONCLUSION

A. The system is designed for -60°C evaporating temperature but actual temperature obtained is about -50°C.
B. Same compressor can be used for both stage of refrigeration system by replacing suitable lubricating oil in the compressor.
C. If small diameter of capillary tube is taken then the length of capillary tube is decreases and vice-versa.
D. Actual Pressure COP of the combined system is less than the Design Pressure COP of individual stage.
E. Actual Pressure COP of the combined system is less than the Design Pressure COP of combined system, i.e. 3.3113 < 3.6643.

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[1] Rohit B. Nichit, Nitin S. Shinde, Priyanka S. Mandhare, Tejas H. Mulik, Design and Development of Cascade Refrigeration System for Testing at Low Temperature Applications, IRJET, V6I437, pp. 172-175, April 2019.
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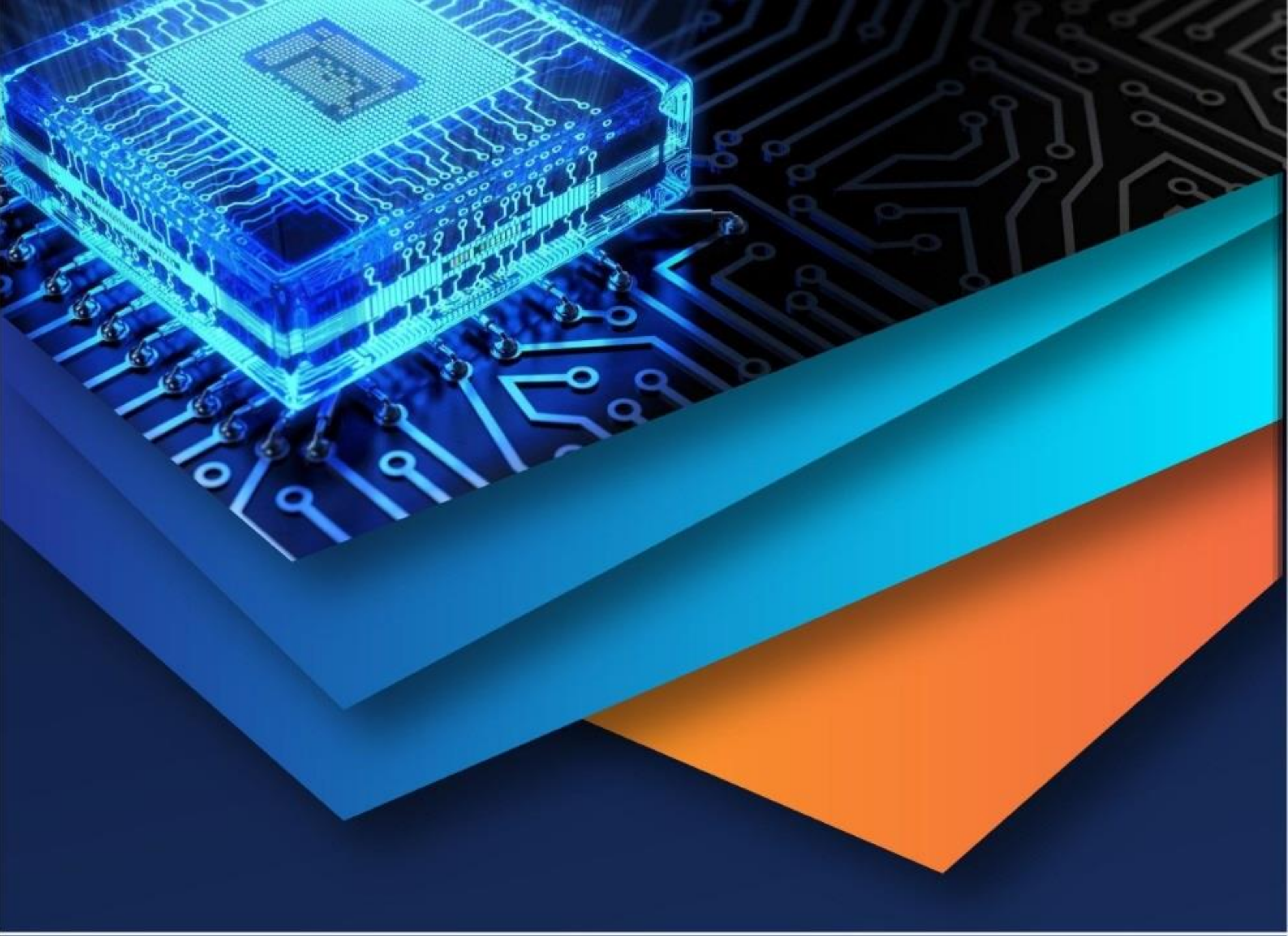

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