CHAPTER – I
INTRODUCTION

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In the field of Bio-medical science, we require to stores biological specimens. These biological specimens may be various organs of Human and animals, stem cell, blood, sperm etc. For storing of these specimens, a temperature of below -80^0 C is required. But due to devitrification & crystalization effect temperature below -120^0 C is assumed to be safe **[1]**.

With the help of simple vapour compression refrigeration system, we can achieve -40^0 C temperature comfortably. If the temperature difference between the condensing temperature and evaporating temperature is more, than the COP or efficiency of the system drops rapidly. This rapid decrease in efficiency occurs below -35^0 C in a single stage vapour compression system. Thus to achieve the lower temperature one should use cascade refrigeration system **[2]**.

In a cascade refrigeration system, two or more refrigeration systems are connected with the help of cascade heat exchanger. These refrigeration system works independent to each other. The cascade heat exchanger works, as a condensor of low temperature circuit (LTC) and as an evaporator of high temperature circuit (HTC). The heat released in condenser of LTC should be equal to the heat absorbed from the evaporator of HTC.

When the temperature required is very low than three stage cascade refrigeration system is utilized. Three stage Cascade refrigeration systems consist of three simple vapour compression refrigeration systems that work independently. The all three refrigeration systems are connected by two cascade heat exchanger. The first cascade heat exchanger works as the evaporator for the 1st stage and the condenser for the 2nd stage. The second cascade heat exchanger works as the evaporator for the 2nd stage and the condenser for the 3rd stage. In cascade heat exchanger (HE-1) heat is released in the condenser of medium-temperature circuit (MTC or stage-II) and is absorbed from the evaporator of high-temperature circuit (HTC or stage-I). In the HE-II heat is released in the condenser of low-temperature circuit (LTC or stage - III) and is absorbed from the evaporator of medium-temperature circuit (MTC or stage II).

The Montreal Protocol [3] UNEP (1999) emphasize to reduce the use of chloro-fluoro carbons (CFCs) & Hydro chloro-fluoro carbons (HCFCs). These CFCs has been phased out by year 2000 and HCFCs to be phased out by 2030 AD. These both CFCs & HCFCs are having ozone depletion potential (ODP) and mainly responsible for the depleting of Ozone layer**[3]**.

Kyoto Protocol, UNFCC (1998) stress on strengthen the policies for reducing the use of HFCs refrigerant. These HFCs refrigerant have global warming potential (GWP) and responsible for Global Warming. Due to these both effect on environment CFCs, HCFCs & HFCs are becoming less useful to us **[4]**.

On the other end, the natural refrigerants are gaining popularity for using in refrigeration systems. Many researchers found that the use of hydrocarbon refrigerant and its mixtures are energy efficient and environment friendly. These hydrocarbon refrigerants or natural refrigerants are the alternative to replace to replace the R-22 in vapour compression systems. **[M.Mohanraj, S.Jayaraaj & C. Muraleedharan] [5].**

Now-a-days carbon-dioxide is becoming most popular and energy efficient refrigerant in refrigeration system. Carbon dioxides offers many advantages i.e. non-toxicity, non-flammability, easily available, less costly and environmental friendly. It has zero ODP & very low GWP.

The triple points of CO_2 is -56.6^0 C, therefore it should be mixed with other refrigerant may be hydrocarbons for achieving the temperature of the order of -85^0 C in the evaporator of cascade refrigeration system.

In present time hydrocarbons and its mixtures are being used for replacing R-22. Since R-22 has ODP = 0.050 & GWP = 1810, While on the other end hydrocarbons having zero ODP and low GWP. **[6] (Calm and hourahan, 2001).** They did only the energy analysis during their research. But exergy analysis is the first and foremost technical tool which guides us how to improve efficiency in engineering and related fields.

Some hydrocarbon gas can also be used as a refrigerant in the cascade system. In the binary mixture of azeotropic refrigerants there is a problem of temperature glide. Analysis of the system becomes difficult due to temperature glide. Hydrocarbon gases have many remarkable properties, such as non-toxic & safe if the charge mass are below the 1.5 kg per sealed system. The freezing point of the R-600a, R-290 and R170 are -159.6 °C,-187.1 °C and -183.2 °C respectively.

To keep the positive operative pressure throughout the system, R-600a can be operated up to the temperature limit of -11°C, R-290 can be operated up to the temperature limit of -42°C and R-170 can be operated up to the temperature limit of -88°C when operated above the atmospheric pressure.

In present study thermodynamic analysis of three stage cascade refrigeration system has been carried out using ozone friendly refrigerants R-600a, R-290 and R170. A thermodynamic analysis of cascade system has been carried to optimize the design and operating parameters of the system. In this study R-600a is being used in the high temperature stage, R290 is used in the medium temperature stage and R-170 is being used in the low temperature stage.

Hydrocarbon refrigerants have good thermo physical properties. As stated earlier hydrocarbon are environmental friendly **[7].** Hydrocarbon shows low flammability when it's used in small quantity or mixed with CO_2.

The experimental study of **Niu and Zhang** using a mixture of propane and carbon dioxide at low temperatures found the energy efficiency and cooling capacity of this mixture to be higher than R13 **[8].** However,**Kim JH & Cho JM** found that this mixture barely reached a minimum temperature of -72 °C and the azeotrope mixture of carbon dioxide and propane produces a temperature glide **[9].**

Therefore an azeotrope mixture produces more efficient results and azeotrope mixture of ethane and carbon dioxide for low temperature applications **[10]**, appears to offer better efficiency (COP) than a mixture of carbon dioxide and propane **[11]**.

Several researchers have evaluated the thermodynamic performance of the two-stage cascade refrigeration systems.

1. **Bhattacharyya et al.** [**12**] studied a carbon dioxide–propane (R744–R290) optimum cascade evaporating system to define an evaporating temperature of R744 for application in heating circuits.
2. **Lee et al. [13]** analyzed a carbon dioxide–ammonia (R744–R717) cascade system thermodynamically to determine the optimum condensing temperature of R744 in the low-temperature circuit.
3. **Getu and Bansal [14]** analyzed a carbon dioxide–ammonia (R744–R717) cascade system thermodynamically to determine the optimum condensing temperature of R744 in the low-temperature circuit and mass flow ratio, to give the system maximum COP in terms of subcooling, superheating, evaporating temperature, condensing temperature and temperature difference in the system's cascade condenser.

When there is a requirement to keep the evaporating temperature between -40^0 C and -130^0 C, the cascade refrigeration system is a convenient option provided two or more suitable working fluids are selected. The temperature of the order of -40^0 C to -130^0 C is required in low temperature refrigeration application i.e. biomedical application and cryogenics. These applications are rapid freezing storage of frozen food, liquefaction of petroleum vapour, Dry ice manufacturing etc.

In a two stage cascade refrigeration system, refrigerant pairs commonly used in the past were R-12, R-502 in high temperature cycle and R-13 in low temperature cycle. Since these refrigerant have chlorine atoms, these have been phased out since 1996 in the developed countries. As per Montreal protocol and its amendment from the United Nations Environment

Programme (UNEP) **[3,4].** These refrigerant should be completely phased out by 2010 in developing countries.

Therefore it is becoming very important to search for alternative refrigerants which can be good substitute for R-12, R-502 and R-13. Di-nitrogen mono-oxide (N_2O) can be used as a cascade refrigerant for achieving temperature of -80^0 C **[15].** Carbon-dioxide [CO_2] can be used in the low temperature stage of two stage cascade refrigeration system. But due to the carbon-dioxide has high triple point temperature, we can achieve the lowest temperature up to -55^0 C. Mixtures of various refrigerant exhibiting azeotropic phase equilibrium behaviors show good potential in cascade refrigeration system.

Experiment on phase equilibrium measurement of two binary system containing R-170 + R-23 and R-170 + R-116 **[16] c**arried out and found that it shows positive azeotropic vapour liquid phase equilibrium. Hence there is great possibilities to use the both above mention binary mixtures as alternative refrigerants in low temperature stage of two stage cascade refrigeration system. Carbon-dioxide (CO_2) and Nitrous oxide (N_2O) can be mixed to develop binary mixture **[17]** which is also used in low temperature circuit while in high temperature circuit R-404a is used. The comparison of results of this set of refrigerant carried out with R-23 in low temperature circuits and R-40 in high temperature circuit and found higher COP.

Baolian Niu and Yufeng Zhang **[18]** used a new binary mixture of R-744 and R-290 as an alternative natural refrigerant to R-13 and Experimental studies for this mixture on a cascade refrigeration system shows COP and refrigeration capacity of this binary mixture were higher than those of R-136.