Table 4 Optimal pumping comparison for complete optimal case

| $S_o$     | $n$ | $Q'_0$ semic | $Q'_0$ V-lobe | $Q'_0$ V/Q|$S$
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 10^{-6}$</td>
<td>3</td>
<td>5.526</td>
<td>8.206</td>
<td>1.48</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5.678*</td>
<td>12.389</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.484</td>
<td>16.736</td>
<td>3.05</td>
</tr>
<tr>
<td>$1 \times 10^{-3}$</td>
<td>3</td>
<td>174.8</td>
<td>259.5</td>
<td>1.48</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>179.6*</td>
<td>391.8</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>173.4</td>
<td>529.2</td>
<td>3.05</td>
</tr>
</tbody>
</table>

*Designates maximum flow and optimal number of lobes.

Table 5 Optimal pumping comparison for complete optimal case

<table>
<thead>
<tr>
<th>$S'$</th>
<th>$n$</th>
<th>Semicircular lobe</th>
<th>Nonsymmetric V-lobe</th>
<th>$Q'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 10^{-6}$</td>
<td>3</td>
<td>173.66</td>
<td>233.46</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>178.18*</td>
<td>350.22</td>
<td>2.04</td>
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<td></td>
<td>7</td>
<td>174.65</td>
<td>432.09</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>171.81</td>
<td>467.36</td>
<td>2.75</td>
</tr>
<tr>
<td>$1 \times 10^{-3}$</td>
<td>3</td>
<td>4.443*</td>
<td>6.315</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.310</td>
<td>9.337</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4.036</td>
<td>11.304</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3.888</td>
<td>12.108</td>
<td>3.05</td>
</tr>
</tbody>
</table>

*Designates maximum flow and optimal number of lobes.

tiguous and there is no room at the center of the pump for the fluid to exit. In practice an exit hole must exist and its radius should be large enough to minimize resistance to outflow. It should be noted, however, that the exit hole can undercut the lobes from beneath, subject to the constraint that its radius, $R_o$, does not reach the low pressure zone. Referring to Fig. 2 for the semicircular lobes, $R_s < R_o + \Delta r$, and to Fig. 4 for the V-lobes, $R_s < R_o \sin \alpha + \delta$. Practically, these conditions are not very restrictive because of the additional space that $\Delta r$ and $\delta$ provide.

An angle $\alpha$ greater than zero imposes a constraint on the optimization process. Therefore, the value of maximum $Q'$ decreases as $\alpha$ increases. The following is a check to ensure that even when $\alpha$ takes on a physically reasonable value, the V-lobe design still outperforms the semicircular lobe design. For this check also the small clearance, $c$, is nonzero.

A generous angle $\alpha = 11.54$ deg (which corresponds to $R_h = 0.2R_o$) was selected to provide a wide separation between lobes. Table 5 lists a comparison between the optimal $Q'$ values for the semicircular and V-lobes at two extreme values of $S'$.

Table 5 proves again that the V-lobe design provides a more efficient pumping mechanism even when $\alpha$ takes on a non-optimal value. (Note in Table 5 that the $Q'$ values for the nonsymmetrical V-lobes are lower than those in Table 3, as expected. Hence, one should always attempt to design with the smallest $\alpha$ possible.)

Conclusions and Recommendations

Both a semicircular lobe and a new V-lobe viscous pump have been analytically investigated. The analysis was performed using several approaches. The solution for the semicircular lobe is exact (it is based on closed form integration (Etsion and Yaier, 1988)). For the V-lobe, however, a closed form solution does not exist. An analytical model is provided based on reasonable approximations. The approximations are validated using shape factors and finite element models. For both lobe designs, pump geometry is optimized for maximum pumping capacity. The results of the optimization show that the V-lobe produces a superior pumping mechanism to the semicircular lobe.

The V-lobes have two major advantages over the semicircular lobe. The first is that simply making the lobes straight, as opposed to being curved, reduces the pumping losses. The second, and most important advantage, is that the radial extent of the V-lobes and the number of lobes, are not limited by geometry constraints (such as the tangency requirement of the semicircular lobes). For the straight lobes, pumping capacity increases with the number of lobes and the radial extent.

Increased pumping capacity could be realized by locating the rotor between two stators. This is equivalent to operating two pumps in parallel. Further improvements could probably be made on the lobe leg configuration such as variable lobe width and step height along the length of the lobe legs. Modifications of this nature, however, would be made at the cost of increased manufacturing complexity. The optimization here was performed on the basis of maximizing the flow rate, $Q'$. An alternate optimization could have been performed to maximize the pressure.

Acknowledgments

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References


Yaiier (1988) to get a pump geometry with better performance. The authors optimized the lobe configuration under the condition that the lobe width is kept constant. The performance of the multi-lobe type pump is determined by the difference.
between the amount of dragged fluid and that of the leakage due to pressure difference. Since most of the leakage flows over the lobe with greater gap height \( C \), increasing the width of the lobe with greater gap \( C \) reduces the leakage effectively. For example, if the width of the lobe with greater gap is doubled, the leakage becomes approximately one half when the step height is large (e.g., \( \sigma \geq 3 \)). As a result the flow rate is increased.

There is a reversed step in the middle of a lobe (for example, Fig. 1). Negative pressure will be built up due to the presence of the step. Is the effect of the negative pressure on the flow rate included in the analysis?

I. Etsion

This paper presents an interesting modification of the basic design and optimization of the original circular lobes viscous pump that was introduced by Etsion and Yaier (1988).

The authors rightfully claimed that the step height should be treated as a design variable to be optimized for maximum flow. They clearly demonstrated the improvement in pump performance obtained by this approach. The authors also showed that the V-lobe is superior to the semicircular lobe design. This is mainly due to the larger radial extent, from \( R_s \) to \( R_o \), over which pumping takes place. Based on this reasoning it is almost self evident from Fig. 3 (b) that \( \alpha = 0 \) is the best case for maximum pumping. It should be noticed that for this special case (\( \alpha = 0 \)) the results for a symmetric and a nonsymmetric V lobe will be the same.

The conclusion that there is no optimal value for the number of V-lobes, and that the flow rate increases indefinitely with \( n \), is somewhat unexpected and needs clarification. Considering the optimal V-lobe case with \( \alpha = 0 \) it can be seen from Eq. (14) that

\[
R_s = \frac{\delta}{\sin \beta} \quad (A1)
\]

From Fig. 4 it is clear that

\[
\beta = \frac{\pi}{n} \quad (A2)
\]

Hence, as \( n \) increases \( \beta \) decreases and for a given \( \delta \) the radius \( R_s \) increases too. The pumping effect will vanish as soon as \( R_s = R_o \) (see Fig. 4). Therefore, the requirement for positive pumping is from (A1) and (A2):

\[
\frac{\delta}{\sin \frac{\pi}{n}} < R_o
\]

or since \( \xi = \delta/R_o \)

\[
n < \frac{\pi}{\sin^{-1} \xi} \quad (A3)
\]

From (A3) it can be seen that for a finite lobe thickness \( \xi > 0 \) there is an upper limit for \( n \) above which pumping will stop.

Finally, it is worth noticing that possible use of various lobe configurations other than the semicircular one, as well as variable lobe width and step height along the lobe are covered in a patent from 1985 (see Etsion, 1985).

Additional Reference