

Modern Techniques in the Direction of the Global Heat Treatments Applied to Largest Devices

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The paper includes aspects specific to the design and the direction of the global heat treatments (GHT) applied to the largest static devices. There are studied the combustion processes specific to the GHT in the variant of heating with flame inside the largest structure. The elaborated calculus algorithm is finalized under the form of combustion diagram and is the base of the recommendations concerning the correct combustion leading, specific to the periods of heating and maintenance of the device to the temperature of heat treatment. Also, there are presented the principles, the conditions and the working algorithms of which application assure optimal conditions from the technological and economic point of view for the direction of the stress relaxation heat treatment applied to a largest device in welded structure.

Keywords: global heat treatments, combustion processes, combustion diagram, welded structure, residual tensions, optimization

The largest equipment used in the chemical and petrochemical industry are made at the site. The great number of welded joints which supposes their realization leads to the development of some important tension states that claims the application of a stress relaxation heat treatment before the tank starting. The heat treatment consists in the heating of the device with a certain temperature gradient till the maximal recommended temperature, the maintenance for a while to this temperature and then the cooling with a certain dropping temperature.

The necessary heat flux and the treatment temperature having relatively high values, the heating is made with gas combustion, thus consuming the gaseous fuel (rarely liquid fuel). The gas combustion may be made in an exterior furnace of the device (the circulation of the combustion gases is realized inside or outside of the device) or, even frequently, inside the equipment. The equipment is foreseen with sight hole in the superior part and the internal one also, thus the circulation of the combustion gases may be descendent, ascendant or mixed and the draft may be forced (the air is introduced with a ventilator) or, eventually, by natural circulation.

Regardless of the heating process used, in order to realize a global heat treatment work of a device, there are taken some special measures:

- the device is isolated in the exterior with mineral wadding. The thickness of the provisory isolation is of 160 ... 180 mm;

- the support legs of the device are leaning on roles in order to allow the free removal as a result of dilatation, avoiding the appearance of some unwished efforts in the jacket; the legs removal during the treatment is carefully watched with the help of certain special indicators;

- by surveillance, control and registration of the treatment operation on the external surface of the device's jacket, there is foreseen a number of temperature measure points (thermocouple) attached to the registration devices;

- the heating and cooling speeds are limited, they do not have to be more than 60...80 °C/h (the cooling is made practically in a free way by closing all the outlets); the

maintaining duration on the connection is of about 2 min/mm thickness of the jacket; the temperature departure between the extreme temperatures of the jacket has to be maintained in the interval 40 ... 60°C; the connection temperature is previously established to a value in the interval 560 ... 600°C depending on the material and on the dimensional factors.

Study of the GHT specific combustion processes in the variant of direct heating with flame inside the spherical tank; heat treatment diagrams

The practice proved that an efficient control of the parameters of the heat treatment may be realized by the correct direction of the combustion processes. Then, it is presented a calculus algorithm of the GHT specific combustion processes (heating and maintenance to treatment temperatures) applied to the largest devices.

The heat loss from the exterior of the isolating layer to the environment is made by convection and radiation. The heat flux transferred from the external surface of the isolation to the environment is (Newton's Law):

$$Q = (\alpha_c + \alpha_r) \cdot A \cdot (t_{iz} - t_a) \text{ [W]} \quad (1)$$

where: A represents the internal area of the device, in m^2 (to very high and thick layers of steel and very small mineral wadding layers, the metal wall may be assimilated with a plan wall).

α_c represents the coefficient of heat transfer by convection

$$\alpha_c = \left(1,73 - 0,0043 \cdot \frac{t_{iz} + t_a}{2} \right) \cdot (t_{iz} - t_a)^{\frac{1}{3}} \text{ [W/m}^2 \cdot \text{°C]} \quad (2)$$

In the relation 2 t_{iz} represents the temperature of the isolating wall to the exterior, in °C; t_a - atmospheric temperature (20 °C); t_0 - tank's (steel's) temperature, in °C; Q - transfer heat flux (fig. 1), in W; s - thickness of the metal wall, in m; s_{iz} - thickness of the isolating layer, in m. α_r represents the coefficient of heat transfer by radiation

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$$\alpha_r = \frac{5,67 \cdot e}{t_{iz} - t_a} \cdot \left[\left(\frac{t_{iz} + 273}{100} \right)^4 - \left(\frac{t_a + 273}{100} \right)^4 \right] \quad [W/m^2 \cdot ^\circ C] \quad (3)$$

where e represents the emission coefficient for the mineral wadding ($e = 0.8$).

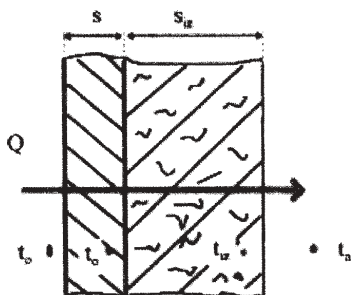


Fig. 1. Heat transfer to the environment scheme

In the stationary regime (or pseudo-stationary, when it is working in average conditions) Q represents also the heat transfer transmitted by conduction in the mineral wadding layer (Fourier's Law):

$$Q = \frac{\lambda_{iz}}{s_{iz}} \cdot A \cdot (t_0 - t_{iz}) [W] \quad (4)$$

where λ_{iz} represents the average heat conductivity for the mineral wadding, in $W/m^\circ C$.

The heat necessary to the heating of the steel wall with a temperature gradient Δt_0 is established with the following relation:

$$Q_0 = m_0 \cdot c_0 \cdot \Delta t_0 \quad [kJ] \quad (5)$$

where: m_0 is the steel mass that has to be heated

$$m_0 = A \cdot s \cdot \rho_0 \quad [kg] \quad (6)$$

ρ_0 represents the steel density; $\rho_0 = 7850 \text{ kg/m}^3$.

The heat necessary to the heating of the isolating layer with a temperature gradient Δt_{iz} is determined with the relation:

$$Q_{iz} = m_{iz} \cdot c_{iz} \cdot (\Delta t_{iz})^1 \quad [kJ] \quad (7)$$

where: m_{iz} is the mass of the mineral wadding

$$m_{iz} = A \cdot s_{iz} \cdot \rho_{iz} \quad [kg] \quad (8)$$

ρ_{iz} represents the isolation density; $\rho_{iz} = 185 \text{ kg/m}^3$

$$(\Delta t_{iz})^1 = (t_{iz} + t_0) / 2, \text{ in } ^\circ C.$$

In the relations (5) and (7) c_0 and c_{iz} represent the average specific heats for the steel respectively for the isolation ($c_0 = 0.5 \text{ kJ/kg}^\circ C$; $c_{iz} = 0.8 \text{ kJ/kg}^\circ C$).

The heat flux absorbed from the burned gases in the time interval τ is:

$$Q_a = \frac{Q_0 + Q_{iz}}{t} + 3,6 \cdot Q \quad [kJ/hour] \quad (9)$$

Application

There is considered the case of a spherical tank having the capacity of 1000 m^3 , interior diameter $D_i = 12400 \text{ mm}$; thickness of the jacket $s = 40 \text{ mm}$. The tank's jacket (made by steel P255GL) is submitted to a stress relaxation GHT according to the diagram from the figure 2. The tank is

isolated to the exterior with a mineral wadding layer having the thickness of 180 mm .

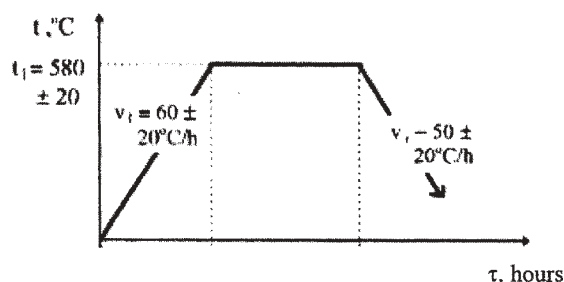


Fig. 2. Diagram of GHT applied to the spherical tank

There is admitted as combustible the methane that burns completely with 20% air excess, the combustible and the air having the temperature of $20^\circ C$ and the methane having the inferior caloric power 50.000 kJ/kg . By calculus there are obtained the following results:

- the molar total quantity of combustion gases $n_{ga} = 0.7768 \text{ kmol/kg comb.}$;

- the temperature of the flame $t_{fl} = 1800^\circ C$;

- the specific isobar and molar heat of the combustion gases, average in the interval of the operation temperatures $C_{p,ga} = 32 \text{ kJ/kmol } ^\circ C$;

- the average molar mass of the of the combustion gases $M_{ga} = 29 \text{ kg/kmol}$.

There is considered that the average temperature of the burned gases evacuation is with $150^\circ C$ bigger than the average temperature of the steel wall. By cooling from the flame temperature till the evacuation temperature, the combustion gases yield the following heat quantity:

$$q = n_{ga} \cdot C_{p,ga} \cdot \Delta t_{ga} \quad [kJ/kg \text{ comb.}] \quad (10)$$

Using the data previously presented there is determined the debit of the combustible necessary during the heating of the tank (relation 11).

$$B = \frac{22,4 \cdot Q_a}{16 \cdot q} \quad [N \cdot m^3/hour] \quad (11)$$

During the maintenance of the treatment temperature (1.5 h to the temperature of $580^\circ C$), $Q_0 = Q_{iz} = 0$.

The debit of the combustible necessary to the maintenance of the treatment temperature to the value of $580^\circ C$ is established with the relation:

$$B = \frac{22,4 \cdot 3,6 \cdot Q}{16 \cdot q} \quad [N \cdot m^3/hour] \quad (12)$$

where, the values of the dimensions Q , q are established applying the known relations (9 and 10) and $t_0 = 580^\circ C$.

With the help of a calculus program conceived by the authors (fig. 3) there was made the variation diagram of the combustible debit in time for the global stress relaxation heat treatment applied to the considered tank (fig. 4).

Aspects concerning the calculus of the combustible consumption to the GHT application

Starting from the relations (11) and (12) it may be established, depending on the heat treatment parameters, the mass of combustible necessary to the heating and to the maintaining of the device's jacket to the treatment temperature. Using an appropriate computer program (conceived by the authors of the paper), the results may be presented under a graphical form (fig. 5).

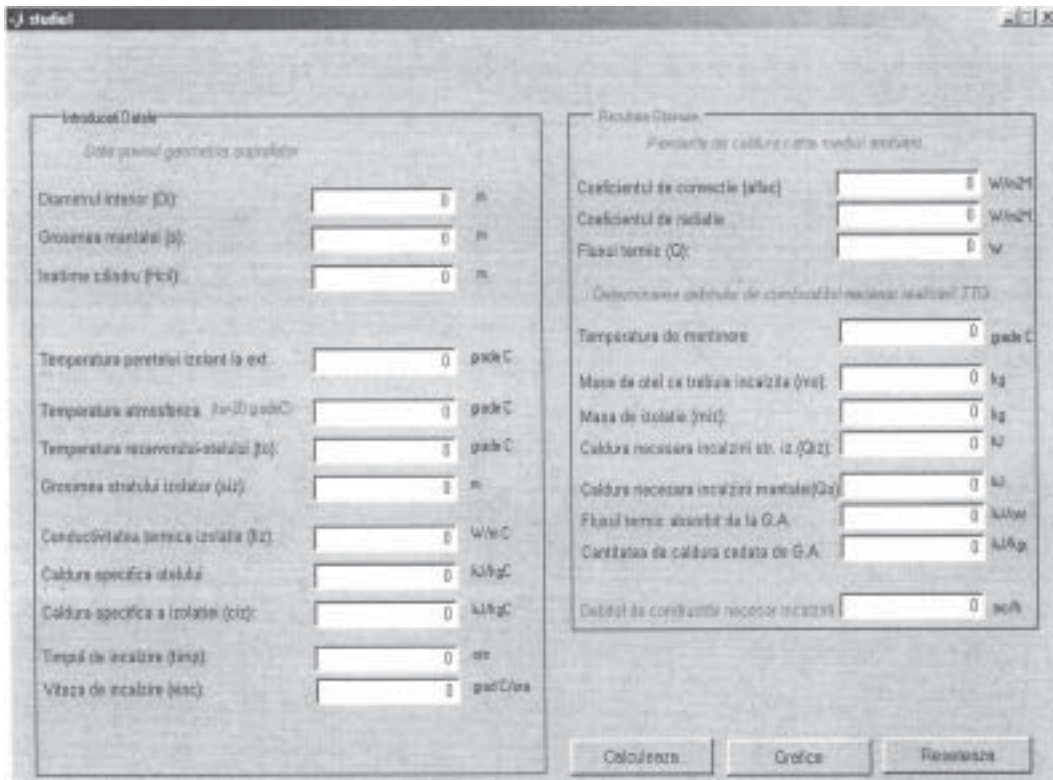


Fig. 3. Dialog window for GHT monitoring program

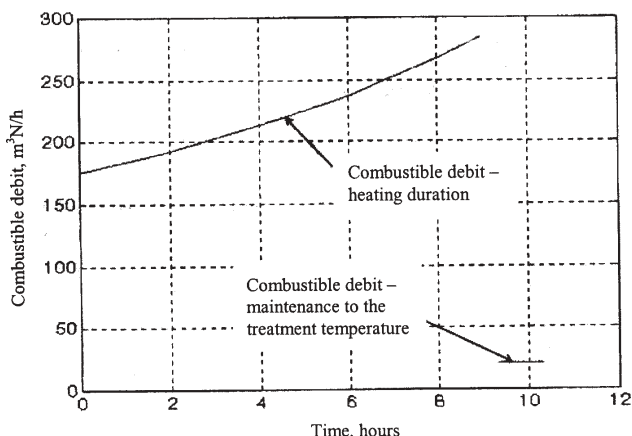


Fig. 4. Establishing of the combustable debit necessary to the heating of the spherical tank for stress relaxation

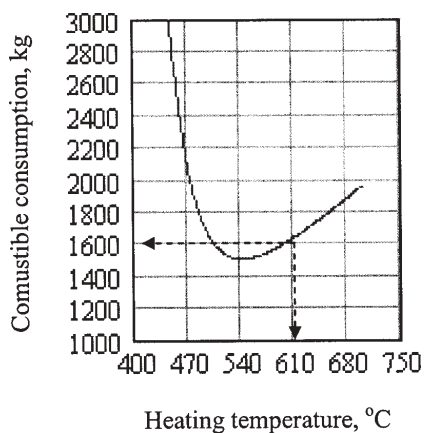


Fig. 5. Combustible consumption necessary to GHT (according to a relaxation degree of the residual tensions RD = 75%)

The choice (the opportunity to choose) of the safe regimes of heat stress relaxation

The heat stress relaxation process of a welded structure assures a certain relaxation degree of residual tensions (RD), according to the pair (t_r, τ_m) that represents the

SRC for RD = 75 %

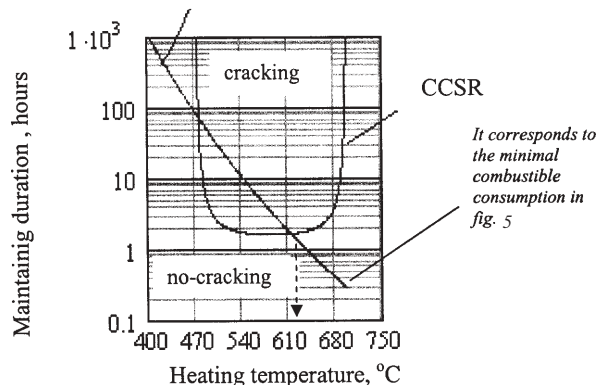


Fig. 6. Diagram of the safe heat stress relaxation for a welded construction from steel P 255GL (for GR = 75%)

coordinates of one of the points of the equi - stress relaxation curve (SRC) having the parameter RD to an wished level [5] (fig. 6).

The safe heat stress relaxation regimes of a welded structure (for which there is no danger to appear cracks in the heat influenced zone of the welded joints) have the parameters (t_r, τ_m) according to the coordinates of the points situated in the exterior of the cracking curve characteristic to the stress relaxation (CCSR) of the material structure [5] (fig. 6).

Optimization of the GHT applied to the largest equipments

For a metal structure type device made from certain steel, submitted to a stress relaxation GHT, there may be established, using the graphical representations as those from the figures 5 and 6, the optimal treatment variants from the economic point of view, thus:

- from the figure 6 it is identified for a certain value RD the safe domain of heat stress relaxation;
- according to the value pairs (t_r, τ_m) identified in the diagram from figure 6 it is chosen from figure 5 the

economical stress relaxation regime (it supposes a minimal combustible consumption).

In the previously presented example it was considered that the jacket's tank is submitted to a stress relaxation GHT in the conditions where it is wished the internal stress relaxation tensions according to a value $GR = 75\%$.

As a result of the analysis of the possible variants concerning the GHT regimes it was established that the economical optimal variant is characterized by the parameters $t_1 = 620^\circ\text{C}$, $\tau_m = 1,2 \text{ h}$.

Conclusions

The heat treatments constitute the most usual method of reducing internal tensions from the spherical tanks body. The most used variant of treatments for the stress relaxation of the spherical tanks consists in the heating of the recipient directly with flame in the interior.

Analyzing the previous graphic representations, it may be observed as it was expected that the debit of the combustible necessary to do *GHT* has to increase in time, according to the tank heating, the curve having a concavity downwards; during the stationary regime the combustible debit decreases considerably.

The kind of the diagram previously presented together with the calculus programs that were used to do it may constitute a useful instrument in the correct direction of the combustion to the global heat treatment of the spherical tanks.

Thus, on the basis of an attentive control of the combustible debit (according to the diagram fig. 4) there may be assured the wished parameters in different stages of the stress relaxation treatment application (heating to treatment temperature and maintenance to this temperature).

Also, in the paper there are presented the principles, the conditions and the working algorithms of which application assure optimal conditions from the

technological and economic point of view for the direction of the stress relaxation heat treatment applied to the a largest device in welded structure.

From the technical point of view, analyzing the situations as those presented in the figures 5 and 6 it is found out the existence of two possibilities of heat stress relaxation:

-the heating to a low temperature and the maintaining for a long period of time,

-the heating to a higher temperature and the maintaining to this temperature a shorter period of time.

In most cases it proves to be economical the second one to whom it corresponds a minimal combustible consumption.

Such graphical representations may constitute useful instruments for the correct direction of GHT.

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