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EXPERIMENTAL COMPARISON OF SINGLE AND MULTISTAGE AIR COMPRESSOR EFFICIENCIES UNDER THE SAME RECEIVER TANK PRESSURE

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ABSTRACT
Compressors are widely used for many engineering applications in day to day life. Compressors are classified based on design as reciprocating and rotary compressors, Reciprocating compressors are single acting ,double acting ,air cooled ,water cooled and single stage ,multistage ,depends on application of usage. It is clear by theory as given by author's multistage compressors having advantage over single stage compressors but practically not aware to what extent the variations in efficiencies are taking place and exact experimental figures in that area not focused with clarity. So here focus is given to conduct experiment on both single stage and multi stage compressors at the different receiver tank pressure. Obtained readings are calculated for the same receiver tank pressure and then comparing the results for both the compressors. To know the variations in efficiencies of both compressors results are tabulated and compared to find out the efficiencies for better understanding the subject.

Keywords: *single stage compressor, multistage compressor, LP cylinder, HP cylinder, volumetric efficiency, isothermal efficiency.*

1.0 INTRODUCTION

Reciprocating air compressors are widely used to get high discharge pressure. To get high discharge pressure single stage compressor has to work against high compression ratio in terms of pressure so to withstand high compression ratio body of compressor also be made robust in construction . It will add more weight to compressor and also leads many mechanical problems because it is working for the development of high pressure in single cylinder and also it is not suitable because of this reasons when to go for developing high delivery pressure for industrial applications. So alternative is increasing the delivery pressure in number of cylinders step by step and reducing the weight of the compressor. first developing pressure in one cylinder of cylinder say L.P cylinder and allow this pressurized air to another cylinder say Intermediate cylinder (IP) and develop Higher pressure higher than the LP cylinder and allow this pressurized air in another cylinder say HP cylinder and develop more pressure then intermediate cylinder finally highly developed pressurized air is delivered to the end user applications. This is possible by going for multi stage cylinder compressor. This paper focused on conducting the experiment on compressors to find what differences made when using single and multistage compressor in efficiencies and comparing its experimental results for giving the conclusions for the usage.

2.0 EXPERIMENTAL SET UP OF SINGLE STAGE COMPRESSOR

The details of the experimental setup of single stage reciprocating Air compressor is as follows

Fig1: single stage reciprocating Air compressor

Specifications of the compressor:

Make	: ELGI
Type	: Reciprocating Type
Stage	: single stage
Cylinder	: single cylinder
Bore	: 60 mm
Stroke length	: 60 mm
Motor rating	: 2 HP
Motor speed	: 1420 RPM
Compressor speed	: 930 RPM
Electric supply	: 415V/380V, 3ph, 50 HZ
Type of starter	: DOl
Belt size	: B40
Type of lubrication	: splash
Type of cooling	: Air cooled
Type of fan	: forced draught

3.0 SINGLE STAGE COMPRESSOR

Table1: table of Readings of single stage compressor as follows

S. NO	Receiver Tank Pressure (bars)	Suction Pressure P1(bars)	Discharge pressure P2(bars)	Suction Temperature T_1 ^{0}C	Discharge Temperature T2 ^{0}C	Speed RPM	Manometer Reading(h)mm	Time per 10 Revolutions-sec
1	2	1	3.8	24	109	876.0	20	6.78
2	4	1	6.4	24	125	872.2	15	6.5
3	6	1	8.4	24	136	869.3	14	6.0

T_1 = suction Temperature of air entering in to the cylinder
T_2 = discharge Temperature of air leaving the compressor
T_a = Ambient Temperature of air
P_1 = suction pressure of air
P_2 = discharge (cylinder outlet) pressure

3.1 Sample calculations for Reading -1 at 2 bar pressure

Sample calculations for Reading -1

Volume of air sucked in to the cylinder

$$Va = Cd \times Ao \times \sqrt{2gH} \times 3600 \quad M^3/hr$$

Where $H = \frac{20}{1000} x \frac{1000}{1.187} = 16.825$ meters

$Va = 0.62 \times 1.767 \times 10^{-4} \times \sqrt{2 \times 9.81 \times 16.825} \times 3600 = 7.1656 \quad M^3/hr$

Theoretical volume of air

$$Vth = \frac{\pi}{4} d^2 xLxNx60 \quad M^3/hr$$

$$Vth = \frac{\pi}{4} x0.06^2 \; x0.06 \; x876x60 = 8.9165 \; M^3/hr$$

Volumetric efficiency

$$\eta vol = \frac{Va}{Vth} \times 100$$

$$\eta vol = \frac{7,1656}{8.9165} \times 100 = 80.3\%$$

Compression ratio $Rp = \frac{P2}{P1} = \frac{3.8}{1} = 3.8$

$$P_{iso} = ma \; RaxT_1 \times \ln(Rp)$$

Where ma = Va x ρa

ρa =density of air

ma = 7.1656 x 1.1887 =8.5117 M^3/hr

$$P_{iso} = ma \; RaxT_1 \times \ln(Rp)$$

$P_{iso} = \frac{8.5117}{3600} x \; 0.287xT_1 \; (273+24)x \; \ln(3.8)$ =0.269 KW

As per the relation (temperature, pressure and volume) for polytrophic process $\frac{T2}{T1} = (\frac{P2}{P1})^{\frac{n-1}{n}}$

$\ln(\frac{273+109}{297}) = \frac{n-1}{n} x \ln(3.8)$

$\frac{n-1}{n} = \frac{0.2516}{1.335} = 0.1885$

I.P = $\frac{n-1}{n}$ x max RaxT$_1$ $[(\frac{P2}{P1})^{\frac{n-1}{n}} - 1]$

I.P = $\frac{1}{0.1885}$ x $\frac{8.5117}{3600}$x 0.287x297 $[(3.8)^{0.1885} - 1]$ =0.302 KW

Power input to Motor (Pm)

Pm = $\frac{10\ rev\ x\ 3600}{t\ in\ sec\ x\ 3200}$

Where 3200 = Energy meter constant

Pm = $\frac{10\ rev\ x\ 3600}{6.78\ x\ 3200}$ = 1.659 KW

Power input to compressor Pc = Pm x 0.8
Pc = 1.659 x 0.8 = 1.327 Kw

Mechanical efficiency $\eta = \frac{I.P}{Pc}$ x 100
$\eta = \frac{0.302}{1.327}$ x 100 = 22.75 %

Overall efficiency $\eta = \frac{Piso}{Pc}$ x 100
$\eta = \frac{0.269}{1.327}$ x 100 = 20.27 %

Isothermal efficiency $\eta = \frac{Piso}{IP}$ x 100

$\eta = \frac{0.269}{0.302}$ x 100 = 89 %

3.2 Similarly Sample calculations for Reading -2 at 4 bar pressure

Volume of air sucked in to the cylinder

Va =Cd x Ao x $\sqrt{2gH}$ x 3600 M^3/hr

Where H = 12.618 meters

Va = 6.256 M^3/hr

Theoretical volume of air

Vth = $\frac{\pi}{4}$ d^2xLxNx60 M^3/hr

Vth = 8.877 M^3/hr

Volumetric efficiency
ηvol = $\frac{Va}{Vth}$ x 100

ηvol = 70.46%

Compression ratio Rp = $\frac{P2}{P1}$ = 6.4

P_{iso} = max RaxT$_1$ x ln(Rp)

Where ma = Va x ρa

ρa =density of air

ma = 7.4365 M^3/hr

P_{iso} = max RaxT$_1$ x ln(Rp)

P_{iso} =0.326 KW

As per the relation (temperature, pressure and volume) for polytrophic process $\frac{T2}{T1} = (\frac{P2}{P1})^{\frac{n-1}{n}}$

$\ln(\frac{273+125}{297}) = \frac{n-1}{n} x \ln(6.4)$

$\frac{n-1}{n} = 0.15768$

I.P = $\frac{n-1}{n}$ x max RaxT$_1$ $[(\frac{P2}{P1})^{\frac{n-1}{n}} - 1]$

I.P =0.3796 KW

Power input to Motor (Pm)

Pm = $\frac{10\ rev\ x\ 3600}{t\ in\ sec\ x\ 3200}$

Where 3200 = Energy meter constant

Pm = 1.7307 KW

Power input to compressor Pc = Pm x 0.8

Pc = 1.7307 x 0.8 = 1.384 Kw

Mechanical efficiency $\eta = \frac{I.P}{Pc}$ x 100

η = 27.41 %

Overall efficiency $\eta = \frac{Piso}{Pc}$ x 100

η = 23.5 %

Isothermal efficiency $\eta = \frac{Piso}{IP}$ x 100

η= 85.8%

3.3 Similarly Sample calculations for Reading -3 at 6 bar pressure

Volume of air sucked in to the cylinder

Va =Cd x Ao x √2gH x 3600 M^3/hr

Where H = 11.77 meters

Va = 5.995 M^3/hr

Theoretical volume of air

Vth = $\frac{\pi}{4}$ d^2xLxNx60 M^3/hr

Vth = 8.877 M^3/hr

Volumetric efficiency

ηvol = $\frac{Va}{Vth}$ x 100

ηvol = 67.52 %

Compression ratio Rp = $\frac{P2}{P1}$ = 8.4

P_{iso} = ma RaxT$_1$ x ln(Rp)

Where ma = Va x ρa

ρa =density of air

M_a = 7.126 M^3/hr

P_{iso} = ma RaxT$_1$ x ln(Rp)

P_{iso} =0.359 KW

As per the relation (temperature, pressure and volume) for polytrophic process $\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{\frac{n-1}{n}}$

$\ln\left(\frac{273+136}{297}\right) = \frac{n-1}{n} \times \ln(8.4)$

$\frac{n-1}{n} = 0.1503$

I.P = $\frac{n-1}{n}$ x ma RaxT$_1$ $\left[\left(\frac{P2}{P1}\right)^{\frac{n-1}{n}} - 1\right]$

I.P =0.423 KW

Power input to Motor (Pm)

Pm = $\frac{10\, rev \times 3600}{t\ in\ sec \times 3200}$

Where 3200 = Energy meter constant

Pm = 1.875 KW

Power input to compressor Pc = Pm x 0.8

Pc = 1.875 x 0.8 = 1.5 Kw

Mechanical efficiency $\eta = \frac{I.P}{Pc}$ x 100

η = 28.2 %

Overall efficiency $\eta = \frac{Piso}{Pc}$ x 100

η = 23.9 %

Isothermal efficiency $\eta = \frac{Piso}{IP}$ x 100

η= 84.8%

3.4 Comparisons table of values for single stage compressor

Table2: table of results

Bar	η_{vol}	P_{iso}	IP	P_c	η_{mech}	$\eta_{overall}$	η_{iso}	T2	RPM
2	80.3	0.269	0.302	1.327	22.75	20.27	89.0	109	876
4	70.46	0.326	0.3796	1.384	27.41	23.5	85.8	125	872.2
6	67.52	0.359	0.423	1.5	28.2	23.9	84.8	136	869.3

Comparison shows as pressure is increasing volumetric efficiency and isothermal efficiency is decreasing but isothermal power increases and also other efficiencies like mechanical, overall efficiencies are increases with increase of the pressure

4.0 EXPERIMENTAL SET UP OF MULTISTAGE COMPRESSOR

Fig2: multistage compressor test rig.

Specifications of the compressor:

Make : ELGI
Model : TS 03120
Type : Reciprocating Type
Stage : two stages
Cylinder : two cylinders
LP cylinder bore : 70 mm
HP cylinder bore : 50 mm
Stroke length : 85mm
Motor rating : 3 HP
Motor speed : 1420 RPM
Compressor speed : 930 RPM
Electric supply : 415V/380V, 3ph, 50 HZ
Type of starter : DOl
Belt size : A68
Type of lubrication : splash
Type of cooling : Air cooled
Type of fan : forced draught

5.0 MULTISTAGE COMPRESSOR

Table3: Table of Readings of multistage compressor as follows

Tank Pressure	P1	P2	P3	Manometer	Time per 5 revolutions	RPM	T1	T2	T3	T4
2	1	0.95	1.9	200	42.75	928	28	100	86	88
4	1	1.05	4.45	193	36.97	923	29	114	96	131
6	1	1.1	6.4	189	34.59	917	29	114	98	157

T_1 =Temperature of air entering L.P cylinder
T_2 =Temperature of air leaving L.P cylinder
T_3 =Temperature of air after intercooler and entering H.P cylinder
T_4 = temperature air leaving HP cylinder
T_a = ambient temperature/
P_1 = atmosphere pressure 1 bar
P_2 = L.P cylinder outlet pressure
P_3 = H.P cylinder outlet pressure

5.1 Sample calculations for Reading -1 at 2 bar pressure

Sample calculations for Reading -1

Volume of air sucked in to the cylinder

$Va = Cd \times Ao \times \sqrt{2gH} \times 3600$ M^3/hr

Where H $=\frac{200}{1000}x\frac{1000}{1.1729}$ = 170.517 meters

Va =0.62 x 1.767 x10^{-4} x $\sqrt{2x9.81x170516}$x 3600 = 22.812 M^3/hr

Theoretical volume of air
Vth = $LxN_c(A_1 + A_2)$ x60 M^3/hr

Area of first cylinder-$A_1=\frac{\pi}{4}d1^2$
Area of first cylinder-$A_1=\frac{\pi}{4}d2^2$

Vth = 0.085x928 (1.9634 x 10^{-3} + 3.848 x 10^{-3}) x60 M^3/hr

Vth = 27.506 M^3/hr

Volumetric efficiency
$\eta vol = \frac{Va}{Vth}$ x 100

$\eta vol = \frac{22.812}{27.506}$ x 100 = 82.9%

Compression ratio Rp = $\frac{P3}{P1} = \frac{1.9}{1}$ = 1.9

P_{iso} = ma RaxT_1 x ln(Rp)

Where ma = Va x ρa
ρa =density of air
ρa =density of air = $\frac{101.325}{0.287\,x\,301}$ =1.1729

ma = 22.812 x 1.729 =26.756 M^3/hr

P_{iso} = ma RaxT_1 x ln(Rp)

$P_{iso} = \frac{26.756}{3600}$x 0.287x (273+28)x ln(1.9) =0.4121 KW

As per the relation (temperature, pressure and volume) for polytrophic process $\frac{T4}{T1} = (\frac{P3}{P1})^{\frac{n-1}{n}}$

$\ln(\frac{273+88}{273+28}) = \frac{n-1}{n}$x ln(1.9)

$\frac{n-1}{n} = \frac{0.18176}{0.641}$ = 0.28317 and n=1.396

I.P = $2x\frac{n-1}{n}$ x ma RaxT_1 $[(\frac{P3}{P1})^{\frac{n-1}{2n}} - 1]$

I.P = $\frac{2}{0.283179}$ x $\frac{26.756}{3600}$x 0.287x301 $[(1.9)^{\frac{1.396-1}{2x1.396}} - 1]$ =0.430 KW

Power input to Motor (Pm)

Pm = $\frac{5\,rev\,x\,3600}{t\,in\,sec\,x\,3200}$

Where 3200 = Energy meter constant

Pm = $\frac{5\,rev\,x\,3600}{42.75\,x\,3200}$ = 2.105 KW

Power input to compressor Pc = Pm x 0.8
Pc = 2.105 x 0.8 = 1.684 Kw

Mechanical efficiency $\eta = \frac{I.P}{Pc}$ x 100

$\eta = \frac{0.430}{1.684}$ x 100 = 25.53%

Overall efficiency $\eta = \frac{Piso}{Pc}$ x 100
$\eta = \frac{0.4121}{1.684}$ x 100 = 24.47 %

Isothermal efficiency $\eta = \frac{Piso}{IP}$ x 100

$\eta = \frac{0.4121}{0.430}$ x 100 = 95.9 %

5.2 Sample calculations for Reading -2 at 4 bar pressure

Sample calculations for Reading -2

Volume of air sucked in to the cylinder
Va =Cd x Ao x $\sqrt{2gH}$ x 3600 M^3/hr

Where H =164.549 meters

Va =0.62 x 1.767 x10^{-4} x $\sqrt{2x9.81x170516}$x 3600 = 22.812 M^3/hr

Theoretical volume of air
Vth = LxN$_c$ (A_1 + A_2) x60 M^3/hr

Area of first cylinder-A_1=$\frac{\pi}{4}\, d1^2$
Area of first cylinder-A_1=$\frac{\pi}{4}\, d2^2$

Vth = 0.085x923 (1.9634 x 10^{-3} + 3.848 x 10^{-3}) x60 M^3/hr

Vth = 27.354 M^3/hr

Volumetric efficiency
$\eta vol = \frac{Va}{Vth}$ x 100

$\eta vol = \frac{22.409}{27.345}$ x 100 = 81.9%

Compression ratio Rp = $\frac{P3}{P1}$ =4.45

P_{iso} = m_a x $_{RaxT1}$ x ln(Rp)

Where ma = Va x ρa
ρa =density of air
ρa =density of air $= \frac{101.325}{0.287\, x\, 301}$ =1.1729

m_a = 22.409 x 1.729 =26.283 M^3/hr

P_{iso} = max RaxT$_1$ x ln(Rp)

$P_{iso} = \frac{26.756}{3600}$x 0.287x (273+28)x ln(4.45) =0.9415 KW

As per the relation (temperature, pressure and volume) for polytrophic process $\frac{T4}{T1} = (\frac{P3}{P1})^{\frac{n-1}{n}}$

$\ln(\frac{273+131}{273+28}) = \frac{n-1}{n}$x ln(4.45)

$\frac{n-1}{n} = \frac{0.18176}{0.641}$ = 0.1971 and n=1.2454

I.P = $2x\frac{(n-1}{n}$ x max RaxT$_1$ $[(\frac{P3}{P1})^{\frac{n-1}{2n}} - 1]$

I.P = 1.0143 KW

Power input to Motor (Pm)

Pm = $\frac{5\, rev\, x\, 3600}{t\, in\, sec\, x\, 3200}$

Where 3200 = Energy meter constant

Pm = 2.434 KW

Power input to compressor Pc = Pm x 0.8
Pc = 2.434 x 0.8 = 1.947 Kw

Mechanical efficiency $\eta = \frac{I.P}{Pc}$ x 100

$\eta = \frac{1.0143}{1.947}$ x 100 = 52.09%

Overall efficiency $\eta = \frac{Piso}{Pc}$ x 100
$\eta = \frac{0.9415}{1.947}$ x 100 = 48.3 %

Isothermal efficiency $\eta = \frac{Piso}{IP}$ x 100

$\eta = \frac{0.9415}{1.0143}$ x 100 = 92.8 %

5.3 Sample calculations for Reading -3 at 6 bar pressure

Sample calculations for Reading -1

Volume of air sucked in to the cylinder
Va =Cd x Ao x $\sqrt{2gH}$ x 3600 M^3/hr

Where H = 161.139 meters

Va = 22.175 M^3/hr

Theoretical volume of air
Vth = LxN$_c$ (A_1 + A_2) x60 M^3/hr

Area of first cylinder-A_1=$\frac{\pi}{4}\, d1^2$
Area of first cylinder-A_1=$\frac{\pi}{4}\, d2^2$

Vth = 0.085x917 (1.9634 x 10^{-3} + 3.848 x 10^{-3}) x60 M^3/hr

Vth = 27.178 M^3/hr

Volumetric efficiency

$\eta vol = \frac{Va}{Vth} \times 100$

$\eta vol = 81.59\%$

Compression ratio $Rp = \frac{P3}{P1} = 6.4$

$P_{iso} = m_a\, RaxT_1 \times \ln(Rp)$

Where $m_a = Va \times \rho a$

ρa =density of air

ρa =density of air $= \frac{101.325}{0.287 \times 301}$ =1.1729

$m_a = 22.175 \times 1.729 = 26.009\ M^3/hr$

$P_{iso} = m_a\, RaxT_1 \times \ln(Rp)$

$P_{iso} = \frac{26.009}{3600} \times 0.287 \times (273+28) \times \ln(6.4)$ =1.1585 KW

As per the relation (temperature, pressure and volume) for polytrophic process $\frac{T2}{T1} = (\frac{P2}{P1})^{\frac{n-1}{n}}$

$\ln(\frac{273+157}{273+28}) = \frac{n-1}{n} \times \ln(6.4)$

$\frac{n-1}{n} = 0.1921$ and $n=1.2377$

$I.P = 2x\frac{n-1}{n} \times m_a\, RaxT_1 [(\frac{P2}{P1})^{\frac{n-1}{2n}} - 1]$

I.P =1.2377 KW

Power input to Motor (Pm)

$Pm = \frac{5\, rev \times 3600}{t\, in\, sec \times 3200}$

Where 3200 = Energy meter constant

Pm = 2.6019 KW

Power input to compressor Pc = Pm x 0.8

Pc = 2.6019 x 0.8 = 2.0815 Kw

Mechanical efficiency $\eta = \frac{I.P}{Pc} \times 100$

$\eta = 59.6\%$

Overall efficiency $\eta = \frac{Piso}{Pc} \times 100$

$\eta = 55.6\ \%$

Isothermal efficiency $\eta = \frac{Piso}{IP} \times 100$

$\eta = 93.5\%$

5.4 Comparisons of values for multi stage compressor

Table 4: table of results for multistage compressor

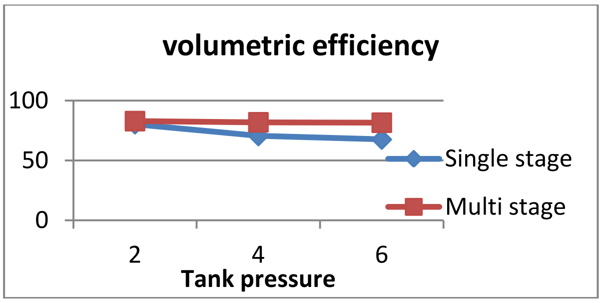
pressure	η_{vol}	P_{iso}	IP	P_c	η_{mech}	η_{ovr}	η_{iso}	T4	RPM
2	82.9	0.4121	0.4519	1.684	26.8	24.47	91.1	89	928
4	81.92	0.9415	1.094	1.947	56.1	48.3	86.06	131	923
6	81.59	1.1585	1.337	2.0815	64.23	55.6	86.6	157	917

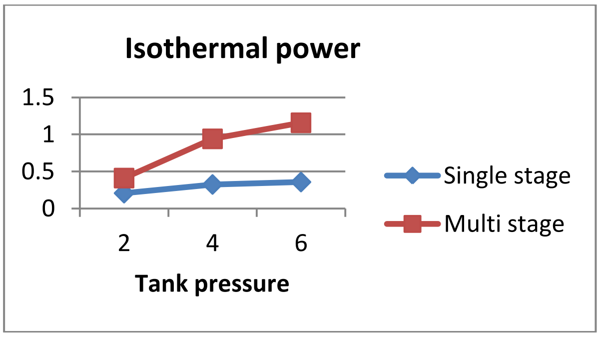
Comparison shows as pressure is increasing volumetric efficiency and isothermal efficiency is decreasing but isothermal power and indicated power increases and also other efficiencies like mechanical, overall efficiencies increases with increase of the pressure. It was observed this is same in both cases of single and multi stage compressor

5.5 Comparisons tables for single stage and multi stage compressors

Table: 5 -Comparisons table for single and multi stage compressor

Tank Pressure	Volumetric Efficiency		P_{iso}		IP	
	Single stage	Multi stage	Single stage	Multi stage	Single stage	Multi stage
2	80.3	82.9	0.209	0.4121	0.302	0.451
4	70.46	81.92	0.326	0.9415	0.3796	1.094
6	67.52	81.59	0.359	1.1585	0.423	1.337





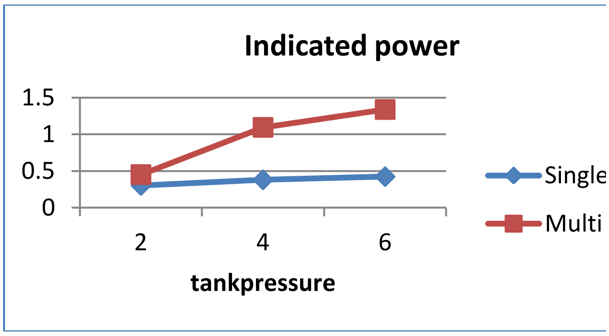
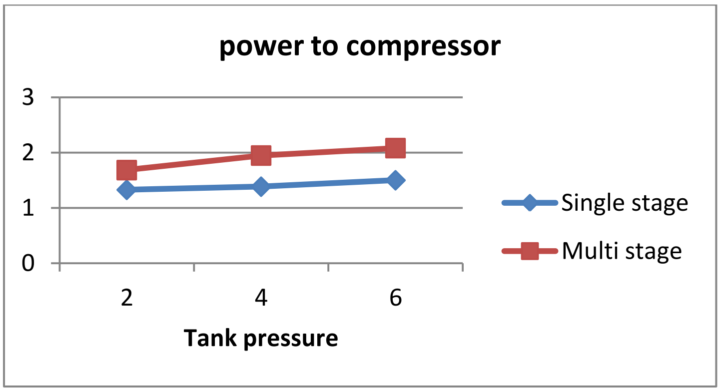
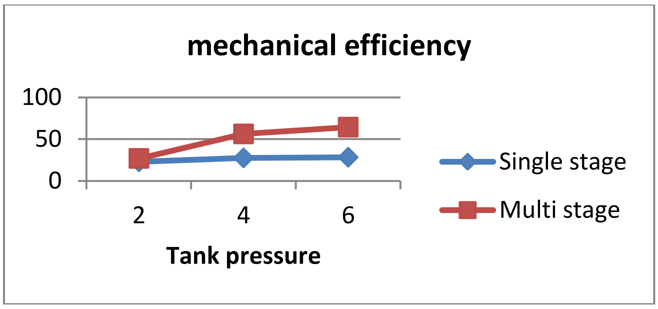


Table: 6 -Comparisons table for single and multistage compressor

Tank Pressure	P_c		η_{mech}		η_{over}	
	Single stage	Multi stage	Single stage	Multi stage	Single stage	Multi stage
2	1.327	1.684	22.75	26.8	20.27	24.47
4	1.384	1.947	27.41	56.1	23.5	48.3
6	1.5	2.0815	28.2	64.23	23.9	55.6





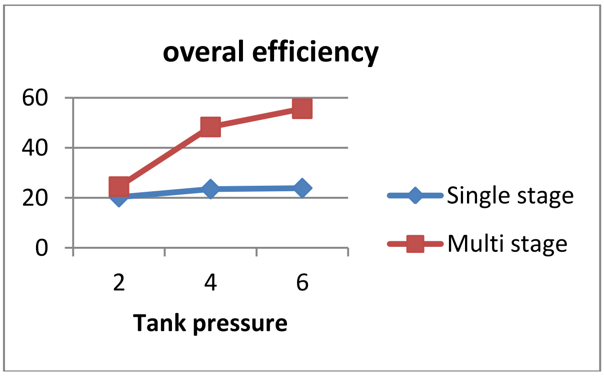
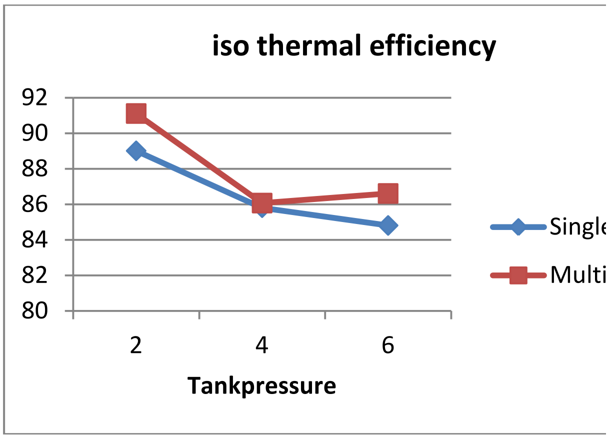


Table: 7 -Comparisons table for single and multi stage compressor

Tank Pressure	η_{iso}		Delivery temperature		RPM	
	Single stage	Multi stae	Single stage	Multi stage	Single stage	Multi stage
2	89.0	91.1	109	88	876	928
4	85.8	86.06	125	131	872.2	923
6	84.8	86.6	136	157	869.3	917



6.0 CONCLUSIONS

It was observed with increase of tank pressure isothermal power, indicated power mechanical efficiencies are increasing for both single and multistage compressors and also observed with increase of delivery pressure volumetric efficiency is reducing in both cases. As temperature of incoming air increasing, the density of air decreasing and volume of air sucked in to cylinder increases, it may be the reason because of less dense of air which may be entering in to the engine cylinder. On comparison of volumetric efficiency, isothermal power indicated power, mechanical efficiency; isothermal efficiencies are higher for multistage compressor then the single stage compressor with marginal rise of power input to the compressor. We may conclude for almost same equal power consumption multistage compressor having higher efficiency then the single stage compressor.

REFERENCES

[1] Internal combustion engines and Air pollution by professor (Dr.) R.Yadav Third revised edition –central publishing house 18-C, Sarojini Naidu Marge-Allahabad-211001

[2]A Text book of internal combustion Engines (Including Air compressor, Gas turbines and Jet propulsions) Unit second Edition By R.K.Rajput published by Laxmi Publications Pvt Ltd 113, Golden house,Daryaganj,New Delhi-110002

[3] A Text book of Thermal Engineering by J.K Gupta and R.S.Khurmi