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# EVALUATION OF COP OF A VAPOUR COMPRESSION REFRIGERATION SYSTEM WITH VARYING LENGTH OF AIR COOLED CONDENSER

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**ABSTRACT:** Vapour-compression refrigeration is a significant refrigeration technology that is extensively used for air conditioning and refrigeration in buildings. Refrigerators used in large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services are among the many types of industrial plants that use large vapour-compression refrigeration systems. Natural gas processing plants are among the many types of industrial plants that use large vapour compression refrigeration systems. A circulating liquid refrigerant is used as the medium for vapour-compression, which absorbs and eliminates heat from the area to be cooled. The condenser is a device that cools a material to make it condense from a gas to a liquid form. It provides latent heat to the material by utilizing the condenser coolant. There are a variety of heat exchangers available, each with its own design and size.This paper provides an experimental and numerical analysis of two alternative options for improving COP in vapour compression systems, and we aim to design an evaporative condenser using the CREO-2 Software, which will assist the refrigerant cool at a quicker pace and improve the COP of the VCRS.

## 1. INTRODUCTION

### 1.1 Vapour Compression Refrigeration System Experimental Procedure:

The evaporator and condenser in a vapour compression refrigeration system are fabricated as shell and tube type adiabatic (insulated shell) heat exchangers, with the refrigerant fluid flowing through tubes and the external fluid remaining in the shell of both the evaporator and condenser. The refrigerant HFC-134a flows through copper tubes with outside and inside diameters of 9.5 mm and 8.5 mm. Water from the supply may flow through the shells of both the evaporator and the condenser, and there is a system in place for controlling and measuring the water flow rate.

During each trial, however, the evaporator shell's input and exit valves are closed, and a set quantity of brine is placed in the shell, which is cooled from ambient temperature to ultimate refrigeration temperature. An agitator is also installed in the evaporator shell to stir the brine and maintain temperature consistency throughout the shell. RTDs (Pt 100 at 0°C) firmly insulated throughout the length of tubes by polyurethane cellular foam are used to detect temperature at different locations. (Axial heat conduction was thus ignored.) In the meanwhile, the temperature of cooling water flowing at the entrance and exit of the condenser shell, as well as the temperature of a fixed quantity of brine filled in the evaporator shell, is recorded in the same manner. Pressure gauges indicate the refrigerant pressure.

## 2. LITERATURE REVIEW

Vapour compression refrigeration systems are now widely used in all refrigeration systems. It is a more advanced kind of air refrigeration cycle that employs a suitable working material known as refrigerant. Refrigeration is achieved in a vapour compression refrigeration system when the refrigerant evaporates at low temperatures. Ammonia ($NH_3$), carbon dioxide ($CO_2$) and sulphur-dioxide ($SO_2$) are the most common refrigerants used for this purpose. The mechanical energy needed to operate the compressor serves as the system's input. As a result, mechanical refrigeration systems are also known as mechanical refrigeration systems. The refrigerant utilized in the system is cycled throughout the system, condensing and evaporating alternately. The Evans-Perkins cycle, often known as the reverse Rankin cycle, provides the basis for the real vapour compression cycle. The refrigerant receives its latent heat from the solution used for circulating it around the cold chamber and condensing when it evaporates. It is critical to determine the top limit of performance of vapour compression cycles before discussing and analyzing the actual cycle. Due to a finite rate of heat exchange against a finite value of temperature difference and heat capacity, external irreversibility develops over the heat exchangers (condenser and evaporator). A fully reversible cycle sets this limit. The greater the temperature differential between the external fluid and the refrigerant as it passes through the evaporator and condenser, the better the heat transfer in the evaporator and condenser, as well as the cooling system. Using finite time thermodynamics, a vapour compression refrigeration system may be theoretically optimized and balanced under steady-state circumstances for design parameters such as evaporator and condenser pressure depending on the provided refrigeration. Domestic refrigerators, water coolers, cooling cabinets, cold storage, and food storage lockers are examples of applications. Because of the temperature differential between the refrigerant and the external fluid across the evaporator tubes as a function of time, heat transfer across the evaporator tubes should be minimized, lowering the system's performance. In this way, a condition may arise prior to the completion of the cooling job, i.e. the attainment of the required refrigeration temperature, when the temperature difference between the refrigerant and the external fluid over the evaporator is insufficient to maintain a reasonable amount of heat transfer and evaporation rate. The evaporator and condenser pressures are determined by the length of the capillary tube, and the length of the capillary tube may theoretically be optimized if the heat transfer conditions over the evaporator and condenser are steady state.

The evaporator pressure rises as the length decreases, and vice versa. We investigate the experimental values of refrigeration rate, power consumption, condenser duty, COP, and overall heat transfer coefficient in the condenser and evaporator, as well as their variation over time, and the role of capillary tube length, while the system is operating under real-world transient conditions. This research aids in the design and balancing of components of a "vapour compression refrigeration system" in order to improve its performance in real-world situations.

The research of the expansion device in a basic vapour compression refrigeration system by Sunil M. Telling et al. (2019) is required in order to understand the factors that may improve the overall performance of the system. The experiment was carried out on capillary tubes of various lengths (3 feet, 3.5 feet, and 4 feet), with each test segment being examined in three different configurations: helical coiled, straight coiled, and serpentine coiled. Each test section's diameter was maintained constant at 0.036 inch. The impact of the configuration and capillary tube length on the system's overall performance was investigated. The mass flow rate is highest for the straight design and lowest for the helical coiled form, according to the results of the experimental research. The helical coiled design had the greatest cooling impact, whereas the straight coiled shape had the least. As the system's load was raised, the compressor's work was found to decrease.

## 3. INPUT DATA OF COP OF A VAPOUR COMPRESSION REFRIGERATION SYSTEM WITH CHANGE IN LENGTH OF CONDENSER

| FLUID | | | |
|---|---|---|---|
| **Hot fluid** | | **Cold fluid** | |
| **Refrigerant- R134a** | | **Air** | |
| **Inlet mass flow** | **Pressure outlet** | **Inlet mass flow** | **Pressure outlet** |
| **0.05 kg/sec** | **2 bar** | **0.1 kg/sec** | **Environmental pressure** |

| CONDENSER | | |
|---|---|---|
| | **Long length** | **Short length** |
| **Length** | **1600mm** | **1200mm** |
| **Tube length** | **8000mm** | **7500mm** |
| **Diameter** | **20mm** | **20mm** |
| **Thickness** | **2mm** | **2mm** |

**Evaporative Condenser Design Using CREO:**

We are manually evaluating the values of an evaporative condenser based on the air and refrigeration data. For the condensation of ammonia vapours, an evaporative condenser is considered.

Cooling there are many kinds of condensers used in refrigerators, so we must choose one and install it.

The tube's length

L = 4000mm

W=2000mm width of the bundle

di=18.5mm inner diameter

do=19.5mm outside diameter

R134a was utilized as the refrigerant.

Temperature at the inlet:

| Temperature | pressure | | Density of liquid | Specific volume of vapour | Heat content enthalpy | |
|---|---|---|---|---|---|---|
| Fahrenheit | Psia | Psig | (lb./cu. ft.) | (cu.ft./lb.) | Liquid | Vapour |
| 100 | 138.28 | 123.58 | 71.70 | 0.340 | 44.393 | 114.782 |
| 125 | 198.27 | 183.57 | 67.68 | 0.232 | 53.385 | 117.660 |
| 150 | 276.12 | 261.42 | 63.13 | 0.159 | 62.989 | 119.879 |

## 4. MODELS OF EVAPORATIVE CONDENSER:

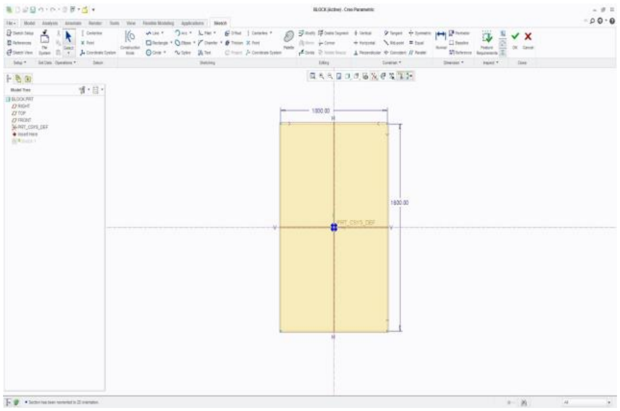

Fig: 4.1 2D Modeling of Evaporative condnser

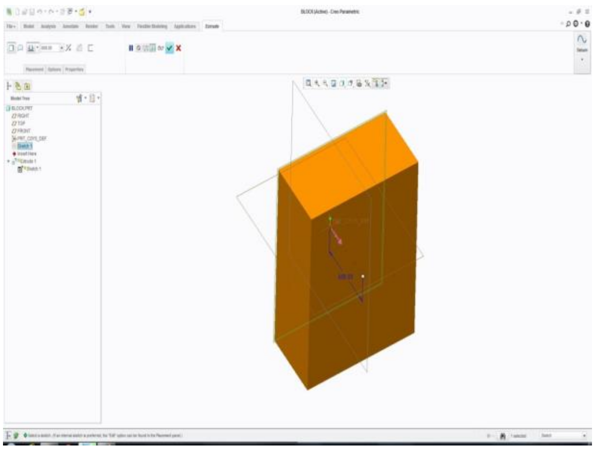

Fig 4.2 Extrusion of 2D Model of Evaporative condnser

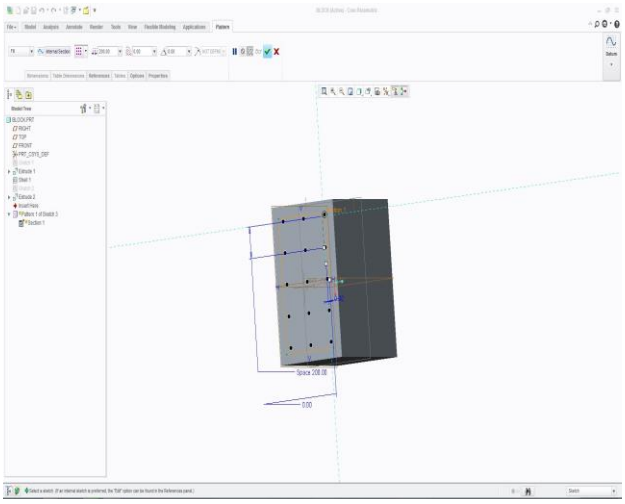

Fig: 4.3 Condenser tube nodal points width

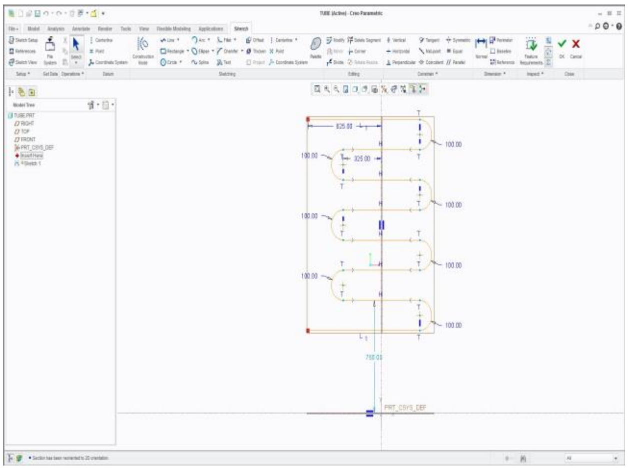

Fig: 4.4 Drawing Condenser tube axis

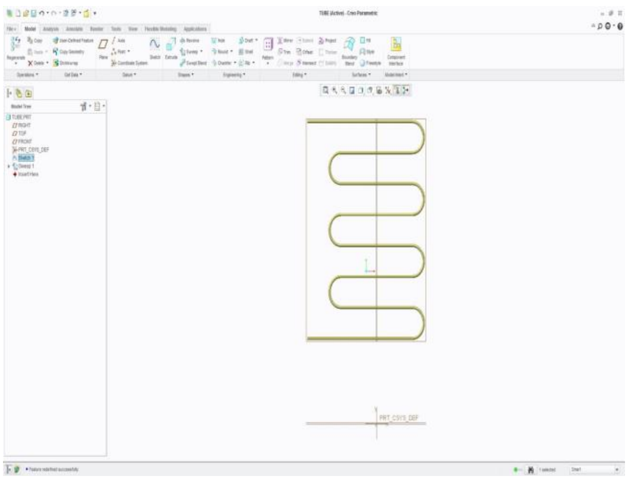

Fig: 4.5 Condenser tube modeling using sweep pattern

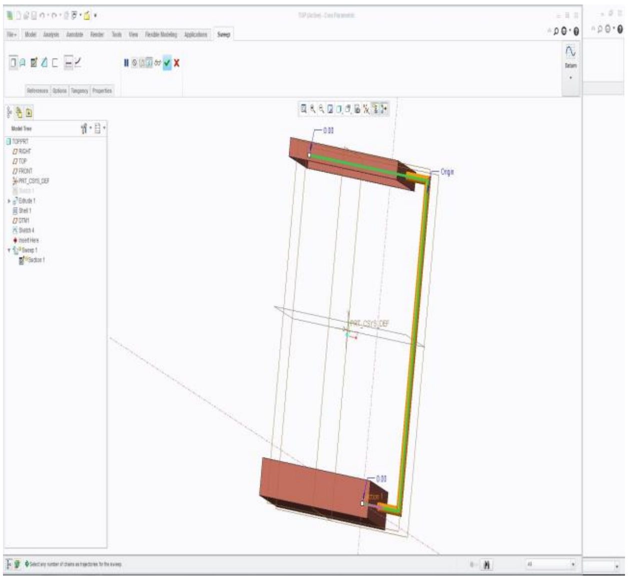

Fig 4.6 Inserting of Condenser tube

## 5. RESULTS AND DISCUSSION

### 5.1 Analysis of the Short Length Condenser by ANSYS:

While doing analysis the temperature changes take place fig shown below

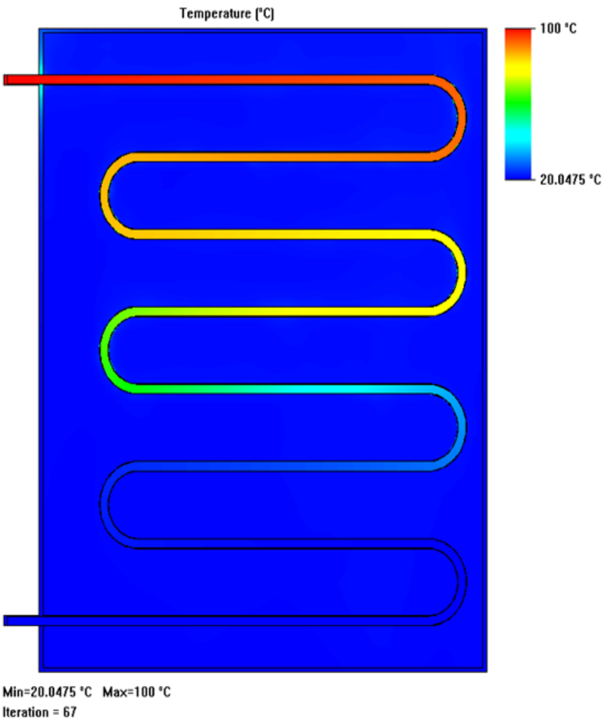


Fig 5.1 Temperature analysis using 67 Iteration

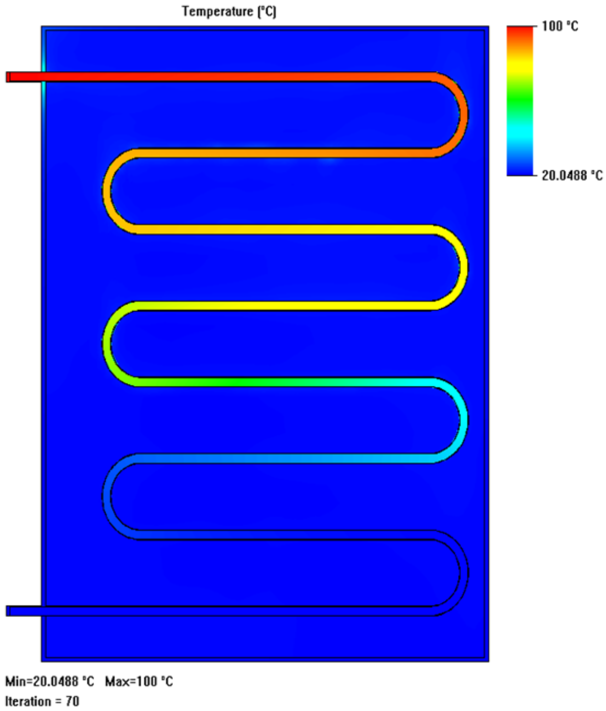


Fig 5.2 Temperature analysis using 70 Iteration

**Temperature at short length condenser:**

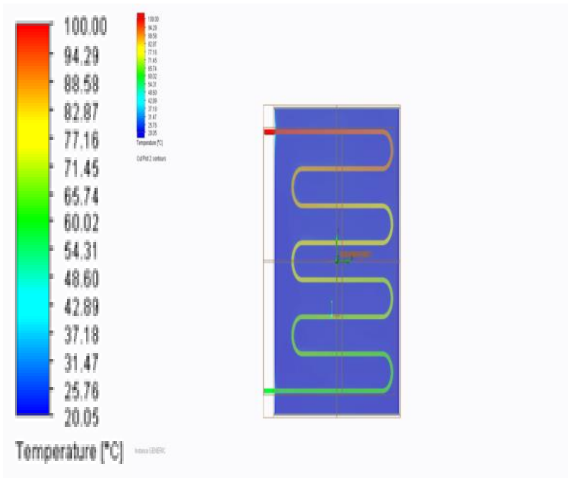


Fig 5.3 Temperature analysis of short length condenser

**Pressure:**

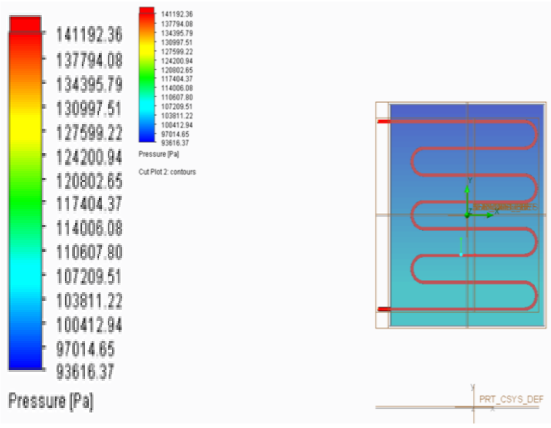


Fig 5.4 Pressure analysis of short length condenser

**Density:**

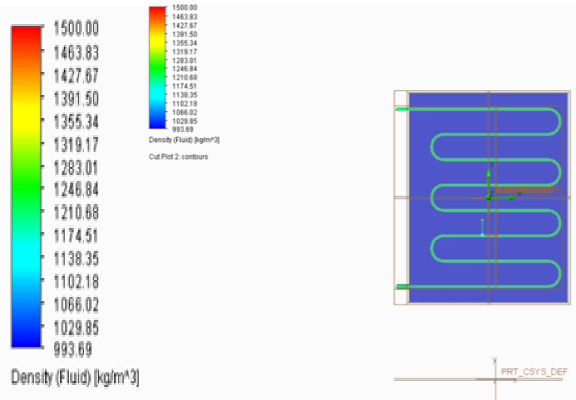


Fig 5.5 Density analysis of short length condenser

**Velocity:**

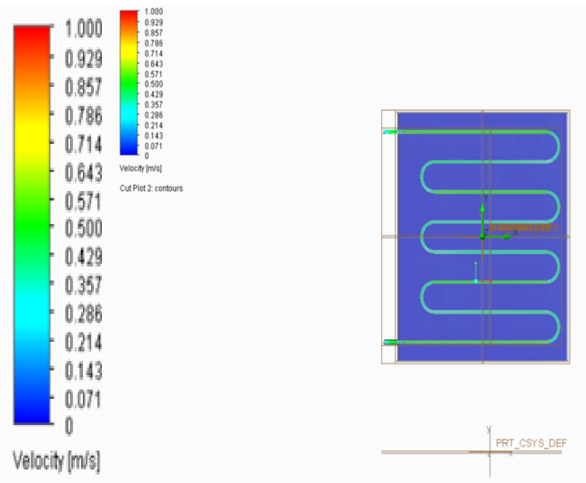


Fig 5.6 Velocity analysis of short length condenser

**Temperature Graph for short Length Condenser:**

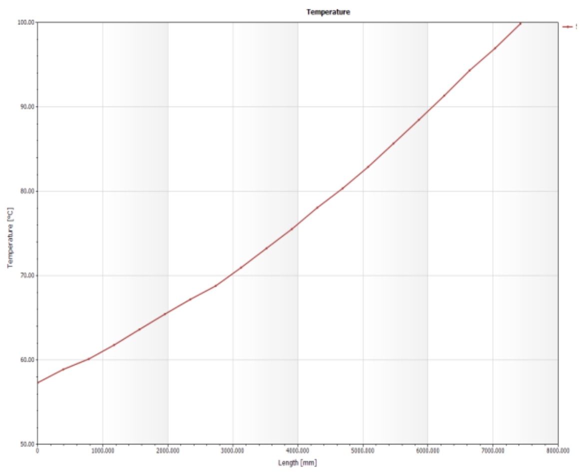


Fig 5.7 Temperature Graph for short Length Condenser

Table 5.1 Temperature Graph results

| Length (mm) | Temperature (°C) |
|---|---|
| 0.001 | 57.34595867 |
| 390.6043817 | 58.9086427 |
| 781.2077633 | 60.13520461 |
| 1171.811145 | 61.79762283 |
| 1562.414527 | 63.64386931 |
| 1953.017908 | 65.4573121 |
| 2343.62129 | 67.19949855 |
| 2734.224672 | 68.79916396 |
| 3124.828053 | 70.96431469 |
| 3515.431435 | 73.25033865 |
| 3906.034817 | 75.53290247 |
| 4296.638198 | 78.06286903 |
| 4687.24158 | 80.35103216 |
| 5077.844961 | 82.89024114 |
| 5468.448343 | 85.66985017 |
| 5859.051725 | 88.47499281 |
| 6249.655106 | 91.34149361 |
| 6640.258488 | 94.33034695 |
| 7030.86187 | 96.95371421 |
| 7421.465251 | 99.86033957 |

**Pressure Graph for Short Length Condenser:**

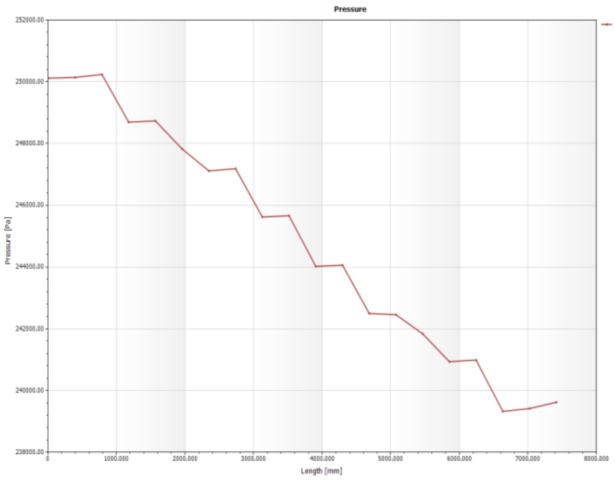


Fig 5.8 Pressure Graph for Short Length Condenser

Table 5.2 Pressure Graph Results

| Length (mm) | Pressure (Pa) |
|---|---|
| 8.692103042 | 250117.7146 |
| 398.4265779 | 250142.6772 |
| 788.1610528 | 250236.1804 |
| 1177.895528 | 248692.9246 |
| 1567.630003 | 248733.7135 |
| 1957.364477 | 247825.4632 |
| 2347.098952 | 247114.7909 |
| 2736.833427 | 247186.4945 |
| 3126.567902 | 245622.2098 |
| 3516.302377 | 245662.8824 |
| 3906.036852 | 244021.2674 |
| 4295.771327 | 244062.561 |
| 4685.505802 | 242499.0487 |
| 5075.240277 | 242458.0113 |
| 5464.974751 | 241841.1102 |
| 5854.709226 | 240937.3641 |
| 6244.443701 | 240987.8554 |
| 6634.178176 | 239326.0194 |
| 7023.912651 | 239419.9705 |
| 7413.647126 | 239621.711 |

**Density Graph for Short Length Condenser:**

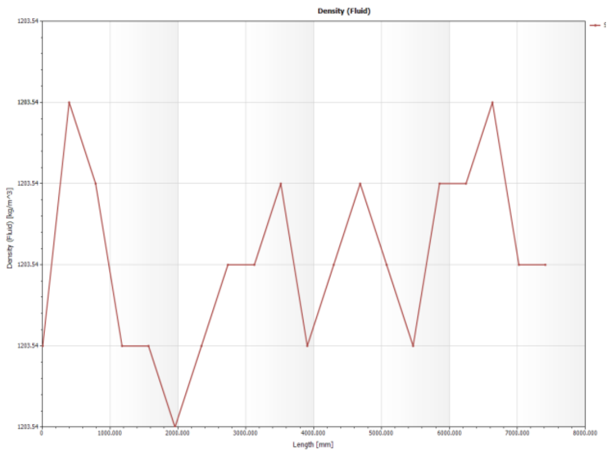


Fig 5.9 Density Graph for Short Length Condenser

Table 5.3 Density Graph Results

| Length (mm) | Density (Fluid) (kg/m^3) |
|---|---|
| 8.692103042 | 1203.53511 |
| 398.4265779 | 1203.53511 |
| 788.1610528 | 1203.53511 |
| 1177.895528 | 1203.53511 |
| 1567.630003 | 1203.53511 |
| 1957.364477 | 1203.53511 |
| 2347.098952 | 1203.53511 |
| 2736.833427 | 1203.53511 |
| 3126.567902 | 1203.53511 |
| 3516.302377 | 1203.53511 |
| 3906.036852 | 1203.53511 |
| 4295.771327 | 1203.53511 |
| 4685.505802 | 1203.53511 |
| 5075.240277 | 1203.53511 |
| 5464.974751 | 1203.53511 |
| 5854.709226 | 1203.53511 |
| 6244.443701 | 1203.53511 |
| 6634.178176 | 1203.53511 |
| 7023.912651 | 1203.53511 |
| 7413.647126 | 1203.53511 |

**Velocity Graph of Short Length Condenser:**

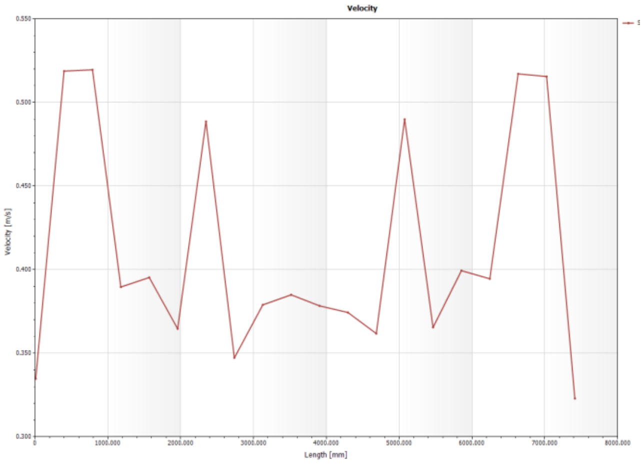


Fig 5.10 Velocity Graph for Short Length Condenser

Table 5.4 Velocity Graph Results

| Length (mm) | Velocity (m/s) |
|---|---|
| 8.692103042 | 0.334753654 |
| 398.4265779 | 0.518724717 |
| 788.1610528 | 0.519513216 |
| 1177.895528 | 0.389616189 |
| 1567.630003 | 0.395310989 |
| 1957.364477 | 0.364666339 |
| 2347.098952 | 0.488594717 |
| 2736.833427 | 0.347264241 |
| 3126.567902 | 0.378946198 |
| 3516.302377 | 0.384940163 |
| 3906.036852 | 0.37836263 |
| 4295.771327 | 0.374370263 |
| 4685.505802 | 0.361783484 |
| 5075.240277 | 0.489863951 |
| 5464.974751 | 0.365477312 |
| 5854.709226 | 0.39940467 |
| 6244.443701 | 0.39453166 |
| 6634.178176 | 0.517075322 |
| 7023.912651 | 0.515501528 |
| 7413.647126 | 0.322941516 |

**5.2 Temperature Analysis of Long Length Condenser by ANSYS:**

While doing analysis the temperature changes take place fig shown below

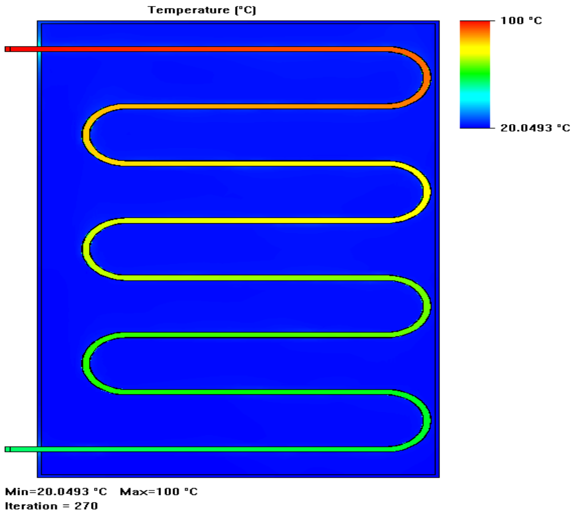


Fig 5.11 Temperature analysis using 270 Iterations

**Temperature:**

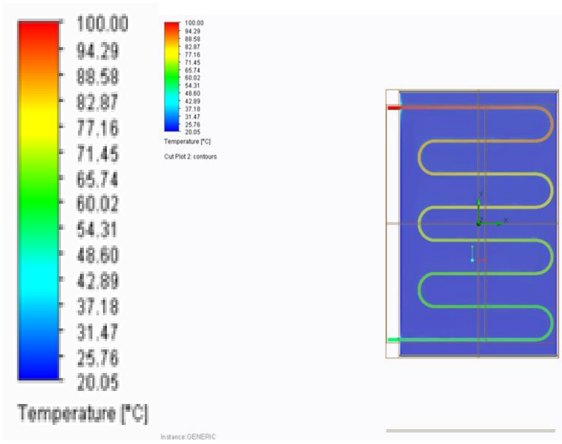


Fig 5.12 Temperature analysis for Long length condenser

**Pressure:**

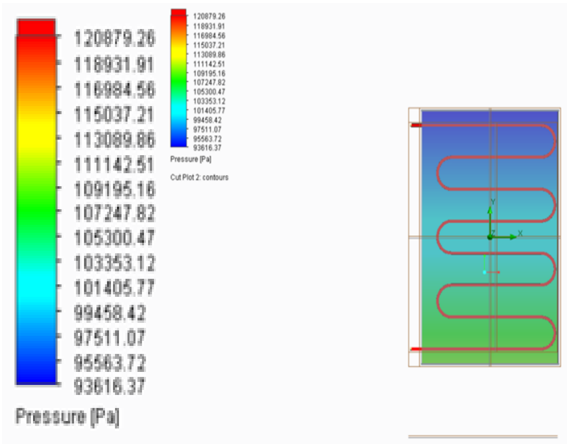


Fig 5.13 Pressure analysis for Long length condenser

**Density:**

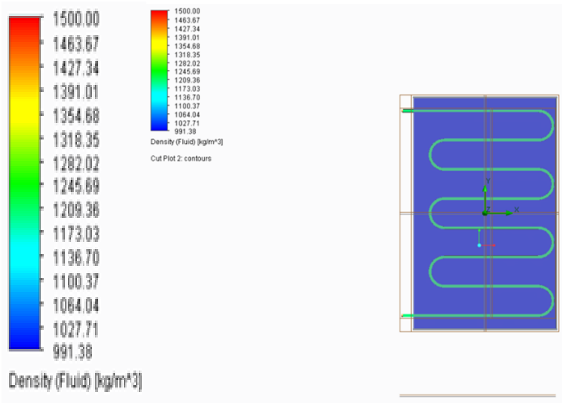


Fig 5.14 Density analysis for Long length condenser

**Velocity:**

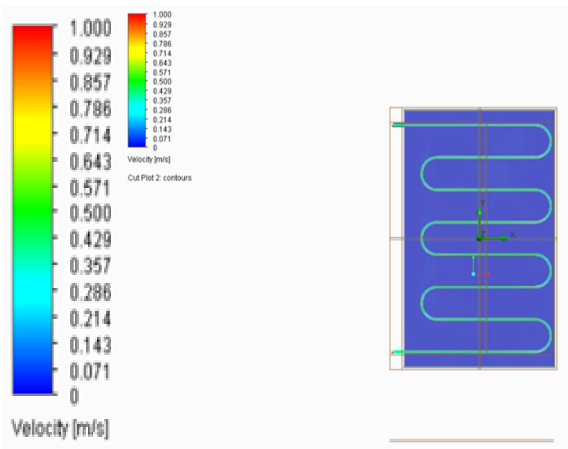


Fig 5.15 Velocity analysis for Long length condenser

**Temperature Graph for Long Length Condenser:**

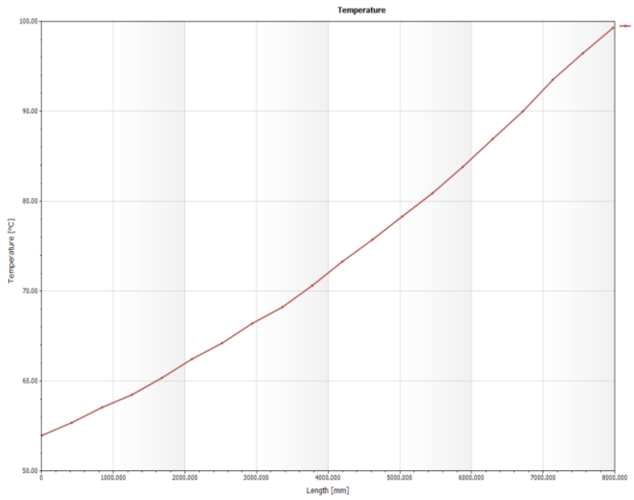

Fig 5.16 Temperature Graph for Long Length Condenser

Table 5.5 Temperature Graph Results

| Length (mm) | Temperature (°C) |
|---|---|
| 4.44089E-13 | 53.96297663 |
| 332.8319183 | 55.04635496 |
| 665.6638366 | 56.42301546 |
| 998.4957548 | 57.77625852 |
| 1331.327673 | 58.74881243 |
| 1664.159591 | 60.30561664 |
| 1996.99151 | 61.96937617 |
| 2329.823428 | 63.36647377 |
| 2662.655346 | 64.87834195 |
| 2995.487264 | 66.31103175 |
| 3328.319183 | 67.99908447 |
| 3661.151101 | 70.0311358 |
| 3993.983019 | 71.95977769 |
| 4326.814938 | 74.01379432 |
| 4659.646856 | 75.97257098 |
| 4992.478774 | 77.9396234 |
| 5325.310692 | 79.97323471 |
| 5658.142611 | 82.0801168 |
| 5990.974529 | 84.83358548 |
| 6323.806447 | 87.05272486 |
| 6656.638366 | 89.415464 |
| 6989.470284 | 92.27550838 |
| 7322.302202 | 94.76427911 |

| | |
|---|---|
| 7655.13412 | 97.08584892 |
| 7987.966039 | 99.26701338 |

**Pressure Graph for Long Length Condenser:**

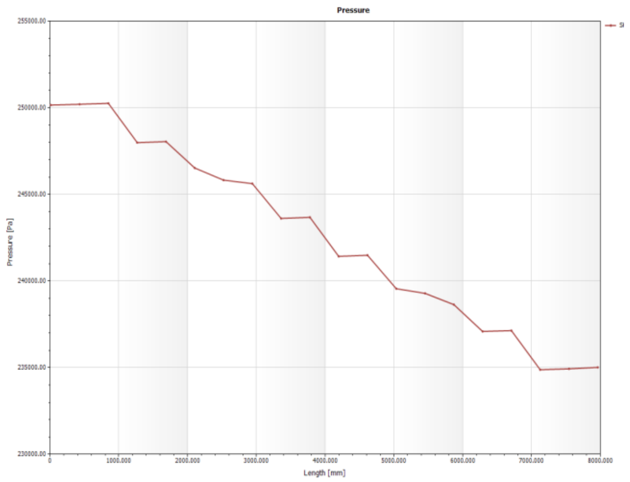


Fig 5.17 Pressure Graph for Long Length Condenser

Table 5.6 Pressure Graph Results

| Length (mm) | Pressure (Pa) |
|---|---|
| 11.38987423 | 250156.9528 |
| 343.272678 | 250189.9247 |
| 675.1554817 | 250230.7424 |
| 1007.038285 | 250099.7308 |
| 1338.921089 | 247997.8853 |
| 1670.803893 | 248041.0425 |
| 2002.686697 | 247656.2409 |
| 2334.569501 | 245795.7638 |
| 2666.452304 | 245842.078 |
| 2998.335108 | 245120.5105 |
| 3330.217912 | 243605.355 |
| 3662.100716 | 243656.9943 |
| 3993.983519 | 242559.774 |
| 4325.866323 | 241441.4119 |
| 4657.749127 | 241492.2049 |
| 4989.631931 | 240029.6899 |
| 5321.514734 | 239268.6451 |
| 5653.397538 | 239314.1811 |

| | |
|---|---|
| 5985.280342 | 237539.6761 |
| 6317.163146 | 237092.3429 |
| 6649.045949 | 237134.5521 |
| 6980.928753 | 235074.6731 |
| 7312.811557 | 234902.042 |
| 7644.694361 | 234942.6583 |
| 7976.577164 | 235015.8219 |

**Density Graph of Long Length Condenser:**

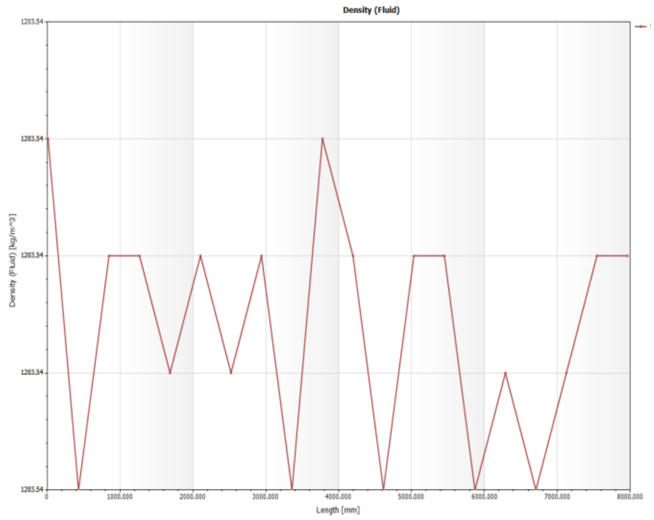


Fig 5.18 Density Graph for Long Length Condenser

Table 5.7 Density Graph Results

| Length (mm) | Density (Fluid) (kg/m^3) |
|---|---|
| 11.38987423 | 1203.53511 |
| 429.87936 | 1203.53511 |
| 848.3688458 | 1203.53511 |
| 1266.858332 | 1203.53511 |
| 1685.347817 | 1203.53511 |
| 2103.837303 | 1203.53511 |
| 2522.326789 | 1203.53511 |
| 2940.816275 | 1203.53511 |
| 3359.305761 | 1203.53511 |

| | |
|---|---|
| 3777.795247 | 1203.53511 |
| 4196.284732 | 1203.53511 |
| 4614.774218 | 1203.53511 |
| 5033.263704 | 1203.53511 |
| 5451.75319 | 1203.53511 |
| 5870.242676 | 1203.53511 |
| 6288.732161 | 1203.53511 |
| 6707.221647 | 1203.53511 |
| 7125.711133 | 1203.53511 |
| 7544.200619 | 1203.53511 |
| 7962.690105 | 1203.53511 |

**Velocity Graph of Long Length Condenser:**

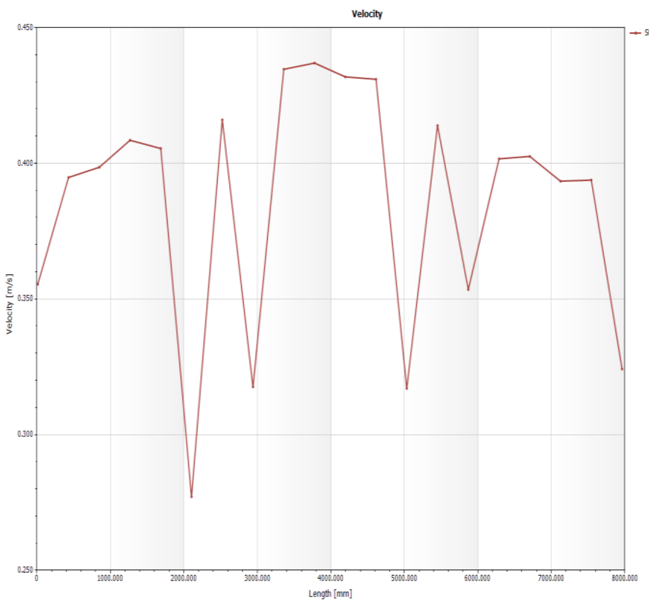


Fig 5.19 Velocity Graph of Long Length Condenser

Table 5.8 Velocity Graph Results

| Length (mm) | Velocity (m/s) |
|---|---|
| 11.38987423 | 0.355408375 |
| 343.272678 | 0.394491589 |
| 675.1554817 | 0.396598205 |
| 1007.038285 | 0.283652915 |
| 1338.921089 | 0.403446063 |
| 1670.803893 | 0.405279831 |
| 2002.686697 | 0.315617614 |
| 2334.569501 | 0.415578148 |
| 2666.452304 | 0.41666662 |
| 2998.335108 | 0.364711394 |
| 3330.217912 | 0.434562871 |
| 3662.100716 | 0.435770266 |
| 3993.983519 | 0.403058562 |
| 4325.866323 | 0.431726593 |
| 4657.749127 | 0.430704056 |
| 4989.631931 | 0.359387818 |
| 5321.514734 | 0.413705043 |
| 5653.397538 | 0.413186805 |
| 5985.280342 | 0.320848026 |
| 6317.163146 | 0.401691263 |
| 6649.045949 | 0.401177727 |
| 6980.928753 | 0.33651849 |
| 7312.811557 | 0.393514809 |
| 7644.694361 | 0.393879206 |
| 7976.577164 | 0.324153889 |

**5.3 Summary of Results and Discussion:**

Table 5.1 Results for Short Length Condenser

| **Short Length Condenser** | |
|---|---|
| Change in Temperature (°C) | 42.66 |
| Change in Specific Enthalpy (KJ/kg) | 124.7 |
| Heat Rejection from Condenser (KJ/sec) | 6.0185 |
| Refrigeration Effect (KJ/sec) | 3.9 |

| | |
|---|---|
| COP | 1.92 |

Table 5.2 Results for Long Length Condenser

| Long Length Condenser | |
|---|---|
| Change in Temperature (°C) | 46 |
| Change in Specific Enthalpy (KJ/kg) | 129.37 |
| Heat Rejection from Condenser (KJ/sec) | 6.46 |
| Refrigeration Effect (KJ/sec) | 4.4 |
| COP | 2.13 |

Table 5.3 Comparison of Short and Long Length Condensers

| Condenser | Length (mm) | COP |
|---|---|---|
| Short Length Condenser | 7500 | 1.92 |
| Long Length Condenser | 8000 | 2.13 |

**Reduction in Temperature at Exit of Condenser tube:**

As the Length of Condenser increases Surface area of Condenser increases, as a result we obtain Reduction in Temperature at Exit of Condenser tube.

**Reduction in Enthalpy at Exit of Condenser tube:**

We know that Enthalpy is function of Temperature,

$$h = f(T)$$

So, As the Length of Condenser increases there is an Reduction in Enthalpy at Exit of Condenser tube.

**Heat Rejection from Condenser tube:**

$$Q_c \ \alpha \ \triangle T$$

$$Q_c \ \alpha \ \triangle h$$

So, As the Length of Condenser increases there is an increase in Heat Rejection from Condenser tube taking place.

**COP of Evaporative Condenser:**

By varying the length of air cooled condenser in vapour compression refrigeration System COP increased from 1.92 to 2.13.

## 6. CONCLUSIONS:

This research looks at how the length of the condenser and capillary tubes, as well as the refrigerant charge, affect the performance of a basic vapour compression refrigeration system.

It was discovered that as soon as the compressor is turned on, the charge is quickly transferred from the evaporator to the condenser through the compressor, followed by a relatively sluggish refilling of the evaporator via the capillary tube.

The decrease in system performance from the homogeneous (best case scenario) to the liquid pooling (worst case scenario) distribution varied from 0% to 3% in terms of COP, according to the findings.

The negative impact of mal-distribution on COP is further increased by lower values of condenser sub cooling and higher capacity, according to the findings.

Despite the fact that liquid pooling distribution is arguably the worst scenario in terms of condenser mal-distribution, its effect on COP was minor when compared to evaporator mal-distribution.

The COP degradation was shown to be significantly lower in milder situations, such as the linear refrigerant distribution, at about 1%.The COP of a vapour compression refrigeration System was improved from 1.92 to 2.13 by changing the length of the air cooled condenser.

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