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# OPENINGS IN THE SHELL WITHOUT REINFORCEMENT WITH STEEL SHEETS

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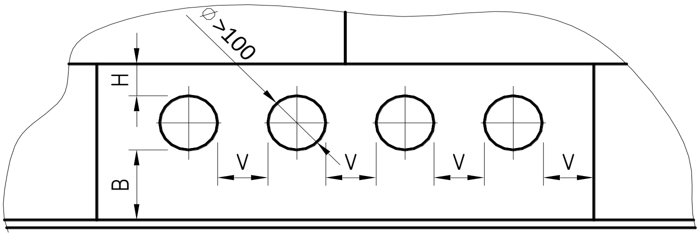
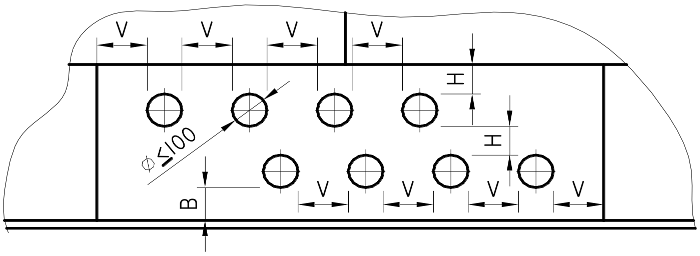
## 1. Introduction.

All vessels that are designed for storage of liquids and in which some technological process take place, have relevant openings. The quantity and location of all technological openings depend on volume and basic dimensions of the tank, on type and technological facilities and on specific properties of the stored product.

The minimal distances between periphery welding joints of the joint shell- nozzle and shell welds are shown on the fig.1 and are reported on the Table 1.



Location of openings in shell with diameter > 100 mm



Location of openings in shell with diameter ≤ 100 mm

Fig.1 Permissible use of different openings in the shell

**TABLE 1**

| Dimension | Minimal distances between joints, mm | |
|---|---|---|
| | $t_s \leq 10$ mm | $t_s > 10$mm |
| **B** | 150 | bigger than 250 or 8.$t_s$ |
| **H** | 75 | bigger than 250 or 8.$t_s$ |
| **V** | 150 | bigger than 250 0r 8.$t_s$ |

When the tank has volume V ≥ 1000 $m^3$, one sheet of the course which surface is not smaller than 7 $m^2$, must not have more than 4 openings [2].

Openings for heating coils and other small nozzles could be executed on the shell sheet that does not have any other openings. One sheet of course must not have more than 8 nozzles and their diameter could not be bigger than Ø 100 mm.

Although the observing of the above mentioned constructive requirements for minimal distance between welding joints, the openings have some influence upon the shell construction and they can cause concentration of tensions and decrease its strength.

The influence of every one joint into the sheet should be analyzed and reported.

The nozzle must be installed in the shell according to the following constructive requirements:

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- Nozzles with diameter $\boldsymbol{D} \leq Ø50$ and thickness of neck of the nozzle $\boldsymbol{t_p} \geq 5$ mm can be installed without reinforcing sheet, no matter how thick is the shell $\boldsymbol{t_s}$ [4], [5];
- Nozzles whit diameter $\boldsymbol{D} \leq Ø100$ can be installed without reinforcing of the shell when they have increased thickness of the nozzle neck $\boldsymbol{t_p}$ and when shell has thickness $\boldsymbol{t_s} \leq 10$mm;
- Nozzles with diameter $\boldsymbol{D} > Ø50$ can be installed with lap reinforcing sheets;
- Nozzles with any internal diameter ***D*** and at any shell thickness $\boldsymbol{t_s}$ and at any projected temperature can be installed with inserted reinforcing sheet [3].

## 2. Adding of new openings without extra reinforcing the shell.

The installation of nozzles is easiest and with minimal quantity of used metal and weld joints when they do not have additional reinforcing sheets.

The maximal diameter of the opening $\boldsymbol{d_{om}}$ which does not require reinforcement is limited. According to [1] the maximal diameter of the opening may be calculated by formula:

(1) $$d_{om} \leq 8{,}1.\sqrt[3]{D.t_s.(1-k)} \leq 200\,mm,$$

where:

***D*** is the diameter of the tank, mm ;

$\boldsymbol{t_s}$ – thickness of the shell where the nozzle will be located, mm ;

***k*** – coefficient which is calculated by the following formula:

(2) $$k = \frac{p.D}{2{,}3.R_y.t_s} \leq 0{,}99,$$

where:

$\boldsymbol{R_y}$ is design resistance according to the yield strength of the shell, kg/mm$^2$;

***p*** – design internal pressure, kg/mm$^2$ . It is calculated by formula:

(3) $$p = \gamma_{f\rho}.\rho.h_i + \gamma_{fa}.p_0,$$

where:

$\boldsymbol{\gamma_{f\rho}} = 1{,}2$ – coefficient for hydrostatic load;

**ρ** - normative value of density of product;

$\boldsymbol{h_i}$ - distance from maximal level of filling with product to ax of the nozzle;

$\boldsymbol{\gamma_{fa}} = 1{,}2$ – coefficient of pressure overloading;

$\boldsymbol{p_o}$ - normative value of the overpressure in the tank.

The formulas (1) and (2) are empirical and the value used there must be in [kg] and [mm].

In the above-mentioned formulas (1) and (2) the thickness of the nozzle is not considered and this thickness is very important when the maximal diameter of the opening which does not require enforcement $\boldsymbol{d_{om}}$ has been calculated. In this reason the author of the article has made several tests to determine the maximal diameter of the opening $\boldsymbol{d_{om}}$ which does not require additional reinforcement when the thickness of the pipe $\boldsymbol{t_p}$ accounts for investigations.

The survey has been carried out by 3D computer modeling and the ANSYS has been used.

### 2.1 Conditions of survey:

a) the shell courses have been made from steel and have the following qualities:

- yield strength $\boldsymbol{R_{yn}} = \mathbf{200 \div 375}$ **MPa;**
- modulus of elasticity $\boldsymbol{E} = \mathbf{2{,}1.10^5}$ **MPa;**
- coefficient of Poisson **ν = 0,3.**

b) the openings have been located far from the bottom and the shell has been loaded with tension strength only, without bending. The conditions of supporting do not cause additional bending in the surveyed plate. The used in calculation tensile strengths in the sheets $\boldsymbol{\sigma_2}$ ,Table 2 , are proportional on the yield strength of the steel $\boldsymbol{R_{yn}}$ and have been calculated according to:

(4)
$$\sigma_2 \approx \frac{R_{yn}}{1{,}3}$$

**TABLE 2**

| $R_{yn}$, MPa | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 |
|---|---|---|---|---|---|---|---|---|
| $\sigma_2$,MPa | 155 | 175 | 195 | 212,5 | 230 | 250 | 270 | 290 |

The purpose of the relation between $R_{yn}$ and $\sigma_2$ is to show the tensions in the shell, which are as closer to the real tensions of exploitation as possible.

The yield strength of the steel $R_{yn}$ and the tensile strengths $\sigma_2$ used in this calculation represents all kind of steel used in tank design.

c) the neck of nozzle has the same physical and mechanical properties as the shell itself. The nozzle has been welded to the shell with full penetration of the joint and cathetus k = 5mm. The length $L$ of the part of the neck which is outside of the shell is according fig. 2 and is calculated following the formula [4].

(5)
$$L \geq 1{,}17.\sqrt{r_m . t_p}\ ,$$

where:
$L$ is the minimal length of the neck part outside of the shell, mm.
$t_p$ – thickness of the neck, mm.
$r_m$ – average value of the pipe radius, mm.

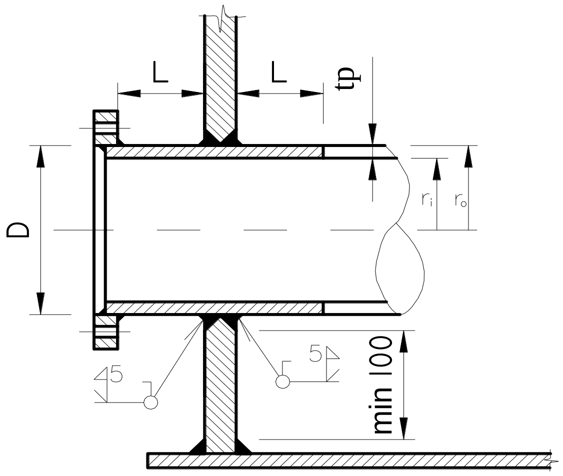

Fig.2 Adding of new openings without shell reinforcement

### 2.2 Results of the investigation

The nozzles break the integrity of the shell and change the evenly distributed stress in it. All nozzle joints are stress concentrators and they are represented on the fig. 3.

The analysis of obtained results shows that there is so called plastification of the steel. These very small areas are located in the places where the geometry has been changed (closer to the joint of the nozzle and shell) where the radius of curvature is very small. In above-mentioned reason when the nozzle is being mounted, the following operations are recommended:

- decrease of the maximal tensions in the shell;
- welding joint between the shell and the nozzle executed with full penetration must be smooth from the pipe surface to the shell surface.

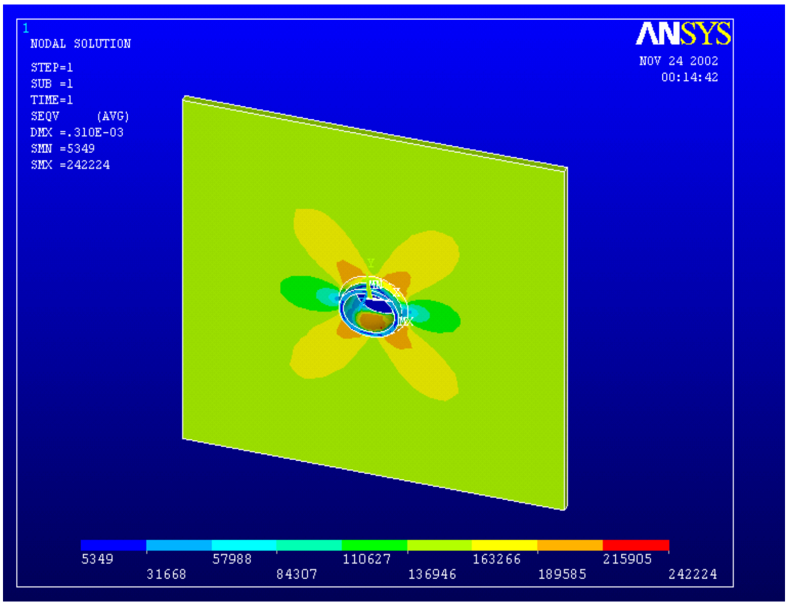

Fig 3 Distribution of the tensions around the nozzle

Depending on the thickness of the neck $t_p$ and the thickness of the shell $t_s$ the calculated maximal diameters of the opening that do not require additional reinforcement are as follow:

**TABLE 3**

| Shell thickness $t_s$, mm | Wall pipe thickness $t_p$, mm | | |
|---|---|---|---|
| | 5 | 6 | 7 |
| 5 | $Ø20 \leq d_{om} \leq Ø100$ | | |
| 6 | $Ø20 \leq d_{om} \leq Ø100$ | | |
| 7 | $Ø20 \leq d_{om} \leq Ø75$ | $Ø75 < d_{om} \leq Ø100$ | |
| 8 | $Ø20 \leq d_{om} \leq Ø75$ | $Ø75 < d_{om} \leq Ø100$ | |
| 9 | $Ø20 \leq d_{om} \leq Ø65$ | $Ø65 < d_{om} \leq Ø85$ | $Ø85 < d_{om} \leq Ø100$ |
| 10 | $Ø20 \leq d_{om} \leq Ø65$ | $Ø65 < d_{om} \leq Ø80$ | $Ø80 < d_{om} \leq Ø100$ |

The results shown in Table 3 are appropriate for use for installation of new nozzles in the shell without its reinforcement and for analysis of the existed ones if these requirements are observed:

- the nozzle material has physical and mechanical qualities not worse than shell themselves;
- the nozzle will be installed through the weld joint with full penetration and additional cathetus k = 5 mm. (according to fig. 2);
- the nozzle part that is outside the shell is done according to (5) but not less than 15mm. The outsider length ***L*** depend on technological reason;
- maximal radial tension $\sigma_2$ in the shell at level of the nozzle depend on the following equitation:

(6) $$\sigma_2 = \frac{(\gamma_{f\rho}.\rho.h_i + \gamma_{fa}.p_0).r}{t_{si}}$$

and must observe the requirement according the formula (7):

(7) $$\sigma_2 \leq \gamma_c.R_y\,,$$

where:

$\gamma_{f\rho}$ = 1,2 - coefficient for hydrostatic load;

$\rho$ - normative value of the density of the product;

$h_i$ - distance from maximal level of filling of product to the axe of nozzle;

$\gamma_{fa}$ = 1,2 - coefficient of over pressure;

$r$ - radius of the shell of the tank;

$t_s$ - thickness of the shell sheet where the nozzle will be mounted;

$R_y$ - calculated resistance by the yield of strength of the shell;

$\gamma_c$ - 0,75 – coefficient of condition of joint shell-nozzle without additional reinforcement on the shell.

### 2.3 Assessment of the calculated results

For the assessment of the calculated results by the author may be used methodology described in [4]. In order to apply this methodology the part of the nozzle located outside must be in both directions and not less than calculated by (5) values. Minimal distance between neck of the nozzle and tank bottom is 100 mm.(fig. 2).

The thickness of the nozzle neck is chosen in this reason that tension concentration ***j*** not be more than **2,0**. This coefficient ***j*** have to be calculated through fig.4 where the parameter ***y*** must be used. The value of ***y*** depends on the following formula:

(8)

$$y = 1{,}56.\frac{t_p}{t_s}\sqrt{\frac{t_p}{r_m}+\left(\frac{t_p}{2.r_m}\right)} ,$$

where:
$t_s$ is thickness of shell of the tank, mm;
$t_p$ - thickness of the neck, mm;
$r_m$ - medium radius of the nozzle, mm.

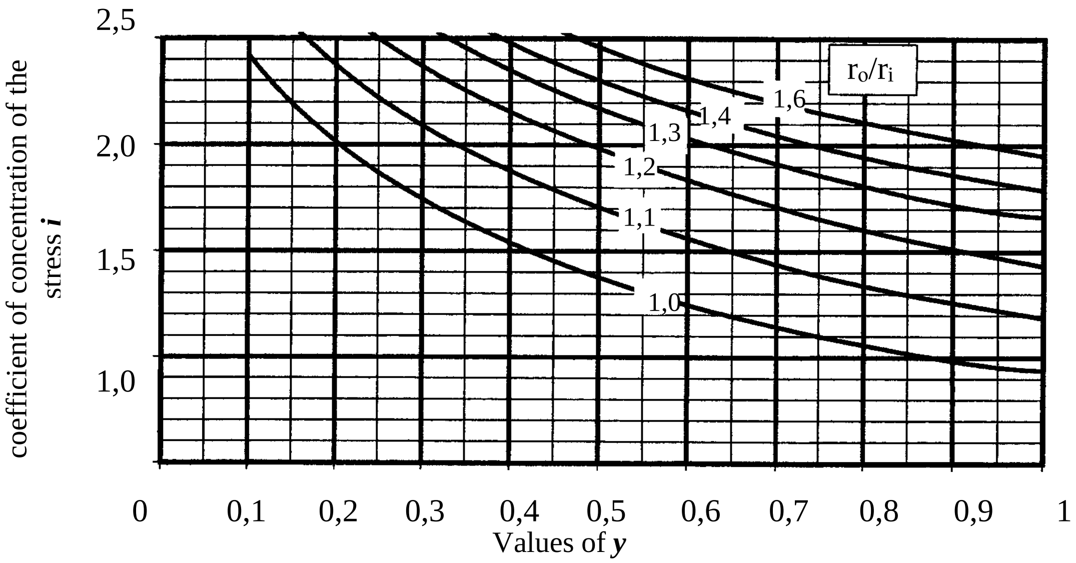

fig.4 Concentration of the stress in the nozzle without reinforcement

In the Table 4 are compared received by the author results and calculated ones by the above-mentioned [4] methodology. It is clear that the applied by the author thickness of the neck of nozzles are convenient for the requirements in the mentioned in [4] methodology.

**TABLE 4**

| Thickness of shell $t_s$, mm | Internal diameter of neck, mm | External radius of neck $r_o$, mm | Thickness of neck $t_p$, mm | Internal diameter of neck $r_i$, mm | Average radius of neck $r_m$, mm | $r_o/r_i$ | *y* | *j* |
|---|---|---|---|---|---|---|---|---|
| 5 | 48,3 | 24,15 | 5 | 19,15 | 21,65 | 1,261 | 0,981 | 1,65 |
| | 60,3 | 30,15 | 5 | 25,15 | 27,65 | 1,199 | 0,844 | 1,55 |
| | 76,1 | 38,05 | 5 | 33,05 | 35,55 | 1,151 | 0,726 | 1,52 |
| | 88,3 | 44,15 | 5 | 39,15 | 41,65 | 1,128 | 0,661 | 1,51 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6 | 48,3 | 24,15 | 5 | 19,15 | 21,65 | 1,261 | 0,856 | 1,68 |
| | 60,3 | 30,15 | 5 | 25,15 | 27,65 | 1,199 | 0,734 | 1,67 |
| | 76,1 | 38,05 | 5 | 33,05 | 35,55 | 1,151 | 0,628 | 1,7 |
| | 88,3 | 44,15 | 5 | 39,15 | 41,65 | 1,128 | 0,570 | 1,65 |
| 7 | 48,3 | 24,15 | 5 | 19,15 | 21,65 | 1,261 | 0,766 | 1,74 |
| | 60,3 | 30,15 | 5 | 25,15 | 27,65 | 1,199 | 0,655 | 1,77 |
| | 76,1 | 38,05 | 6 | 32,05 | 35,05 | 1,187 | 0,724 | 1,65 |
| | 88,3 | 44,15 | 6 | 38,15 | 41,15 | 1,157 | 0,656 | 1,65 |
| 8 | 48,3 | 24,15 | 5 | 19,15 | 21,65 | 1,261 | 0,700 | 1,83 |
| | 60,3 | 30,15 | 5 | 25,15 | 27,65 | 1,199 | 0,595 | 1,83 |
| | 76,1 | 38,05 | 6 | 32,05 | 35,05 | 1,187 | 0,655 | 1,76 |
| | 88,3 | 44,15 | 6 | 38,15 | 41,15 | 1,157 | 0,593 | 1,7 |
| 9 | 48,3 | 24,15 | 5 | 19,15 | 21,65 | 1,261 | 0,647 | 1,91 |
| | 60,3 | 30,15 | 5 | 25,15 | 27,65 | 1,199 | 0,549 | 1,9 |
| | 76,1 | 38,05 | 6 | 32,05 | 35,05 | 1,187 | 0,601 | 1,8 |
| | 88,3 | 44,15 | 7 | 37,15 | 40,65 | 1,188 | 0,676 | 1,68 |
| 10 | 48,3 | 24,15 | 5 | 19,15 | 21,65 | 1,261 | 0,606 | 1,96 |
| | 60,3 | 30,15 | 5 | 25,15 | 27,65 | 1,199 | 0,513 | 1,98 |
| | 76,1 | 38,05 | 6 | 32,05 | 35,05 | 1,187 | 0,558 | 1,85 |
| | 88,3 | 44,15 | 7 | 37,15 | 40,65 | 1,188 | 0,625 | 1,77 |

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