Experimental study of Bell Coleman cycle using Air as Refrigerant

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Abstract

Air refrigeration system is the oldest refrigeration method. Initially it was developed by a scientist called Bell-Coleman. The aim of this study is to know the refrigeration effect using both Bell-Coleman cycle using air as the refrigerant and finding its COP because air is available free of cost and abundantly in nature. Bell-Coleman cycle air refrigeration can be used in aircrafts and ships to produce refrigeration effect in them.

Air refrigeration system generally uses air as medium, whereas other refrigeration systems use refrigerants (Freon's, ammonia etc.,) as medium. Since air is used as refrigerant is safe and it won't do any harm and no damage to atmosphere.

By using other refrigerants like CFC's damage to atmosphere such as ozone layer depletion takes place. In this study compressed air is selected as the refrigerant and it is produced by compressor. It need electric power to produce Compression of air. This system produces low COP because of which it has become obsolete. Other refrigeration systems have high COP but have severe impact on atmosphere. Moreover these refrigerants are too expensive and there is a handling difficult of these refrigerants.

This study gives the working of components of Bell-Coleman cycle by using air as refrigerant and knowing the coefficient of performance (cooling effect)for future development and application. This study gives the scope of replacing conventional refrigeration systems with air refrigeration system.

1. Introduction

Bell-Coleman *c*ycle consists of an air compressor, a cooler, an expander or throttling device and a evaporator. Initially air is sucked into the compressor at ambient conditions and is compressed to higher pressures. This high pressure air is sent into a cooler where it gets cooled to low temperatures and this low temperature, high pressure air is expanded isentropically to lower pressures, thus resulting in fall of temperature. This low temperature air is sent into an evaporator where it is heated up by absorbing the heat from an evaporator and thus producing the cooling effect. In this study instead of heat is absorbing in evaporator is replaced by vertex tube to get cooling effect.

In this process the compression and expansion processes are reversible adiabatic processes and there is a perfect inter-cooling in the heat exchanger. There are no pressure losses in the system .

2. Experimental setup:

The experimental setup consists of the following

Reciprocating Air Compressor, Heat Exchanger,

Throttle valve (Air Regulator) and Evaporator (Cabin)

Fig.1 Bell Coleman cycle experimental setup

2.1 Reciprocating compressors:

The reciprocating air compressor uses piston to compressor the air driven by a crankshaft in a straight line back and forth motion. This rotary motion is achieved by the use of an electric motor and the construction is quite similar to that of an automobile engine. The piston moves up and down inside a cylinder. Air from the suction line is moved through the intake valve as the piston move downward. As the piston moves upward, it compresses the air which is then pushed through the exhaust valve. The compressor may has more than one cylinder which is also known as multi-cylinder compressor. The common ones are the two-cylinder, four-cylinder and eight-cylinder compressors.

Compressor specifications:

Make	ELGI
Model	TS03120
Type	Reciprocating
Stages	two
LP cylinder bore	70 mm
HP cylinder bore	50 mm
Stroke length	85mm
Motor type	Sq.cage induction motor
Motor rating	3 HP
Motor speed	1420 RPM
Compressor speed	925 RPM
Electricity supply	415V/380V, 3phase, 50HZ
Type starter	DOL
Belt size	A68
Type of lubrication	splash
Type of cooling	Air cooled
Type of fan	Forced draught

2.2 Heat Exchanger:

Heat exchangers are devices that transfer heat in order to achieve desired heating or cooling. An important design aspect of heat exchanger technology is the selection of appropriate materials to conduct and transfer heat fast and efficiently.

Fig.2 copper tube heat exchanger

Copper tube of 8mm diameter and 1m length is bent into 9 spiral ring coil which is placed in a plastic bottle of 100mm diameter. The outer diameter of the spiral coil is 80mm. Water is poured into this bottle which removes heat from the copper coils. Copper coil is selected because it has high thermal conductivity. Copper is having high thermal conductivity allows heat to pass through it quickly. Other desirable properties of copper in heat exchangers include its corrosion resistance, bio fouling resistance, maximum allowable stress and internal pressure, creep rupture strength, fatigue strength, hardness, thermal expansion, specific heat, antimicrobial properties, tensile strength, yield strength, high melting point, alloy ability, ease of fabrication, and ease of joining.

2.3: Air regulator:

Air regulator used is equipped with a pressure gauge which shows the outlet pressure of the air. It consists of a rotating knob which is used to adjust the outlet pressure. It is made by KUSHAKO pneumatics limited. Its capacity is 10Kgf/cm^2. It can deliver air with pressure range of 0.5Kgf/cm^2 to 10Kgf/cm^2. It has inlet and outlet coupling threads of ½ inch. Pressure guage used is of 10Kgf/cm^2 capacity. Expansion of air upto desired pressure can be adjusted by rotating the knob of this air regulator. Maximum inlet air pressure should not exceed 10Kgf/cm^2.

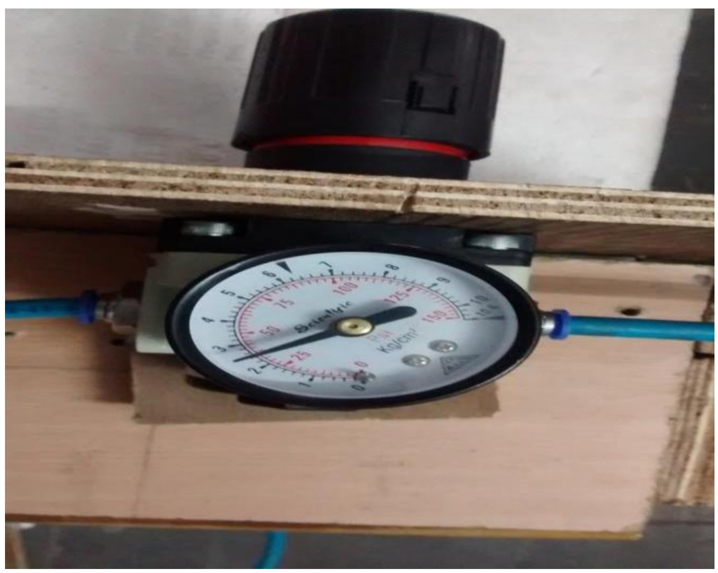


Fig.3 Air Regulator with pressure gauge

2.4: Evaporator or Cabin:

The evaporators are other important parts of the refrigeration and air conditioning systems. It through the evaporators that the cooling effect is produced in the refrigeration systems .It is in the evaporators where the actual cooling effect takes place in the refrigeration and the air conditioning systems. The evaporators are heat exchanger surfaces that transfer the heat from the substance to be cooled to the refrigerant, thus removing the heat from the substance. Generally cabins or evaporators are used to remove heat from the cooling space. In this study a thermocol box of size 2X1.5X1.5 feet is selected and used as an evaporator. It has to holes which act as an inlet and outlet for air. Cooled air is passed through inlet air. This cool air cools down the cabin by absorbing the heat and removes that heat through the outlet hole. Hence by this process cooling effect is achieved. In the domestic refrigerators the evaporators are commonly known as the freezers since the ice is made in these compartments. In case of the window and split air conditioners and other air conditioning systems where the evaporator is directly used for cooling the room air, it is called as the cooling coil. In case of large refrigeration plants and central air conditioning plants the evaporator is also known as the chiller since these systems are first used to chill the water, which then produces the cooling effect.

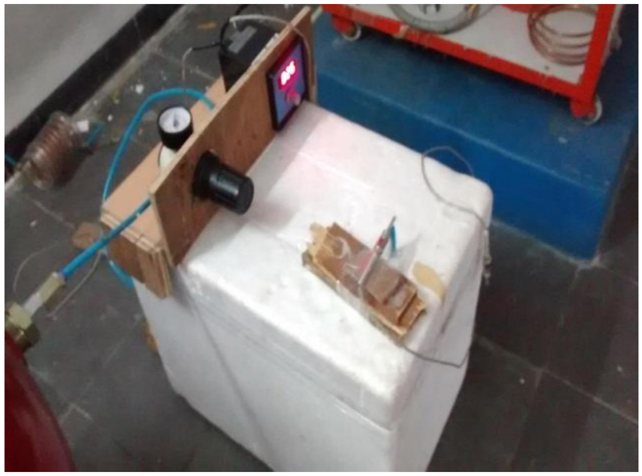


Fig.4 Evaporator or Cabin

2.5 Thermocouples:

Thermocouples are made by connecting two dissimilar metal wires together at one end. The open end of the wires will have a potential difference between them if the open ends and the connected ends are at different temperatures. If the open ends of the wires are held at a constant temperature, the voltage measured between them is proportional to the temperature difference between the open ends and the connected ends. With this arrangement, temperatures can be measured because the voltage created is consistently repeated versus temperature differences if the open ends are held at a reference temperature. The open ends are connected to Terminals referred to as the “cold junction terminals“

Fig.5 J-Type Thermocouple

3.0 Experimental Procedure of Bell-coleman of air refrigeration system

1. Connect the power supply to compressor.

2. Check the oil level through the slight valve.

3. Switch on the compressor and check direction of rotation of motor.

4. Open circulating water valve in heat exchanger.

5. Store the compressed air in the tank up to 9Kgf/cm^2.

6. Pass the air through the heat exchanger.

7. Expand the air in the air regulator up to different pressures.

8. Send this expanded air into cabin and wait for stable conditions.

9. Note the following readings,

- Inlet air pressure (P_1)
- Inlet air temperature (T_1)
- Compressed air temperature (T_2)
- Compressed air pressure (P_2)
- Cooled air temperature in heat exchanger (T_3)
- Air pressure in heat exchanger (P_3)
- Expanded air pressure (P_4)
- Expanded air temperature (T_4)
- Temperature of air coming out of cabin (T_5)
- Manometer readings h_1 and h_2

t"time taken for "X" revolutions of energy meter
Speed of motor and compressor in rpm

10. Expand the air up to desired pressures and note above all readings.

11. Repeat the experiment for different delivery pressures say 5, 4.5, 4, 3.5, 3, 2.5,2 Kgf/cm^2.

12. Then switch off the compressor and open the outlet valve so that there should not be compressed air in the collecting tank.

13. Switch off the mains.

4.0 formulas used for calculation:

Heat rejected by air during constant pressure process

$Q_R = m\,C_p\,(T_2 - T_3)$

Where

1. m= mass of air in kg,
2. C_p = specific heat at constant pressure = 1.005 KJ/KgK
3. T_2 = temperature of the air after isentropic compression
4. T_3 = temperature of the air after constant pressure cooling process in cooler

Heat observed by air during constant pressure process.

$Q_A = m\,C_p\,(T_1 - T_4)$

Where

1. m= mass of air in kg,
2. C_p = specific heat at constant pressure = 1.005 KJ/KgK
3. T_1 = temperature of the air before isentropic compression (ambient air temp.)
4. T_4 = temperature of the air after constant pressure heating process in evaporator

 Work energy supplied to compress the air,is equal to power input to the compressor to compress the air (P_c)

P_c = power input to motor (P_m) X efficiency of the compressor

Where $Pm = \frac{x \times 3600}{t\ X EMC}$

Here

x= no. of revolutions of energy meter

t=time taken for X revolution in seconds

EMC= energy meter constant = 200

Efficiency of the compressor is taken as 60%

Coefficient of performance of the cycle

C.O.P = Heat absorbed / energy supplied

$C.O.P = \frac{m\,Cp\,(T_1 - T_4)}{Pc}$

Mass of air supplied = volume of the air compressed X density of the air

Volume of the air compressed,

$Va = Cd\,A_0 V\sqrt{2gH} \times 3600$

1. Cd =coefficient of discharge of orifice=0.62
2. A_o = area of orifice, diameter of orifice = 0.015m
3. H = head of the air in meters

Density of the air = 1.181 Kg/m^3

5.0 Experimental -observations and readings.

Density of air = 1.181 Kg/m^3

Manometer readings

h_1 = 90mm and h_2 = 135mm

Time taken for 5 revolutions of an energy meter = 62seconds

sno	Readings	symbol	observations
1	Ambient pressure (Kgf/cm^2)	P_1	1
2	Ambient temperature (K)	T_1	306
3	Compressed air pressure (Kgf/cm^2)	P_2	6
4	Compressed air temperature(K)	T_2	308
5	Pressure of the air after cooling	P_3	9
6	Temperature of air after cooling(K)	T_3	304

reading	symbol	observation
Pressure of the air after expansion(Kgf/cm^2)	P_4	5
	P_4	4.5
	P_4	4.0
	P_4	3.5
	P_4	3.0
	P_4	2.5
	P_4	2.0
	P_4	1.0

reading	symbol	observation
Temperature of the air after expansion(K)	T_4	303
	T_4	302
	T_4	301
	T_4	299
	T_4	297
	T_4	295
	T_4	294
	T_4	293

reading	symbol	observation
Temperature of the air leaving the cabin (evaporator) (K)	T_5	308
	T_5	307
	T_5	306
	T_5	304
	T_5	302
	T_5	300
	T_5	299
	T_5	298
No. of revolutions of energy meter	x	5
Time taken for energy meter revolutions (sec)	t	62

6.0. Sample calculations of Bell-Coleman cycle

Volume of air $Va = Cd\ A_0 \text{ X } \sqrt{2gH} \text{ x } 3600$

$V_a = 0.62 \text{ X } 1.77 \text{ X } 10^{-4} \text{ X } \sqrt{2X9.81} \text{ X } 190.51 \text{ x } 3600 = 24.15\ M^3/hr$

. A_O = area of orifice, diameter of orifice = 0.015m

. A_O=1.77 X10^{-4} m^2

Mass of air

Ma= 24.15 X 1.81 = 28.52 kg/hr

Power in put to motor

$$Pm = \frac{5 \text{ X } 3600}{62 \text{ X } 200}$$

Power input to compressor,

P_C = 1.45 X0.60 = 0.87Kw

Mass of air supplied m_a= volume of the air V_a X density of the air ρ_a

M_a=24.15 x1.181=28.52 kg/hr

COP of bell Coleman cycle,

$$C.O.P = \frac{maCp\ (T_1 - T_4)}{Pc}$$

$$Cop = \frac{28.52 \text{ X } 1.005(306-293)}{0.87 \text{ X } 3600}$$

Cop=0.119

7.0 Scope of development

Since availability of air at free of cost. Air does not change its phase throughout the cycle and carrying capacity of air per Kg is very small as compared to vapor absorbing systems. The air- cycle refrigeration systems, as originally designed and installed, are now practically obsolete because of their low coefficient of performance and high power requirements. However, this system continues to be favored for air refrigeration because of the low weight and volume of the equipment the advent of high speed passenger air craft, jet air craft and missiles has introduced the need for compact of high capacities with minimum reduction of pay load. When the power requirement, needed to transport the additional weight of the refrigerating system are taken into account, the air cycle systems usually prove to be the most efficient and convenient to use

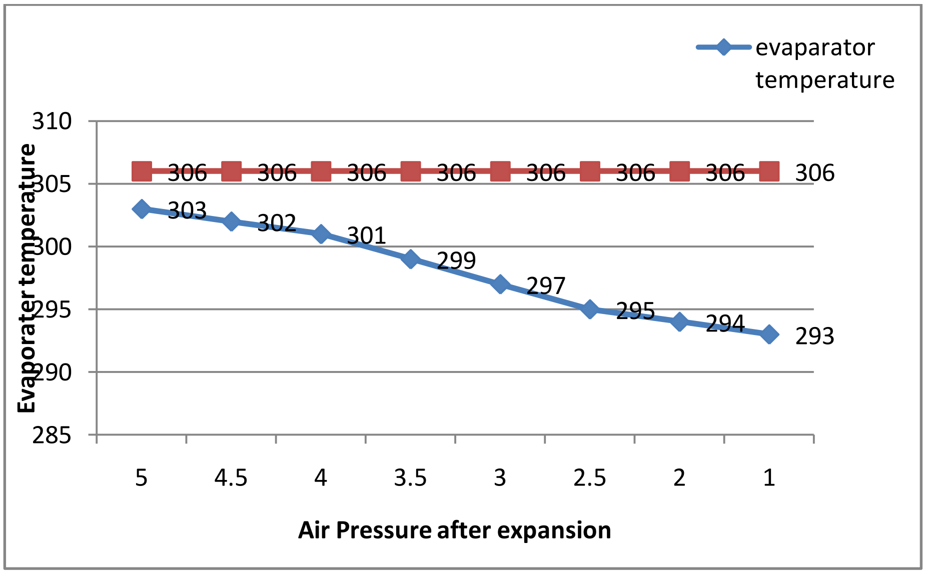
In an air refrigeration system, the air is used as refrigerant as a medium, whereas other refrigeration systems use refrigerants (Freon's ammonia etc.,) as medium. Since air is used as refrigerant no damage to atmosphere is done. By using other refrigerants damage to atmosphere such as ozone layer depletion takes place. Compression of air needs much power compared to compression of refrigerants. This system produces low COP because of which it has become obsolete. Other refrigeration systems have high COP but have severe impact on atmosphere. Moreover these refrigerants are too expensive and handling of these refrigerants is difficult.

8.0 Results and graphs

8.1 Results and graphs of bell Coleman cycle:

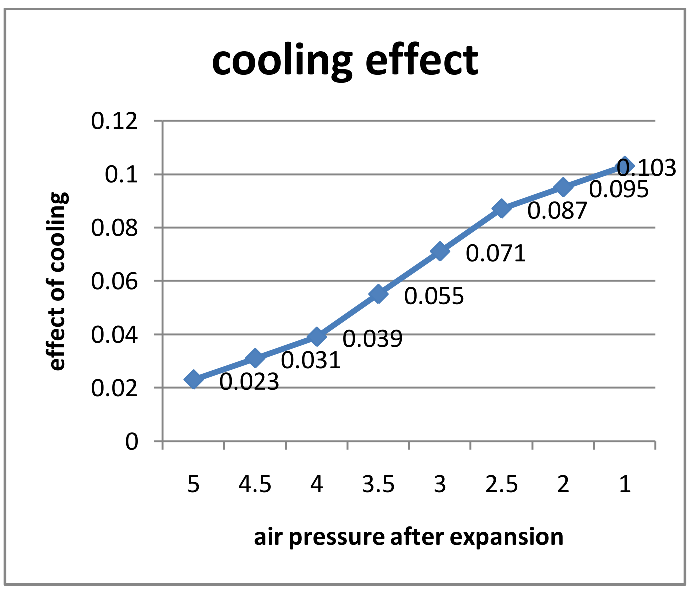
Compressed air pressure	Air pressure after expansion	Ambient temperatue	Evaporator inlettemperature(K)	Cooling effect	COP
6	5	306	303	0.023	0.02
6	4.5	306	302	0.031	0.036
6	4	306	301	0.039	0.045
6	3.5	306	299	0.055	0.064
6	3	306	297	0.071	0.082
6	2.5	306	295	0.087	0.1006
6	2	306	294	0.095	0.112
6	1	306	293	0.103	0.119

8.2. Variation of temperatures with expanded air pressure:

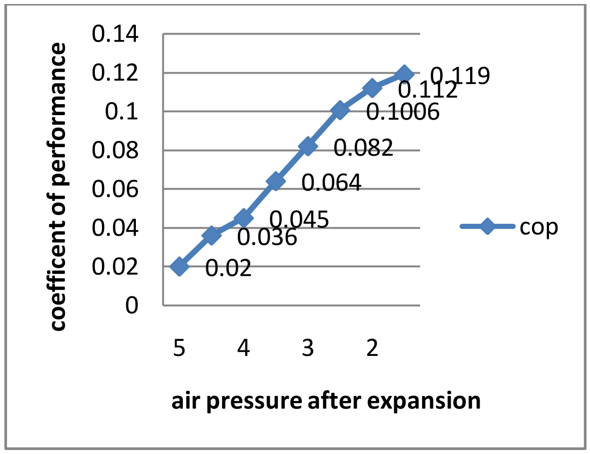


From the above graph as the air pressure after expansion increases the evaporator inlet temperature decreases.

8.3. Variation o f cooling effect and COP with air pressure after expansion:



8.4 Variation COP with change in air Pressure after Expansion



9.0 Conclusions

In an air refrigeration system, the air is used as refrigerant as a medium, whereas other refrigeration systems use refrigerants (Freon's ammonia etc.,) as medium. Since air is used as refrigerant no damage to atmosphere is done. By using other refrigerants damage to atmosphere such as ozone layer depletion takes place. This system produces low COP because of which it has become obsolete. Other refrigeration systems have high COP but have severe impact on atmosphere. Moreover these refrigerants are too expensive and there is a handling difficult of these refrigerants.

REFERENCES

[1] S. M. Metev and V. P. Veiko, *Laser Assisted Microtechnology*, 2nd ed., R. M. Osgood, Jr., Ed. Berlin, Germany: Springer-Verlag, 1998.
[2] J. Breckling, Ed., *The Analysis of Directional Time Series: Applications to Wind Speed and Direction*, ser. Lecture Notes in Statistics. Berlin, Germany: Springer, 1989, vol. 61.
[3] S. Zhang, C. Zhu, J. K. O. Sin, and P. K. T. Mok, "A novel ultrathin elevated channel low-temperature poly-Si TFT," *IEEE Electron Device Lett.*, vol. 20, pp. 569–571, Nov. 1999.
[4] M. Wegmuller, J. P. von der Weid, P. Oberson, and N. Gisin, "High resolution fiber distributed measurements with coherent OFDR," in *Proc. ECOC'00*, 2000, paper 11.3.4, p. 109.