Design Based Comparative Study of Several Condensers

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Abstract:

Condenser is an important component of any refrigeration system. In this paper we have considered three different types of condenser based on the cooling medium, namely, Air Cooled Condenser, Water Cooled Condenser and Evaporative Cooled Condenser. The paper deals with detail design of the three condensers and their qualitative as well as quantitative comparison.

Keyword: *Air Cooled Condenser, Water Cooled Condenser, Evaporative Condenser, Design of Condenser, Comparison of Condensers*

1. INTRODUCTION

Condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium. The refrigerant may leave the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the external medium and design of the condenser.

In actual refrigeration systems with a finite pressure drop in the condenser or in a system using azeotropic refrigerant mixture, the temperature of the refrigerant changes during the condensation process also. However, at present for simplicity, it is assumed that the refrigerant used is a pure refrigerant and the condenser pressure remains constant during the condensation process.

2. CLASSIFICATION OF CONDENSER

Based on the cooling medium used, condensers used in refrigeration systems can be classified into the following three categories:

1. Air-cooled condensers
2. Water-cooled condensers
3. Evaporative condensers

2.1 Air Cooled Condenser

As the name implies, in air-cooled condensers air is the external fluid, i.e., the refrigerant rejects heat to air flowing over the condenser. Air-cooled condensers can be further classified into natural convection type or forced convection type.

2.1.1 Natural convection type:

In natural convection type, heat transfer from the condenser is by buoyancy induced natural convection and radiation. Since the flow rate of air is small and the radiation heat transfer is also not very high, the combined heat transfer coefficient in these condensers is small. As a result a relatively large condensing surface is required to reject a given amount of heat. Hence these condensers are used for small capacity refrigeration systems like household refrigerators and freezers. The natural convection type condensers are either plate surface type or finned tube type. In plate surface type condensers used in small refrigerators and freezers, the refrigerant carrying tubes are attached to the outer walls of the refrigerator. The whole body of the refrigerator (except the door) acts like a fin. Insulation is provided between the outer cover that acts like fin and the inner plastic cover of the refrigerator. It is for this reason that outer body of the refrigerator is always warm. Since the surface is warm, the problem of moisture condensation on the walls of the refrigerator does not arise in these systems. These condensers are sometimes called as flat back condensers.

The finned type condensers are mounted either below the refrigerator at an angle or on the backside of the refrigerator. In case, it is mounted below, then the warm air rises up and to assist it an air envelope is formed by providing a jacket on backside of the refrigerator. The fin spacing is kept large to minimize the effect of fouling by dust and to allow air to flow freely with little resistance.

In this design, the condenser tube (in serpentine form) was attached to a plate and the plate was mounted on the backside of the refrigerator. The plate acted like a fin and warm air rose up along it.

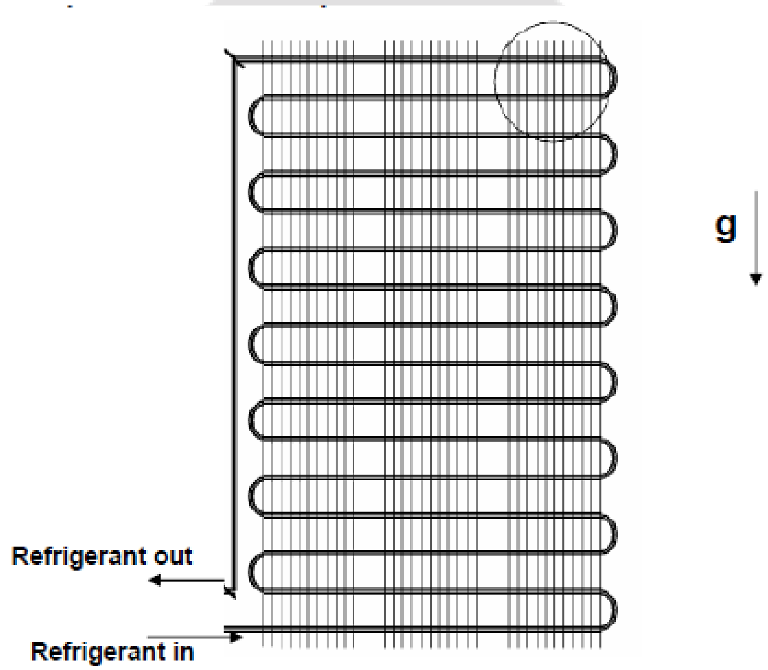

Figure 1: Schematic of a wire-and-tube type condenser used in small refrigeration systems

2.1.2 Forced convection type:

In forced convection type condensers, the circulation of air over the condenser surface is maintained by using a fan or a blower. These condensers normally use fins on air-side for good heat transfer. The fins can be either plate type or annular type. Figure 2 shows the schematic of a plate-fin type condenser. Forced convection type condensers are commonly used in window air conditioners, water coolers and packaged air conditioning plants. These are either chassis mounted or remote mounted. In chassis mounted type, the compressor, induction motor, condenser with condenser fan, accumulator, HP/LP cut- out switch and pressure gauges are mounted on a single chassis. It is called condensing unit of rated capacity. The components are matched to condense the required mass flow rate of refrigerant to meet the rated cooling capacity.

The remote mounted type, is either vertical or roof mounted horizontal type. Typically the air velocity varies between 2 m/s to 3.5 m/s for economic design with airflow rates of 12 to 20 cmm per ton of refrigeration (TR). The air specific heat is 1.005 kJ/kg-K and density is 1.2 kg/m^3. Therefore for 1 TR the temperature rise Δt_a = 3.5167/ (1.2x1.005 x 16/60) = 10.9^{o}C for average air flow rate of 16 cmm. Hence, the air temperature rises by 10 to 15^{o}C as compared to 3 to 6^{o}C for water in water cooled condensers.

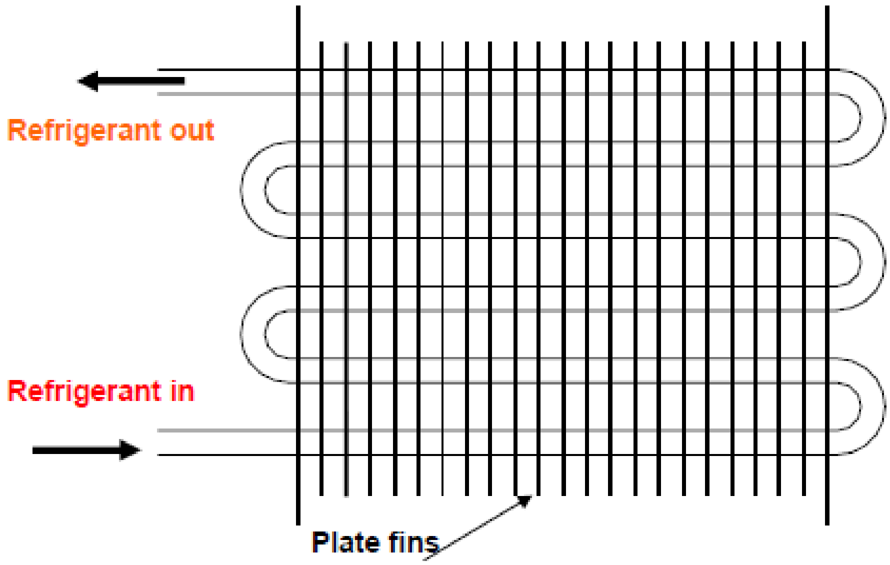

Figure 2: Forced convection plate fin and tube type condenser

The area of the condenser seen from outside in the airflow direction is called face area. The velocity at the face is called face velocity. This is given by the volume flow rate divided by the face area. The face velocity is usually around 2m/s to 3.5 m/s to limit the pressure drop due to frictional resistance. The coils of the tube in the flow direction are called rows. A condenser may have two to eight rows of the tubes carrying the refrigerant. The moist air flows over the fins while the refrigerant flows inside the tubes.

The fins are usually of aluminum and tubes are made of copper. Holes of diameter slightly less than the tube diameter are punched in the plates and plates are slid over the tube bank. Then the copper tubes are pressurized which expands the tubes and makes a good thermal contact between the tube and fins. This process is also known as bulleting. For ammonia condensers mild steel tubes with mild steel fins are used. In this case the fins are either welded or galvanizing is done to make a good thermal contact between fin and tube. In case of ammonia, annular crimpled spiral fins are also used over individual tubes instead of flat-plate fins. In finned tube heat exchangers the fin spacing may vary from 3 to 7 fins per cm. The secondary surface area is 10 to 30 times the bare pipe area hence; the finned coils are very compact and have smaller weight.

2.2 Water Cooled Condenser

In water cooled condensers water is the external fluid. Depending upon the construction, water cooled condensers can be further classified into:

1. Double pipe or tube-in-tube type
2. Shell-and-coil type
3. Shell-and-tube type

2.2.1 Double Pipe or tube-in-tube type:

Double pipe condensers are normally used up to 10 TR capacity. These condensers the cold water flows through the inner tube, while the refrigerant flows through the annulus in counter flow. Headers are used at both the ends to make the length of the condenser small and reduce pressure drop. The refrigerant in the annulus rejects a part of its heat to the surroundings by free convection and radiation. The heat transfer coefficient is usually low because of poor liquid refrigerant drainage if the tubes are long.

2.2.2 Shell-and-coil type:

These condensers are used in systems up to 50 TR capacity. The water flows through multiple coils, which may have fins to increase the heat transfer coefficient. The refrigerant flows through the shell. In smaller capacity condensers, refrigerant flows through coils while water flows through the shell. When water flows through the coils, cleaning is done by circulating suitable chemicals through the coils.

2.2.3 Shell-and-tube type:

This is the most common type of condenser used in systems from 2 TR upto thousands of TR capacity. In these condensers the refrigerant flows through the shell while water flows through the tubes in single to four passes. The condensed refrigerant collects at the bottom of the shell. The coldest water contacts the liquid refrigerant so that some subcooling can also be obtained. The liquid refrigerant is drained from the bottom to the receiver. There might be a vent connecting the receiver to the condenser for smooth drainage of liquid refrigerant. The shell also acts as a receiver. Further the refrigerant also rejects heat to the surroundings from the shell. The most common type is horizontal shell type.

Vertical shell-and-tube type condensers are usually used with ammonia in large capacity systems so that cleaning of the tubes is possible from top while the plant is running.

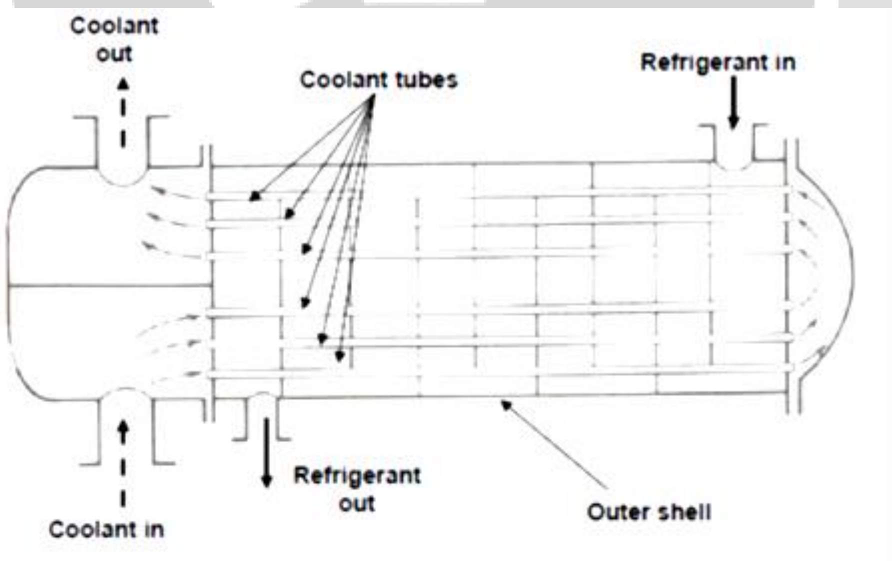

Figure 3: Shell and tube

2.3 Evaporative condenser

In evaporative condensers, both air and water are used to extract heat from the condensing refrigerant. Figure 4 shows the schematic of an evaporative condenser. Evaporative condensers combine the features of a cooling tower and water-cooled condenser in a single unit. In these condensers, the water is sprayed from top part on a bank of tubes carrying the refrigerant and air is induced upwards. There is a thin water film around the condenser tubes from which evaporative cooling takes place. The heat transfer coefficient for evaporative cooling is very large. Hence, the refrigeration system can be operated at low condensing temperatures (about 11 to 13 K above the wet bulb temperature of air). The water spray countercurrent to the airflow acts as cooling tower. The role of air is primarily to increase the rate of evaporation of water. The required air flow rates are in the range of 350 to 500 m^3/h per TR of refrigeration capacity.

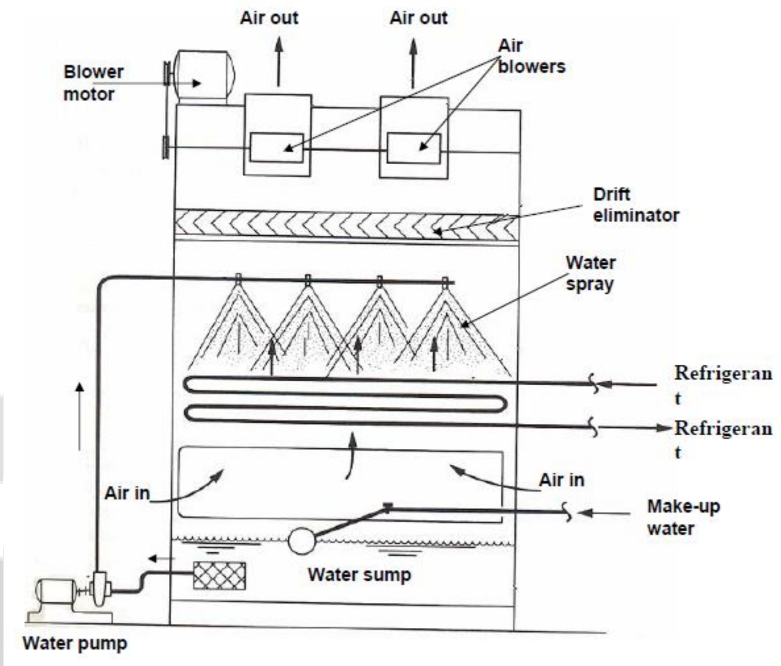

Figure 4: Schematic of evaporative condenser

3. CASE STUDY

Case Study – 1 (Water Cooled Condenser)

A chilling plant is designed to achieving 703 kW (≈ 200 TR) heat exchange capacity to supply aqueous ethylene glycol brine at -25 °C by evaporating liquid ammonia in the evaporator at -33.3 °C (and 1 atm.). Ammonia vapor at -28 °C leave the evaporator and sent to compressor. In first alternative, a shell and tube heat exchanger (BEM) is considered as condenser. Superheated ammonia vapor at 120 °C and at 16.435 bar a from the compressor enters the shell of the condenser at 42 °C. Cooling water enters the tubes at 32 °C and leaves at 38 °C. For this duty design a BEM type horizontal condenser. Consider the tube OD and length as 19.05 mm (16 BWG) and 2.4383 m (8 ft) respectively. Triangular pitch = $1.25d_o$

Case Study – 2 (Air Cooled Condenser)

An air cooler is considered for condensing ammonia. Ambient air at 45 °C is supplied to the condenser while ammonia is condensed at 60 °C in the tubes. Compressed ammonia gas enters the condenser at 130 °C. A pressure drop of 15 kPa is permitted in the condenser. Condenser will have two pass arrangements in finned tubes and leaves from top at 50 °C. each horizontal tube row can be considered as a pass.

Effective tube details:

SS 304 with OD = 19.05 mm and triangular pitch of 43 mm

Fin details:

Type fin : Spiral wound transverse fins, SS 304 MOC, Fin OD = 38 mm

8 fins per linear inch and fin thickness = 0.889 mm

Tube length = 3 m

Width of air cooler = 3 m

Design of an air cooler for ammonia condensation duty.

Case Study – 3 (Evaporative Condenser)
An evaporative condenser is considered for condensing ammonia. An evaporative condenser is basically a rectangular tube bundle installed in cooling tower. Cooling tower falls over the tubes at a required rate at essentially a constant temperature; 4.5 °C above the design wet bulb temperature of air. Ambient air at 40 °C dry bulb temperature (DB) and 28 °C wet bulb temperature (WB) is supplied from sides of the tower. An induced draft fan sucks the air from the louvers and discharges it from top with 95% relative humidity (RH). Ammonia gas enters at 120 °C the tubes and condenses at 1.5 °C higher that the cooling water temperature. Design the tube bundle to be placed in the evaporative condenser. For the evaporation of water film over tube bundle, heat transfer coefficient can be determined by Kallam's equitation.

$h_o = 7.3 \times 10^{-9} \times N^{0.05} \left(\frac{G^{0.3}\ YZ\ d_o}{\mu\ P_v}\right)^{4.4}$

where, h_o = heat transfer coefficient, W/(m^2. °C)

Parameters to be calculated	**Water Cooled Condenser**		**Air Cooled Condenser**	**Evaporative Condenser**	
Total heat duty of condenser	ϕ	905.2	917.797	897.45	kW
Heat duty for desuperheating zone	ϕ_{de}	159.6	168.825	155.303	kW
Heat duty for condensation zone	ϕ_c	745.6	748.972	742.45	kW
Circulation rate of ammonia	$\dot{m}_a$	2462.8	2703.56	2372.11	kg/h
Circulation rate of water /air	$\dot{m}_w$ /$\dot{m}_{air}$	129724	515196	1332	kg/h
Mean temp. difference for desuperheating zone	ΔT_{mde}	27.62	37.83	21.15	°C
Mean temp. difference for condesation zone	ΔT_{mc}	7.25	14.133	1.5	°C
Tube side heat transfer coefficient	h_i				
For desuperheating zone		6576.12	434.4	370.45	W/m^2.°C
For condensation zone			6673.36	6556.2	W/m^2.°C
Shell side heat transfer coefficient for desuperheating zone	h_o	223.2	196.3	12071	W/m^2.°C
Shell side heat transfer coefficient for condensation zone	h_{oc}	11910.4	1240.5		W/m^2.°C
Overall heat transfer coefficient for desuperheating zone	U_{ode}	190.3	302.3	248.5	W/m^2.°C
overall heat transfer coefficient for condensation zone	U_{oc}	1165.28	865.07	1327.4	W/m^2.°C
Area required for desuperheating zone	A_{rde}	30.36	14.726	29.55	m^2
Area required for condensation zone	A_{rc}	88.155	61.26	372.88	m^2
Total area required	A_r	118.515	76.03	402.43	m^2
Area provided	A_{pr}	136.59	86.773	457.64	m^2
Excess area		15.25%	14.213%	13.720%	
Tube side pressure drop	ΔP_t	69.6			kPa
Shell pressure drop /Air side pressure drop	ΔP_s	0.2849	3.255		kPa

Table 1: Summary of Design results of three condensers

4. CONCLUSION

From the results it is conclude that the heat duties for desuperheating and condensation descends in the order of Air Cooled Condenser, Water Cooled Condenser and Evaporative Condenser, this implies that the overall heat duty for Evaporative Condenser is the least.

The circulation rate for Ammonia and Water is also least for evaporative condenser; in fact it is 100 times less for water circulation rate for water cooled evaporator and 386 times less from air cooled.

The Tube side heat transfer coefficient is maximum for Water cooled evaporator and minimum for evaporative condenser on the other hand for condensation the tube side heat transfer coefficient is higher for air cooled condenser.

The Shell side heat transfer coefficient for desuperheating zone is highest for evaporative condenser and lowest for Air Cooled Condenser, on the flip side the Shell side heat transfer coefficient for condensation zone is highest for Water Cooled Condenser.

Therefore, Overall heat transfer coefficient for desuperheating zone and condensation zone is falling in between the Air Cooled Condenser and the Water Cooled Condenser for evaporative condenser.

Here, it is evident from the results that the heat transfer area required is greatest for evaporative condenser.

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