Madras Agric. J. 80 (9) : 503 - 510 September 1993
https://doi.org/10.29321/MAJ.10.A01691

DEVELOPMENT OF AN EMPERICAL EQUATION FOR COMPUTING PRESSURE LOSS OF FOOT VALUES IN PUMP SETS.

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ABSTRACT

Out of total loss of pressure in a pump, foot valve alone contributes 10% to 15% of the loss. However, with improved foot valves, it is possible to reduce this loss considerably. This paper reports about different shapes of foot valves (such as cylindrical, conical and hemispherical) having enhanced values of dome surface area and strainer opening area. Based on experiments and dimensional analysis, an emperical equation has been obtained to quantify the pressure loss in foot value for design and operation purposes.

Key Words : *Foot Value, Corrosion, Strainer*

INTRODUCTION

The pressure loss in the conventional foot value is 1 to 1.5m. By reducing this loss to 0.4 to 0.5 m in about 9 lakhs pump sets operating the whole of Tamil Nadu, it is possible to save considerable electricity. Twelve existing foot valves have been reviewed through for possible identification of the improtant papameters that govern the pressure loss. From the review, it was gathered that the shape of the foot value, total area of the dome surface, the strainer opening area, the valve opening area and the sectional area of the suction pipe are important in causing the pressure loss. Though most of the existing foot valves are hemispherical in shapre, a few are cylindrical, noteworthy of the latter being Sujala Foot Valves. There are synthetic rubber foot valves also available in the market. They are advantageous in being rust free but suffer from the undesirable feature of causing heavy pressure loss to an extent of three meteres of water.

METHODS AND MATERIALS

The foot valve is a sort of check valve fitted at the base of the suction pipe. The foot valve consists of casing or dome, valve system and strainer. Normally the foot valve is made up of cast iron to be cheper and corrosion free. The shape of the casing or dome may be cylindrical or hemispherical. The top portion of casing or dome ends with

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threaded or flanged coupling and this would be fitted with the bottom end of the suction pipe. The casing and the strainer are coupled together by means of bolts and nuts. The valve system is of leather washer or rubber washer with a dead weight on top. The valve opens upward only during pumping and rests on the annular projection in off-condition. The cast iron dome is detachable from the top end of the strainer. In some cases the dome is rigidly fixed with the top of the strainer portion. The valve is having free hinging arrangement with the Washer. The valve washer is detachable from the annular platform. The other side of the valve washer is fitted by means of bolt and nuts sandwiching between the casing and strainer. Normally the valve opening will be in the centre of the leather flap.

In some cases the opening will be eccentric and the valve washer will be hinged by means of iron plate with casing wall. Instead of leather washer hinged at one end of washer, poppet valve arrangement may also be used.

Locally available foot valve

The study was taken up to analyse the performance of locally available foot valves, to identify areas of deficiency and incorporate any modification or to fabricate new types of foot valves if necessary. With this view in mind, the locally available foot valves were first tested to study their perormance. The very commonly used foot valves of sizes 21/2", 4" were tested in the laboratory. The ratio of the strainer opening area to strainer surface area and the rtio of valve opening area to its suction cross section area were computed and pressure loss that took place in the foot valves were observed. With a view to increase the strainer ocning area as a desirable feature, additional opnings were made at the base of the cylindrical foot valves with the help of the drilling machine. A class of cylindrical foot valves were also designed incorporating larger strainer opening areas. However the leather flap assempbly was retained as in the Sujala type. These new cylindrical valves were fabricated with vertically arranged rods welded with circumferentially arranged rods. The base of the valves was of a circular plate with holes drilled on it. In some of the experiments, since the holes were felt to be too large in size, the strainer was covered with different types of wiere meshes and coconut pannadai (leaf sheath) to prevent the entry of floating materials into the suction line. This caused a slight increase in the pressure loss. In some of the experiments, the strainer dome was removed keeping only the foot valve assembly in the suction pipe line. In all, the total number of the experiments was forty. In the course of the experiments, water was pumped from the sump with a five horse power centrigugal pump and recirculated back. The suction pipe line was 3" in diameter and delivery 21/2". The discharge pumped out was metered by actually collecting in a tank. The pressure loss in the foot valve was observed on the manometer. An equation was obtained to work out the pressure loss using the observed data. Considering two points for this purpose, One at the entrance to the foot valve and the other at the outlet of the foot valve and applying Bernoulli's theorem, we get

$$Ha + X = Hs + \frac{Vs^2}{2g} + hf$$

But Hs = Ha + H - 13.6 ΔH-(H-ΔH) + W' [(H-ΔH) + Y+X)]
That is, Hs =Ha - 12.6ΔH-H.
(∴W' ≈O)

Eliminating 'Hs' and rearranging for 'hf'

$$hf = x + 12.6\ \Delta H - \frac{Vs^2}{2g}$$

Where h_f = head loss due to foot valve, m

x = Submergence of foot valve tapping, m

Hs = Suction velocity, m/sec

W' = Weight density of air

Δ = differential head in the manometer, M.

Ha = Head due to atmosphere, M

In this analysis, the weight of the air column from the manometer to the outlet point of the valve is neglected. Hence headloss can be experessed as

$$B = K\frac{V^2}{2g} = hf = x + 12.6\ \Delta H\ \frac{-Vs^2}{2g}$$

Where 'K' is the resistance coefficient and 'V' is Velocity of the liquid to be pumped. This resistance coefficient 'K' can be determined with the computation of velocity head $V^2/2g$ and the observed pressure head h_f.

RESULTS AND DISCUSSION

One of the important factors affecting the pressure loss is the strainer opening area in comparison with the dome surface area. This value was worked out for the different valves and the same furnished in Table (1). For 21/2" foot valve the maximum surface area was 453.96 cm^2 in the case of locally available foot valve manufactured by Mohan Kumar and the minimum was 311 cm^2 in the case of Sujala foot valve. However, the maximum strainer opening area was 256 cm^2 in the case fabricated foot valve and minimum was 94.20 cm^2 in the case of Sujala foot valve. By combining the surface strainer area and the strainer opening area, minimum value for (S/A) was obtained as 0.12 for the case of Mohan Kumar foot valve and 0.63 for the case of fabricated foot valve. Like-wise, a minimum value of the ratio of valve opening to the suction cross suction area was 0.63 for the Mohan Kumar foot valve and 2.56 for the case of fabricated foot valve. Since the values of these two ratios are high in the case of fabricated foot valve, the performace of this should be better than others. The hgichst pressure loss was observed in the Mohan Kumar foot valve and the lowest in the case of fabricated foot valves.

In the case of 3" foot valves a minimum strainer surface area was obatined in the case of fabricated foot valve with a value of 204.98 cm^2 and a maximum value of 508.93 cm^2 in the case of Dhandapani Foundry foot valve and Mohan Kumar foot valves. However,

Table 1. Details of $2\frac{1}{2}$" and 3" foot valves (13)

Sl. No.	Name	Surface area of Strainer (A) cm^2	Strainer opening area (S) cm^2	Valve Opening area (O) cm^2	Suction Cross section area (A) cm^2	Strainer opening Ratio $\frac{S}{A}$	Valve opening ratio (O/a)	Range of head loss 'h_f' 'm'
Details of $2\frac{1}{2}$" Foot valves								
I	Locally available							
	1. Mohankumar	453.96	158.00	19.60	30.67	0.120	0.63	1.39 to 2.05
	2. Sujala	311.00	94.20	32.60	30.67	0.302	1.06	0.56 to 1.00
II	Modified							
	1. Sujala	311.00	94.39	32.60	30.67	0.303	1.06	0.55 to 0.99
III	1. Fabricated	402.90	256.00	78.53	30.67	0.630	2.56	0.35 to 0.64
Details of 3" Foot valves								
I	Locally available							
	1. Gowri	453.96	158.63	70.88	44.17	0.34	1.60	0.70 to 1.55
	2. Green	470.19	145.76	44.17	44.17	0.31	1.00	0.95 to 1.72
	3. DPF	508.93	142.20	38.48	44.17	0.27	0.87	1.11 to 1.90
	4. Mohankumar	508.93	123.20	38.48	44.17	0.24	0.87	1.31 to 1.97
	5. Kirloskar	453.96	158.63	70.88	44.17	0.34	1.60	0.52 to 0.97
	6. Sujala	392.68	127.50	44.00	44.17	0.32	0.99	0.73 to 1.14
	7. Jothi	207.96	66.55	44.00	44.17	0.31	0.99	0.59 to 1.15
	8. Synthetic	414.68	45.00	44.00	44.17	0.10	0.99	2.15 to 3.05

II	Modified							
	1. Sujala	392.68	132.00	44.00	44.17	0.35	0.99	0.79 to 1.10
III	Fabricated							
	1. Fabricated	346.35	339.35	44.00	44.17	0.98	0.99	0.22 to 0.51
	2. Fabricated	487.72	258.00	44.00	44.17	0.52	0.99	0.30 to 0.65
	3. Fabricated	346.35	171.00	44.00	44.17	0.49	0.99	0.39 to 0.71
	4. Fabricated	204.98	86.00	44.00	44.17	0.41	0.99	0.44 to 0.81

Table 2. Estimated values of 'm' 'n' 'c_2' and 'P'

O/a	C_0	S/A	m	c_1	n	c_2	P
2.56	1.95	1.00	-0.90				
	2.40	0.63	-0.94				
	3.05	0.43	-1.00	1.85	-0.71	3.5	-1.0
	3.40	0.40	-1.03				
	5.00	0.25	-1.10				
	6.40	0.19	-1.14				
0.99	2.10	1.00	-0.95				
	2.60	0.98	-0.97				
	3.40	0.52	-0.98				
	4.00	0.49	-1.03	2.70	-0.70		
	4.70	0.41	-1.03				
	5.60	0.39	-1.06				
	6.80	0.32	-1.11				
	7.20	0.31	-1.07				
0.87	15.00	0.27	-1.30	6.4	-0.70		
	18.00	0.24	-1.29				

the minimum value of strainer opening area was 45 cm^2 in the case of synthetic Rubber foot valve. But more importantly the S/A ratio value was maximum at 0.98 in the case of fabricated foot valve. In the same way, the ratio of O/a was minimum at 0.87 in the case of Mohan Kumar and Dhandapani Foundry foot valves and maximum in the case of Gowri foot valve. It may be noted, in respect of O/a ratio, the optimum value of around 1.0 is more desirable than a value even greater than one. If this ratio value is less than 1.0 it means that the flow is divergent and if its greater than 1.0, the flow is convergent both of which are not desirable from the point of view of pressure loss. However if the ratio is 1.0, the flow would be straight and the expected loss also would be small. A value of 0.99 has been accomplished in all the four fabricated foot vaves; it may be also remarked that the different values of strainer surface area were obtained in the case of fabricated foot valves by altering their lengths. In the case of 4" foot valves, the maximum and the minimum values of the S/A ratio were 0.3 and 0.96 respectively and they were found to occur for the fabricated foot valve. As before, a value of 0.99 was obatined for O/a ratio in all the four fabricated foot valves.

Theoretical Analysis

The method of diemnsional analysis was employed to arrange the different factors affecting the foot valve pressure loss and also to carryout experiments in a methodical way. The factors identified were the strainer opening ara, the strainer surface area, leather opening area, suction pipe cross sectional area, viscosity of liquid, roughness factor, weight density of liquix, inclination of the leather flap, velocity of flow, acceleration due to gravity and diameter of the suction pipe. Checking the dimensions on either side and arranging them in dimensionless form, the pressure loss 'hf' for the foot valve was obained as

$$K = \int \left(\frac{V}{\sqrt{gd}}, \frac{S}{A}, \frac{O}{a}, \frac{\mu}{\rho g^{1/2}\, d^{3/2}}, \theta, \frac{E}{d} \right)$$

- (1)

Where K = coefficient of resistance (-)

V = Velocity of flow at the foot valve (LT^{-1}

d = diameter of the suction pipe (L)

S = Strainer opening area (L^2)

O = Valve opening area (L^2)

A = Surface area of strainer of foot valve (L^2)

a = Suction cross section area (L^2)

μ = dynamic viscosity of pumping fluid ($ML^{-1}T^{-1}$):

Q = angle of inclination when the valve is opening upward

E = Roughness due to projections in the inner side of pide wall (L)

P = Weight density of liquid (ML^{-3})

Though visosity is a key factor affecting the frictional loss, the effect is merged in the coefficient involved in the dimensionless equation, in as much as it is a constant for the only liquid namely water that has been used at room temperature. Owing to the difficulty of estimating the roughness factor 'E' and the angle of inclination 'θ', they could not be considred for analysis. However the ratio of strainer opening area to strainer suface area and the ratio of valve opening area to the suction pipe cross section area could be included in the theoretical equation and their effect quantified. The final non-dimensional equation (1) could be simplified as

$$K = f\ \frac{V}{\sqrt{gd}},\ \frac{S}{A},\ \frac{O}{a}\text{------}(2)$$

This may be also rewritten in the form

$$K = C_2\left(\frac{V}{\sqrt{gd}}\right)^m \left(\frac{S}{A}\right)^n \left(\frac{O}{a}\right)^p\text{------}(3)$$

C_2 = coefficient (computed from log sheet as 'intercept')

m,n,p = Indices. (Computed from log sheet as slope of respective strainght lines)

By conducting experiments on different foot valves having various values of (S/A) and (O/a) and observing the pressure loss within them, the coefficient as well as indices can be evaluated from log sheets. The resistance coefficient 'K' can be used for prediction purpose.

For constant values of O/a, equal to 2.56, 0.99, 0.87 the values of K were plotted against the values (V/,γδ) for different parametric values of S/A. When O/a and S/A were considered with their constant values, equation (3) degenerated as $K = C_0\left(\frac{v}{\sqrt{gd}}\right)^n$. This ploted as straight lines on logrithmic sheets. From these, the values of 'm' were computed as the slope of different lines taking a full log cycle for $\frac{V}{\sqrt{gd}}$. The intercepts on 'K' axis corresponding to $\frac{V}{\sqrt{gd}}$ equal to unity, furnished the values of C_0.

The values of 'm' did not show anyu systematic variation with respect to either S/A or O/a but they seemed to have a constant value of -0.1. However the values of C_0 varied with (S/A) for any particular values of (O/a). That is, C_0 could be of the form $C_0 = C_1\ (S/A)^n$

The above equation ploted as a straight line in logrithmic sheet for different parametric values of)/a. The slopes of the straight line gave the values of 'n' and they were essentially constant having a value of -0.7. The intercept values varied implying they depended on O/a. That is C_1, could be of the form $C_1 = C_2\ (O/a)^P$.

Another grapth was plotted connecting C_1 and O/a. The slope of this line was found to be -0.1 with intercept value of 3.5. Estimated values of m,n,C_2 and 'P' are given in table (2). Feeding back the values of C_2, m, n, P in equation (3) we get

$$K = \left(\frac{V}{\sqrt{gd}}\right)^{-1.01/-0.7} \left(\frac{S}{A}\right)^{-0.7} \left(\frac{O}{A}\right)^{-0.1}$$
..... (4)

This is the final equation obtained to depict the inter-relationship between 'K' the frictional resistance coefficient on one side (V/sqrt gd) the velocity head, S/A - the ratio of valve opening area to the suction pipe area on the other side. Reynold's number apparently seems to be absent. In as much as the Reynoldls number also is a function of 'V' for a constant value of μ, the Froud number which involved the elocity may be also considered as the substitute. The above equation can be used for estimating the value of 'K' knowing all other variables.

CONCLUSION

The improved foot valves have the values of 1.0 to 0.19 for S/A and 2.56 to 0.99 for O/a. However the mostly used hemispherical convntional foot valves have values of 0.12 to 0.34 for S/A and 1.6 to 0.81 for O/a. Due to this improvement, the pressure loss could be reduced to 0.3 to 0.5 m from the average the pressure loss could be reduced to 0.3 to 0.5 m from the average value of 1.25 m noticed in the case of conventional foot valves. The Sujala Type of foot valves which are cylindrical in shape also have been improved upon by increasing the strainer opening area through putting more holes at the circular base plate. This resulted in the increased values for the said ratios.

For formulating an empirical equation based on dimensional analysis, the S/A and O/a values were combined to have a systematic permutation and combination. Finally and equation in the form.

$$K = 3.5 \times \left(\frac{V}{\sqrt{gd}}\right)^{-1.01} \left(\frac{S}{A}\right)^{-0.7} \left(\frac{0}{a}\right)^{-0.1}$$

has been arrived at. This equation can be advantageously used for computing the pressure loss in foot valves while designing a pump or while selecting and using a pump.

REFERENCES

PATEL, S.M. and K.K.GUPTA, 1979. Study on conservation of light diesel oil used in pumpsets for lift irrigation in Gujarat state. A report of Institute of Co-operative Management, Ahmedabad.

PARIKH, P.P. RAJAGOPALAN, S.R. NAGARAJ, V., KUMARAN, K.P. ISRANI, A.R. 1981. Conservation of diesel fuel in low HP stationary engines. Report proto type Development and Training Centre, Rajkot (Gujarat).

PATEL, S.M. 1982. Sujala Foot valve can save energy worth 10 crore rupees every year in agricultural pumpsets in Gujarat State, Agricultural Engineering, To-day, January-February 1982.

PATEL, B.L. 1982. Save crores of rupees for the country by selecting a proper foot valve. Farmer and parliament, Jan. 1982.

SEWA RAM, et.al. 1982. Panthnagar foot valve. Technical bulletin of G.B.Panth University of Agricultural and Technology Pantnagar.