NUMERICAL AND EXPERIMENTAL ANALYSIS OF LEAKAGE RATE OF O-RING ELASTOMERIC SEALING MATERIAL

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Abstract: An experimental setup was designed and developed for measurement of leakage rate past O-ring elastomeric seal. Available numerical formulation was used to calculate the leakage rate which was validated using the experimental analysis. Leakage rate was calculated by changing six different pressure values and six different values of piston velocity. Comparison of numerical data and experimental values was done by interpretation of graph of the results. In this project numerical analysis is done by calculation using formula available in literature for different experimental and velocity. This data is the validated using experimental setup and finally both the results are compared. The behavior of elastomeric material in different loading condition is unpredictable unlike elastic metals, so these types of study is required to understand the operation through which elastic material go through which elastomeric material go through.

***Index Terms*: Leakage rate, numerical, experimental, pressure, velocity, elastomeric.**

I. INTRODUCTION

There is an ever-increasing demand for reliability and long life which should be economical. Statistics shows that the main reason for the failure of machines is not breakage but wear of the moving parts resulting from rubbing stresses. Seals are used for many industrial applications in wide range for different temperature and pressure [1]. The behaviour of the seal should be studied properly because there cannot be a universal seal that will serve every application. Basically, seals are the component which are mostly smaller in size as compared to other parts of the machines, but most of the time major contact pressure and load is transferred through these components. Seals are generally replaced once it cannot perform its task which it was designed for. Replacement of the seal stays the only optimum solution in this case because it may take lot of time and cost to maintain a small piece of machine part. Now as replacement remains only solution industries has to invest lots of money in replacement so to reduce the overall investment and effort taken by industries which uses lot of seals can be done by increasing the lifespan of the seal. The lifespan of the seal can be increased by studying the various parameters of the seals and improving it [2]. Before increasing the lifespan of the seal, we need to take into consideration that what are the various performance parameters that has its effect on operation and effectiveness of a seal. The most important performance parameter of the seal is its leakage rate.

Theoretically speaking there cannot be any seal which does not leak irrespective of its shape, size and application. The study focuses mainly on the leakage rate. There are various parameters of seals on which leakage rate depends those are contact pressure, clearance, film thickness, friction between sliding surfaces, density of the fluid ‘ρ’, viscosity of the fluid etc. These parameters when varied as its effect on leakage rate as mentioned in this article further.

II. NUMERICAL CALCULATION FOR LEAKAGE RATE

As we know leakage rate depend on number of factors. Calculating the leakage rate numerically must include all the factors so that the value of leakage rate is as close as possible to the actual leakage rate. The factors on which leakage rate depends, should not only be accounted for the calculation but it should also closely resemble its behaviour as it would actually do.
The cross section of seal and cylinder is as shown in fig.1.

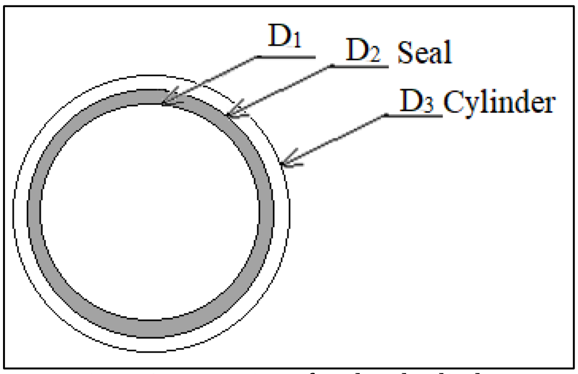

Fig.1: Cross section of seal and cylinder

Let us discuss some of such factors. One of the small but important factor is surface roughness. Let us say that S_{cyl} is the surface roughness for inner part of the cylinder which is in contact with seal and S_{seal} is the surface roughness of the seal surface sliding inside the cylinder. The value of surface roughness used are average values. As the surface roughness value increases the leakage rate also increases because larger roughness will give more space for fluid to exit.

Other factor on which leakage rate depends is diameter of cylinder ‘D_{cyl}’. As the diameter of cylinder increase the leakage rate will increase which is obvious as it will also increase the circumference of the circle formed by the contact. Normal surface displacement is something which is seen due to the effect of pressure acting on the surfaces of the fluid. The inner surface of the cylinder and surface of seal can be assumed as thick cylinder under pressure in a two-dimensional plane hence following formulas can be used.

Let us say u, is normal surface displacement due to pressure 'p' therefore normal surface displacement on inner side of cylinder and both surfaces of the seal is given as,

$$u_{cyl} = \frac{pD_2}{E_{rod}}\left[\frac{D_3^2+D_2^2}{D_3^2-D_2^2} + \mu\right] \quad (2.1)$$

$$u_{seal}^{i} = \frac{pD_1}{E_{seal}}\left[\frac{D_2^2+D_1^2}{D_2^2-D_1^2} + \mu\right] \quad (2.2)$$

$$u_{seal}^{o} = \frac{pD_2}{E_{seal}}\left[\frac{D_2^2+D_1^2}{D_2^2-D_1^2} - \mu\right] \quad (2.3)$$

where, μ is poisson's ratio, E is Young's modulus

There is a pressure acting on the fluid which is hold by the O-ring seal. The value of pressure on one side of the seal is the pressure acting due to the fluid and atmospheric pressure on the other side i.e. zero pressure (gauge pressure). This means that there is a pressure gradient across the seal with this pressure gradient denoted by dp/dy is also a factor on which leakage rate depends. Viscosity of fluid 'η' is inversely proportional to the leakage rate. Another important factor on which leakage rate depends is velocity of the piston. Major changes were seen as the velocity was changed, a thin film of fluid is created between the seal and cylinder called film thickness. It is clear that as film thickness will increase the leakage rate will also increase.

The film thickness 'h' is given by [3],

$$h = S_{cyl} + S_{seal} + u_{cyl} + u_{seal} \quad (2.4)$$

The formula for calculating the leakage rate 'q' is given by,

$$q = \int_0^{2\pi} \left\{ \int_0^h \rho \left[\frac{(h-z)}{h} V \cdot \frac{D_{cyl}}{2} - \frac{z(h-z)}{\eta}\frac{dp}{dy} \cdot \frac{D_{cyl}}{2} + \frac{z(h-z)}{h} \cdot V - \frac{z^2(h-z)}{2\eta} \cdot \frac{dp}{dy} \right] dz \right\} d\phi \quad (2.5)$$

z is distance from cylinder surface. This formula can be reduced by solving the integration,

$$q = 2\pi\rho \left[-\frac{h^4}{24\eta}\frac{dp}{dy} - \frac{h^3}{12\eta}\frac{dp}{dy}\frac{D_{cyl}}{2} + \frac{h^2}{6}V + \frac{h}{2}V\frac{D_{cyl}}{2} \right] \quad (2.6)$$

The factor present in this formula was given the value on which experimental test was done. Using those values of variable leakage rate was calculated numerically which will be discussed further in the article.

III. EXPERIMENTAL SETUP FOR LEAKAGE RATE CALCULATION

An experimental setup was designed and developed for calculating the leakage rate. The schematic diagram of the setup is shown in fig. Before creating the concept design of the setup, some objective was set which the setup should be able to fulfil. The two objectives are leakage rate of O-ring seal should be tested for static as well as dynamic conditions and there should be provision to change pressure acting on the fluid. Hence the given setup was developed.

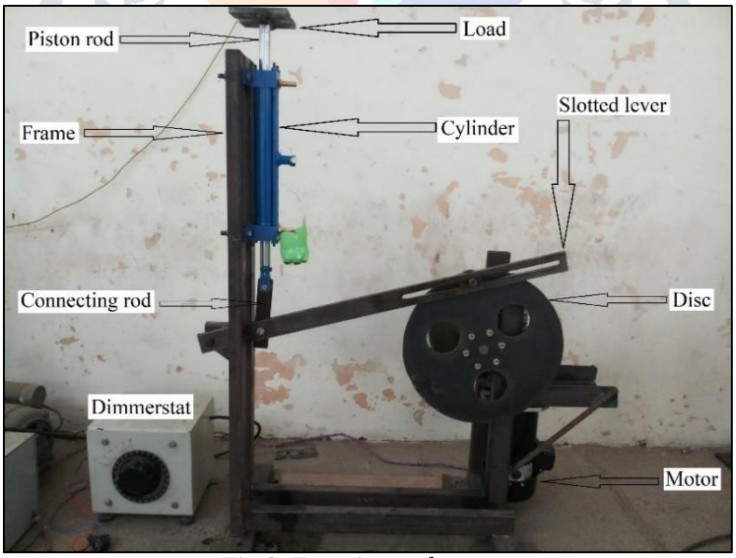

Fig.2: Experimental setup

As seen in fig.2 the setup consists of load, tie rod, cylinder, piston, slotted Lever, disc, worm and worm wheel, motor, and frame. The cylinder consists of two Pistons on its ends. Load is applied on the upper Piston rod and the lower Piston rod consist of O-ring seal of which leakage rate is to calculated. There is an oil column between both the piston. This column of oil reciprocates along with the piston. The lower Piston rod is connected to the slotted lever using a connecting plate. One end of the Lever is hinged to the frame while other slotted end is connected to the disc in such a way that as the disc rotates it gives oscillating motion to the slotted lever. The disc is given rotating motion by a motor which is connected through worm and worm wheel arrangement as shown in fig. Experiment was performed by giving different velocities and pressure to the fluid and leakage rate was measured. Leakage rate was calculated my measuring the volume of oil which leaks through the exit of cylinder which was collected in beaker shown in fig.3.1. This oil was transferred to test tube to measure difference in level of oil as shown in fig.3.2.

Fig. 3.1. Beaker

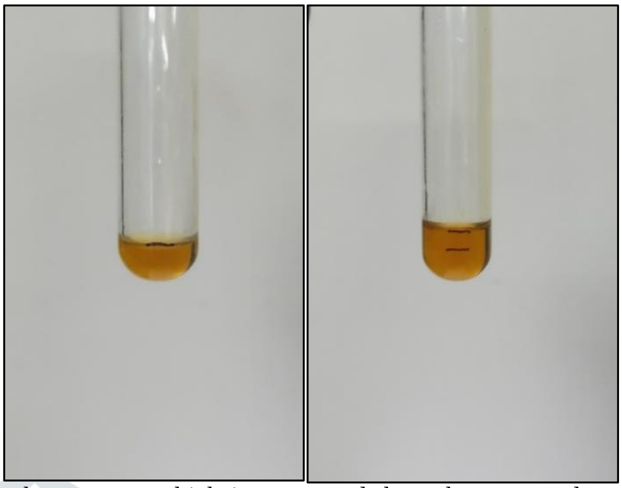

Fig. 3.2. Volume measurement

IV. Results and plots

Experiment was performed considering six different values of pressure and six different values of velocity including zero velocity of piston. For each pressure leakage was measured by changing all six velocity and is given in Table 1.

Table 1: Results of leakage rate

Pressure (Pa)	Velocity (m/s)	Leakage Rate (ml/min)		Pressure (Pa)	Velocity (m/s)	Leakage Rate (ml/min)	
		Theoretical	Experiment			Theoretical	Experiment
21546	0	0.002	0	44989	0	0.011	0
	0.02	0.203	0.03		0.02	0.283	0.07
	0.04	0.404	0.07		0.04	0.555	0.12
	0.06	0.605	0.12		0.06	0.828	0.25
	0.08	0.806	0.17		0.08	1.1	0.3
	0.1	1.008	0.2		0.1	1.372	0.39
29360	0	0.004	0	52798	0	0.016	0
	0.02	0.229	0.035		0.02	0.312	0.08
	0.04	0.454	0.12		0.04	0.608	0.2
	0.06	0.678	0.17		0.06	0.904	0.31
	0.08	0.903	0.24		0.08	1.2	0.41
	0.1	1.128	0.29		0.1	1.496	0.5
37170	0	0.007	0	60610	0	0.024	0
	0.02	0.255	0.05		0.02	0.344	0.09
	0.04	0.504	0.14		0.04	0.663	0.22
	0.06	0.752	0.23		0.06	0.983	0.38
	0.08	1.001	0.31		0.08	1.303	0.52
	0.1	1.25	0.37		0.1	1.622	0.65

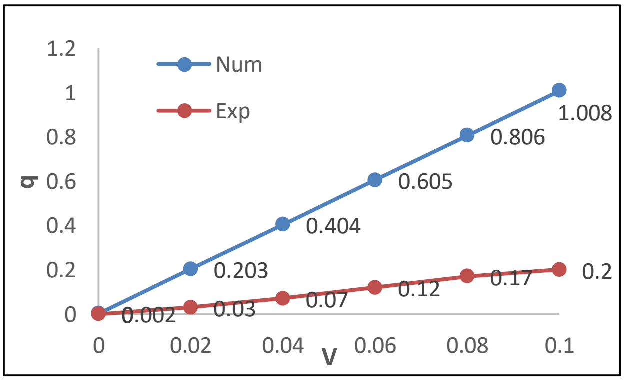

Fig. 4.1. Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for 21.546 kPa

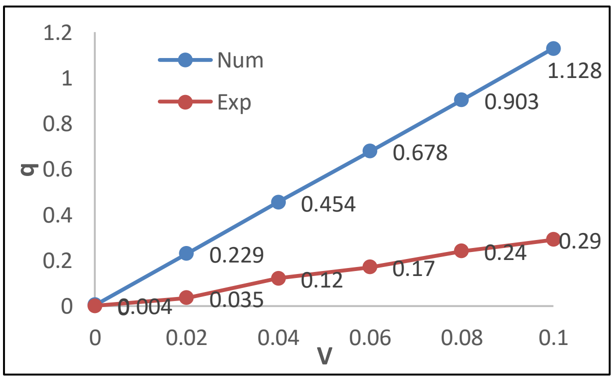

Fig. 4.2. Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for 29.360 kPa

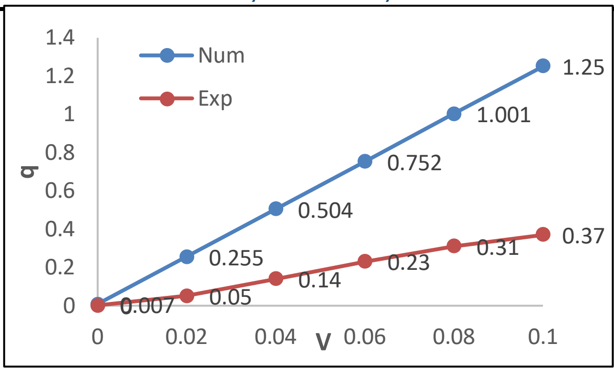

Fig. 4.3. Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for 37.170 kPa

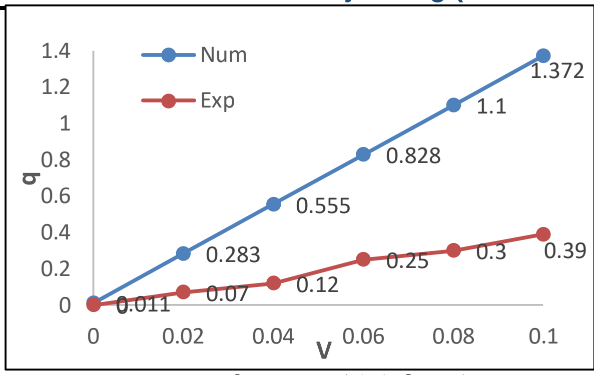

Fig. 4.4. Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for 44.989 kPa

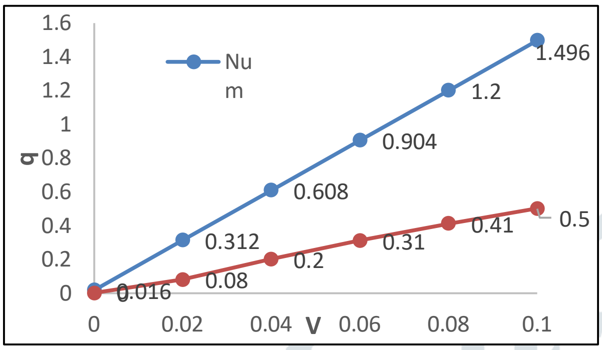

Fig. 4.5. Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for 52.789 kPa

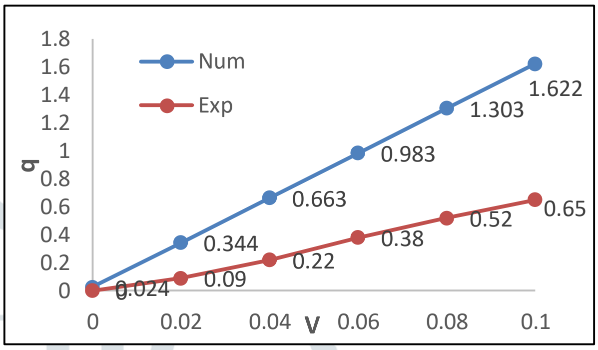

Fig. 4.6. Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for 60.610 kPa

V. Comparison of numerical and experimental results

The investigation of the noise generated by faulty bearing compared to healthy bearing shows that there is a significant rise in the noise ranging from 5 to 10 dBA which clearly indicates that the faulty bearing is not performing the intended function. In order to reduce noise from the system the bearing needs to be changed and must be replaced with the new one. The investigation leads to a point where clutch bearing during its working should be regularly checked for any noise. If there is a significant noise developed due to the prolonged working, it indicates that the bearing is damaged. At this point where the noise is heard significantly along with the background noise, the bearing needs to be replaced with the new bearing.

5.1 Leakage rate verses velocity plots

As shown in fig. 4.1 to fig 4.6,

i. Experimental values of leakage rate is less than numerical values due to uncertainty present in actual process, as it is not possible to maintain the state of each variable as mentioned in theory.

ii. The numerical plot shows linear variation which can also be seen in experimental data.

iii. Percentage difference in leakage rate between numerical and experimental values decrease as velocity increases.

iv. At static state of piston, leakage can be considered zero.

5.2 Leakage rate verses pressure graph

i. In numerical analysis values the plot is a straight line but in experimental values it cannot be approximated as straight line as shown in fig. 5.1.

ii. The curve of experimental values is not straight but it is a monotonic curve.

iii. Numerical and experimental lines seems more parallel as compared to leakage rate verses velocity plots.

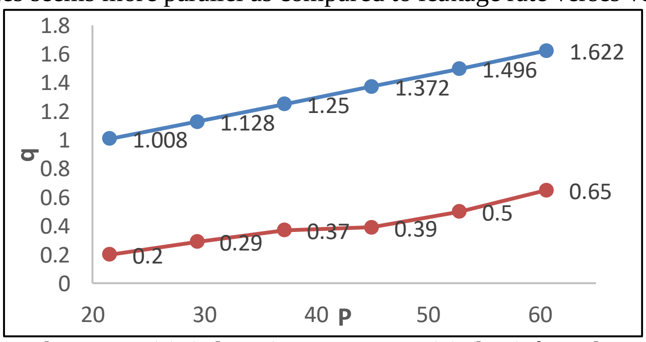

Fig. 5.1. Leakage rate (q) (ml/min) Vs. Pressure (P) (kPa) for velocity 0.1 m/s

5.3 Leakage rate verses velocity for different pressures

These two fig. 5.2 and fig. 5.3 also shows leakage rate verses velocity plots but numerical and experimental separately.

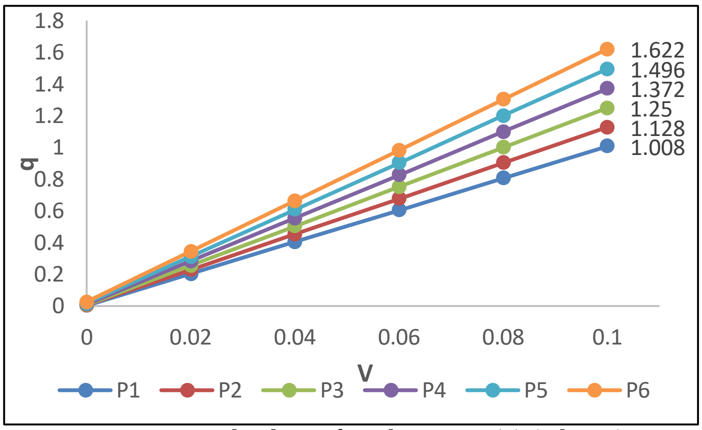

Fig. 5.2. Numerical values of Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for different pressure

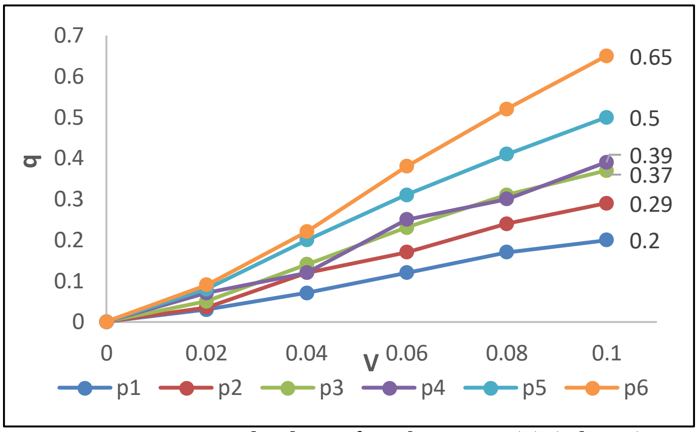

Fig. 5.3. Experimental values of Leakage rate (q) (ml/min) Vs. Velocity (V) (m/s) for different pressure

i. In numerical plot as pressure increases slope of the line increases.
ii. For different pressures, increase in slope of line is more in experimental plots as compared to Theoretical plot.

VI. Conclusion

The behavior of elastomeric materials changes significantly as external force applied on it is changed. Major effect of leakage rate is due to pressure and even more due to velocity of piston. As oil leaking across the seal is very less its measurement is difficult, hence large difference can be seen between theoretical and actual results. Life of a mechanical seal can be increased by; reducing the difference between maximum a minimum pressure acting on it; reducing impurities present in the lubricant; using appropriate size of seal according to the pressure and velocity requirements.

VII. References

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