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Integrated Approach for Enhancement of Vapor Compression Refrigeration Systems with Spiral Condenser Retrofitting and Refrigerant Blend Compatibility

Abstract: - An integrated approach for enhancing Vapor Compression Refrigeration Systems (VCRS) through Spiral Condenser retrofitting and compatibility with refrigerant blends is proposed in this paper. The objectives include the design and development of an experimental setup compatible with refrigerant blends, experimentation and analysis of results for retrofitting the setup with a Spiral Condenser, validation of experimental results, and determination of system energy effectiveness and payback period. The methodology involves systematic design, experimentation, validation, and analysis, culminating in insights into VCRS enhancement strategies. The findings contribute to advancing VCRS technology, optimizing performance, and promoting sustainability in refrigeration systems.

Keywords: Vapor Compression Refrigeration Systems, Enhancement, Spiral Condenser Retrofitting, Refrigerant Blend Compatibility, Experimental Setup, Experimentation.

I. INTRODUCTION

The demand for efficient and environmentally friendly cooling solutions continues to escalate, driven by factors such as increasing energy costs, environmental regulations, and the imperative to mitigate climate change. In this context, Vapor Compression Refrigeration Systems (VCRS) represent a cornerstone technology widely employed across diverse industries for refrigeration, air conditioning, and cooling applications[1]. However, traditional VCRS configurations face challenges related to energy consumption, refrigerant leakage, and environmental impact, particularly with refrigerants like R134a, which have relatively high ODP (ozone depletion potential) and GWP (global warming potential).

To address these challenges and meet the evolving needs of modern refrigeration systems, there is a critical need for innovative approaches that enhance VCRS performance while minimizing environmental impact. Retrofitting existing VCRS systems with advanced components, such as Spiral Condensers, presents one promising avenue for improving energy efficiency and overall system performance. Spiral Condensers offer advantages such as enhanced heat transfer characteristics, reduced pressure drop, and compact design compared to traditional condenser configurations[2].

Moreover, with the phase-down of high-GWP refrigerants underway under international agreements like the Montreal Protocol's Kigali Amendment, there is growing interest in exploring the compatibility of VCRS systems with alternative refrigerants and refrigerant blends [3]. Research efforts have demonstrated the potential benefits of using refrigerant blends, which often exhibit lower GWP and ODP values compared to pure refrigerants like R134a, thereby contributing to climate change mitigation efforts[4].

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Against this backdrop, this study adopts an integrated approach aimed at enhancing VCRS performance through Spiral Condenser retrofitting and compatibility with refrigerant blends. The objectives of the study encompass designing and developing an experimental setup capable of accommodating refrigerant blends, conducting experimentation and analysis to assess the performance gains achieved through Spiral Condenser retrofitting, validating experimental results, and evaluating the energy effectiveness and payback period of the enhanced VCRS system.

By addressing these objectives, this study seeks to contribute to the advancement of VCRS technology by providing practical insights into retrofitting options, refrigerant compatibility, and energy efficiency improvements. The findings are expected to be valuable for industries seeking to enhance the performance and sustainability of their refrigeration systems, thereby supporting global efforts towards energy conservation and environmental protection.

II. LITERATURE REVIEW

In vapor compression refrigeration, sub-cooling impact of condenser refrigerant has been explored by a number of researchers. Linton [5] used an experiment to study the impact of subcooling of condenser liquid on the operation of a refrigeration system. According to the findings, the sub-cooling increases improved the COP as well as refrigeration capability of three refrigerants at constant condensing temperature: R152a (10%), R12 (10.5%), and R134a (12.5%).

Yumrutas [6] investigated a first law and second law analysis, as well as a computational model-based exergy study, of a refrigeration cycle for vapor compression with a working fluid like ammonia. The degree of subcooling at the condenser has a major impact on performance, as per the first law. In particular, the refrigerant subcooling at the outlet of the condenser results in lower-quality refrigerant inflowing the cycle evaporator. This permits higher heat absorption by the refrigerant in the evaporator, improving the enthalpy variance through the evaporator and raising the system's coefficient of performance.

Dalkilic and Wongwises [7] explored a refrigeration system for vapor-compression using numerous refrigerants at a 50°C of condensation temperature with -30°C to 10°C of evaporation temperatures. A comparison was made between R32, R134a, R290, R152a, R600a, and R1270 regarding the impact of subcooling degree on refrigeration. Jensen [8] conducted a theoretical investigation on the sub-cooling optimality in a basic refrigeration cycle. A refrigerant used in the cycle was ammonia and using subcooling approximately 2% save in compressor power was achieved.

Pottker [9] provided a theoretical investigation in addition to experimental details of the condenser subcooling impact on vapor-compression system’s performance. The findings indicated that, as there is an increase in condenser subcooling, the COP achieves a maximum, since a trade-off between the growing effects of refrigerating as well as particular compression work. Furthermore, based on the simulation outcome, it was determined that when compared to R410A, R134a, and R717, the most advantage gained by R1234yf from condenser subcooling. According to the experimental findings, the system COP for R1234yf and R134a climbed to 18% and 9%, respectively, for a given operating environment.

Zhang [9] used refrigerants R12 and R22 to create the effect of sub-cooling by adding a supplementary circuit to the key cycle. In line with the findings, the new cycle's COPs rise by 5% to 11% when linked to those of a traditional cycle. For supermarket applications, Thornton [10] used specific design solutions for mechanical sub-cooling. It was discovered that using a sub-cooler increased overall COP by about 10% under a variety of circumstances typical of retail applications. A model presented by Khan [11] showed that the refrigerant saturation temperature of the subcooler has a bearing on the improvement in the complete cycle's performance (sub-cooling and main cycle) over the initial cycle.

A sub-cooling loop connected to the refrigeration cycle of vapor-compression was employed by Syed [12] in order to lower energy consumption and improve system performance. It was discovered that the novel technology can considerably increase system performance when it is used in areas where there is a big temperature differential between the temperatures of evaporation and condensing. When the refrigeration system is working at the ideal temperature of sub-cooler saturation, it can reduce power input by up to 85% and the irreversibility rate by 65%. Syed [13] discovered in another investigation that the performance, including a subcooling loop, peaks halfway between the evaporating and condensing temperatures at a temperature of sub-cooler saturation. According to simulations, there could be a 20% increase in performance during the highest condensing temperature peak times.

III. METHODOLOGY

The methodology for this experimental study involves a comprehensive examination of Vapor Compression Refrigeration Systems (VCRS) by meticulously selecting and detailing the specifications of key system components. Firstly, two types of condensers are considered: the Fins Type Condenser and the Spiral Condenser. The Fins Type Condenser, an air-cooled variant with fins, is constructed with a coil diameter of 5mm, and a coil length of 9m, and utilizes mild steel material with 10 turns. In contrast, the Spiral Condenser, fabricated from copper, boasts a coil diameter of 7mm, a coil length of 7m, and features 5 turns. Moving to the evaporator, a wooden construction is chosen with internal coiling using copper tubing of 7mm diameter.

The evaporator is insulated to prevent heat load from the surroundings, ensuring consistent cooling capacity across all units. A 0.32 hp hermetically sealed compressor (model KCN415LAG-BXX) by Emerson, operating at 230V and 50Hz, is selected for the experimental setup. Additionally, a capillary tube with a 2mm diameter, and pressure gauges capable of measuring up to 150 psi and -30 psi for suction pressure, and up to 300 psi and 0 psi for discharge pressure from the compressor are utilized. The chosen refrigerant is 134a (Tetrafluroethane), with a boiling point, freezing point, critical temperature, and critical bar pressure values specified. A glass tube rotameter with a flow rate range of 0.50 to 50 Lph is installed to measure fluid or gas flow rate.

For experimentation purposes, four distinct cases are identified, varying from normal VCRS setups to configurations involving series arrangements of evaporators and integration of Spiral Condensers. These arrangements are facilitated by the use of valves to control the flow and arrangement of components. The experimental setups, as depicted in Figures 4 and 5, illustrate the Spiral and Fin type condenser arrangements, respectively. Through this detailed methodology, the study aims to provide a comprehensive understanding of VCRS performance under various configurations, facilitating insights into system optimization and efficiency enhancement.

Specifications of VCRS system components selected for this experimental study are described below:

3.1 Condenser

A. Fins type Condenser

Air cooled condenser with fins:

1. Length of the coil = 9m
2. Diameter of the coil = 5mm
3. Number of turn = 10
4. Mild steel Material used for the coil

B. Spiral Condenser

1. Length of the coil = 7m
2. Diameter of the coil = 7mm
3. No of turns = 5
4. Copper Material is used

3.2 Evaporator

For this experimental study, the evaporator is made of wood and the coiling is made inside with a copper tube of diameter 7mm. The insulation is provided inside the evaporator to prevent taking heat load from the surroundings. The cooling capacity of all the evaporators is identical.

3.3 Compressor

The compressor used for this setup was a 0.32 hp Emerson manufactured hermetically closed compressor model KCN415LAG-BXX operating at 230 V – 50 Hz.

3.4 Capillary Tube

The diameter of the capillary tube used for this setup is 2mm.

3.5 Pressure Gauges

Pressure gauges of max 150 psi and -30 psi were used to record the suction pressure and max 300 psi and 0 psi pressure gauges recorded the compressor’s discharge pressure.

3.6 Refrigerant

Tetra fluro ethane (134a) Refrigerant is used with Freezing point (K) = 176.55,

Boiling point temperature (K) = 247 @1 atm, Critical bar pressure = 40, Critical temperature (K) = 374.25. Propane and Isobutane.

3.7 Rotameter

A device called a Rotameter measures the flow rate of Gas or Fluid. The rotameter used for this experimental setup is a Glass Tube of 0.50 to 50 Lph.

For experimentation purposes following four cases are identified:

- Normal VCRS (Condenser, Compressor, Evaporator I and Expansion Device)
- Normal VCRS with a series arrangement of evaporators (Expansion Device, Compressor, Evaporator I and II, Condenser,)
- Spiral Condenser with Normal VCRS (Expansion Device, Compressor, Spiral Condenser, and Evaporator I)
- Spiral Condenser with series arrangement of VCRS (Compressor, Spiral Condenser, Expansion Device, Evaporator I and Evaporator II)

These arrangements were achieved with the help of valves.

Figures 1 and 2 show the Spiral and Fin type condenser arrangement.

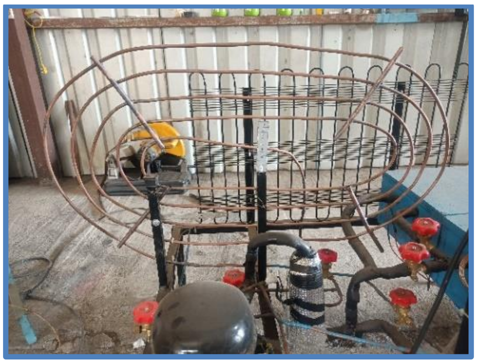

Fig-1 Spiral Condenser Arrangement

Fig-2 Fins Type Condenser Arrangement

IV. RESULTS AND DISCUSSION

A robust framework for evaluating the performance and efficiency of Vapor Compression Refrigeration Systems (VCRS) under various configurations is proposed in this paper. By meticulously selecting and detailing the specifications of key system components such as condensers, evaporators, compressors, capillary tubes, pressure gauges, refrigerants, and rotameters, the study ensures a comprehensive examination of the experimental setup. The inclusion of both Fins Type and Spiral Condensers allows for comparative analysis, while the utilization of identical evaporators ensures consistency in cooling capacity across all units. Furthermore, the choice of a hermetically sealed compressor and the specification of pressure gauges and capillary tubes contribute to precise control and monitoring of system parameters. The use of refrigerant 134a, along with considerations for alternative refrigerants like propane and isobutane, reflects the study's awareness of environmental and regulatory concerns. The identification of four distinct experimental cases enables the investigation of different system configurations, ranging from standard setups to those integrating Spiral Condensers and series arrangements of evaporators. Overall, the methodology provides a solid foundation for conducting rigorous experimentation and analysis, aiming to generate valuable insights into VCRS performance optimization and efficiency enhancement.

i.Results from R134a

- Normal VCRS, Pressure 1008hpa, humidity 45%

Sr. No.	Location	Name	10min	20min	30min	40min	50min	60min	70min	80min	90min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	28	29	32	32	33	33	33	30	28	28	28	28
2	T2	Temp at Compressor Discharge	62	65	67	68	71	71	74	74	72	72	72	71
3	T3	Temperstur e After Condenser	43	42	41	41	42	42	43	43	42	42	42	42

4	T4	Temperature after expansion	7	7	6	6	6	6	9	9	8	8	8	8
5	T5	Temp of Evaporator Box	45	45	47	46	47	47	47	46	46	46	46	46
6	P1	Suction Pressure	12	12	12	10	10	10	15	15	15	15	15	15
7	P2	Discharge Pressure	160	160	160	160	160	160	170	170	160	160	160	160
8	LPH	Rotameter Flow Rate	4	4	4	4	4	4	4	4	4	4	4	4
9	Time (s)	Energymeter Flash time 10 blinks	57	58	1.01	1	59	58	56	56	56	56	57	57
10	V	Voltmeter	129	130	129	129.5	135	131.5	132	130	135	133	128	134
11	I	Ammeter	1.21	1.22	1.21	1.21	1.27	1.23	1.23	1.23	1.27	1.24	1.2	1.26

- Spiral Condenser with Normal VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	32	33	34	36	37	37	37	38	39	40	41	42
2	T2	Temp at Compressor Discharge	60	63	68	71	71	72	71	72	71	74	75	77
3	T3	Tempersture After	50	46	46	46	45	43	43	43	42	43	44	44

		Condenser												
4	T4	Temperature after expansion	9	7	9	9	9	9	9	10	11	11	12	16
5	T5	Temp of Evaporator Box	45	48	50	51	51	51	51	53	55	56	57	58
6	P1	Suction Pressure	10	10	10	10	10	10	10	10	10	10	10	10
7	P2	Discharge Pressure	180	180	180	180	180	180	160	160	160	160	160	160
8	LPH	Rotameter Flow Rate	4	4	4	4	4	4	4	4	4	4	4	4
9	Time (s)	Energymeter Flash time 10 blinks	1.01	59	59	59	59	1.01	1.01	59	1	1	1.056	1.04
10	V	Voltmeter	132	135	135.5	133	141	145	147	154	160	155.7	156	149.8
11	I	Ammeter	1.24	1.26	1.26	1.24	1.32	1.36	1.37	1.43	1.5	1.44	1.45	1.38

- Normal Condenser with Seriers VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	41	45	47	47	48	48	48	48	48	47	47	47

2	T2	Temp at Compressor Discharge	66	65	69	69	72	72	73	72	72	71	71	71
3	T3	Tempersture After Condenser	43	40	40	39	38	37	37	36	37	36	36	36
4	T4	Temperature after expansion	7	5	6	8	10	12	19	21	17	18	18	18
5	T5	Temp of Evaporator Box 1	42	47	48	49	50	51	50	51	51	51	51	51
6	T6	Temp of Evaporator Box 2	54	57	56	58	57	57	56	56	56	56	56	56
7	P1	Suction Pressure	10	7	7	6	5	5	5	5	5	5	5	5
8	P2	Discharge Pressure	160	150	140	140	140	140	130	130	130	120	120	120
9	LPH	Rotameter Flow Rate	5	5	5	5	5	5	5	5	5	5	5	5
10	Time (s)	Energymeter Flash time 10 blinks	58.91	1.02	1.03	1.04	1.05	1.06	1.06	1.08	1.08	1.08	1.08	1.08
11	V	Voltmeter	129.2	136.4	134.2	135.4	136.2	135.6	136.2	132.9	138.2	135.1	136.2	140.3
12	I	Ammeter	2.4	2.59	2.56	2.59	2.6	2.58	2.63	2.54	2.62	2.56	2.62	2.68

- Spiral Condenser with Seriers VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	39	43	45	47	48	49	50	51	51	52	52	52
2	T2	Temp at Compressor Discharge	61	70	76	77	81	83	84	83	85	83	85	85
3	T3	Tempersture After Condenser	47	45	44	43	42	43	42	41	41	41	42	41
4	T4	Temperature after expansion	8	7	7	8	8	11	12	15	16	19	19	19
5	T5	Temp of Evaporator Box 1	42	43	45	46	47	49	49	50	51	51	51	51
6	T6	Temp of Evaporator Box 2	54	56	56	57	55	55	55	55	55	55	55	55
7	P1	Suction Pressure	13	10	10	10	8	8	8	6	6	6	6	6
8	P2	Discharge Pressure	180	180	170	165	160	160	160	150	150	150	150	150
9	LPH	Rotameter Flow Rate	4	4	4	4	4	4	4	4	4	4	4	4

10	Time (s)	Energymeter Flash time 10 blinks	58.49	58.96	1.02	1.02	1.04	1.04	1.04	1.05	1.06	1.04	1.04	1.05
11	V	Voltmeter	125.3	124.2	122.9	129.6	131.5	130.4	136	132	128.7	139.7	136.4	137.5
12	I	Ammeter	2.42	2.34	2.41	2.48	2.5	2.48	2.5	2.52	2.45	2.62	2.58	2.55

*ii.**R134a + Nanofluid***

- Normal VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	36	37	38	38	38	39	38	38	38	38	39	37
2	T2	Temp at Compressor Discharge	64	67	72	74	73	76	73	73	74	74	72	73
3	T3	Tempersture After Condenser	45	45	44	44	44	44	43	42	41	41	41	41
4	T4	Temperature after expansion	7	9	9	9	9	10	8	7	9	10	10	8
5	T5	Temp of Evaporator Box	47	48	49	50	50	49	47	47	47	47	48	47

6	P1	Suction Pressure	10	10	10	10	10	10	10	10	10	10	10	10
7	P2	Discharge Pressure	180	180	180	180	170	170	170	160	160	160	160	160
8	LPH	Rotameter Flow Rate	3	3	3	3	3	3	3	3	3	3	3	3
9	Time (s)	Energymeter Flash time 10 blinks	58	58	58	58	58	58	58	60	1.02	1.01	1.02	59
10	V	Voltmeter	140	135	138	138	138	140	130	133	135	138	134	135
11	I	Ammeter	1.3	1.26	1.29	1.28	1.28	1.33	1.2	1.25	1.26	1.29	1.25	1.26

- Spiral Condenser with Normal VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	37	37	37	36	36	36	36	36	36	35	36	36
2	T2	Temp at Compressor Discharge	63	68	74	75	77	77	78	79	78	74	78	77
3	T3	Tempersture After Condenser	47	48	48	49	48	49	48	49	48	46	48	48

4	T4	Temperature after expansion	9	10	9	8	9	7	9	10	10	9	6	8
5	T5	Temp of Evaporator Box	46	47	47	45	44	44	43	43	43	43	43	42
6	P1	Suction Pressure	10	10	10	15	15	15	15	15	10	15	15	15
7	P2	Discharge Pressure	190	190	190	200	190	200	190	200	190	190	190	190
8	LPH	Rotameter Flow Rate	3	3	3	3	3	3	3	3	3	3	3	3
9	Time (s)	Energymeter Flash time 10 blinks	56	55	1.02	56	57	56	56	57	57	57	56	56
10	V	Voltmeter	124	119	110	116	115	113	108	105	105	108	108	111
11	I	Ammeter	1.16	1.12	1.04	1.1	1.09	1.08	1.03	1	1	1.03	1.03	1.08

- Normal Condenser with Seriers VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	28	29	30	31	30	32	32	35	36	36	35	35
2	T2	Temp at Compressor	45	51	68	67	75	73	75	76	77	80	83	82

		Discharge												
3	T3	Tempersture After Condenser	42	44	47	48	48	48	46	46	47	46	48	48
4	T4	Temperature after expansion	11	8	13	14	14	14	11	12	13	13	12	6
5	T5	Temp of Evaporator Box 1	40	42	43	44	43	47	46	49	49	48	50	50
6	T6	Temp of Evaporator Box 2	40	42	43	45	44	47	46	49	50	50	50	50
7	P1	Suction Pressure	20	20	20	25	25	25	20	20	20	20	20	20
8	P2	Discharge Pressure	180	200	210	220	220	220	200	200	200	200	210	210
9	LPH	Rotameter Flow Rate	5	5	5	5	5	5	5	5	5	5	5	5
10	Time (s)	Energymeter Flash time 10 blinks	52	48	48	48	48	48	48	48	50	48	46	48
11	V	Voltmeter	120	125	130	124	132	140	142	138	135	135	138	137
12	I	Ammeter	2.3	2.4	2.48	2.38	2.53	2.69	2.72	2.63	2.58	2.58	2.67	2.62

- Spiral Condenser with Seriers VCRS

Sr. No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	36	38	39	39	39	39	40	39	39	39	39	39
2	T2	Temp at Compressor Discharge	64	73	78	79	82	85	88	87	89	90	91	91
3	T3	Tempersture After Condenser	40	41	42	43	43	44	46	45	46	46	46	47
4	T4	Temperature after expansion	-1	1	0	0	0	1	0	2	2	1	1	0
5	T5	Temp of Evaporator Box 1	52	52	53	54	54	54	54	54	53	53	53	53
6	T6	Temp of Evaporator Box 2	46	47	48	48	49	49	49	50	49	49	48	48
7	P1	Suction Pressure	5	5	10	10	10	10	10	10	15	15	15	15

8	P2	Discharge Pressure	150	150	160	160	170	180	180	180	180	180	180	190
9	LPH	Rotameter Flow Rate	4	4	4	4	4	4	4	4	4	4	4	4
10	Time (s)	Energy meter Flash time 10 blinks	1.07	1.04	1.02	1.01	1.04	58	56	56	56	56	56	54
11	V	Voltmeter	123	125	128	127	125	129	128	128	128	128	126	125
12	I	Ammeter	2.37	2.43	2.46	2.44	2.41	2.47	2.46	2.44	2.44	2.46	2.42	2.38

*iii.**R290 + R600a***

- Normal VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	5	7	9	10	12	12	14	16	18	17	21	23
2	T2	Temp at Compressor Discharge	54	59	66	64	70	73	74	70	75	70	73	72
3	T3	Tempersture After Condenser	46	46	48	46	45	49	46	46	43	46	44	40

4	T4	Temperature after expansion	11	13	13	13	13	13	13	13	11	12	11	10
5	T5	Temp of Evaporator Box	44	47	46	45	45	46	44	45	43	45	46	46
6	P1	Suction Pressure	25	25	25	25	25	25	25	25	20	20	20	15
7	P2	Discharge Pressure	200	200	200	200	200	200	190	190	180	180	160	160
8	LPH	Rotameter Flow Rate	5	5	5	5	5	5	5	5	5	5	5	5
9	Time (s)	Energymeter Flash time 10 blinks	48	47	46	48	48	48	48	50	52	52	56	58
10	V	Voltmeter	131	130	128	123	127	126	121	118	124	126	122	128
11	I	Ammeter	1.23	1.22	1.19	1.16	1.2	1.18	1.15	1.11	1.18	1.2	1.16	1.2

- Spiral Condenser with Normal VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	23	26	25	26	26	26	27	26	25	24	26	26

2	T2	Temp at Compressor Discharge	52	71	76	79	80	79	72	77	75	77	79	71
3	T3	Tempersture After Condenser	50	57	39	58	58	59	60	58	58	58	59	58
4	T4	Temperature after expansion	11	15	15	16	17	16	17	17	17	16	16	16
5	T5	Temp of Evaporator Box	44	45	45	46	46	45	45	45	44	43	44	44
6	P1	Suction Pressure	20	25	25	25	25	30	30	25	25	25	25	25
7	P2	Discharge Pressure	180	200	210	210	210	220	230	220	220	220	220	220
8	LPH	Rotameter Flow Rate	5	4	4	4	4	4	4	4	4	4	4	4
9	Time (s)	Energymeter Flash time 10 blinks	52	48	46	46	46	46	46	46	46	46	46	46
10	V	Voltmeter	135	132	133	131	130	128	130	125	122	125	127	125
11	I	Ammeter	1.27	1.24	1.25	1.23	1.22	1.21	1.22	1.16	1.14	1.18	1.2	1.17

- Normal Condenser with Seriers VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	29	30	31	32	33	33	33	34	35	35	35	34
2	T2	Temp at Compressor Discharge	63	70	74	76	78	77	63	74	79	63	78	75
3	T3	Tempersture After Condenser	40	40	40	38	37	34	34	32	32	29	30	28
4	T4	Temperature after expansion	7	10	9	8	8	7	9	9	12	14	14	13
5	T5	Temp of Evaporator Box 1	42	43	42	44	44	44	45	47	48	50	49	49
6	T6	Temp of Evaporator Box 2	37	38	38	39	39	39	39	40	40	41	41	40
7	P1	Suction Pressure	20	20	20	15	15	15	10	10	10	10	10	10
8	P2	Discharge Pressure	160	160	170	160	160	150	140	140	140	130	130	120
9	LPH	Rotameter Flow Rate	5	5	5	5	5	5	5	5	5	5	5	5

10	Time (s)	Energymeter Flash time 10 blinks	58	56	56	58	58	1.02	1.04	1.06	1.06	1.06	1.08	1.1
11	V	Voltmeter	127	130	127	128	130	126	129	131	132	135	135	132
12	I	Ammeter	2.45	2.51	2.45	2.45	2.48	2.43	2.46	2.5	2.55	2.53	2.6	2.51

- Spiral Condenser with Seriers VCRS

Sr.No.	Location	Name	10 min	20 min	30 min	40 min	50 min	60 min	70 min	80 min	90 min	100 min	110 min	120 min
1	T1	Temp at Compressor Suction	33	33	33	34	34	32	33	34	34	34	34	34
2	T2	Temp at Compressor Discharge	74	77	80	81	84	59	82	83	82	82	81	77
3	T3	Tempersture After Condenser	55	59	59	58	60	39	60	60	62	58	61	61
4	T4	Temperature after expansion	16	14	17	16	19	10	16	17	19	19	18	16
5	T5	Temp of Evaporator Box 1	44	46	47	48	48	50	47	49	50	50	51	50

6	T6	Temp of Evaporator Box 2	41	42	43	43	43	46	44	45	45	45	46	46
7	P1	Suction Pressure	25	25	25	25	30	15	25	30	30	35	30	35
8	P2	Discharge Pressure	210	220	220	220	230	150	230	230	240	240	240	250
9	LPH	Rotameter Flow Rate	3	3	3	3	3	3	3	3	3	3	3	3
10	Time (s)	Energymeter Flash time 10 blinks	48	46	46	46	44	58	44	44	42	42	34	40
11	V	Voltmeter	120	124	120	125	122	125	128	130	125	131	132	132
12	I	Ammeter	2.3	2.39	2.32	2.42	2.34	2.4	2.45	2.5	2.41	2.56	2.52	2.52

V. CONCLUSION

In conclusion, this study introduces an integrated approach aimed at enhancing Vapor Compression Refrigeration Systems (VCRS) through the retrofitting of Spiral Condensers and exploration of refrigerant blend compatibility. By systematically designing, experimenting, validating, and analyzing, the study provides valuable insights into VCRS performance optimization. The objectives, including the design and development of an experimental setup compatible with refrigerant blends, experimentation with Spiral Condenser retrofitting, validation of results and determination of energy effectiveness and payback period, have been effectively addressed. The findings contribute significantly to advancing VCRS technology by offering practical insights into retrofitting options, refrigerant compatibility, and energy efficiency improvements. Through the integration of Spiral Condenser retrofitting and compatibility with refrigerant blends, the study aligns with the industry's goals of optimizing performance and promoting sustainability in refrigeration systems. Overall, the study's outcomes hold promise for improving VCRS performance, reducing environmental impact, and fostering energy conservation in refrigeration technology. Further research and implementation of these findings can lead to tangible advancements in VCRS systems, benefiting industries and society as a whole.

REFERENCES

[1] M. F. Sukri, M. N. Musa, M. Y. Senawi, and H. Nasution, "Achieving a better energy-efficient automotive air-conditioning system: a review of potential technologies and strategies for vapor compression refrigeration cycle," Energy Effic., vol. 8, no. 6, pp. 1201–1229, Dec. 2015, doi: 10.1007/s12053-015-9389-4.

[2] M. Isaac and D. P. van Vuuren, “Modeling global residential sector energy demand for heating and air conditioning in the context of climate change,” Energy Policy, vol. 37, no. 2, pp. 507–521, 2009, doi: 10.1016/j.enpol.2008.09.051.

[3] S. Kulkarni, S. Chavali, and S. Dikshit, “A review on analysis of Vapour Compression Refrigeration System (VCRS) for its performance using different ecofriendly refrigerants and nanofluids,” Mater. Today Proc., vol. 72, pp. 878–883, 2023, doi: 10.1016/j.matpr.2022.09.085.

[4] Ashwni, A. F. Sherwani, and D. Tiwari, “Exergy, economic and environmental analysis of organic Rankine cycle based vapor compression refrigeration system,” Int. J. Refrig., vol. 126, pp. 259–271, 2021, doi: 10.1016/j.ijrefrig.2021.02.005.

[5] B. A. Qureshi and S. M. Zubair, “Mechanical sub-cooling vapor compression systems: Current status and future directions,” International Journal of Refrigeration, vol. 36, no. 8. pp. 2097–2110, 2013. doi: 10.1016/j.ijrefrig.2013.07.026.

[6] R. Yumrutaş, M. Kunduz, and M. Kanoğlu, “Exergy analysis of vapor compression refrigeration systems,” Exergy, An Int. J., vol. 2, no. 4, pp. 266–272, 2002, doi: 10.1016/s1164-0235(02)00079-1.

[7] A. S. Dalkilic and S. Wongwises, “A performance comparison of vapour-compression refrigeration system using various alternative refrigerants,” Int. Commun. Heat Mass Transf., vol. 37, no. 9, pp. 1340–1349, 2010, doi: 10.1016/j.icheatmasstransfer.2010.07.006.

[8] J. B. Jensen and S. Skogestad, “Optimal operation of simple refrigeration cycles. Part I: Degrees of freedom and optimality of sub-cooling,” Comput. Chem. Eng., vol. 31, no. 5–6, pp. 712–721, 2007, doi: 10.1016/j.compchemeng.2006.12.003.

[9] G. Pottker and P. Hrnjak, “Effect of the condenser subcooling on the performance of vapor compression systems,” Int. J. Refrig., vol. 50, pp. 156–164, 2015, doi: 10.1016/j.ijrefrig.2014.11.003.

[10] J. W. Thornton, S. A. Klein, and J. W. Mitchell, “Dedicated mechanical subcooling design strategies for supermarket applications,” Int. J. Refrig., vol. 17, no. 8, pp. 508–515, 1994, doi: 10.1016/0140-7007(94)90026-4.

[11] J. ur R. Khan and S. M. Zubair, “Design and rating of dedicated mechanical-subcooling vapour compression refrigeration systems,” Proc. Inst. Mech. Eng. Part A J. Power Energy, vol. 214, no. 5, pp. 455–471, 2000, doi: 10.1243/0957650001538010.

[12] S. M. Zubair, “Thermodynamics of a vapor-compression refrigeration cycle with mechanical subcooling,” Energy, vol. 19, no. 6, pp. 707–715, 1994, doi: 10.1016/0360-5442(94)90009-4.

[13] S. M. Zubair, “Improvement of refrigeration/air-conditioning performance with mechanical sub-cooling,” Energy, vol. 15, no. 5, pp. 427–433, 1990, doi: 10.1016/0360-5442(90)90039-5.