ISSN 2395-1621

Design and Development of Vapour Absorption Refrigeration System based on working cycle of Vapour Adsorption Refrigeration System

[#1]Dhanashree S.Ware, [#2]Dr. H.U.Tiwari

[1]dhanashree1888@gmail.com
[2]harish.tiwari@pccoepune.org

[1]PG Student, Department of Mechanical Engineering, SPPU,PCCoE,Pune.
[2]Professor, Department of Mechanical Engineering, SPPU,PCCoE,Pune.

ABSTRACT

The present work is focused towards the development of prototype of vapour adsorption refrigeration system and design of innovative vapour absorption system using aqua ammonia which is based on working cycle of adsorption system and a prototype of 1 KW capacity has been designed, developed and tested in laboratory for vapour adsorption system. A cooling effect of 111.37 KJ to 278.44 KJ has been obtained. The heating time required to achieve the cooling effect is around 10 minutes. The COP of the system is in the range of 0.08 to 0.190. The dimensions of the system are compact. Based on the working cycle of adsorption system, A vapour absorption refrigeration system has been designed and developed in laboratory. The theoretical COP obtained is 0.72. Still the system is in development phase because of some inherent difficulties. The major problem in absorption system is that, along with the ammonia, water also enters into the condenser and evaporator tube which hampers the cooling effect. In this paper the design of the innovative absorption system is given.

Keywords — **Absorption, Adsorption, Ammonia-water, Heat source.**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. Introduction

During the recent years research has attempted to develop new technologies that can reduces energy consumption and cost without decreasing the level of comforts. In view of shortage of energy production and fast increasing energy consumption, there is a need to minimize the use of energy and conserve it in all possible ways. For this purpose previously vapour adsorption system is designed, developed and tested successfully.The results from this work were encouraging and got COP in the range of 0.08 to 0.190 for obtaining refrigerating effect of 1 to 1.2 KW. The presented work is also focused to minimize the energy consumption by developing an innovative vapour absorption refrigeration test rig based on working cycle of vapour adsorption system. The objective of this work is to design and develop a prototype of an environment friendly vapour absorption refrigeration system of 1 KW capacity using NH_3 and water as the working pair.The system contains only one control valve and same coil act as condenser as well as evaporator. This research work makes effective contribution in the area of design and development of simplified Vapour absorption system for utilizing waste heat effectively.[1][4]

Vapor absorption refrigeration (VAR) is one of the oldest refrigeration technologies. French scientist Fero Dinonel developed the first absorption refrigeration machine in 1816. At the start of 20th century first vapour absorption refrigeration system was developed. As vapour absorption system is heat operated cooling system due to which it attracts the attention of researchers in the field of refrigeration.[2]

Jose Fernandez-Seara in his research work gives the single-effect absorption refrigeration system is the simplest and most commonly used design. Abaut when volatility absorbent such as water/NH_3 is used, the system requires an extra component called a rectifier, which will purify the refrigerant before entering the condenser. As the absorbent used (water) is highly volatile, it will be evaporated together with ammonia (refrigerant). Without the rectifier, this water will be condensed and accumulate inside the evaporator, causing the performance to drop.[3]

Marcriss et al in his work provided survey of absorption fluids. He suggests that, there are some 40 refrigerant compounds and 200 absorbent compounds available. However, the most common working fluids are Water/NH_3 and LiBr/water.[5]

Park YM et al suggest that in an absorption refrigeration system, water NH_3 has been widely used for both cooling and heating purposes. Both NH_3 (refrigerant) and water (absorbent) are highly stable for a wide range of operating temperature and pressure. NH3 has a high latent heat of vaporization, which is necessary for efficient performance of the system. It can be used for low temperature applications, as the freezing point of NH3 is -77°C. Since both NH3 and water are volatile, the cycle requires a rectifier to strip away water that normally evaporates with NH_3. Without a rectifier, the water would accumulate in the evaporator and offset the system performance. There are other disadvantages such as its high pressure, toxicity, and corrosive action to copper and copper alloy. However, water/NH3 is environmental friendly and low cost.[6]

To provide air cooling for the driver of a truck is never given importance in India, the basic reason is the use of available methods of air cooling affects the fuel consumption and the initial cost of the truck. For automobile air conditioning normally vapour compression refrigeration cycle is used. The cycle run on engine power and consumes around 10% of the total power produced by the engine and thereby increases the fuel consumption shown by Lambart and Jones, 2006.[7]

II. PROPOSED SYSTEM AND WORKING PRINCIPLE

In the proposed system necessary heat to the absorber is supplied by using kerosene burner. The schematic diagram of the system is shown in Figure 1.This is an absorption refrigeration system with a single control valve. This system requires only one coil connected to the absorber through control valve. The coil connected to the absorber through a control valve acts as condenser as well as evaporator. The absorber-generator unit is actually a pipe in pipe type of heat exchanger. Two concentric pipes are used such that the exhaust gases passes through the inner pipe and gap between two pipes is filled with the water in which ammonia is charged in later stage.The absorber is heated and refrigerant is absorbed and condensed in the coil at high pressure, here the coil acts as condenser and is filled with liquid refrigerant. The control valve is closed and the absorber is cooled. The pressure in the absorber reduces and the absorber regains its absorptivity. The control valve gradually opened and the liquid refrigerant evaporates and flows back to the absorber, where the absorber absorbs the refrigerant. The coil this time act as evaporator and refrigerating effect is generated at the evaporator coil. The pressure of the refrigerant in the absorber gradually increases.

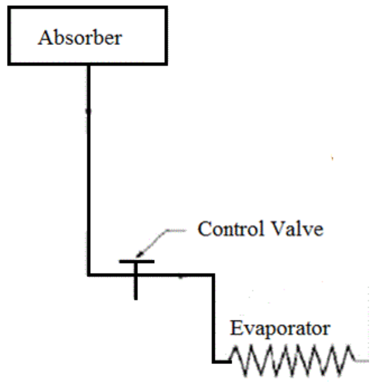

Fig.1 line diagram of Vapour absorption system

III. DESIGN OF PROPOSED SYSTEM

The main system components are Absorber-generator unit, condenser & evaporator coil and control valve. These are basically heat exchangers and are designed by using heat transfer equations and thermal correlations. It is decided to first develop a prototype to study the effect of different variables and optimization of the system parameters. A prototype of 1 kW capacity is designed and developed in the Laboratory. The absorber and refrigerant are selected as water and Ammonia. Considering the temperature of exhaust gases and high latent heat of Ammonia this combination is found to be suitable. The absorber, condenser, evaporator and the control valves are the main components of the system. The absorber has been designed and developed to enhance the heat transfer.

A. Design of Absorber-Generator Unit:

In absorption refrigeration system, absorber is the most important component Absorber works like generator as well as absorber both of an absorption system. It is double pipe heat exchanger. There are two concentric tubes of stainless steel. The absorbing water is filled between the gap of inner tube and the outer tube. The absorbing material is water and the refrigerant is ammonia. End covers are fitted at the ends of these tubes to hold the absorbing material. The exhaust gases flow through the inner tube. The system is designed for heating and cooling time of 600 s. Absorber temperatures are decided as $T_{ab,max}$ = 80 ^oC and $T_{ab,min}$ = 30 ^oC. Designed refrigerating effect (R.E.) = 1 kW, latent heat of evaporation of ammonia (L) at evaporator pressure is 1250 kJ/kg. Amount of ammonia is obtained by dividing the R.E. by latent heat as 0.48 kg. Mass of absorber, m_{ab} is obtained as 1.40 kg. Density of absorbing material (ρ_{ab}) is 1000 kg/m^3, absorbent thickness = 14.5 mm. Volume of absorber, is calculated, V_{ab} = 81.779 * 10^-6 m^3

a) Mass of absorber and refrigerant

Refrigerant- Ammonia
Absorbent- Water
Concentration of ammonia in water
X_{max} = Concentration at 30°C
X_{min} = Concentration at 80°C

$$\text{Mass of refrigerant} = \frac{\text{Refrigeration effect}}{\text{Latent heat of evaporation}} \times \Delta t$$

$$\text{Mass of absorber } (\dot{m}_{ab)} = \frac{\dot{m}r}{Xmax - Xmin}$$

b) Selection of inner tube :-

The inner tube of the absorber-generator unit is selected based on the heating method and available raw material. The dimensions of the inner and outer diameter of tube and length of the tube are decided. The thickness and mass of tube is calculated by,

$$\text{Thickness} = \frac{do-di}{2}$$

$$\text{Volume} = \frac{\pi}{4}(do^2-di^2)\times L$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Density of steel = 7800 kg/m^3

c)Design of outer tube

The outer tube is designed based on the properties of the absorbing material (that is water) used in between the gap of the two tubes. The mass of the absorber is previously known with its density then calculate volume of the absorber. This volume is expressed in terms of the outer diameter of the inner tube and inner diameter of the outer tube. Calculate the inner diameter of the tube.

Density of water = 1000 kg/m3

Calculate Volume

$$\text{Volume} = \frac{\pi}{4}(do^2-Di^2)\times L$$

From this calculate value of Di

B. Design of condenser and evaporator coil

In presented vapour absorption refrigeration system same coil is used as the condenser & Evaporator both. The coil is designed based on the amount of heat to be rejected to the cooling water. The rise in temperature of the cooling water is assumed as 10^{o}c. The condenser coil is connected to the Absorber-Generator unit through the control Valve.

1. Enthalpy of refrigeration
   Consider enthalpy at given temperature and pressure and values are taken
2. Mass of refrigerant,
   $$\dot{m}_r = \frac{\text{R.E.}}{\text{Latent heat}}$$
3. The amount of heat to be rejected in the condenser
   $$Q_{condenser} = m_r(H_2 - H_1)$$
4. The log mean temp. difference is given by ,
   $$LMTD = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$
5. The area of the condenser coil to reject the calculated heat is given by ,
   $$Q_{condenser} = U.A.\,(\Delta T)_{LMTD}$$

Consider the diameter of the coil. Hence the length of the coil is calculated as ,

$$A = \pi Dl$$

C. COP of the system

Sensible and Latent heat can be given as ,

$$Q_{sensible} = (m_{ab}\times cp_{ab}\times\Delta T_{ab})+(m_{tube}\times cp_{tube}\times\Delta T_{ab})/\Delta t$$

Where,

Cp_{water} = 4.187 KJ/Kg .k

$$Q_{Latent} = \frac{m_{ab}(X_2 - X_1)(H_2 - H_1)}{\Delta t}$$

Total heat can be given as ,

$$Q_{total} = Q_{sensible}+Q_{latent}$$

COP of the system

$$COP = \frac{Q_{evaporated}}{Q_{total}}$$

D. Development of the prototype

Fig.2 Assembly of Vapour Adsorption Setup

A small prototype for a cooling capacity of 1 KW has been designed and built as shown in the Fig. 2. The major components of the prototype are double pipe heat exchanger, Expansion valve and condenser & Evaporator coil. The remaining most of the components are standard components and used as per the requirement.

a.Material Consideration for Ammonia /Water System

Ammonia is a very good solvent for copper. Thus the use of any copper or copper-containing material is impossible. Experience in the laboratory indicates that even chromium-plated brass parts are susceptible to ammonia corrosion. The most common material for the construction of ammonia/water systems is steel or stainless steel. When steel is the material of choice, corrosion inhibitors are required for most applications. These are salts that are added in small quantities (1% by weigh or so.).They form a protective oxide layer on the metal surface so that there is no direct contact with the working fluid. The influence of these salts on the thermodynamic properties of the working fluid is usually neglected. Traditionally, the corrosion inhibitors are salts that contain heavy metals. These are being banned by the U.S., Environmental Protection Agency and manufacturers find themselves needing to develop new, environmentally acceptable replacements. The thermal conductivity of steel is about one tenth of that of copper.

b.Selection of standard components

The different standard components used are Pressure Gauge, Two end threaded collars and Two Expansion valves. The pressure gauge is selected for the range of 0-20 bar pressure as the maximum pressure in the system is 15 bar. The pressure gauge is dedicated for ammonia gas pressure measurement. The expansion valves are steel needle valves. In auxiliary devises we use blower stove to supply heat.

IV. CONCLUSIONS

This research work proposes an innovative, compact, and improved absorption refrigeration system design, powered by waste heat. The system, which has been designed, developed and tested during the course of the presented research work, makes the following contributions in the field of absorption refrigeration technology.

1. An innovative absorption refrigeration system powered by heat has been designed, developed and

tested.

2. An absorption heat exchanger, which is compact and at the same time has more heat transfer area, has been successfully designed, developed and tested.
3. An environment friendly cooling system has been developed that does not rely on electric power, and thus helps in reducing resulting pollution as well as global warming. The Global Warming Potential (GWP) of ammonia is zero.
4. A cooling system has been developed that does not use CFC refrigerant, and thus protect ozone layers over the atmosphere.
5. The developed absorption system design provides platform for further development of absorption refrigeration technology and for waste heat operated cooling systems.

ACKNOWLEDGEMENT

Any accomplishment requires efforts of many peoples and this Research work is no different. I am highly obliged and grateful to all those who helped me in this research and provided all encouragement that has helped me in this research work.

I wish to express my deep sense of gratitude and honor towards my respected guide Dr. H.U.Tiwari sir for his inspiring guidance and constant encouragement. His committed devotion, dedication and encouragement with full faith on me throughout research work.

I would like to express my honor and gratitude to my M.E. Co-ordinator Dr.N.R.Deore sir for consistent encouragement for completing my research work successfully.

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