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COMPARATIVE STUDY OF AIR COOLED AND WATER COOLED CONDENSER OF A COLD STORAGE

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Abstract— **One of the major component of a cold storage is Condenser which acts as an heat exchanger, where heat rejected form cold room to the surrounding. In air cooled condenser's heat exchanger material should be very high thermal conductivity. Our job is to replace water cooled condenser with air cooled condenser. Where controlled air takes heat from the condenser coil. We used condenser coil material as copper(thermal conductivity = 385 w/m.k), and high velocity air has been passing through the coil(cross flow, air velocity = 3 m/s); we assumed that environmental temperature is 27 °C or 300K. Super heated ammonia is flowing through the coil and inlet temperature of ammonia is = 35°C, and exit temperature is = 32°C; and through the condenser pressure remains constant, that is P=1226.25 kPa, we measured that data for water cooled condenser and that condenser reject heat around Q= 5 KW; to do that job energy required to cooled the condenser with following water is around 3.1 KWH, Now we are going to replace water cooled condenser with air cooled condenser remaining heat load and others data are same.**

Index terms- **Phase change material(ammonia), vapour compression cycle, Thermal conductivity, Convection heat transfer coefficient, Gnilisky co-relation, Inline heat exchanger, Nusselt no, Reynolds no.**

I. INTRODUCTION

The salient components of vapour compression refrigeration system used in Indian cold storage system are: evaporator, compressor, condenser and manually operated expansion valve. The type of the cold storage are

1) Vapour campression refrigeration cycle is used
2)Ammonia refrigerent is used in the cycle

For the analysis of the various parameter of the Jalpaiguri cold storage, some **assumption[6]** are taken.

1. The compression and expansion process are an isentropic process ie. Entropy of those process are remains same [6]
2. The ammonia vapour behaves as an ideal gas
3. Specific heat, specific heat ratio and local gas constant does not change in different temperature and pressure.
4. The specific heat capacities at constant pressure and constant volume processes, and the ratio of specific heat and the individual gas constant - R – for ammonia vapour at 20 °c and 1a.t.p are given below [8]

C(p)= 2.19; C(v)= 1.66 ; γ= 1.31 ; R= 0.53

A typical schematic diagram of the refrigeration stem is shown below

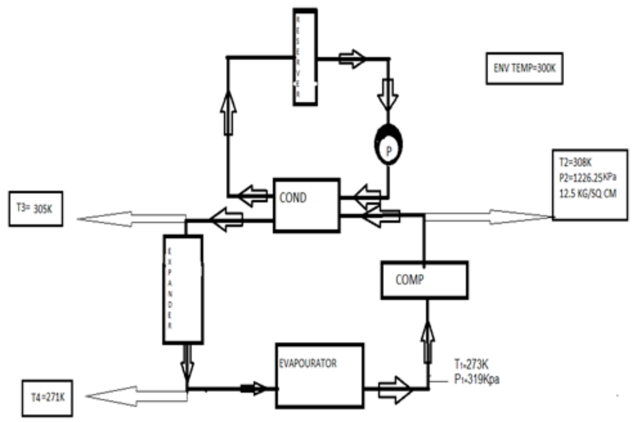


Fig.1 Cold storage diagram

- Suction pressure of the compressor P_1= 319.9 KPa≈320KPa
- Suction temperature of compressor T_1=273K
- Discharge pressure of the compressor P_2=1226.25KPa
- Discharge temperature of compressor T_2=308K
- Discharge pressure of the condenser P_3=P_2=1226.25KPa
- Discharge temperature of the condenser T_3=305K

In air cooled condenser heat transfer basically happens by the convection process. Convection heat transfer takes place whenever a fluid is in contact with a solid surface that is a different temperature than fluid. If the fluid is moving past the solid surface because of an external driving force, like pump or blower, then it is called forced convection. A major components of most convection heat transfer calculation is obtaining a good estimate for a **convection heat transfer coefficient**. [4]

In our case both convection and conduction heat transfer takes place. hot fluid is super heated ammonia(temp=35°C) which flows through the coils and cold fluid is environmental air(temp=27°C), between the two fluids copper coil presents and conduction takes place in that copper coils. Our main objective is to design a such type air cooled heat exchanger where less energy required to cool down the air cooled condenser than water cooled condenser. During this study we have to keep same all data. That's means we are just replacing water cooled condenser with air cooled condenser. So we can divide our works with several steps. Those steps would be

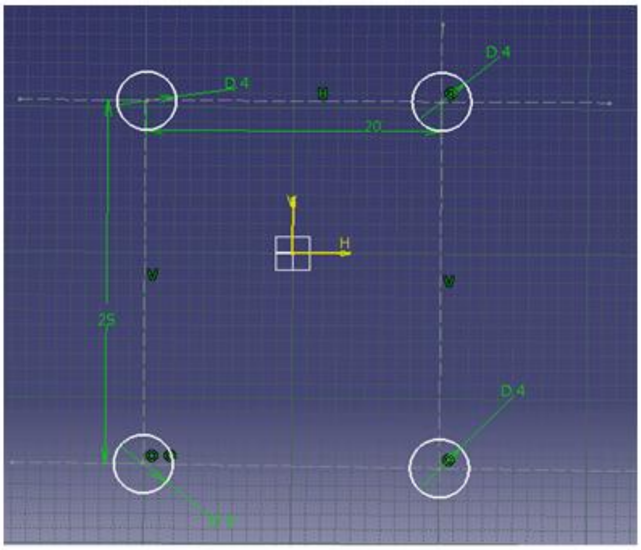
- Step 1 : choose a heat exchanger material such a way which is suitable for our condenser coil.
- Step 2: Doing calculation and designing an air cooled heat exchanger with reliable cost.
- Step 3: Choosing a suitable fans or blowers as per heat exchanger required to cool down them.
- Step 4: Calculating fan power and cost and compare with water cooled condenser pump power and cost required.

II. MATHEMATICAL MODEL DEVELPOMENT

Air cooled condenser

Firstly we have to choose a heat exchanger material and as our research copper is very good heat exchanger material with thermal conductivity 385W/m K; assuming that super heated ammonia comes to a header and from that header 60 small diameter tubes are extended and every tubes are parallel to each other. The selected diameter of each tube is D=4 cm; and we also assuming that the arrangement of the tubes are inline arrangement. Now it can be calculate there internal and external heat transfer coefficient by **Gnielinski Co-relation. [1]** Though there are no particular value of finding forced convection heat transfer coefficient but there are some particular experiment and co relation to find there force convection heat transfer coefficient. Gnielinski co-relation is one of them and it is vey near to practical value. In that co-relation there are certain variables and dimensionless numbers which are helps us find the forced convection heat transfer coefficient. Our main goal in these target is to find the length of each tube, velocity of air and fan power to maintain that velocity.

In the above picture has been shown an In-line tube arrangement. Where



Inline tube arrangement

D= diameter of the tube= 4cm;

SQ= transverse length= 25cm; SL= longitudinal length= 20cm;

Transverse pitch ratio a= SQ/D= 6.25;

Longitudinal pitch ratio b= SL /D=2.5;

void ratio=ψ= 1- $\frac{3.141}{4*a}$ = 0.125;

characteristic length λ= $\frac{\pi D}{2}$ = 6.2832;

Renolds no= $\frac{\lambda v p}{\psi \mu}$ where

V= velocity of air across the tube

p= density of air

$\mu = \text{dynamic viscocity of air}$

theoretically calculated renolds no is

Re= $\frac{6.283*1.177*v}{0.1256*1.846*10^{-5}}$

= 3189598.44*v

From these relation reynolds no must be less than 10^7; so from reynolds no we have limited value of v. We are taking v= 3m/s;

So Re= 9568795.33;

So the **Gnielinski Co-relation is [1]**

$$Nuo = 0.3 + [(Nulam)^2 + (Nutur)^2]^2$$

Where

$$Nulam = 0.66(Re)^{0.5} * \mathrm{Pr}^{0.33}$$

= 0.66*3093.3*0.8905

=1818.77

And Nutur= $\frac{0.037*(Re)^{0.8}*(pr)}{[1+2.44(Re)^{-.1}*(1-\mathrm{Pr}^{.88})}$

= 9094.83

So over all nusselt no is

Nuo=0.3+ $\sqrt{1818.77^2 + 9094.83^2}$

=9275.20

We know that Nu= $\frac{h\lambda}{k}$

So h= $\frac{Nu.k}{\lambda}$

h=38.73 W/mK;

at the exit of the condenser temperature is 305K and pressure $12.5Kg/cm^2$, so we can say condensation take place.so standard value of ammonia condensation heat transfer coefficient from the engineering tool box we find that.

condensation heat transfer coefficient h=6000 W/mK

We assume that thickness of the copper coil is 0.5 cm,

Now we can find the overall heat transfer coefficient from the given formula

$$\frac{1}{u} = \frac{1}{hi} + \frac{x}{k} + \frac{1}{h0}$$ **[6]**

u= Over all heat transfer coefficient;

hi= internal heat transfer coefficient;

ho= air side heat transfer coefficient;

x= thickness of the tube .5 cm;

k= thermal conductivity of air(273K)

Inside the tube there are condensation of ammonia take place so we can take hi=6000W/m^2K;

After the calculation overall heat transfer coefficient wouldbe

$$u = 38.46\ W/m^2K$$

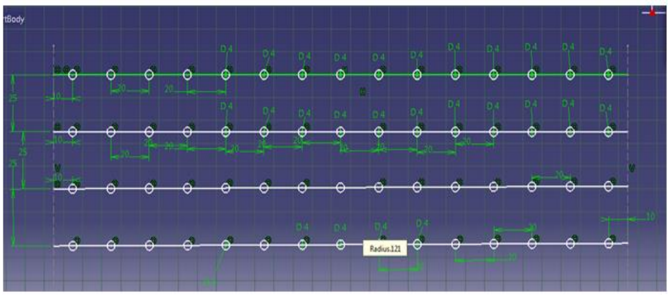


Fig 3. Heat exchanger

Now we already divided the heat exchanger with 60 no of tubes and the arrangement of the tube is inline arrangement.

We take 4 rows and 15 columns.

Heat rejected from the condenser

Compression work Wc=n/$n-1$(P_2V_2-P_1V_1)[3]

=n/n – 1(RT_2 - RT_1)

= 78.38 KJ/ Kg of ammonia

Volume of ammonia per cycle of compression per cylinder [6]

V_1= $\frac{\pi}{4}D^2L$ [from the observation table we can find bore and stroke]

= 0.002796 m³ ≈ 0.0028m³

So work of compression per cycle per cylinder

$W'c = \frac{n}{n-1}(P_2V_2 - P_1V_1)$ [6]

$= \frac{n}{n-1}P_1V_1\{(\frac{P_2}{P_1})^{\frac{n}{n-1}} - 1\}$

= 4.226 × 320 × 0.0028 × (1.3846 - 1)

= 1.456KJ / cycle per cylinder

≈1.5 KJ / cycle per cylinder

There are two cylinder of a KC 4 type compressor and average R.P.M = 1400

SoWork of compressor per second

W'c = (1.5 × 2 × 1400)/ 60 KJ / sec

= 70 KJ/ sec

Mass flow rate of ammonia per second

$= \frac{W'c}{Wc} = \frac{70}{78.38}$ = 0.893 Kg / sec

Heat dissipated from the condenser

Qc = mCp(T_2- T_3) [6]

=4.8KJ/s

We take it as 5 KJ/s;

So we can write

$$Q = 38.4 \times 60 \times \pi DL(Ti - To)$$

Where L is length of each tube;

Ti=35 °C and To= 27°C;

From that relation we will find that

$$Q = 38.4 \times 60 \times \pi 0.04L(308 - 301)$$

L= 2.5meter

So surface area of the heat exchange

$$A = 3 \times 2.5\ m^2$$

$$A = 7.5m^2$$

So air flow through the heat exchanger is = $7.5 * 3\ m^3/s$

= 22.5m^3/s

Now our next steps would be fan selection. We are using suitable fan that can supply 3m/s velocity over the surface 7.5 sq meter

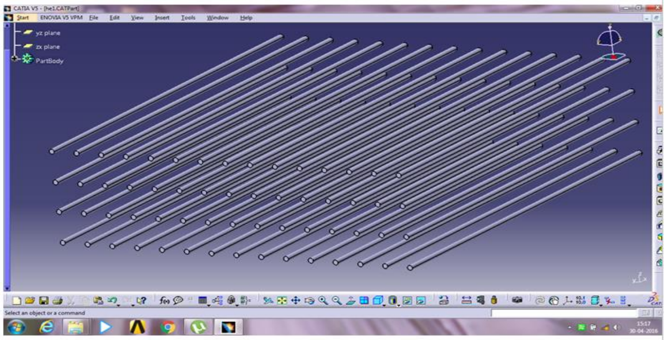


Fig 4. Heat exchanger tubes

We are choosing **ISO 12759 fan**

Standard efficiency of the fan is 75% and standard pressure developed is 100Pa.

air flow through the heat exchanger per hour= $81000\frac{m^3}{hour}$;

so fan power $P = \frac{Q \times \Delta p}{\eta}$ (11)

$$P = \frac{22.5 \times 100}{0.75}$$

P= 3000 W

Fan power in one hour in KHW

P= $\frac{3000W \times 1h}{1000}$ KWH (11)

P=3 KWH

THE ENGINEERING TOOL BOX we can find the characteristics of the fan ISO12759. From that characteristics graph we will find the power required to flow the required amount of air per hour.

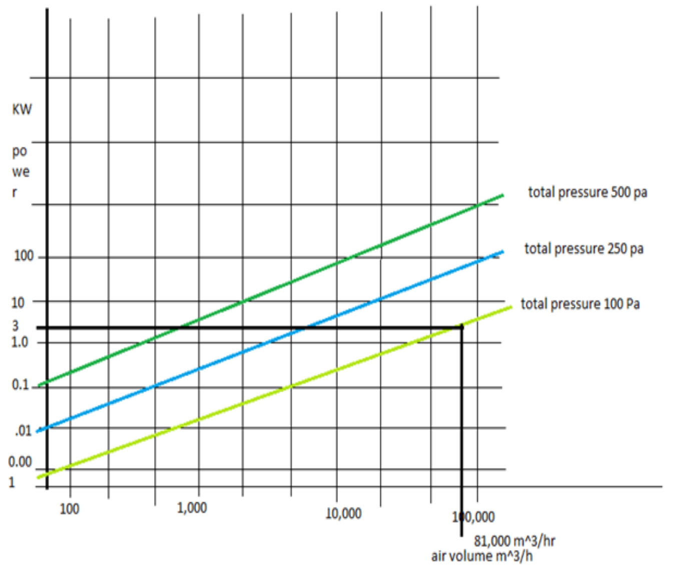


Fig 5. ISO 12759 fan characeristics by reference engineering tool box

Water cooled condenser

Power consumed by the 3 phase induction motor can be calculated by the given formula

P(watt)= V $\times$ **I** $\times \cos\emptyset$ **[9]**

V= voltage of the motor

I = current flow through the motor

$\cos\emptyset$ = power factor = 0.85

We can find V & I from the volt meter and ammeter

Power factor of W.B.S.E.D.C.L is 0.85

Power consumed by the condenser motor

MOTOR NAME	VOLTAGE(V)	CURRENT FLOW(AMP)	POWER FACTOR	Watt	KWh
C.G	415	12	0.85	4233	4.233

Velocity vs heat transfer coefficient(for air cooled condenser)

Renolds no= $\frac{\lambda v p}{\psi\mu}$

And $Nulam = 0.66(Re)^{0.5} * \Pr^{0.33}$ [6]

Again $Nu = \frac{h\lambda}{k}$

So $\frac{h\lambda}{k} = 0.66(Re)^{0.5} * \Pr^{0.33}$

$$\frac{h\lambda}{k} = 0.66\left(\frac{\lambda v p}{\psi\mu}\right)^{0.5} * \Pr^{0.33}$$

or $h = 0.66 \times \left(\frac{\lambda v p}{\psi\mu\lambda}\right)^{0.5} \times \Pr^{0.33}$

or **h=**$c\sqrt{v}$

where c is constant for a particular heat exchanger at a particular environmental temperature.

$$c = 0.66 \times \left(\frac{\lambda p}{\psi\mu\lambda}\right)^{0.5} \times \Pr^{0.33}$$

Programme in c

```
#include<stdio.h>
#include<math.h>
Int main(_)
{
        Float
l=6.28,d=1.177,sai=0.1256,vis=0.00001846,pr=0.707,k=0.026
24;
        Float v,h,i,a,b;
        For(i=1; i<10; i++)
{
                Printf("enter the velocity of air\n");
                Scanf("%f", &v);

        a=0.66*k*pow(pr,0.333)*pow(d,0.5)*4.9*pow(v,0.5);
                b=pow(sai,0.5)*pow(vis,0.5)*pow(l,0.5);
                h=a/b;
                printf("heat transfer coefficient of air
h=%f\n", h);
        }
        return 0;
}
```

Environmental temperature vs heat transfer coefficient

$$h = 0.66k \times \left(\frac{\lambda v p}{\psi\mu\lambda}\right)^{0.5} \times \Pr^{0.33}$$

μ=(.0060453+0.000042899*T)

k=$A + BT + CT^2 + DT^3$

c=a+bT

$Pr = \frac{cu}{k}$.

in that relation prandelt no(Pr), viscosity(μ), thermal conductivity(k) and density(ρ) depends on environmental temperature. At different temperature of environment heat transfer coefficient will be different. So for same heat exchanger or paramiters the heat transfer coefficient can be different

```
#include<stdio.h>
#include<math.h>
float conductivity(int);
float capacity(int);
float viscosity(int);
int main()
{
    float l=6.28,d,sai=0.1256,k,pr,a,b,c,u,h;
    int v=3,t,i;
    for(i=1; i<10; i++)
    {
        printf("define environmental temperature\n");
        scanf("%d",&t);
        c=capacity(t);
        k=conductivity(t);
        u=viscosity(t);
        pr=c*u/k;
        d= 353.1/t;

    a=0.66*k*pow(pr,0.333)*pow(d,0.5)*4.9*pow(v,0.5);
        b=pow(sai,0.5)*pow(vis,0.5)*pow(l,0.5);
        h=a/b;
        printf("heat transfer coefficient of air h=%f\n", h);
    }
    return 0;
}
float capacity(int t)
{
    float c1, a=1.0653697,b=-0.0004473085,c=0.00000098719042,d=0.00000000046376;
    c1=a+b*t+c*t*t+d*t*t*t;
    return c1;
}
float conductivity(int t)
{
float k,a=-0.00056827429,b=0.00010805198,c=-0.000000073956858, d=0.00000000037302922;
k=a+b*t+c*t*t+d*t*t*t;
return k;
}
float viscosity(int t)
{
    float u, a=0.0060453459,b=0.0000428993;
    u=a+b*t;
    return u;
}
```

III. RESULTS AND DISCUSSSIONS

From that graph we can calculate the fan power in any air flow rate if we assuming that total fan pressure is 100 Pa.

In one hour total fan power would be = 3 KWH
Or =3 unit;

in the water cooled condenser there are power required to cool the condenser is=4.2KWH.

so difference of energy in air cooled condenser to water cooled condenser is
=(4.2–3)KWH
= 1.2KWH

May be 1.2 unit is quit little but if we add look at the figure with respect to in several year that would not be considered as a little figure

For air cooled condenser the energy and cost saving cart is given below

energy & cost	One hour	One day	One week	One month	One year
Energy saved(KWH)	1.2	28.8	201.6	864	10368
Cost saved(₹)	9	216	1512	6480	77760

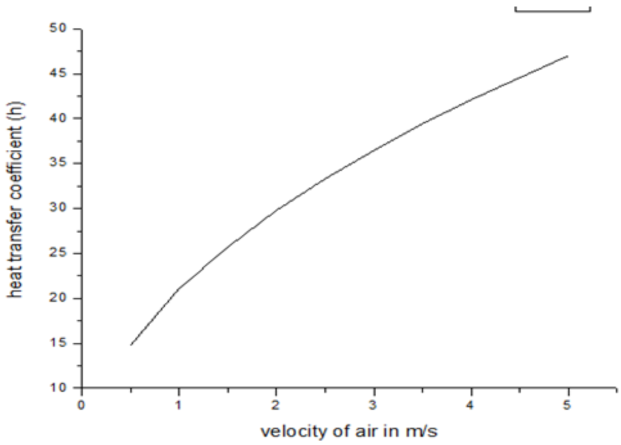


Fig 6. Variation of heat transfer coefficient with velocity of air

From that graph we can say that air heat transfer coefficient increases as velocity of air increases

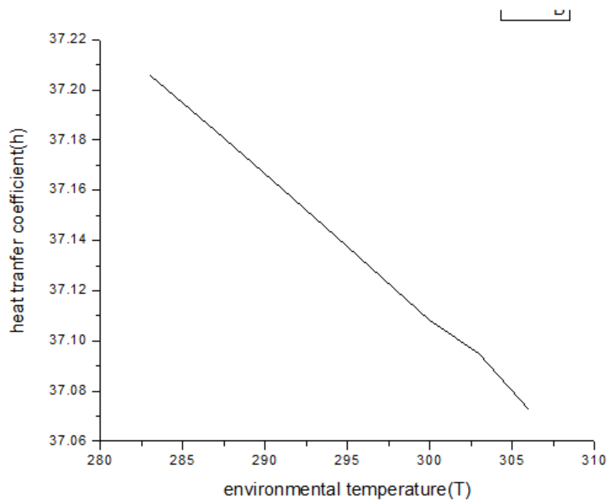


Fig 7. Variation of Heat Transfer coefficient with Environmental Temperature (k)

From the graph it has observed that as environmental temperature increase heat transfer coefficient decrease. So at the summer time and the winter time heat transfer coefficient will be different.

IV. CONCLUSION

It is clear that in air cooled condenser a good figure of energy can save. So in these energy crisis corporate world air cooled condenser can help us to reduce energy uses and save energy for our next generation.

Rather than air cooled condenser has several advantages

- Air cooled condenser is easy to operate
- Less noise and vibration
- Environmentally safe

It has also some disadvantages

- Capital cost is high as copper coil is costly.
- Maintenance cost is higher than water cooled condenser.
- Surface of copper coil need to be clean regularly.

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