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Improving the Flow Rate of Sonic Pump by Means of Parabolic Deflector

Ivan A. Loukanov ^α, Mothaedi M. ^σ & Keaitse M. ^ρ

Abstract- This paper investigates the effect of a parabolic deflector on the flow rate of a sonic (resonance) pump. A specially shaped parabolic deflector is designed and manufactured to fit to a 1.5" spring-loaded poppet valve and tested on a solar powered sonic pump at resonance frequency of 5.33 Hz. It was found that the flow rates increased by as much as 51% at 22 Watt and by 5.1% at 38 Watt as compared to the case without a deflector and no air in the pipe system. Whenever air is present in the pipes the deflector enhanced the flow rate by as much as 216% at 22 Watt and by 63% at 38 Watt forcing to remove quickly the air from the system. These results are dependent upon the position of the deflector with respect to the valve body, the power input to the oscillating system and the existence of air in the pipe system. It is concluded that the deflector is a simple and suitable means for increasing the pump flow rate.

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I. INTRODUCTION

The sonic pumps were used for many decades in the oil industry all over the world. They have the capacity to pump crude oil from as deep as 2000 m (Usakovskii 1973) and are energy efficient since they operate in resonance. Some investigators employ successfully these pumps for pumping ground water from medium to deep boreholes (Loukanov 2007,) and a pumping depth of 100 m is achieved by Usakovskii, 1973. It is also found that the pump performance depends mainly upon the valve design and the number of valves employed (Usakovskii 1973). If poppet valves are to be used the pump performance depends upon valve spring stiffness, valve spring preload, valve stroke and valve diameter (Loukanov, 2010). Since the valves are the only pumping elements involved in the pump design they have to be submersed at suitable depth under the water level in the well (Loukanov, Uziak 2011). Therefore to design sonic pumps with desirable flow rate one should be familiar with the operating cycle of the pumps, the mechanical parameters of the valves to be used, as well as of how to enhance the valve discharge to satisfy the flow rate requirements. In the study conducted by Loukanov (2013) three valve designs with low friction losses were designed, manufactured and

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tested: Mainly cluster poppet valve and valves with lateral suction ports. It was found that these valves improve the sonic pump performance. As a result of the above research a parabolic deflector is invented to further minimize valve's head losses and hence the objective of this study is to investigate the effect of the parabolic deflector connected to a spring-loaded poppet valve and find out its contribution to the flow rate of the sonic pump.

II. MATERIAL AND METHODS

To meet the above objective a special parabolic deflector is designed using the Solid Work software and the shape and overall schematic is shown in Figure 1. The inner and outer design configuration of the proposed deflector is a parabola of rotation to create 3D shaped solid body.

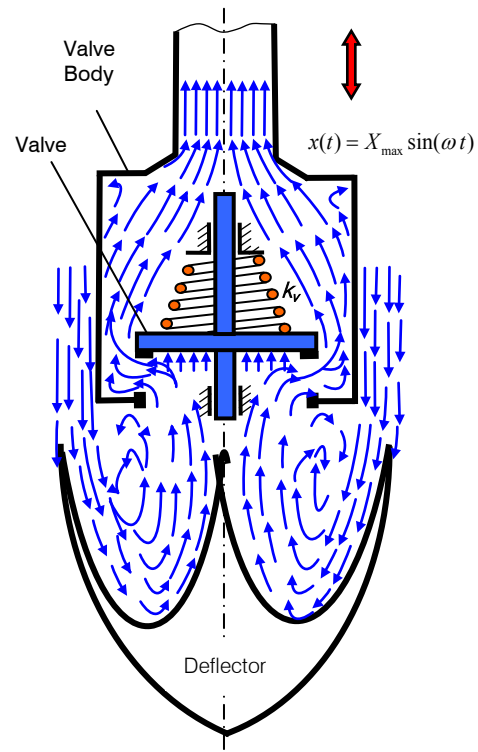


Figure 1 : Diagram of the water flow around and in the valve body as well as within the parabolic deflector

The design is based on the fact that the valve body-parabolic deflector assembly is fixed to the oscillating pipes and hence moving vertically up and

down consequently the still water in the well appears to move relatively to the assembly.

As seen in the Fig. 1 the inner parabolic shape of the deflector is intended to change the direction of the outer water flow moving relatively to the assembly and redirect it towards the valve input port during the upward stroke of the system. Conversely the outer shape of the deflector is designed to provide the necessary streamlines of the valve body-deflector assembly when the latter moves during the downward stroke and helps minimizing the drag forces. The inverted water flow generates upward pressure on the bottom face of the valve pushing it to stay opened after the point of separation of the water column (WC) from the valve seat (Loukanov 2007) until the top dead position of the oscillating system is attained. When WC separates from the valve a vacuum is generated above the valve itself, which forces it to open allowing the water from the well to enter in the valve body. In this case the WC acts as a piston and the valve body and the pipes as a cylinder. It is the authors that the presence of the parabolic deflector will help reducing the head losses in the valve body by keeping it fully opened as well as aiding the water flow to fill in quickly the vacated volume by the suction effect of the WC.

Next the proposed parabolic deflector is machined from a solid aluminum bar and polished to perfection for minimizing the fluid friction. The complete deflector is shown in Fig. 2, where the parabola shape of rotation of the internal and external shape is seen. It can be observed that the deflector is furnished with three taped holes M4 spaced at 120 degrees to each other to provide the necessary ports of attachment to the body of 1.5" spring-loaded poppet valve.



Figure 2 : An interior-exterior view of the parabolic deflector

The internal shape of the deflector is obtained by rotating a quadratic parabola about the longitudinal axis of symmetry and the shape obtained is called a

paraboloid of rotation. After that the parabolic deflector is fixed to a 1.5" poppet valve by means of three aluminum bars and M4 screws. Each bar is furnished with holes to allow three positions of the deflector relative to the valve body. The holes are to be used to determine the correct relative position of the deflector in order to obtain maximum discharge from the valve.



Figure 3 : Assembly view of the parabolic deflector as connected to the 1.5" spring-loaded poppet valve, No. 3

The final assembly of the parabolic deflector as attached to 1.5", No. 3 spring-loaded poppet valve is shown in Fig. 3. The mounting holes on the bars designated as No. 1, 2, and 3 as well as the attached parabolic deflector are seen in the figure. After preparing the valve assembly it is connected to the oscillating pipe system of the pump and a large numbers of tests are conducted at resonance frequency of 5.33 Hz. This frequency is obtained by a careful selection of the resultant stiffness of spring suspension system as related to the total oscillating mass of the system.

The experimental setup of the sonic pump and the valve assembly is shown in Fig. 4, where the solar panel, mechanical shaker, oscillating pipe and the valve assembly is submersed in the water source, the flow meter and the power equipment are noted.

The DC and AC supply equipment of the sonic pump consisted of one 230 Watt solar panel, two 12 Volt silver calcium batteries connected in parallel, a control charger and a DC to AC inverter. The use of DC-AC inverter is necessitated since the driving motors of the mechanical shaker are two single phase AC motors.

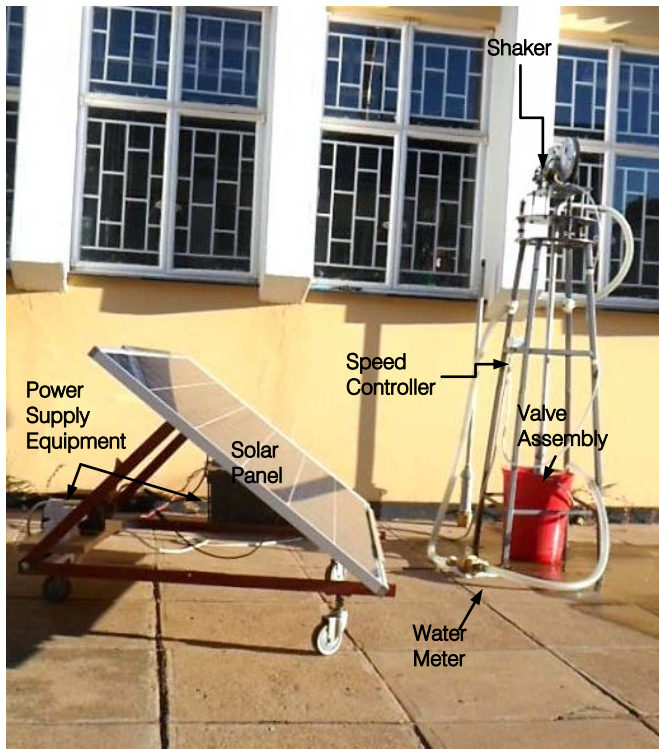


Figure 4 : Test arrangement for the 1.5" spring-loaded poppet valve with and without a parabolic deflector with a model sonic (resonance) pump.

The power supply equipment is shown in figure 5, where the control charger, DC-AC inverter, AC outlet, power meter and the battery pack are noted.

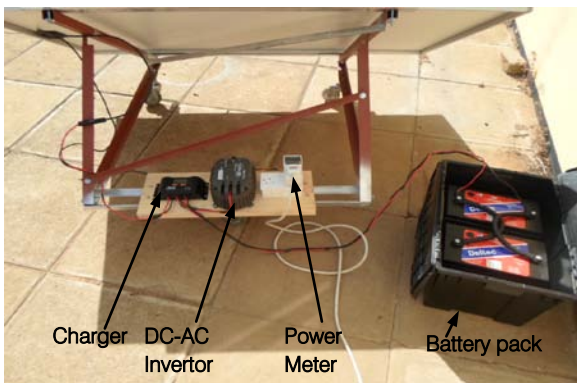


Figure 5 : Back view of the solar panel showing the installation of charger controller, DC-AC inverter, AC socket, power meter plugged in and the battery pack.

III. RESULTS AND DISCUSSION

Experiments are conducted on a model sonic pump operated at resonance frequency of 5.33 Hz employing a 1.5", No.3 spring-loaded poppet valve furnished with and without a parabolic deflector and operated with and without air in the pipe system. The depth of pumping is 1.75 m limited by the height of the pump stand and is measured from the valve inlet port submersed in a container with water to the top end of the oscillating pipes. Water is forced to circulate through

a water meter (HP 35, 3/4-inch) and return back to the container.

Each trial is repeated four times and the input power is varied from 22 to 38 Watt. The data obtained with no air in the pipes and the deflector being positioned at three relative locations to the valve body is listed in Table 1.

Table 1 : Average flow rates obtained with no air in the pipes by using 1.5", No.3 valve with and without deflector vs. the power input to the oscillating system

FLOW RATE [liter/minute]				
Power input [Watt]	Without Deflector [no hole]	With deflector [hole 1]	With deflector [hole 2]	With deflector [hole 3]
38	9.38	9.86	10.1	9.24
36	8.81	9.4	10.06	9.39
34	7.65	9.23	9.81	9.44
30	6.97	8.38	9.01	8.88
26	6.03	7.64	7.58	8.01
22	4.02	6.07	5.64	5.94

Figure 6 shows the variation of the average flow rates with no air in the pipe system showing the effect of the parabolic deflector on the valve discharge.

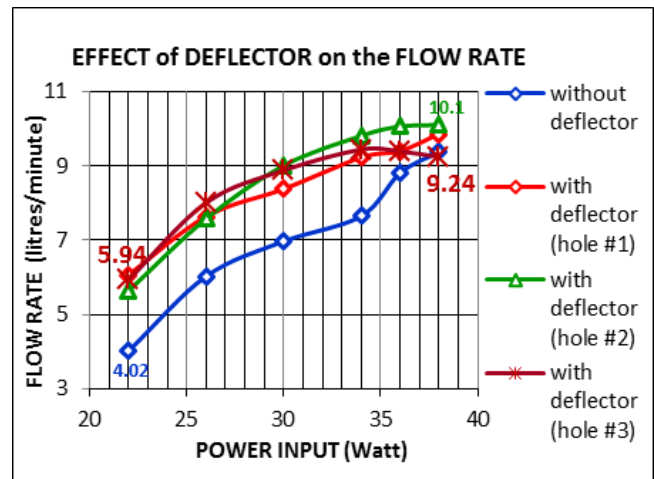


Figure 6 : Comparison of flow rates for 1.5" No. 3 spring-loaded poppet valve with and without a parabolic deflector and with no air in the pipes vs. power input.

A direct observation of the graphs shows that any of the three positions of the deflector give better flow rate than the case without a parabolic deflector.

A comparison made for the effectiveness of parabolic deflector indicates an increase of all flow rates depending upon the input power and the position of the deflector with respect to the valve body. The results show that for power varying from 22 Watt to 38 Watt and deflector positioned in holes No. 1, 2, 3 the percentage increase of the flow rates are found to be: from +5.12% to +51% for the deflector positioned at hole No.1, from +7.7% to +40.2% at hole No.2, and from -1.49% to +47.8% at hole No.3 respectively.

Apparently the presence of the parabolic deflector contributed significantly to the increase of the flow rate and that influence is more noticeable at lower power inputs (22-34 Watt) than at maximum power (36-38 Watt). The reason being is that at maximum power the flow rate values for each setup reached almost their maximums, so the contribution of the deflector is minimal. Obviously the position of the parabolic deflector corresponding to hole No. 2 is the best in terms of the flow rate attained, 10.1 l/min at 38 Watt. It should be noted that in this experimental setup the power input is limited to a maximum of 38 Watt since there were no more spare offset masses to be placed on the shaker. On the other hand the power input may be increased by increasing the speed of rotation but this would require changing the spring suspension system and therefore changing the resonance frequency of the system. To increase the power input for the same resonance frequency more offset masses should be manufactured and installed on the shaker to achieve larger excitation force. So we decided to carry on the experiments at maximum power input of 38 Watt.

The next step in our study was to investigate the effect of the air into the pipe system on the flow rate with and without a parabolic deflector. The experiments were conducted on the same pump setup under the same operating conditions. It is found that when the valve (pump) operates without a deflector it is unable to push the air out of the pipes and only a maximum flow rate of 6.6 l/min at 36 Watt is attained. Surprisingly a further increase in the input power to 38 Watt gave a reduced flow rate of 6.04 l/min . Perhaps it is due to the fact that the valve reached its maximum discharge capacity at 36 Watt. After the experiments it is noted that the air still remained trapped in the pipe system and this is why the flow rate was so little.

A phenomenon similar to this but not exactly the same is detected when the 1.5" No.3 valve is furnished with the parabolic deflector positioned at hole No. 1. The above hole appears to be the most remote with respect to the valve body. It is observed that the valve managed for a short while to gradually push the air out of the pipe system and start increasing the flow rate until a maximum value of about 9.86 l/min is attained corresponding to 38 Watt power input. Obviously this is due to the presence of the parabolic deflector and this fact indicated its strong influence on the flow rate.

Subsequently new experiments were conducted with no air in the pipe system with the same location of the parabolic deflector and the same valve. The results revealed that the pump flow rate varied considerably as compared to that when air is available in the system. To illustrate these, two graphs are constructed showing the effect of the parabolic deflector on the flow rate with air and without air in the pipe system. The graphs are shown in Fig. 7, where some of the values of the

experimental points are revealed for an easy comparison of the data analysis.

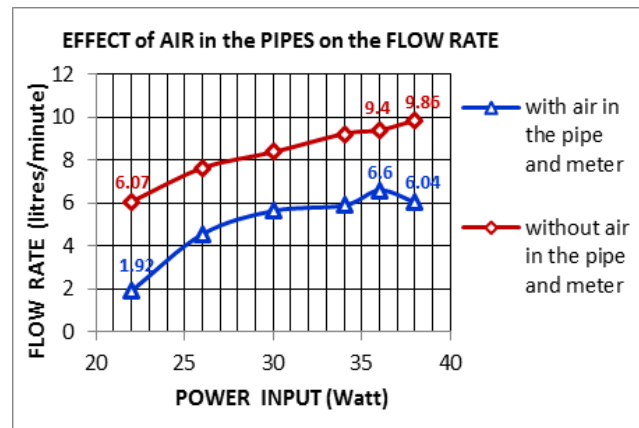


Figure 7 : Comparison of flow rates discharged by a 1.5" spring-loaded poppet valve, hole No.1 with and without air, and with and without a deflector vs power input

From the above graphs one can appreciate the boosting effect on the flow rate caused by the parabolic deflector, where the percentage increase ranges from 216% at 22 Watt to 63% at 38 Watt power input. Once again the higher value is obtained at the lowest power input as found in the case of no air in the system (Fig. 6).

The above results indicate that the effect of the parabolic deflector on the flow rate is significant as compared to the setup without a deflector. The new fact is that the valve with a deflector is capable of pushing the air out of the pipe system and quickly reach the maximum flow rate, which appear to be impossible for the same valve alone. Therefore the presence of the deflector helped the pump to quickly achieve the designed flow rate when air is available in the pipes.

IV. CONCLUSION

In this paper the results of a unique experimental study comprising a special valve arrangement designed for improving the flow rate of sonic pumps is presented. This included a parabolic deflector connected to a spring-loaded poppet valve which redirects the water flow from around the valve body in the well during the upward stroke of the oscillating system, pushing it towards the valve interior and the pipe system.

As a result the valve is kept fully opened due to the pressure build up on the bottom face of the valve which helped minimizing the head losses in the valve body and thus increasing the flow rate of the sonic pump. It is found that the improving effect of the deflector complimented with the existing suction effect caused by WC in the pipes since it acts as a piston and the pipes as a cylinder likewise as the reciprocating pumps. Both effects work simultaneously towards an

increased flow rate of the pump nearly for the same power input delivered by the oscillating system.

Considering the water flow within the parabolic deflector as shown in Fig. 1, it is evident that there are some inevitable energy losses due to fluid friction and changed direction of motion of the fluid. Fortunately these losses are compensated by the energy accumulated in the redirected water flow being taken from the resonance vibrations of the oscillating system. The experimental results revealed that the parabolic deflector contributed appreciably to the increase of the flow rate when there is no air in the pipes by as much as 51% and a flow rate of 10.1 l/min was attained at 38 Watt power input.

It is also found that the deflector is capable of removing the air from the pipe system resulting in substantial increase of the flow rate by an average of 216% at of 22 Watt and about 63% at 38 Watt power input respectively.

Therefore it may be concluded that the parabolic deflector changes radically the performance of the pump when operated with the 1.5" spring-loaded poppet valve.

Considering the substantial increase of the valve discharge when coupled to a parabolic deflector we suggest that more experiments to be conducted with larger sizes of similar valves mainly the 2" and 3" spring-loaded poppet valves connected to a suitable size of parabolic deflectors. Perhaps it may be found a higher increase in the discharge of these valves depending upon the effect of the parabolic deflector combined together with the increased valve diameters and the corresponding valve stroke limiting areas of the valves.

It is also important to investigate the effect of the parabolic deflector in relation to the valve parameters such as valve stroke, valve spring stiffness and valve spring preload and investigate the valve performance.

In conclusion to the above recommendations it is suggested to design deflectors using different parabola equations for the interior and study which one is the most effective in obtaining the largest flow rate. In this regard the best parabolic deflector could be employed for practical applications in pumping ground water from deep boreholes.

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