EVALUATION OF AIRCHAMBERS, AIRSUPPLY SYSTEMS AND OTHER SOFT ELEMENTS FOR PUMPS

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1. INTRODUCTION

The design philosophy of CWD is to design light windmills without gears. This has led to fast running windmills equipped with pumps provided with airchambers. For the surface (suction) pumps air supply to the airchambers never was a problem. For deepwell pumps the air supply to the airchamber did give a lot of troubles and still no 100% sound solutions are found. In this report the three systems developed by CWD and three alternative systems are evaluated. The results of the evaluation are given in chapter 5.
2. PRINCIPLE OF SOFT ELEMENTS

A soft element smooths the pulsating flow of a reciprocating piston pump through accumulation and release of the pumped fluid (see fig. 2.1).

![Fig. 2.1 The in— and outgoing flow of an ideal soft element.]

Because the constant outgoing flow of an ideal soft element (no extra force pressure) is needed to accelerate and deaccelerate the flow. The pressure needed to accelerate a flow in a pipe is given by

\[
\Delta P_{ace} = q \cdot \sum_{i=1}^{n} \frac{\rho \cdot l_i}{A_i} \quad [\text{Pa}] \quad (1)
\]

- \( q \) = flow acceleration \([\text{m}^3/\text{s}^2]\)
- \( \rho \) = density of pumped media \([\text{kg/m}^3]\)
- \( l_i \) = length of pipe section \( i \) \([\text{m}]\)
- \( A_i \) = netto cross section of pipe section \( i \) \([\text{m}^2]\)
- \( q = 0 \) for an ideal soft element \([\text{m}^3/\text{s}^2]\)

The mass of water in the pipe beyond a soft element acts as a mass—spring system together with the spring action of the soft element. This means that unwanted resonances can occur that can cause as much damage as the forces that the soft element is supposed to prevent.
Volume variations of an ideal soft element

We assume that an ideal soft element is coupled to a single-acting piston pump. Ideal in this respect means that the outgoing flow is perfectly constant (fig. 3.2).

If the pump has a piston area $A_p$, a stroke $s$ and a rotational speed $\Omega$, then the incoming flow to the soft element can be described as follows:

$\begin{align*}
q_{in} &= A_p \Omega s \frac{1}{2} \sin \Omega t \quad \text{(m}^3/\text{s)} \\
&= 0 \\
\end{align*}$

for $0 < \Omega t < \pi$

for $\pi < \Omega t < 2\pi$

The outgoing flow is assumed to be constant and must be equal to the average of the incoming flow:

$\begin{align*}
q_{out} &= A_p \Omega s \frac{1}{2\pi} \int_0^\pi \sin \Omega t \, d\Omega t \\
&= \frac{A_p}{\pi} \\
\end{align*}$

resulting in:

$q_{out} = A_p \Omega s \frac{1}{\pi}$

Comparing (3) with (2) we see that only for the moment at which $\sin \Omega t = \frac{1}{\pi}$ the ingoing and outgoing flows are equal. For all other moments the flows are different, or, in other words, the air chamber has to absorb or supply water. The two moments, or better, position angles, concerned can be found with:
\[ \Omega t = \arcsin \frac{1}{\pi} \] \[ \Rightarrow \Omega t_1 = 0.324 \text{ rad or } 18.56^0 \] \[ \Rightarrow \Omega t_2 = 2.818 \text{ rad or } 161.44^0 \] 

At \( t_1 \) the water volume of the soft element is at its minimum and at \( t_2 \) the water volume is maximal. In order to find the volume variations in the ideal soft element we have to integrate \( (q_{\text{in}} - q_{\text{out}}) \) with respect to \( t \) (fig. 2.3).

For \( 0 < \Omega t < \pi \) we can write:

\[ \int (q_{\text{in}} - q_{\text{out}}) \, dt = A_p \frac{1}{2} s \int (\sin \Omega t - \frac{1}{\pi}) \, d\Omega t \]

\[ = A_p \frac{1}{2} s (-\cos \Omega t - \frac{\Omega t}{\pi} + \text{constant}) \]

The boundary condition of zero volume at \( \Omega t = 0 \) leads to:

\[ \int (q_{\text{in}} - q_{\text{out}}) \, dt = A_p \frac{1}{2} s (1 - \cos \Omega t - \frac{\Omega t}{\pi}) \] \[ (5) \]

For \( \pi < \Omega t < 2\pi \) one finds:

\[ \int (q_{\text{in}} - q_{\text{out}}) \, dt = A_p \frac{1}{2} s (2 - \frac{\Omega t}{\pi}) \] \[ (6) \]

These two parts of the function are shown in the lower graph of fig. 2.3; note that the stroke volume is equal to \( V_s = A_p s \).
The difference between the minimum and maximum volume can be found with (4) and (5):

\[ V_{\text{max}} - V_{\text{min}} = \frac{1}{2} V_s \left( 1 - \cos \Omega t_2 - \frac{\Omega t_2}{\pi} + \cos \Omega t_1 + \frac{\Omega t_1}{\pi} \right) \]

\[ V_{\text{max}} - V_{\text{min}} = 0.551 V_s \]
3. TYPES OF SOFT ELEMENTS DEVELOPED BY CWD

3.1 Open airchamber with mechanical air supply
This type of soft element is usually applied with reciprocating pumps. In figure 3.1 and 3.2 CWD construction of open airchambers for a surface and deepwell pump are given.
The open airchamber behavior is almost ideal if dimensioned well, figure 3.3 shows the differences in pump rod force between a pump with and without airchamber (R 981 D).
With an open airchamber air and water are in direct contact, and water can release and absorb air. For this reason suction airchambers have no problems with supply of air, water releases air by low pressures, but the delivery airchamber looses air all the time because the air dissolves in water under pressure. Hence open delivery airchambers need an air supply system.

Waterdrip air-supply systems
Within CWD some simple air-supply systems were developed based on a kind of waterdrip-system which formed a train of water-air mixture in a fall tube to the pump (see figure 3.4). Under laboratoria conditions this system worked well. In the field however it failed because the fall tube clodged with sand, salt and algal growth.

Mechanical air supply system
A new system was developed which compress air by means of pneumatic cylinder coupled to the reciprocating pump rod (see figure 3.5). This system works well in the laboratory and endurance test are still going on, while field experience is gained. The air pump already made $40 \times 10^6$ numbers of revolutions in the laboratory test stand. Several air pumps have been installed on windpumps at CWD testfields and CWD 5000 windpumps in the field (12 in Sudan, 2 in Cape Verde and 1 in Niger).

3.2 Closed airchamber air/water separation by membrane
This type of soft element is not often used for reciprocating pumps for water but in the hydraulic systems it is often used as accumalator to prevent pressure peaks in the hydraulic systems.
In a closed airchamber the water and air (or any other gas) are separated by a membrane to prevent the air from being absorbed into the water. A design of a closed airchamber is shown in figure 3.6. This design is tested with a CWD 108 D pump (the results are reported in R 942 D. The main conclusion in this report is that if the initial pressure of the airchamber is \( \leq 0.85 \) times the static pressure and the initial volume is about 3 times the stroke volume. The behavior of it is almost ideal. Field experience showed a decrease in pressure due to diffusion of air through membrane and corrosion.

### 3.3 Expansion tube

This is CWD latest design of soft element and applied on the CWD 49 D pump. The working principle of this element is, (see figure 3.7), that due to expansion of the pvc flexible hose around the rising main water can be accumulated and released later on. Due to the small accumulation capacity of this flexible element it's behavior is far from ideal however pumprod forces can be reduced with \( \approx 30\% \) measured on the CWD 49 D (see fig. 3.8). With this type of soft element it is necessary to use wide rising mains with a ratio of \( A_{\text{rising main}}/A_{\text{pump}} \) in the order of 0.8–1.

### 3.4 Airchamber with water air separation by means of a piston

In this type of airchamber water and air are separated with a piston, figure 3.9. With this construction contact between water and air is reduced to a minimum, but still some air can dissolve in the water.

The behavior of this airchamber can be influenced by the friction of the separator.

### 3.5 Suction deepwell pump with sniffer

In this case the pump is installed above the static level of the well and a suction tube goes down into the water. The foot valve is equipped with a sniffer to supply air (see fig.3.10). This system can only be used if variation of the water level in the well is not more than 6 meter on the short term. Seasonal variations can be solved by lowering or lifting the pump.
3.6 Open airchamber with air supply with an injector

Air can be supplied to the air chamber by means of an injector which uses the pressure difference over the piston as driving force. A drawing of an injector is shown in fig. 3.11 and fig. 3.12 and gives some possibilities to connect a conjector with a piston pump.

Some preliminary research is done on an injector system under steady condition, see lit [2].
Fig. 3.1 open airchamber deepwell pump

Fig. 3.2 open airchamber suction pump
Fig. 3.3 difference in pump force by pump with and without air chamber.

Fig. 3.4 water drip air supply system
Fig. 3.5 mechanical air supply system coupled with pumprod
Fig. 3.6 closed airchamber with membrane

Fig. 3.7 pump with expansion tube
Fig. 3.8 effects of expansion tube on the pump rod force

Fig. 3.9 air–water separation by means of piston
Fig. 3.10 air supply with sniffer

Fig. 3.11 injector
Fig. 3.12 combinations of in- and outlet
4 EVALUATION OF SOFT ELEMENTS DEVELOPED BY CWD

The soft elements are evaluated on the following points.

1) Behavior: smooths the soft element the flow enough (ideal behavior see chapter 2).

2) Fail safe: if the soft element fails to function pump rod force do not increase.

3) Air supply: is continue air supply necessary for the good function of the soft element.

4) Damage during installation: can damage during installation be of such kind that proper function of the pump system is impossible.

5) Mal installation: is there any possibility that mal adjustment of soft element or air supply has a fatal effect on the system.

6) Sensitivity to: has dust, salt, accid or algae growth any negative effect on the function of the system.

7) Production: is production of the system possible with local materials and craftsmen.

8) Wear: can the function of the system fail due to wear.

9) Life time: is the lifetime of the system sufficiently long.

10) Efficiency: has the device a positive or negative effect on the mechanical or volumetric efficiency.

11) Application: can the system be used for all dimensions of piston pumps.

12) Costs: is the cost of the system acceptable.

13) Corrosion: has the system a negative or positive effect on corrosion of the pumping system.

14) Dimensions: does dimensions of the soft element determine the minimum diameter of the wells.
The 6 systems as such i.e. assuming that the systems would have been developed are judged on 14 points by three persons. For every point a rating of 1 to 5 was given in which 1 is negative and 5 is positive. Also a weight factor was given to each point, ranging from 1 to 3; 1 not important; 2 important; 3 very important. (The results are given in table 4.1.)

The six different systems are evaluated and their score is:

1) open airchamber air supply with sniffer 115\%\text{\textsuperscript{9}}
2) expansion tube 108\%\text{\textsuperscript{9}}
3) open airchamber air supply with injector 101
4) closed airchamber separation with membrane 93\%\text{\textsuperscript{4}}\text{\textsuperscript{9}}
5) open airchamber air supply mechanical 86\%\text{\textsuperscript{3}}\text{\textsuperscript{9}}
6) closed airchamber separation with piston 83\%\text{\textsuperscript{3}}\text{\textsuperscript{9}}

table 4.1

Some remarks have to be made:

a) the expansion tube is developed for small pumps up to ± 80 mm. For larger pumps the expansion tube has a too small capacity.

b) using the closed airchamber for small pumps is impossible due to the limited dimensions of the pump.
<table>
<thead>
<tr>
<th></th>
<th>Air chamber</th>
<th>Open air chamber with air supply by means of a suffer (deep well pump)</th>
<th>Open air chamber with air supply by means of an injector</th>
<th>Open air chamber with mechanical air supply</th>
<th>Closed air chamber</th>
<th>Expansion tube (force hose)</th>
<th>Weight factor</th>
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<td>2</td>
<td>3</td>
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<td>1</td>
<td>1</td>
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<td>1</td>
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<td>4</td>
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<td>9</td>
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<td>5</td>
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<td>3/9</td>
<td>115</td>
<td>6/9</td>
<td>101</td>
<td>867/9</td>
<td>935/9</td>
</tr>
</tbody>
</table>

Table 4.1
5. STATUS OF DEVELOPMENT OF SOFT ELEMENTS

In chapter 4 the soft elements are evaluated as if they are 100% developed. This is of course not the case and for a good choice of soft element the status of development has to be taken in account.

Table 5.1 gives an overview of this status.

<table>
<thead>
<tr>
<th>system</th>
<th>principle</th>
<th>experimental stage test rig</th>
<th>duration tests in lab or</th>
<th>applied in the field</th>
</tr>
</thead>
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<tr>
<td>3.1a</td>
<td>water drip air supply</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>b</td>
<td>air supply pump</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>3.2</td>
<td>closed air chamber by membrane (HAC)</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>3.3</td>
<td>expansion tube</td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>3.4</td>
<td>air chamber with air separator by means of a piston</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>sniffer</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3.6</td>
<td>injector</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.1

**Water drip air supply:**
This system has proven not to be reliable in the field (Sudan, and Cape Verde) all action on this system is stopped.
Air supply pump:
This system is still under duration test and has already made $40 \times 10^6$ number of revolutions. Serval systems have been installed on CWD 5000 windpumps in the field (12 Sudan, 2 Cape Verde, and 1 in Niger).

Closed airchamber:
This system is still in a experimental stage and phase of duration test. Experiments with new membrane materials are still going on.

Expansion tube:
This system has just survived a heavy duration test of $27.6 \times 10^6$ number of revolutions in the CWD 2000/CWD 49 D configuration. The results are good only for larger pumps this system is still in a experimental phase.

Air chamber with air separation by means of a piston:
Only the principle is known from a pump handbook.

Sniffer:
This system is applied on the first CWD pump, the so called Tanzania pump (CWD 145S) and has passed all phases. The system is applied in Tanzania, at Eindhoven testfield and St. Maartensdijk.

Injection:
This system is still in an experimental stage; some steady state test have been done.
6. CONCLUSIONS AND RECOMMENDATIONS

Considering the score of the evaluation of the soft elements and the status of development of the various systems, the following can be concluded and recommended:

- The open airchamber air supply with sniffer is a well known technic used in suction pumps. No basic research is necessary to develop such a system. Some design and duration test have to be done to come to an optimal and reliable design.

- The expansion tube is a proven design for small pumps with large rising mains. Up to now tests, done with the CWD 49 D pump with expansion tube gave good results. In future tests have to be done to prove this principle for larger pumps (CWD 81D).

- The open airchamber air supply with injector is still in a very preliminary state of development. Still lot of research is needed to develop a full proven working injector system. For the near future this principle is not the solution.

Closed airchamber with membrane functions but still some technical problems have to be solved like material choice of membrane. Although it's sensitivity to mal installation this is one of the best options for the larger CWD pumps. More research has to be done on the material of the membrane.

- Open airchamber with mechanical airsupply is developed as a short term solution. The mechanical airpump has proven to be reliable only the tube from pump to the airpump is the weakest part in the design. This weakness can easily be solved by using reinforced and protected tube. The design at this moment is very expensive and the price has to be reduced.

- Closed airchamber air/water separation with piston is not a realistic solution for the CWD pumps.
7. REFERENCES

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