JOINT PROJECT OF CHEMICAL ENGINEERING - APPLIED MECHANICS:
PART II - CHOICE, CALCULATION AND OPTIMIZATION
OF SUPPORTS FOR CHEMICAL APPARATUSES

M. Karsheva, G.Pandev

ABSTRACT

In the present work a possibility to develop a joint project in Chemical Engineering and Applied Mechanics is enlarged in respect to economical optimization and the mechanical part. For the purpose the same example as in the first part [1] is used (distillation column calculation). The mechanic part consists in column support choice, using as an optimization criterion the support weight and the montage complexity.

Keywords: column chemical equipment, support choice, mechanical calculations.

INTRODUCTION

In our previous work a joint project for students in chemical engineering was presented [1]. The project included a chemical engineering part, consisting in distillation column calculation and a mechanical part, consisting in dimensioning of the mechanical elements: vertical support, fundament, flanges, etc. An interesting part of such work could be the choice of the type of support and its optimization in respect to mechanical and economical point of view. That was the reason to continue this work in the direction of the optimization of the elements choice.

The aim of the present work is to summarize the economic respects of the project and to make a detailed comparison between two types of supports for the same distillation column. As a base for the choice of support its weight and montage complexity is used.

PROCEDURE

Computer aided design of the chemical equipment gives the possibility to calculate some variants of the equipment for the same problem solution and to choose the best of them in technical and economical respect. As an optimisation criterion could be chosen the minimum of the expenses calculated by the relationship:

\[ RE = \frac{C}{T} + OE \]

Here RE is the relative expenses; C is the value of the capital expenses (investments); T is the standard term of the justification of the expenses; OE is the value of the operation expenses. According to this criterion the most effective is the apparatus with minimum relative expenses, i.e.: \( C = \min(RE) = \min\left(\frac{C}{T} + OE\right) \).

The operation expenses could be divided into two groups:

- The first one proportional to the capital investments. To this group could be attributed the amortization deductions, defined by \( K_c \) coefficient; current repairs and maintenance expenses defined by the coefficient \( K_r \).
- The second one is independent of the capital investments.

The relative expenses depend only on the variable part of capital investments \( K \); on the standard term of the justification, amortization deductions and current repairs and maintenance expenses, all of them taken as a part of the capital investments.

The standard term of the justification of the expenses for chemical industry is 3 - 5 years [2]. The amortization deductions usually are taken as a part from
capital investments -10 to 5 %. So, supposing T to be 5 years, $K_2 = 0.1$ and $K_1 = 0.05$ we obtain:

$$RE = C / T + (K_a + K_i)K = 0.35K$$

The important variable part of the capital investments in this case consists on column value, depending on its weight $W_c$, the price per unit weight $P_w$ and also on the supply and mounting expenses (about 20 - 30 % from column value [2]). So:

$$K = W_c (P_w + 0.25P_w) = 1.25W_c P_w$$

The weight of the cylindrical equipment consists on the cylindrical body weight, the plates' weight, as well as the cover and the bottom weight. For our case it was found to be $16.60 \times 10^6$ N [1].

The capital expenses consist of the expenses for apparatus production and mounting. Usually the expenses for mounting of the equipment are relatively low and could be neglected. When the distillation column was calculated at an optimal reflux ratio minimizing $N\left(R + 1\right)$ function, other parameters could be varied. Such construction parameters are: the type and the characteristics of contact equipment, the column diameter, the distance between the plates in relation to their normalized dimensions and the stable work operational conditions.

In such case the solution of optimisation problem excludes the expenses for vapour, water and electrical energy, because they are practically independent on column construction. The same thing regards a part of capital expenses, slightly dependent on column construction - the price of pipelines, control and automation devices, fundamentals, etc.

Usually the expenses for the supports are not calculated. Nevertheless the problem of support choice is quite important. Regarding to the place of column mounting two basic types of supports could be proposed: column standing and claws. Both types must ensure the same equipment stability against wind for outdoor mounting. The differences here come from support weight and the montage complexity resulting in montage costs.

In order to clarify the reasons for support choice, let us present the basic support types.

Mounting of chemical equipment usually is done by special supporting constructions of two basic types: supports for vertical and for horizontal apparatuses [3]. The most often used types of welded supports are presented in Fig.1. The supports of the type I to V are situated under the apparatus and they are fixed to it. Usually this type of the supports is used for the cylindrical apparatuses. The supports of the types VI to IX are situated on the sides of the equipment; they are also fixed to the apparatus and could be used for different forms of the equipment. The supports I - III, VI and VII are whole supporting constructions. Those of the types IV, V, VIII and IX consist of claws, whose number for one apparatus must be not less than 3.

The choice of the type of support for one apparatus depends on place of mounting and working conditions. When mounted inside the industrial premises the supports IV or V should be used. For the case of hanged up on the supporting construction apparatuses the support types VI - IX are to be preferred. The support constructions I - III are used usually for the case of outdoor mounting of the equipment on the foundation, especially if the height to outer diameter ratio $H/D_{out} \geq 5$. The support type III has to be used for the column apparatuses with $D_{out} \leq 1000 \text{ mm}$. When fixing is made by claws of type VIII and IX for thin-walled apparatuses it is necessary to strengthen the place of welding to the column body. The types of claws most spread in chemical machinery are IV and VIII. This must be taken into account when chemical apparatuses design is being made.

![Fig. 1. Supports classification a - (I - III); b - (IV - IX).](image-url)
The calculation of stresses of supports for chemical equipment must be done for the case of maximal weight for operating conditions during hydraulic tests (apparatus full with water). The weight of supplementary equipment as pipelines and fittings has also to be taken into account.

The method for choice and calculation of supports for vertical chemical apparatuses is presented in specialized literature [3]. Its application is demonstrated on the example for a given construction of supports.

For the calculations the data from our previous work on distillation problem calculation are used:

- Full column weight - 18.27.10^4 N [1];
- Type of the mounting – hung up on the claws of the type VIII presented in Fig.1b;
- Number of claws - 4;
- Load per claw - \( G_t = 4.57 \times 10^4 N \);
- Material of the claws - steel 3 (S3 \( \sigma = 146.10^4 N/m^2 \)); according to the standard: S3 (S35K2G2W) [4] – for simplicity the term Steel 3 is used below;
- Number of ribs per claw \( z = 2 \);
- Claw jutting out - \( l = 0.25 m \);
- The claws are based on wooden lining: \( q = 2.10^6 N/m^2 \);
- Thickness of column wall \( s_1 = 16 mm = 0.016 m \).

1. We suppose the ratio between the claw distance \( l \) to rib height to be

\[
\frac{l}{h} = 0.5 m.
\]

So, for the height we can easily obtain:

\[
h = \frac{l}{0.5} = 0.25 = 0.5 m.
\]

2. Calculated claw rib thickness at \( k = 0.6 \)

\[
s' = \frac{2.24 G_t}{k^2 \sigma / f} = \frac{2.24 \times 4.57 \times 10^4}{0.62 \times 146.10^6 \times 0.25} = \frac{10.24 \times 10^4}{438.10^6} = 0.23310^{-2} m
\]

The ratio

\[
\frac{l}{13} = \frac{0.25}{13} = 0.0192 > s' = 0.00233 m.
\]

That is why following the method presented in [3], the value of \( k \) must be decreased. We decreased it to the value \( k = 0.25 \), giving \( s = 22.5 \). A new calculation of claw rib thickness results in:

\[
s'' = \frac{0.0023 \times 0.6}{0.25} = 0.0055 > \frac{0.25}{22.5} = 0.011 m
\]

so, we suppose \( s = 14 mm \).

The length of the supporting plate of the claw is supposed to be \( l_1 = 0.23 m \), the thickness \( s = 14 mm \). So to obtain the width of the supporting plate we use the relationship:

\[
b' = \frac{G_t}{l_1 q} = \frac{4.57 \times 10^4}{0.23 \times 10^6} = 0.0993 m
\]

So, the width of the supporting plate is \( b = 0.1 m \).

We choose for the supplementary \( G_{th} = 8.10^4 N \) the claw lining with following dimensions: \( H = 500 mm; B = 360 mm; S_H = 10 mm \).

The rib is being welded to the lining by closed-line welding with side \( K = 8 mm \).

The entire welding length is

\[
L = 4(h + s) = 4(0.5 + 0.014) = 2.056 m
\]

The strength of the welding must be checked up by the following relationship:

\[
\left[ \tau_m \right] = 80.10^6 Pa
\]

\[
G_c = 4.57 \times 10^4 N < 0.7LK[\tau_m] =
\]

\[
= 0.7 \times 0.056 \times 0.008 \times 10^6 = 92.11 \times 10^4 N
\]

or indeed \( G_c = 4.57 \times 10^4 < 92.11 \times 10^4 N \)

In our previous work a vertical support of type I (Fig.1a) was calculated. From methodological point of view it is useful to give the students a task to compare the supports for the same apparatus (in this case distillation column) and to make conclusions.

For the example presented the supports could be compared by their weight and montage complexity. Here the comparison of vertical support and 4 claws for hanging up the column is presented.

- **Vertical support** (type I). In Fig.2a the design of the vertical support for the distillation column is presented. According to this design, the column was divided into elements to calculate its total volume and weight. The results of these calculations are given in Table 1.

So, the total weight of the vertical support will be the sum of these four weights, or 5378 N. It is necessary to account for the fittings (as bolts, screw-nuts and washers – total number – 80). Their total weight is
Table 1. Vertical support calculations.

<table>
<thead>
<tr>
<th>Detail (No)</th>
<th>Volume, m³</th>
<th>Material</th>
<th>Mass, kg</th>
<th>Weight, N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supporting cylinder</td>
<td>0.058</td>
<td>Steel 3</td>
<td>455</td>
<td>4459</td>
</tr>
<tr>
<td>Supporting ring</td>
<td>0.0097</td>
<td>Steel 3</td>
<td>78</td>
<td>764</td>
</tr>
<tr>
<td>Supporting rib (8 ribs)</td>
<td>9.2 \times 10⁻³</td>
<td>Steel 3</td>
<td>0.728 \times 5.36</td>
<td>57</td>
</tr>
<tr>
<td>Heel (16)</td>
<td>8.1 \times 10⁻³</td>
<td>Steel 3</td>
<td>0.66616 \times 10</td>
<td>98</td>
</tr>
</tbody>
</table>

Table 2. Claws calculations.

<table>
<thead>
<tr>
<th>Detail (No)</th>
<th>Volume, m³</th>
<th>Material</th>
<th>Mass, kg</th>
<th>Weight, N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement (1)</td>
<td>0.00198</td>
<td>Steel 3</td>
<td>15.34</td>
<td>152</td>
</tr>
<tr>
<td>Lining (1)</td>
<td>0.00035</td>
<td>Steel 3</td>
<td>2.73</td>
<td>27</td>
</tr>
<tr>
<td>Rib (2)</td>
<td>0.0016</td>
<td>Steel 3</td>
<td>12.562 = 25.12</td>
<td>246</td>
</tr>
<tr>
<td>Total</td>
<td>Steel 3</td>
<td>37850</td>
<td>ρ = 7850 N/m³</td>
<td>425</td>
</tr>
</tbody>
</table>

N with that for the 4 claws (1764 N), and accounting to easier montage for the claws, this type of support could be chosen for the distillation column calculated.

For the calculations the same mark of steel was chosen to make the comparison easier.

The comparison of prices was not done, for they are quite variable, the same regards the salaries of workers. The comparison was done just by exact parameters. As it was already mentioned in our previous work, it is possible to develop the economic part of the project and to make it a for-diploma project for chemical engineering students.

CONCLUSIONS

In this work an example of comparison of possible mechanical supports for chemical column equipment (distillation column) is presented. Such type of tasks for students’ project gives them the possibility of optimal use of their knowledge not only in Chemical Engineering, but also in Applied Mechanics. This joint project is close to their future work in chemical engineering design. It enlarges the possibilities of students to analyse the situation and to calculate the apparatuses and their mechanical parts dimensions, using criteria of optimal design as well as the economic ones.

REFERENCES