Determination of a Set of Admissible Parameters in Designing of LPG Storage Tanks Considering a Required Safety Factor

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Abstract: *In this study a method to determine a set of admissible parameters in designing of a three-dimensional (3D) hexagonal toroid with regular hexagonal cross-section used in manufacturing of LPG storage tanks from the automotive industry was proposed. A design methodology was applied to determine the safety factor (SF) values according to manufacturing objectives. The numerical simulations of a 3D model with parametric features (created in AutoCAD Autodesk 2017 software, and then analyzed with SolidWorks 2017 software) was applied in correlation with computation of confidence intervals of the safety factor. The proposed flexible numerical simulation framework offer an efficient workflows for integration of data and software packages for coupled process simulations to demonstrate its capabilities. Numerical results were stored in structured data formats to allow for an integrated 3D visualization and result interpretation. Results have shown that the proposed method is useful in CAD design of LPG storage tanks from the automotive industry.*

Keywords: *3D hexagonal toroidal LPG fuel tank, automotive industry, industrial engineering design, optimization methods, safety factor*

1. Introduction

The automobile market in the world of 2018 offers more buying options than in previous years, meaning different styles, sizes, quality and luxury levels or performance. Automotive market is set to grow due to expansion of vehicle production, changing lifestyle, increases in living standard, rising disposable income, rapid urbanization, and favorable government initiatives.

Automotive fuel tanks are used in passenger cars, light commercial vehicles and heavy commercial vehicles. Continuous investments in fuel tank market for the development of efficient, cost effective, with a high shelf life product by various manufacturers are expected to create immense market potential over the upcoming years. In addition, increasing sale of electric vehicles along with rising investments in hybrid vehicles is expected to open new growth avenues.

The current automotive fuel tank market is segmented, based on the capacity of fuel tank, into less than 45 L, 45 L – 75 L, and greater than 75 L. In addition, there is a high demand for automotive fuel tank of 45 L – 75 L due to rise in demand for multi-utility vehicles and sports-utility vehicles. On the other hand, the passenger car segment is expected to dominate the market as compared to the commercial vehicle.

The fuel tanks have complex shapes [1-6], high mechanical and chemical resistance [7-11], in various models manufactured from materials (such as plastic, steel, and aluminum materials) [12-16], with different prices and advanced safety features [17-25]. Due to lightweight capability, aluminum is the most widely used and reduces the overall weight of the vehicle.

A variety of design recommendations are used in the structural design of a storage fuel tank [26-34] according to its intended use, size, structure type, materials, service life, in order to assure life safety and to maintain its essential functions [35-37].

There are various Computer-Aided Engineering softwares for specialized design of storage fuel tanks, which performs calculations in accordance with national and international standards [38-47].

In the technical literature, Factor of Safety (FoS), also known as Safety Factor (SF), can be computed based on different methodologies with advanced numerical procedures, according the national and international standards. In addition, confidence intervals of the SF in calculated due to uncertainty and exploitation conditions, data errors, and model structural inadequacies [48].

Our research aims to determine a set of admissible parameters in designing of a 3D hexagonal toroid with regular hexagonal cross-section used in manufacturing of LPG storage tanks from the automotive industry. The obtained results can be applied at the design or control stage of the LPG storage tank.

2. Design methodology

In our previous studies [14-16], an optimal design of a 3D hexagonal toroid with regular hexagonal cross-section was performed.

2.1 Basic geometry of the parametric 3D model

Let's consider the parametric 3D model generated by revolving of a closed generating curve C_G (a hexagon with rounded corners) along a closed guiding curve C_D (a hexagon with rounded corners) as shown in figure 1 [14].

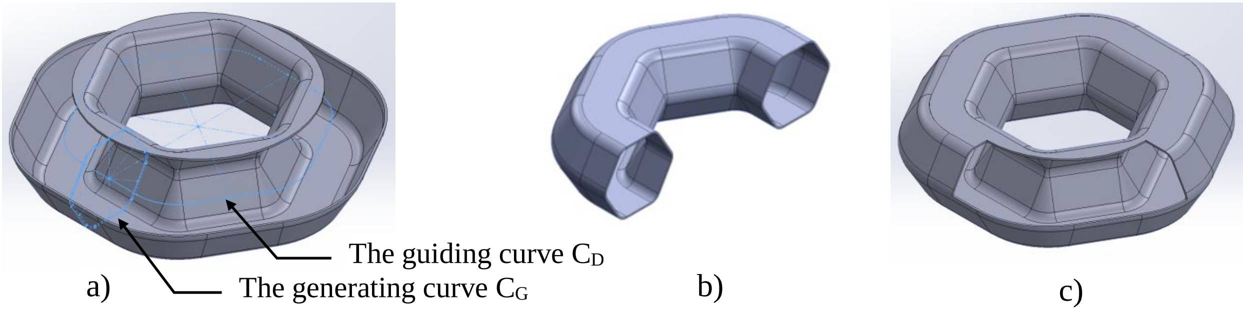

Fig. 1. The axonometric representation of the parametric 3D solid model

The following parameters were applied as input parameters to the 3D parametric model (figure 1): a) a closed generating curve C_G (a hexagon with a side value L = 175 mm, with rounded corners, radius R = 50 mm), and b) the guiding curve C_D (a hexagon with a side value L = 430 mm, with rounded corners, radius R = 180 mm).

2.2 Computational model

Based on the physical model, the parametric model was created in AutoCAD Autodesk 2017 software [45] and numerical analysis was performed with SolidWorks 2017 software [46] with the Static, Thermal and Design Study modules. The design data used were:

- the tank material is AISI 4340 steel;
- the maximum hydraulic test pressure: p_{max} = 30 bar;
- the working temperature between the limits: T = -30 ^{0}C up to T = 60 ^{0}C;
- supporting surfaces located on the inferior side;
- the duration of the tank exploitation: n_a = 16 years;
- the corrosion rate of the material: v_c = 0.07 mm/years.

In our previous study [15], the graph of 3D surfaces (by type surf) corresponding to the variation of minimum SF for SF_{min} (n_a, T), are graphically shown in fig. 2 [15].

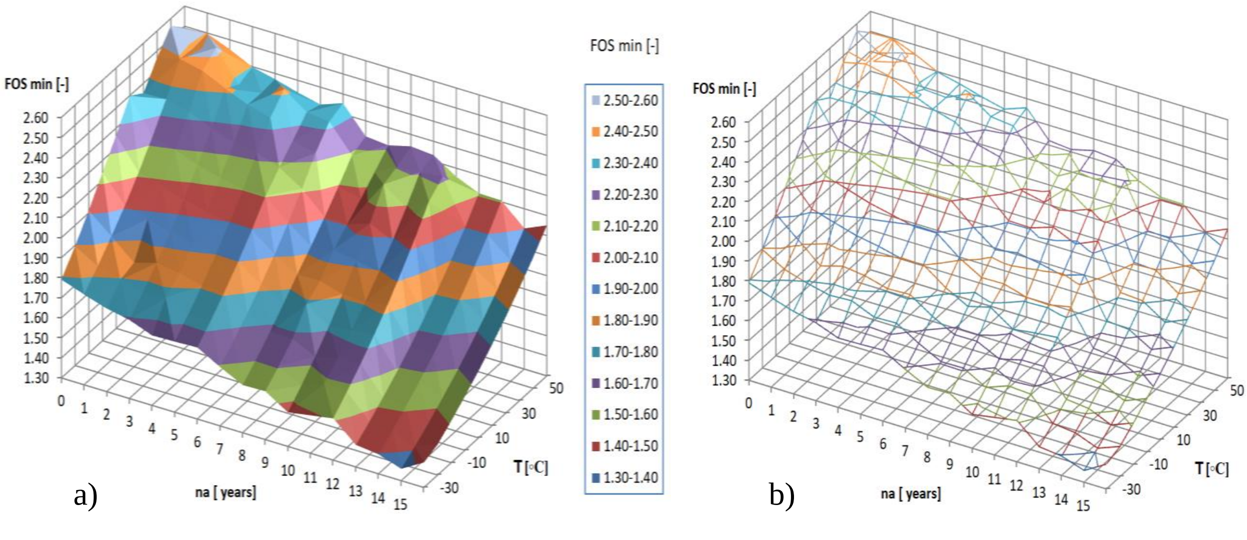

Fig. 2. The 3D graphs SF_{min} (n_a, T): a) surf type; b) fire type

Let's consider that the required safety factor is: $SF_{imp} = 1.6$
If the 3D surface of SF_{min} (n_a, T) (from fig. 2, shown as surf type) is intersected by a horizontal plane (with a height of SF_{imp}), it is obtained a 3D graph with $SF > SF_{imp}$, as shown in fig. 3.

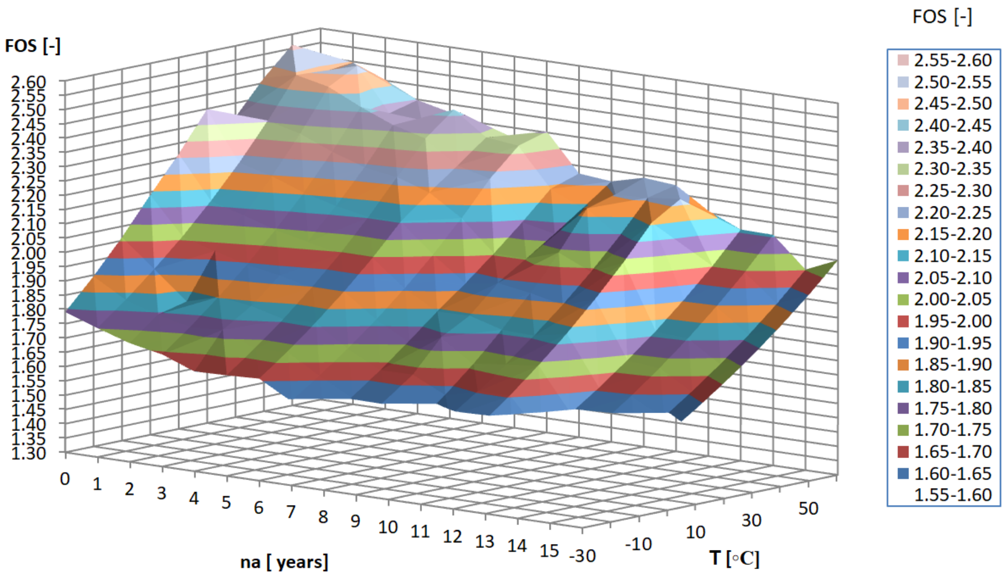

Fig. 3. The 3D graph SF_{min} (n_a, T) shown as surf type, for $SF > SF_{imp}$

A direct determination of 2D graph of SF_{min} (n_a, T), for $SF \geq SF_{imp}$ and $SF < SF_{imp}$ is shown in fig. 4.

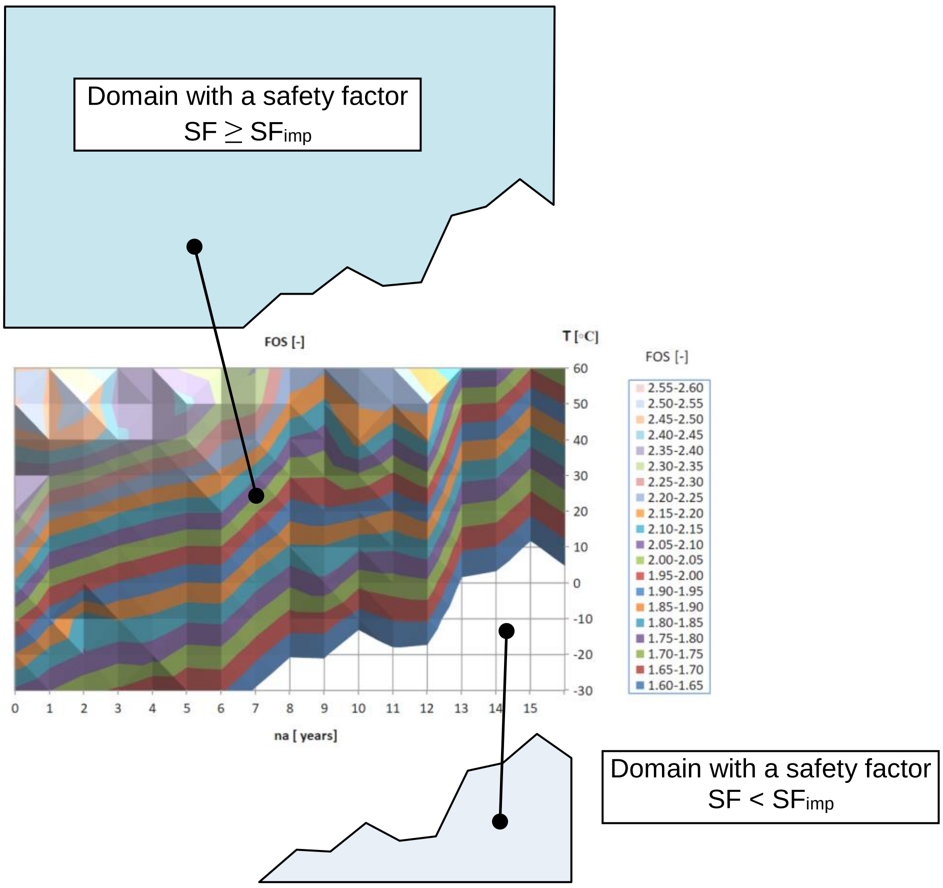

Fig. 4. The 2D graph of SF_{min} (n_a, T), for $SF > SF_{imp}$ and $SF < SF_{imp}$

The corresponding 2D graphs of the isothermal coefficient variation curves, SF_{min} (n_{ao}, T_o) with improper work parameters domain, are graphically shown in fig. 5.

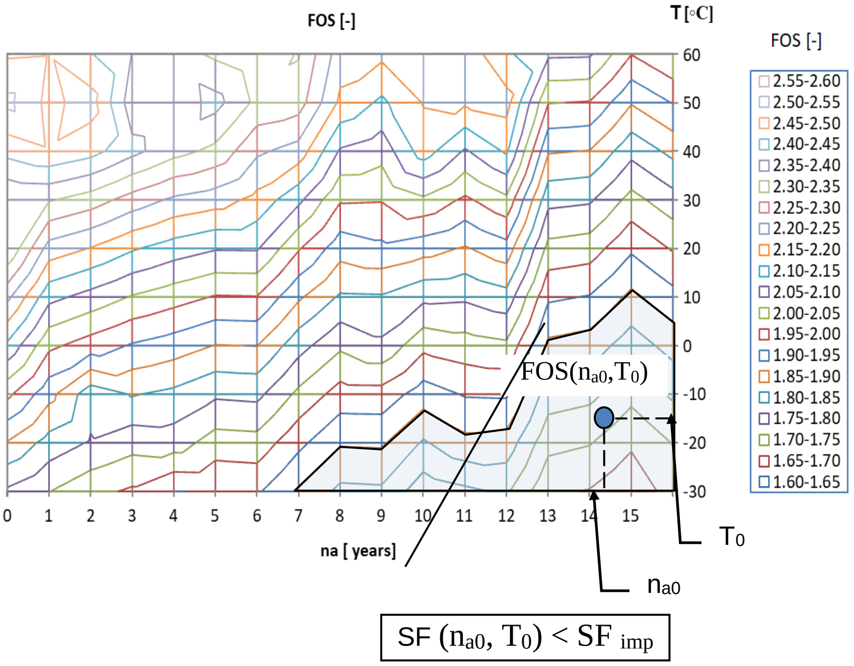

Fig. 5. The 2D graphs of the isothermal coefficient variation curves, SF_{min} (n_a, T), with domain SF (n_{a0}, T_0) < SF_{imp}

Finally, the contour of the planar domain can be described by curves obtained by polynomial interpolation, corresponding to each contour, which allow the analytical calculation relations of the domain, which lead to the rapid determination if a function point characterized by working parameters n_{a0} and T_0, belongs to proper working domain.

3. Discussion

Following the SF analysis and the resulting graphs for the parametric 3D model structure through the method of finite elements it has been found that:
- this method uses specialized computing software based on Finite element methods (FEM);
- this method can be applied at the design stage or during the control stage;
- graphical representations (in 2D or 3D), associated with the analytical curves determined by polynomial interpolation, delimitates the validity domain for which $SF \geq SF_{imp}$.

4. Conclusions

The proposed method identifies a set of admissible work parameters for which $SF \geq SF_{imp}$, structured, on algorithmic details of how to efficiently implement it, and on pre- and postprocessing steps.

Conflict of Interest: The authors declare that they have no conflict of interest.

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