

A Study on Isometric Heating Process to Forecast Explosion and Find Safety Solutions for Pressure Vessels

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ABSTRACT: The article studies isometric heating process in pressure vessels, thereby calculating the risks of explosion in closed heating pressure vessels. Through the function of temperature and pressure distribution, using quantitative calculations, it analyzes potential problems when changing the parameters of equipment structure, heat sources, environment... As a result, it offers solutions in designing, manufacturing, testing and operating of pressure vessels to prevent the problem.

KEYWORDS: isometric heating, pressure vessel, allowable stresses, safety, safety factor

ABBREVIATION: CPs: Combustion Products

I. INTRODUCTION

Most of the explosions of pressure vessels are because medium pressure rises too high when heated in closed vessels. This article will use analytical methods to calculate and find the increased temperature and pressure functions of mediums over time τ and other physical parameters when the medium is heated in a closed vessel. Then it will examine functions $t(\tau)$, $p(\tau)$ to predict the explosion of pressure vessels and recommended safety solutions for pressure vessels.

II. RELATED WORK

Isometric heating process by combustion products or resistors in pressure vessels may cause explosion incidents. By using heat transfer formulas, we determine the function between temperature and pressure over time of heating in pressure vessels. We also calculate to warn pressure vessel explosion incident and energy created during the process. Through that, we give safety recommendation for operating pressure vessels.

III. MODEL OF THE SURVEYED PRESSURE VESSEL

Consider a metal closed vessel V , arbitrary shape, thickness δ , physical parameters ρ , c , λ , δ , β_{cp} , n , contains the liquid medium with physical parameters m, c, t_o, t_s, r , which is heated by resistor P placed in medium or by the combustion products through surface F_1 with physical parameters $t_{f1}, \alpha_1, \epsilon_1$. Tank shell with surface F , calorific into the air with temperature t_f and convection heat transfer coefficient α .

Looking for temperature increase function $t(\tau)$ and pressure function $p(\tau)$ of medium over time τ and the given parameters.

$t(\tau) = f(\tau, \text{ and all given parameters } c_i)$

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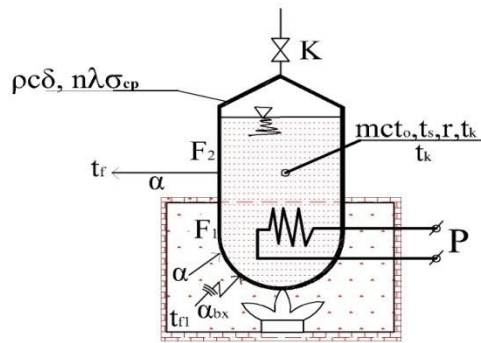


Fig. 1. Model of pressure vessel with heated liquid medium by electricity or combustion products

IV. THE RESEARCH HYPOTHESES

To be able to find analytic solutions of the problem, we need to make the following assumptions:

- 1) At every time τ , consider the temperature $t(\tau)$ of medium is evenly distributed in closed vessel V and equals the temperature of shell V . This hypothesis eliminates the coordinates in the function temperature t . This is reasonable because the heat transfer coefficient α in liquid medium is very big.
- 2) The given physical parameters is unchanged in the surveyed period $\Delta\tau$. In particular the mass of medium m will not change when the vessel is closed ($V = \text{const.}$). When open valve K through the air pressure $P_k = 1 \text{ atm} = \text{const.}$, vessel is open, water will boil at $t_s = 100^\circ\text{C}$ and evaporate and make m decrease.

V. FIND THE FUNCTION OF TEMPERATURE $T(\tau)$, PRESSURE $P(\tau)$ OF MEDIUM

V.1 When the medium is heated by resistor with power P

1) Energy balance equation of the system (medium and shell) at time τ after infinitesimal time $d\tau$ is:

Electrical power fed into the system $dE = dU_v + dH_m + \delta Q_a$

or: $Pd\tau = \rho\delta Fc_v dt + mc_p dt + \alpha F(t - t_f)d\tau$,

with F is the area around the vessel, which calorific into the air

change it into canonical form $\frac{dt}{d\tau} + at = b$:

$$\frac{dt}{d\tau} + t \frac{\alpha F}{(m_v c_v + mc_p)} = \frac{p + \alpha F t_f}{(m_v c_v + mc_p)}$$

set: $a \triangleq \frac{\alpha F}{\sum m_i c_i}, \left(\frac{1}{s}\right); b \triangleq \frac{p + \alpha F t_f}{\sum m_i c_i}, \left(\frac{K}{s}\right);$

$$t_m = t_{mp} \triangleq \frac{b}{a} = t_f + \frac{P}{\alpha F}$$

deduce: $dt = -a \left(t - \frac{b}{a}\right) d\tau \triangleq -a(t - t_m)d\tau$

Separating variables and integrating, we have:

$$\int_{t_0}^t \frac{dt}{t - t_m} = - \int_0^\tau a d\tau \Rightarrow \ln \frac{t(\tau) - t_m}{t_0 - t_m} = -a\tau$$

\Rightarrow Function $t(\tau)$ is formed:

$$t(\tau) = t_m - (t_m - t_0) \exp(-a\tau)$$

2) The increased pressure function $p(\tau)$ of medium is: $p(\tau) = g(t(\tau))$

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With the function $g(t)$ can be determined by $p(\tau) = \rho RT(\tau)$ (τ) when the medium is ideal gas, and other media can be determined by tables, graphs or empirical formula of each medium:

For example, when medium is water, $p(\tau)$ can be calculated by Antoine empirical formula:

$$t(\tau) = \frac{4020}{12 - \ln p[\text{bar}]} - 235 \Rightarrow p(\tau) = 162755 \exp\left[\frac{-4020}{t(\tau) + 235}\right], [\text{bar}]$$

V.2 When the medium is heated by combustion products

1) Energy balance equation of the system is:

$$\delta Q_{\alpha 1} = dU_v + dI_m + \delta Q_{\alpha}$$

$$\Rightarrow \alpha_1 F_1 (t_{f1} - t) d\tau = m_v c_v dt + m c_p dt + \alpha F_2 (t - t_f) d\tau$$

With F_1 and F_2 are the parts of the shell which contact with combustion products and with air (Fig. 1.)

The canonical form of this equation is:

$$\frac{dt}{d\tau} + \frac{t(\alpha_1 F_1 + \alpha F_2)}{\sum m_i c_i} = \frac{\alpha_1 F_1 t_{f1} + \alpha F_2 t_f}{\sum m_i c_i}$$

set: $a \triangleq \frac{\sum \alpha_i F_i}{\sum m_i c_i} \left(\frac{1}{s}\right)$; $b \triangleq \frac{\sum \alpha_i F_i t_{fi}}{\sum m_i c_i} \left(\frac{K}{s}\right)$; $t_m = \frac{b}{a} \triangleq \frac{\sum \alpha_i F_i t_{fi}}{\sum \alpha_i F_i}$

$$\Rightarrow \int_{t_0}^t \frac{dt}{t - t_m} = - \int_0^{\tau} a d\tau \Leftrightarrow \ln \frac{t(\tau) - t_m}{t_0 - t_m} = - a\tau$$

$$\Rightarrow t(\tau) = t_m - (t_m - t_0) \exp(- a\tau)$$

2) The type of the function $t(\tau)$ and $p(\tau)$ of the medium when heated by combustion products is the same as when heated by electric heaters, only the values of coefficients a , b , t_m are different. Especially, when heated by combustion products, then t_m is blocked by:

$$t_m = (\alpha_1 F_1 t_{f1} + \alpha_2 F_2 t_{f2}) / (\sum \alpha_i F_i) < t_{f1}$$

When heated by resistor: $t_m = t_f + \frac{P}{\alpha F}$ can raise unlimitedly when $\alpha \Rightarrow 0$

V.3 Preliminary investigate the rules of increase $t(\tau)$ and $p(\tau)$ of medium in Fig. 2

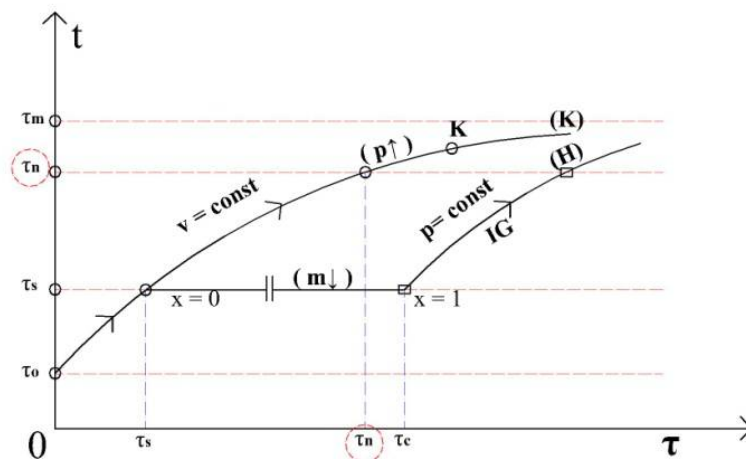


Fig. 2. The rules of increase $t(\tau)$, $p(\tau)$ of the medium, which heated isobarically or isochorically

VI. CALCULATE FOR EXPLOSIVE WARNING OF PRESSURE VESSELS

VI.1 Determine the explosive pressure on the surfaces of vessels

1) Determine allowed pressure p_{cp} :

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From the formula for calculating the thickness of vessel $\delta = f(p, \sigma_{cp}, c, \text{the other coefficients } c_i)$, we can determine the allowed pressure p_{cp} (when checking calculation) as the solution of $p = f^{-1}(\sigma_{cp}, \delta, c, c_i) \triangleq p_{cp}$, with the reserve coefficient of thickness $c[\text{mm}] = 0$ and other factors, which taken the minimum value as stipulated.

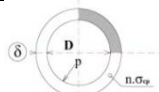
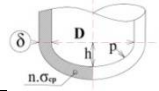
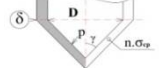
2) Determine explosion pressure p_n :

Since p_{cp} is proportional to σ_{cp} and breaking stress of the material $\sigma_n \triangleq n \sigma_{cp}$, so we can calculate the explosion pressure of vessel by the formula:

$$p_n = f^{-1}(n \sigma_{cp}, \delta, c=0, c_i) = n p_{cp}$$

The formulas for calculating the explosion pressure to the surfaces that are frequently under pressure such as cylindrical shells, spherical shell, elliptical shell, cone shell are presented in the following table:

Table 1: The formula for calculating the explosive pressure on the surface under pressure

Surfaces	Structure	Designed calculation; δ	Checked calculation p_{cp}
Cylinder		$\delta = \frac{pD}{(2\varphi\eta\delta^* - p)} + C$	$P_{ct} = \frac{2\varphi\eta\delta^*\delta}{(D+\delta)}$
Ellipse		$\delta = \frac{pD(D/2h)}{(4\varphi\eta\delta^*kz - p)} + C$	$P_{ce} = \frac{8h\varphi\eta\delta^*kz\delta n}{D^2 + 2h\epsilon\delta}$
Cone		$\delta = \frac{pDt}{2k(\varphi\eta\delta^* - p)\cos\gamma} + C$	$P_{cn} = \frac{2\delta k\varphi\eta\delta^*\cos\gamma}{Dt + 2\delta k\cos\gamma}$

Note:

k: inner/ outer pressure coefficient

z: bottom piercing coefficient

$\sigma_{cp} \triangleq \varphi\eta\delta^*$: allowable stress

φ : coefficient of resistance of manufacturing

η : coefficient of effect of medium (erosion, explosion...)

δ^* : Allowable quantum stress = $f(\text{material, structural, method of manufacturing}) \triangleq \min(\delta_b \text{ pull}, \delta_b \text{ compress}, \delta_b \text{ tired})/n$ (n: safety coefficient)

VI.2 Determine the temperature of explosion of medium t_n and the time of explosion τ_n

When know p_n we can determine the temperature of explosion of medium t_n according to tables or empirical formula takes the following form:

$p_n = g(t_n)$, hence, we can calculate:

$$t_n = g^{-1}(p_n) = t_m - (t_m - t_0) \exp(-a\tau_n)$$

Therefore we can predict the time of the explosion τ_n using formula:

$$\tau_n = \frac{1}{a} \ln \frac{t_m - t_0}{t_m - t_n}, [s]$$

In this formula, a, t_m are calculated using the method of heated medium in Section 4, i.e.:

The time of explosion of vessel when heated by electricity: $\tau_n = \frac{\sum m_i c_i}{\alpha F} \ln \frac{t_{mp} - t_0}{t_{mp} - t_n}, [s]$

The time of explosion of vessel when heated by combustion products: $\tau_n = \frac{\sum m_i c_i}{\sum \alpha_i F_i} \ln \frac{t_{mk} - t_0}{t_{mk} - t_n}, [s]$

VI.3 Warning of the power of the explosion

Explosion is a process in which medium expands very fast, making the pressure of medium $p \downarrow \epsilon(p_n - p_k = 1\text{atm})$ falls rapidly, spreading material and its enthalpy ΔH energy into the environment. The time of explosion is overall stipulated under TNT is $\Delta\tau \approx 0,1\text{s}$

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Vessel containing medium with mass m , temperature t_n , when exploding it releases energy: $Q = mc_p(t_n - t_{sk})$, [MJ], with t_{sk} is the medium boiling temperature at atmospheric pressure $p_k = 1\text{atm}$
The maximum energy can be reached:

$$Q_m = mc_p(t_m - t_{sk}), \text{ [MJ]}$$

The power of the explosion is: $P \triangleq \frac{Q}{\Delta\tau}$, [MW]

The maximum power can be achieved: $P_m = \frac{Q_m}{\Delta\tau}$, [MW]

Usually we compare the power of explosion with 1 kg of TNT's energy:

$$q_{TNT} = 4,187\text{MJ/kg}; P_{TNT} = 41,87\text{MW/kg}, (1\text{kt} = 10^3\text{kgTNT})$$

VII. RECOMMENDED SAFETY SOLUTIONS FOR PRESSURE VESSELS

Conditions that medium heating vessel will not explode:

$$p(\tau) < p_n \text{ hay } t(\tau) < t_n \text{ with all values of } \tau \text{ during operation time, or } t_m < t_n$$

VII.1 The vessels with medium heated by electricity will be safe when

$$t_m = t_f + \frac{P}{\alpha F} < t_n$$

To ensure those conditions, we can do the following solutions:

1. Select or adjust the electric power to

$$P < \alpha F(t_n - t_f), \text{ [W]}$$

2. Increase t_n by increasing δ of the shell of the vessel, or make the shell with heat resistant material, which high δ_{cp} , ...

3. Increase αF by increasing the cooling condition and cooling area F

4. Not to rise temperature t_f in premises to prevent fire

5. Adjust power P to summer mode, winter mode according to the average value t_f

VII.2 The vessels with medium heated by combustion products will be safe when

$$t_m = (\alpha_1 F_1 t_{f1} + \alpha_2 F_2 t_{f2}) / (\alpha_1 F_1 + \alpha_2 F_2) < t_n$$

To achieve this inequality we can take the following solutions:

1. Control the combustion process so that the temperature of combustion products is:

$$t_{f1} < \frac{1}{\alpha_1 F_1} [t_n \sum \alpha_i F_i - \alpha_2 F_2 t_{f2}], \text{ [}^\circ\text{C]}$$

This is important because the maximum temperature:

$$t_{mc} = t_{f1}$$

2. When installing, adjust the area of contact with the combustion products F_1 , so that it is not too big

$$F_1 < \frac{1}{\alpha_1 t_{f1}} [t_n \sum \alpha_i F_i - \alpha_2 F_2 t_{f2}], \text{ [m}^2\text{]}$$

3. Increase $\alpha_2 F_2$ reasonably

4. Adjust t_{f1} and F_1 to summer or winter mode, whichever suits seasonal average temperatures t_f

5. Increase t_n by choosing proper materials and thickness δ when designing and manufacturing vessels.

Other solutions can be inferred when analyse variables of two inequalities 6.1 and 6.2 more detailedly.

VIII. THE STEPS OF CALCULATION CHECK TO PREDICT THE SAFETY OF AN ACTUAL PRESSURE VESSEL

VIII.1 Describing problem

Need to make a check of calculation of the heating process (isometric, isobaric) and explosion safety of a vessel, in which water is heated by resistor or by combustion products with specific structure and parameters as in Figure 3, and preset values given in Table 2

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Table 2: The given parameters of the problem

Details	Parameter	Symbol	Value	Note
Shell	Inner diameter	D	0,25 m	
	height of surface contacting fire	h_1	0,05 m	Height of hot cylinder
	height of other surfaces	$h_2 = h_n = h_e$	0,1 m	
	Thickness	δ	0,003 m	
Steel shell	specific weight	ρ_1	7850 kg/m ³	
	Specific heat	c_1	460 J/kg K	
	safety factor	N	2,5	rolled steel
	allowable stress	σ_{cp}	120 MPa	
	absorption coefficient	E	0,5	
Medium H ₂ O	mass	m_2	10 kg	
	isobaric specific heat	c_p	4180 J/kgK	
	initial temperature = air temperature	$t_0 = t_{f2}$	27 °C	P=1atm
	Boiling temperature of water at 1 atm	t_s	100 °C	
	Latent heat of vaporization	R	2050 kJ/kg	
Heating	power of resistor	P	2000 W	
	Temperature of combustion products	t_{r1}	600 °C	

Sealed vessel with thickness δ and parameters $\delta, \rho, n, \sigma_{cp}$, elliptical bottom, cylindrical shell with cone lid, in the lid fitted K valves, which can close or open to perform the isochoric or isobaric heating process. Cylindrical and elliptical shell is filled with water with parameters $m_2, c_p, t_0, t_s, t_b, r$, which is heated by resistor with power P or by combustion products with complex convection heat transfer coefficient α_1 through hot surface F_1 . Ambient air temperature is $t_{f2} = t_0$

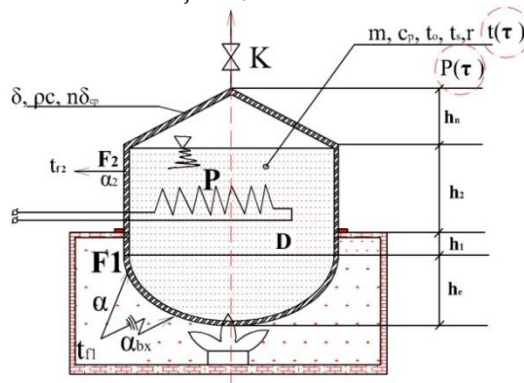


Fig. 3. Pressure water heating vessel

We should make a check of calculation of the parameters of isobaric or isochoric heating process, predict the explosion of pressure vessels and recommend safety solutions for them.

Based on the above theoretical formula, we can present the detailed calculations according to the following table:

VIII.2 Survey the isobaric and isochoric heating process

Table 3: Steps to survey heating process

Parameter	Heated by resistor P		Heated by combustion products		Explanation, Remark, Note
	Symbol, Formula	Answer	Symbol, Formula	Answer	
Conical lid area	$F_n = \pi R \sqrt{R^2 + h_n^2}$			0,0629 m ²	R= D/2
Elliptical bottom area	$F_e = \pi R^2 +$			0,0854 m ²	

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	$\frac{\pi R h_e^2}{\sqrt{R^2 - h_e^2}} \ln \frac{R + \sqrt{R^2 - h_e^2}}{h_e}$				
Calorific-to-air area	$F = F_e + \pi D(h_1 + h_2) + F_n$	0,266 m ²	$F_2 = \pi D h_2 + F_n$	0,141 m ²	Shell area is: $F = F_e + F_t + F_n$
Contacting- fire area	0	0	$F_1 = F_e + \pi D h_1$	0,125 m ²	Only when heated by CPs
Mass of vessel	$m_1 = \rho_1 \delta F$			6 kg	
Mass of vessel and water	$m = m_1 + m_2$			16 kg	
Heat capacity of system	$C = \sum_1^2 m_i c_i$			44560 J/kg	
α on combustion products	0	0	$\alpha_1 = \frac{\lambda}{D} C (GrPr)^n + \frac{\epsilon \delta_0 (t_w^4 - t_w^4)}{t_{f1} - t_w}$	$45 \frac{W}{m^2 K}$	Only available when heated by CPs
α on air	$\alpha = \frac{\lambda}{h_1 + h_2} C (GrPr)^n + \frac{\epsilon \delta_0 (t_w^4 - t_w^4)}{t_w - t_{f2}}$	$14 \frac{W}{m^2 K}$	$\alpha_2 = \frac{\lambda}{h_2} C (GrPr)^n + \frac{\epsilon \delta_0 (t_w^4 - t_w^4)}{t_w - t_{f2}}$	$16 \frac{W}{m^2 K}$	$\alpha = \alpha_{TN} + \alpha_{BX}$ because $F > F_2$
Max temp. of medium	$t_{mp} = t_r + \frac{P}{\alpha F}$	564°C	$t_{mk} = \frac{\sum \alpha_i F_i t_{fi}}{\sum \alpha_i F_i}$	436 °C	
Boiling time	$\tau_{sp} = \frac{\sum m_i c_i \ln \frac{t_{mp} - t_0}{t_{mp} - t_s}}{\alpha F}$	1748s = 0,49h	$\tau_{sk} = \frac{\sum m_i c_i \ln \frac{t_{mk} - t_0}{t_{mk} - t_s}}{\sum \alpha_i F_i}$	1112s = 0,31h	$t_s = 100^\circ C$ at p_k
Duration of water evaporation	$\Delta \tau_{cp} = \frac{mr}{P - \alpha F (t_s - t_{f2})}$	11863s = 3,3h	$\Delta \tau_{ck} = \frac{mr}{\alpha_1 F_1 (t_{f1} - t_s) - \alpha_2 F_2 (t_s - t_{f2})}$	7742s = 2,15h	
Time when water completely evaporates	$\tau_{cp} = \tau_{sp} + \Delta \tau_{cp}$	13610s = 3,8h	$\tau_{ck} = \tau_{sk} + \Delta \tau_{ck}$	8854s = 2,5h	When open valve K , isobaric process

VIII.3 Calculation check to predict pressure vessels safety

Table 4: Steps to make a check of calculation for prediction and results

Surface	Parameter	Heated by resistor P		Heated by combustion products		Note
		Symbol, formula	Answer	Symbol, Formula	Answer	
Elliptical bottom	allowed pressure	$p_{ce} = \frac{8KZ h_e \delta \delta^*}{D^2 + 2h_e \delta}$			45,6bar	
	Explosion Pressure	$p_{ne} = n p_{ce}$			114bar	
	Temp. of medium when explosion	$t_{ne} = \frac{4020}{12 - \ln p_{ne}} - 235$			320°C	
	Time of explosion	$\tau_{ne} = \frac{\sum m_i c_i \ln \frac{t_{mp} - t_0}{t_{mp} - t_{ne}}}{\alpha F}$	9439s=2,6h	$\tau_{nt} = \frac{\sum m_i c_i \ln \frac{t_{mk} - t_0}{t_{mk} - t_{ne}}}{\sum \alpha_i F_i}$	7125s=1,98h	
	Explosion energy	$Q_e = m_2 c_p (t_{ne} - t_s)$			9,2MJ	2,2 kg TNT
	Explosion Power	$P_i = \frac{Q_e}{\Delta \tau_n}$			92MW	$\Delta \tau_n = 0,1$
Cylindrical Shell	Allowed Pressure	$p_{ct} = \frac{2\delta \delta^*}{D + \delta}$			28,5bar	
	Explosive Pressure	$p_{nt} = n p_{ct}$			71bar	
	Temp. of medium when explosion	$t_{nt} = \frac{4020}{12 - \ln p_{nt}} - 235$			285°C	
	Explosive timed	$\tau_{nt} = \frac{\sum m_i c_i \ln \frac{t_{mp} - t_0}{t_{mp} - t_{nt}}}{\alpha F}$	7851s=2,2h	$\tau_{nt} = \frac{\sum m_i c_i \ln \frac{t_{mk} - t_0}{t_{mk} - t_{nt}}}{\sum \alpha_i F_i}$	5634s=1,56h	
	Explosive energy	$Q_t = m_2 c_p (t_{nt} - t_s)$			7,73 MJ	1,9 kg TNT
	Explosive Power	$P_t = \frac{Q_t}{\Delta \tau_n}$			77,3 MW	$\Delta \tau_n = 0,1$
Conical Lid	cone angle cosine	$\cos \gamma = \frac{h_n}{\sqrt{R^2 - h_n^2}}$			0,62	$R = D/2$
	Allowed Pressure	$p_{cn} = \frac{2k\delta \delta^* \cos \gamma}{D + \delta}$			17,6bar	$k=1$
	Explosive Pressure	$p_{nn} = n p_{cn}$			44bar	p_{nn} min, vessel will explode at
	Temp. of medium when	$t_{nn} = \frac{4020}{12 - \ln p_{nn}} - 235$			254°C	

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explosion					conical lid
Explosive timed	$\tau_{nn} = \frac{\sum m_i c_i}{\alpha F} \ln \frac{t_{mp} - t_0}{t_{mp} - t_{nn}}$	6574s=1,8h	$\tau_{nk} = \frac{\sum m_i c_i}{\sum \alpha_i F_i} \ln \frac{t_{mk} - t_0}{t_{mk} - t_{nn}}$	4578s=1,27h	
Explosive energy	$Q_n = m_2 C_p (t_{nn} - t_0)$			6,44 MJ	1,5 kg TNT
Explosive Power	$P_n = \frac{Q_n}{\Delta \tau_n}$			64,4 MW	$\Delta \tau_n = 0,1$
Max Explosive Power	$P_{mp} = \frac{Q_{mp}}{\Delta \tau_n}$	194 MW	$P_{mk} = \frac{Q_{mk}}{\Delta \tau_n}$	140 MW	

VIII.4 Safety limitations of parameters

According to the formula showed in paragraph 6, we can calculate safety limitations of parameters of vessel:

Parameter	Heated by resistor P		Heated by combustion products		Note
	Symbol, formula	Answer	Symbol, formula	Answer	
Safety P in summer	$P_{ah} < \alpha F (t_{nn} - t_{fh})$	816 W	0		$t_{fh} = 35 \text{ }^\circ\text{C}$
Safety P in winter	$P_{ad} < \alpha F (t_{nn} - t_{fd})$	853 W	0		
Temp. of CPs in summer		0	$t_{r1} < [t_{nn} \sum \alpha_i F_i - \alpha_2 F_2 t_{fh}] / (\alpha_1 F_1)$	342 °C	$t_{fd} = 25 \text{ }^\circ\text{C}$
Temp. of CPs in winter		0	$t_{r1} < [t_{nn} \sum \alpha_i F_i - \alpha_2 F_2 t_{fd}] / (\alpha_1 F_1)$	346 °C	
Fire-contacting area		0	$F_1 < \frac{\alpha_2 F (t_n - t_{f2})}{\alpha_1 (t_{r1} - t_n) + \alpha_2 (t_n - t_{f2})}$	0,05 m ²	$F_{1AT} = 0,4 F_{ik}$

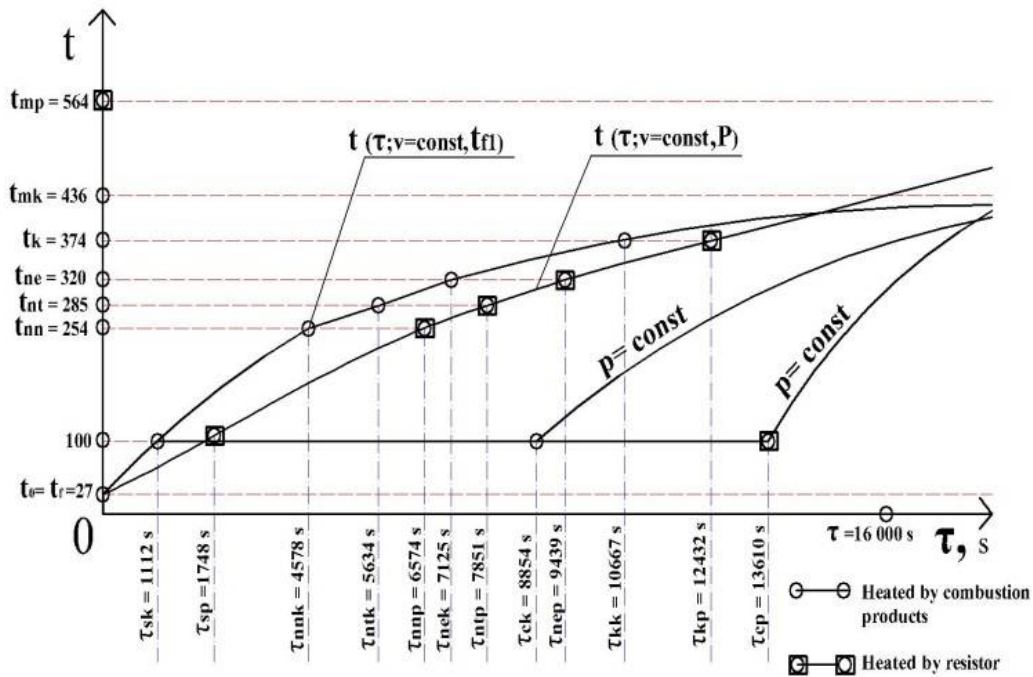


Fig. 4. Graph $t(\tau)$ of water when isobarically or isochorically heated by resistor or combustion products

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IX. CONCLUSIONS

The increasing temperature and pressure of medium functions are derived directly from the derivative heat balance equation of system (medium and shell), with reasonable assumptions so they will have enough accuracy in calculation and design if dependent parameters are determined accurately enough.

The parameters when the vessel explodes are determined by strength of materials and functions $t(\tau)$, $p(\tau)$ above, should be accurate enough to be able to make a reference to forecast explosion of vessel.

The safety solutions derived from the quantitative expression of the safety conditions is $t(\tau) < t_n$, after changing the variables of $t(\tau)$ và t_n ; we can infer safety solutions. The main solutions are outlined in article 7. Specific solutions can be inferred when analyzing the consequence expressions of the above-mentioned safety conditions.

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