Effect of temperature on the thermal behaviour of concrete and steel storage tanks

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Abstract. In this article, we first studied the behaviour of concrete and steel subjected to high temperatures in order to carefully select the characteristics and components of the construction material for storage tanks. To determine the temperature distribution within the storage tanks, we solved the differential equations of conduction using the finite difference method to obtain the temperature value at each point of the studied storage tank. Next, we conducted numerical simulations that allowed us to represent the temperature field distribution on the surfaces of the cylindrical tank and the variation of temperature over time. Based on this study, we were able to determine the sensitivity of Thickness the material selection and the shape of storage tanks in calculating the temperature gradient.

Keywords: concrete, steel, storage, tank, temperature

1 Introduction

The increase in the world demand for water is imperative, in particular due to the demographic growth of the countries, which has pushed the human being to build storage reservoirs, which can meet needs more precisely at high temperature, which require more special care, which we have found for a long time.

Many materials scientists are studying the physical and chemical properties of concrete [1] for proposing a type of concrete that has significant strength and insulation for building high temperature storage tanks.

In the literature[2], there are several formulations of concretes which are dependent on the percentages and the components constituting each type of concrete[3], so there are several types of tanks according to the types of wall: flat walls (rectangular) and circular walls and/or depending on the material for which it was built.

In this context, this article also discusses the thermal behavior of the B30 concrete storage tank[4] by applying the finite difference method to know the effect of temperature increase.

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For a better presentation of the results and the different characteristics of this material, our article is organized as follows: the mathematical modelling, the thermo mechanical behaviour relation and the numerical resolution of the differential equations by the finite difference method are described in Section 1. Section 2 reveals an application and treatment of the results of four high-temperature storage tanks. Discussions on the obtained results are presented in section 3, finally a conclusion will be presented in the last section.

2 Mathematical modelling

2.1 Differential equation of conduction

Modeling assumptions
Heat transfer by conduction is one-dimensional[5].
The characteristic physical quantities are constant
The concrete structure is assumed to be composite.
Equation of thermal conduction in cylindrical coordinates

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \left( \frac{\partial T}{\partial r} \right) + \frac{1}{r^2} \left( \frac{\partial^2 T}{\partial \varphi^2} \right) + \frac{\partial^2 T}{\partial z^2} + \frac{\partial T}{\partial t} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$  \(1\)

$$T = T(r, \varphi, z, t);$$
Where r is radial dimension, \(\varphi\) is phase angle, z is dimension, t is the time and \(\alpha\) is thermal diffusion m²/s.
We assumed that the temperature does not vary significance in the direction \(\varphi\) and z with respect to the radial direction.
Hence equation (1) reduces to the following form with \(g = 0\)

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \left( \frac{\partial T}{\partial r} \right) = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$  \(2\)

$$\left( \frac{\partial T}{\partial r} \right) = \alpha \left[ \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \left( \frac{\partial T}{\partial r} \right) \right]$$  \(3\)

Initial conditions : \(T(r, t=0) = T_{in}\);
Boundary conditions : at \(r=ri\), \(T_{in}\) and at \(r=ro\) we have \(T=Trout\)

2.2 Numerical resolution of partial differential equations by the finite difference method

By applying the finite difference method[6] to solve equation (3), we obtained the temperature value of each reservoir point.
We have replaced both first-order and second-order space derivatives with centered difference approximations and the time derivative.
Hence, equation (3) becomes:

$$\frac{T_{i+1} - T_{i}}{\Delta t} = \alpha \left( \frac{T_{i+1} - 2T_{i} + T_{i-1}}{\Delta r^2} + \frac{1}{r_i} \left( \frac{T_{i+1} - T_{i-1}}{2\Delta r} \right) \right)$$  \(4\)

$$T_{i+1} - T_{i} = \left( \frac{\alpha \Delta t}{\Delta r^2} \right) \left( T_{i+1} - 2T_{i} + T_{i-1} \right) + \left( \frac{\alpha \Delta t}{2r_i \Delta r} \right) \left( T_{i+1} - T_{i-1} \right)$$  \(5\)

$$d = \frac{\alpha \Delta t}{\Delta r^2} \quad et \quad dI = \frac{\alpha \Delta t}{2r_i \Delta r}$$

$$T_{i+1} = T_{i} + \left( d \left( T_{i+1} - 2T_{i} + T_{i-1} \right) + \frac{\partial T}{\partial r} \left( T_{i+1} - T_{i-1} \right) \right)$$  \(6\)
Equation (6) is the finite difference approximation of the conduction equation with:
i represents the location of the next node “r” and j is the time step on the discretized domain
The finite difference stencil is given below.

From this method of space centered ahead of time, we found the temperature at future times (j+1) directly if we already know the current times as shown in equation (6).

**Fig1.** The finite difference.

### 3 Application

We compared the temperature distribution of two cylindrical storage tanks of different thicknesses, which are constructed by steel and concrete. It is a concrete, with CPJ CEM II/A 42.5 cement, from the formulation that was determined by the Skramtaïve method [7].
The characteristics of the concrete and the steel studied is represented in the following table:

**Table 1.** The characteristics of concrete and steel [8].

<table>
<thead>
<tr>
<th></th>
<th>Cellular concrete</th>
<th>steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volumic mass (Kg/m³)</strong></td>
<td>2300</td>
<td>7850</td>
</tr>
<tr>
<td><strong>thermal capacity (J/Kg°K)</strong></td>
<td>880</td>
<td>0.46</td>
</tr>
<tr>
<td><strong>thermal conductivity (W/m.K)</strong></td>
<td>1.8</td>
<td>13.4</td>
</tr>
</tbody>
</table>

We applied the temperature inside the tank T_{int}=1000°K and the temperature outside the lower base of the tank T_{ext}= 300°K. We seek to solve the present system of equations using the finite difference method.

After choosing the material, we chose the tank, which characterized as follows: (fig2)
Outside diameter = 2000mm
Height = 4000mm
Thickness1 = 20cm
Thickness2 = 20mm
The results of numerical simulations allowed us to represent the distribution of the temperature field in Kelvin on the surfaces (see figure 3 and 4).

In the concrete tank, which has a thickness of 20cm, we noticed that the distributed temperature interval is between minimum of 197°K and maximum of $2.87 \times 10^5$°K. Unlike, the tank that has a thickness of 20mm, we found that the temperature varies between 270°K and $2.21 \times 10^5$°K. (fig3).
In the steel tank, that has a thickness of 20cm, we noticed that the distributed temperature interval is between minimum of 299°K and maximum of $3.3 \times 10^3$°K. Unlike, the tank that has a thickness of 20mm, we found that the temperature varies between 296°K and $3 \times 10^4$°K (fig4).

To present the profiles of the temperature as a function of time of both the outer and inner radius.

**Fig 4. Temperature distribution Steel**

**Fig5. Temperature function time.**

**5 Conclusions**

The temperature is the most important parameter for studying and characterizing thermal storage tanks. In this article, we presented a heat transfer modelling in a cylindrical tank.
The results of the numerical calculations allowed us to demonstrate the sensitivity of material selection and the shape of storage tanks. According to the numerical simulation, we found that the temperature gradient in cylindrical storage tanks is more significant. The value of the thickness of the material used to construct the tank had influences on the temperature distribution in the storage tanks subjected to high temperatures.

The prospects of this work are to seek the thicknesses of the storage tanks suitable for each material so that the tank resists large changes in temperature and pressure.

References.


[6] « Attipoe et Tambue - 2021 - Convergence of the mimetic finite difference and f ».
