The Energy Target of A Fluid Machinery Network in a Circulating Water System

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Research background
Research background

Total Water Consumption in a refinery

- Circulating Water: 90%
- Others: 10%

Total Power Consumption in a refinery

- Circulating Water System
- Others

Energy recovery in a circulating water system will obtain a good performance.
Research background

Previous work: auxiliary pumps are introduced

How to obtain the theoretical limit of the network’s energy consumption?
Analysis

Traditional pump network

Optimized pump network with auxiliary pumps

Fluid machinery network

(1): Only main pump(s), power may waste in branch 1, 2, 3, 4

(2): Combination of main pump(s) and auxiliary pump(s), no energy waste

(3): Water turbines are used for excess energy recovery

\[ h_0 = \max (h_1, h_2, h_3, h_4) \]

\[ h_{B,4} = h_4 + h_0 \]

\[ h_{B,3} = h_3 + h_0 \]

....... no energy waste

Fluid Machinery Network
Analysis

Energy target means the theoretical limit of the network’s energy consumption.
Objective function:

\[
\min P_{\text{total}} = \sum_{i=1}^{n} P_{P_i} - \sum_{i=1}^{n} P_{W_i} y_i
\]

- \( P_{P_i} \): pump power consumption of branch \( i \)
- \( P_{W_i} \): power recovery by the water turbine in branch \( i \)
- \( P_{\text{total}} \): represents the total power consumption---energy target
- \( y_i \): binary variable, determines whether a water turbine is installed or not

1. How to set the pump network.
2. How to set the water turbine network
A simple circulating water system

Node 1 or 3 is the point with the minimum pressure

\[ h_{pump} = \max(z_B + h_{f_{0-1}} + (p_1 - p_0)/\rho g, z_{tower} + h_{f_{0-3}} + h_w) \]

\( H_{B,i} \): The effective height of branch \( i \)

\( H_{tower} \): The effective height of tower

If \( h_{pump} = H_{B,i} \) With excess power, water turbine could be added

If \( h_{pump} = H_{tower} \) no excess power, water turbine cannot be added
Analysis

\[
    h_{pump} = \max(z_B + h_p + h_{f0-1}, z_{tower} + h_{f0-3} + h_w)
\]

\[(a): Z_B + h_p > Z_{tower}\]

When less than \(V'\), \(H_B > H_{tower}\) water turbine should be placed.

\[(H_B - H_{tower})\] could be recovered

When more than \(V'\), \(H_B < H_{tower}\) water turbine should not be placed.

\[(b): Z_B + h_p < Z_{tower}\]

In any case, \(H_B < H_{tower}\) water turbine should not be placed.

**CONCLUSION:** necessary condition of a water turbine placement: \(H_B > H_{tower}\)

When the structure of fluid machinery network is determined, the energy target can be solved then.
3

Case study
Table 1 Data for the example (pipes and exchangers)

<table>
<thead>
<tr>
<th>Branch</th>
<th>Pipe</th>
<th>Heat Exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L_i(m)</td>
<td>D_i(m)</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>0.1023</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>0.0627</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>0.0627</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>0.0627</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>0.0627</td>
</tr>
</tbody>
</table>

(a): original network  
(b): optimized network

Main pump: 31.2 m  
Auxiliary pump: 4.4m  
Water turbine placement: Branch 1  
Energy target: 22.05 kW
Case study

$H_B$ and $H_{tower}$ under different flow rate of circulating water

branch 3, 4, 5: no excess energy for water turbine.
branch 1, 2: it depends.

**Water turbine network**

- when less than A, $h_3 = h_4 = h_5 = H_{tower}$, 1 main pump + 2 auxiliary pumps
- when between A and B, $h_2 = h_3 = h_4 = h_5 = H_{tower}$, 1 main pump + 1 auxiliary pump
- when more than B, $h_1 = h_2 = h_3 = h_4 = h_5 = H_{tower}$, 1 main pump

**Pump network**
## Table 2

<table>
<thead>
<tr>
<th>Flow rate</th>
<th>Power Requirement and Recovery (W)</th>
<th>Energy target (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Branch 1</td>
<td>Branch 2</td>
</tr>
<tr>
<td>0.5Q</td>
<td>P1</td>
<td>W1</td>
</tr>
<tr>
<td>Q</td>
<td>11575</td>
<td>913</td>
</tr>
<tr>
<td>1.5Q</td>
<td>27476</td>
<td>0</td>
</tr>
<tr>
<td>2Q</td>
<td>59299</td>
<td>0</td>
</tr>
</tbody>
</table>

With the change ratios of circulating water flow rate Q as 50%, 100%, 150%, 200%, the change ratios of the corresponding energy target are 28.64%, 100%, 262.46%, 563.45%, respectively.
Conclusions
The difference value between the minimum theoretical power requirement of the pump network and the maximum theoretical power recovery by the water turbine network is the energy target of the fluid machinery network.

Based on the concept of effective heights, the necessary condition of setting a water turbine is obtained as that the effective height of the branch should be larger than that of the cooling tower.

By a graphical representation based on the model, how to set the fluid machinery in a circulating water system under different water flow rate can be determined easily.
Thank you for your attention!