International Journal of Engineering, Mathematical and Physical Sciences
ISSN: 2517-9934
Vol:7, No:9, 2013

Study of Thermal Effects while Filling an Empty Tank

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***Abstract*—We are interested in this paper to the thermal effects occurring during the filling of hydrogen tanks. The consequence of this heating on the storage performance of these speakers was appreciated. The motivation comes from the fact that the development of hydrogen as an energy carrier of the future will require strong evolution in the field of storage modes to smaller, less expensive lighter, with a strong security interest and considerable autonomy.

***Keywords*—Hydrogen, Fuel, Storage, Energy, Modeling, Simulation.

I. Introduction

HYDROGEN is the fuel of the future from the perspective of the evolution of human energy needs. Indeed it is the cleanest fuel, its combustion produces only water, has a calorific value three times than oil [9], [5]. However there is no natural state.

One of the major problems in the use of hydrogen as an energy carrier is its storage, warming during dynamic filling: a real problem for the storage thereof.

Thermal effects occurring during the dynamic phase of loading, using a fixed reservoir porous adsorbent bed can have two origins [8]:

- Lift: with the dissipation of the kinetic energy of the gases entering the reservoir and the conversion into heat of the work forces can power the pressure tank.
- Physicochemical: with the adsorption process by exotherm leads to a temperature increase.

The objective of this work is the study of overheating occurring during dynamic loading with hydrogen of an empty tank.

II. Macroscopic Analysis of Phenomena Heat When Filling An Empty Tank [10], [3]

Filling a reservoir with a gas causes the overall heating of the gas in the tank. Initially, the gas flows with a supply internal diameter of 1/16" in a tank with an internal tube diameter of 96mm.

This sudden enlargement of the flow sections on one side lead to a variation in pressure of downstream gas of the opening and a second heating of the same gas by dissipation of mechanical energy.

Another contribution to global warming comes from the conversion of heat into compression force work due to non-stationary nature of the filling. Fig. 1 shows the effects of a sudden change in the flow area of the gas.

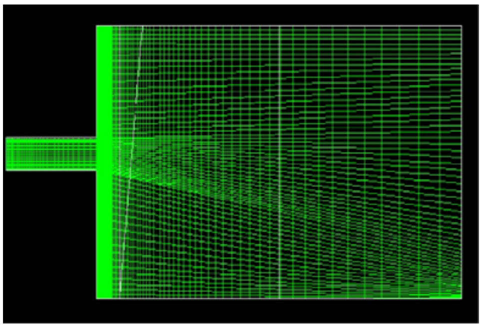

Fig. 1 Mesh of a sudden enlargement

The heat from a sudden change in flow area can be approximated by macroscopic balances of mass, momentum and energy at the expansion [1], [4].

Our goal is to estimate the above heating due to the sudden enlargement of flow for a given input. This mainly depends on the heating rate and the local structure of the flow at the enlargement. The values of the heat obtained in the case of an open and stationary system tell us about the order of magnitude of this heating.

We are interested in radially averaged quantities on the input plane (upstream) and a plane downstream the enlargement (downstream).

III. Formulation of the Problem

We developed the equations treated under Fluent software to implement our approach to the treatment of thermal effects in the reservoir [6], [2].

A. Continuity Equation: (Mass Balance Equation)

The general form of this equation is:

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \times (\rho\, \vec{V}) = 0 \tag{1}$$

The velocity field is written:

$$\vec{V} \quad \begin{cases} u \neq 0 \\ v = 0 \\ w = 0 \end{cases} \tag{2}$$

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We will apply the condition of incompressible fluid using the continuity equation, we find:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z} = 0 \qquad \Rightarrow \qquad \frac{\partial u}{\partial x} = 0 \tag{3}$$

As (u) does not depend on (x) and it depends on (y,z,t), it is written as follows:

$$u = u(y,z,t)$$

In the case of two-dimensional geometry, (v) is function of (y,t), therefore:

$$v = v(y,t)$$

B. Navier-Stokes Equations (Balance Equation of Momentum)

The general form is:

$$\frac{\partial(\rho\vec{V})}{\partial t}+\vec{\nabla}\times(\rho\vec{V}\times\vec{V}) = -\vec{\nabla}p+\vec{\nabla}\bar{\bar{\tau}}+\rho\vec{f} \tag{4}$$

$\bar{\bar{\tau}}$ Representing the viscous stress tensor

$\vec{f}$ Representing the mass forces

C. Cartesian Coordinates

$$\begin{cases} \rho\times\dfrac{\partial u}{\partial t} = -\dfrac{\partial p}{\partial x}+\mu\times\left(\dfrac{\partial^2 u}{\partial y^2}\right) & (Ox) \\ -\dfrac{\partial p}{\partial y} = 0 & (Oy) \\ -\dfrac{\partial p}{\partial z} = 0 & (Oz) \end{cases} \tag{5}$$

IV. Flow Regime

A. Steady Flow

$$\begin{cases} -\dfrac{\partial p}{\partial x}+\mu\left(\dfrac{\partial^2 u}{\partial y^2}\right) = 0 \\ y = \pm 2.5 \end{cases} \tag{6}$$

$$\frac{\partial^2 u}{\partial y^2} = \frac{1}{\mu}\frac{\partial p}{\partial x} \quad \Rightarrow \quad u(y,z) = \frac{1}{2\mu}\frac{\partial p}{\partial x}\times(b^2-y^2)$$

B. Unsteady Flow

$$\rho\times\frac{\partial u}{\partial t}+\frac{\partial u}{\partial t}-\mu\left(\frac{\partial^2 u}{\partial y^2}\right) = 0 \tag{7}$$

With the boundary conditions: $V_0 = 10^{-2}$ m/s and $T_{mur} = 298$ K

$$\rho_{amont}\, V_{amont}\, S_1 = \rho_{aval}\, V_{aval}\, S_2$$

The balance of momentum is written on the axis (ox)

$$\begin{aligned} &\rho_{amont}\, V_{amont} \times V_{amont} \times S_1 + P_{amont}\times S_1 + F \\ &= \rho_{aval}\, V_{aval}\times V_{aval}\times S_2 + P_{aval}\times S_1 \end{aligned} \tag{8}$$

The term describes the force exerted by the walls on the gas in the flow direction; it has two terms [7]:

– Viscous force to the cylindrical walls parallel to the direction of the flow
– A pressing force of the surface of area ($S_2 - S_1$) (the re-circulation of the fluid).

The first contribution can be neglected compared to the second. Thus, the force is a pressure force which is written as:

$$F = P_1(S_2 - S_1) \tag{9}$$

If α is the area ratio and it is assumed that the density of the fluid is substantially constant in the reservoir, the following expression is obtained for the difference pressure:

$$\begin{aligned} P_{aval} - P_{amont} &= \frac{Q_m\times V_{aval}}{S_2^2}\times\left(\frac{1}{\sigma^2}-1\right) \\ &= \frac{Q_m^2}{\rho_{aval}\times S_2^3}\times\left(\frac{1}{\sigma^2}-1\right) \qquad \delta = \left(\frac{S_1}{S_2}\right) \end{aligned}$$

In the case of hydrogen, the pressure variation is very low and the system can be considered isobaric every moment [11].

V. Simulation

We used the Fluent [6] commercial software to simulate numerically, the heating takes place at the expense of a tank. Decoupled resolution allows access to multiple physical models, we chose this method for:

– physical formulation of the speed in the case of porous media,
– pressure which enables us to impose a flow entering the tank.

The simulation of filling a vacuum chamber requires taking into account the small size of the input section of the tank.

A. Results

The results obtained from simulations are presented. Fig. 2 shows the evolution of the dynamic pressure as a function of the position in an adiabatic, filling the empty room with hydrogen, with Q_m = 10-4 kg/s [7], [8].

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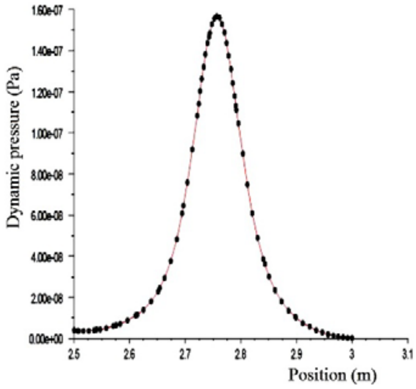

Fig. 2 Distribution of the dynamic pressure according to the position

The pressure distribution is constant as the pressure is low at two ends of the tank. This pressure has reached its limits in the middle of the tank. The velocity distribution in the tank according to the position is shown in Figs. 2 and 3. We note that the speeds are low at the beginning of the filling.

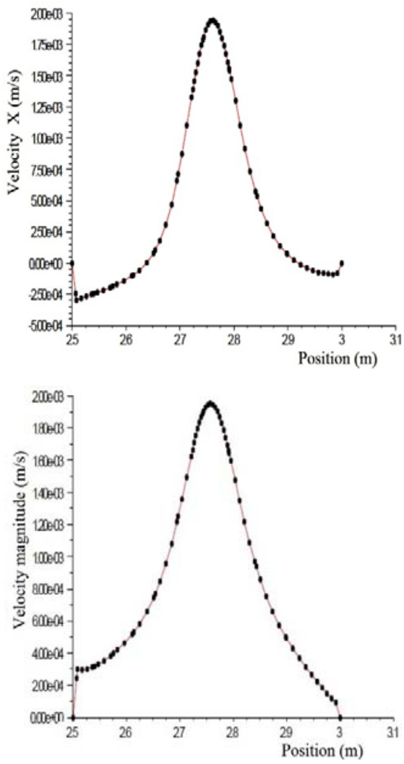

Fig. 3 Simulation speed V_x depending on the position

We also note that the hottest area in the tank is not located in the center of the tank (Fig. 4), but is offset toward the bottom of the tank. This shift is due to the convective cooling effect of fresh gas entering.

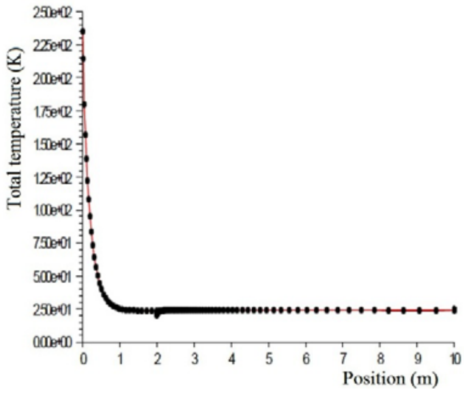

Fig. 4 Evolution of the wall temperature as a function of the position

Fig. 5 shows the profiles of the distribution of reduced temperature at the center of the tank; we found that the temperature increases. This proves a larger low wall temperature on heating.

Fig. 6 shows the pressure distribution in the reservoir according to the positions. We note that the pressure is low at both ends of the reservoir (fixed to 0 Pa.). This pressure reached its limits in the middle of the tank.

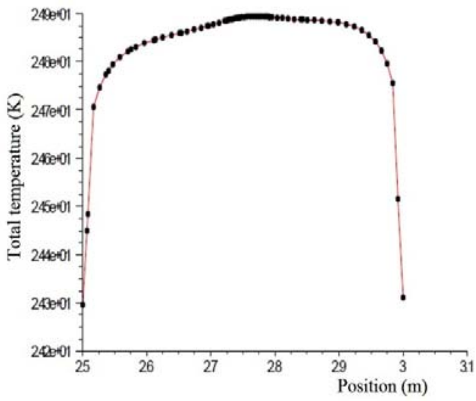

Fig. 5 Simulation of the total temperature in line $x = 2.5$ $y = 2.5$ depending on the position

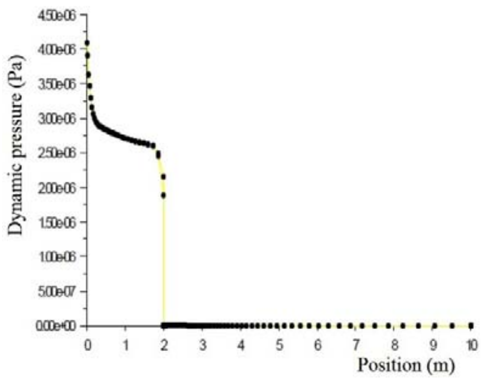

Fig. 6 Simulation pressure the wall according to the position

IV. Conclusion

The analysis in this paper has highlighted the magnitude of the thermal effect when filling an empty tank. The study of this heating was examined using Fluent [6] software.

In different simulations, we found that the temperature increases throughout the filling phase and when the flow becomes zero, the temperature decreases.

Concerning the speed distribution in the reservoir, it is low at the beginning of filling. Concerning the pressure, it is very small at both ends of the reservoir and the maximum center thereof.

This work opens several perspectives on the study of thermal effects during filling an enclosure, a study of the influence of geometry and material of the reservoir could be made on thermal effects.

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