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# Comparison of bursting pressure results of LPG tank using experimental and finite element method

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## Abstract

In this study, the resistance of liquefied-petroleum gas (LPG) tanks produced from carbon steel sheet metal of different thicknesses has been investigated by bursting pressure experiments and non-linear Finite Element Method (FEM) method by increasing internal pressure values. The designs of LPG tanks produced from sheet metal to be used at the study have been realized by analytical calculations made taking into consideration of related standards. Bursting pressure tests have been performed that were inclined to decreasing the sheet thickness of LPG tanks used in industry. It has been shown that the LPG tanks can be produced in compliance with the standards when the sheet thickness is lowered from 3 to 2.8 mm. The FEM results have displayed close values with the bursting results obtained from the experiments.

*Keywords:* Burst pressure; Non-linear finite element analysis; LPG tank

## 1. Introduction

The LPG tanks are evaluated as pressure vessels. There is an operating pressure that alters based on the LPG gas charged inside, usage conditions and environment temperature. The calculations of wall thicknesses at the applications are made according to the hydrostatic test pressure values; not to the operating pressure. This way, a safety pressure has been formed for wall thickness calculation. Burst experiments allow the control of the safety pressure somehow.

The tanks produced for charging and transportation purposes are being subject to some mechanical tests. The leading tests performed on the tanks that pass from production phases are the burst experiment. The tube subjected to the experiment is being torn after reaching a specific burst pressure. In this study, these deformation grades have been reviewed, the records of the wall thickness variations, volume expansion amount, the burst pressure at the moment tearing and tearing location and positions have been kept.

At the articles mentioned below, the tearing formed on LPG tanks by burst pressure has been investigated by experimental methods with different materials, analytical and numerical (FEM).

For the LPG tanks, the comparison of steel and two aluminum alloys (Al–Cu–Mg and Al–Mg) deformation and refraction behaviors [1] and the tearing of steel and aluminum alloys (Al–Cu–Mg, Al–Mg and Al–Mn) have been made [2]. In the article that makes a research on bursting pressure of flat steel strip coiled pressure vessels, for stripe layers the mathematical equations have been constituted and they have been analyzed [3]. An experimental approach has been made on the burst pressure of the thin wall thickness shaped pressure vessels and it has been applied on hardened and tempered AISI 4130 steel material. The burst pressure has been compared with other theories after transforming into mathematical theory [4]. Stawczyk [5] has investigated the effect of boiling liquid vapor explosion (BLEVE) for a LPG tank.

By using finite elements methods, Kim et al. [6] “J” from the estimation equations with General Electric/Electric Power Research Institute (GE/EPRI) has calculated elastic–plastic interior surface deformation at the cylinder that has an internal pressure and Su and Bhuyan [7] determined the linear plastic and non-linear plastic tearing behaviors all gas tanks that have different tearing in different axis’s. Sun et al. [8] has investigated the stresses and burst pressures in a stringy slot of the composite material pressure vessels used in rocket engines, O’Donoghue et

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al. [9] has concentrated on multi surface cracks at pressure vessels and Sang et al. [10] on limit and burst pressures of cylindrical walls intersected of medium size.

In this study, liquefied-petroleum gas (LPG) tanks that have an important position from the point of use and the burst experiments applied on these tanks have been taken into consideration. The sheet material has been selected to be used for the production of the tanks. The design calculation has been made by taking the related standards as a base for this material. The tanks were produced handling the minimum sheet thickness found by calculation. The produced tanks were tested against burst experiment parameters. The burst experiment results and the places of tearing at tanks have been examined. Analyses have been made by finite elements methods and the data obtained have been compared with the experimental results.

## 2. Experimental study

The tanks taken as a basis in this study have 300 mm nominal outer diameter measurement, 26.2 l minimum water capacity. The tanks have been produced by 2.8 and 3 mm nominal sheet thickness and have been undergone through normalization heat treatment and afterwards the burst. The pressure used in the experiment is provided by delivering controlled water to tube and by establishing expansion by volume. In addition, in the experiment, theoretical modeling has been made for the theoretical tanks used in production and subject to experiment and the analyses have been investigated according to the modeling done.

### 2.1. The properties of LPG gas

Liquefied petroleum gas is normally colorless and odorless. For easily distinguishing a possible gas leak by the user it has been specially aromatized. The boiling points of liquefied petroleum gases (the temperatures that they transform from liquid state to gaseous state) are very low. Propane can become gaseous at −42 °C, butane at −0.5 °C. By this property it can be used at very cold regions. The liquid butane and propane is approximately 50-50 lighter than water. Therefore, in a tube with a water capacity of 26.2 l approximately 12 kg of LPG can be filled. When the LPG is in gaseous state, it is approximately two times heavier than air. LPG has a low boiling point and lower than ambient temperature. Hence, LPG evaporates when leak happens. It accumulates in the cavities around the floor level. Thermal values of liquefied petroleum gases are higher than other gases. This height of thermal value gives an important advantage to gas. In Table 1 [11], the relative thermal values per N m$^3$ of various gases have been given in kilocalorie (kcal).

Table 1
Comparison of thermal values of butane and propane with other gases

| | |
|---|---|
| Hydrogen: 2839 kcal/N m$^3$ | Acetylene: 13,127 kcal/N m$^3$ |
| Air-gas: 4717 kcal/N m$^3$ | Propane: 22,447 kcal/N m$^3$ |
| Natural-gas: 9790 kcal/N m$^3$ | Butane: 29,089 kcal/N m$^3$ |

Table 2
The physical properties of propane and butane gases

| | Propane | Butane |
|---|---|---|
| Density (liquid condition) (kg/dm$^3$) | 0.508 | 0.584 |
| Density (gas condition) (kg/dm$^3$) | 1.522 | 2.006 |
| Boiling point (°C) | −42 | −0.5 |
| Min. ignition limit (in air) | 2.37% | 1.86% |
| Max. ignition limit (in air) | 9.50% | 8.41% |
| Required air quantity for burning (m$^3$/m$^3$) | 23.82 | 30.97 |
| Required air quantity for burning (kg/kg) | 15.7 | 15.7 |
| Required air quantity for burning (m$^3$/kg) | 12.15 | 12.02 |
| Evaporation heat (at 15.6 °C) (cal/kg) | 85 | 88.6 |
| Steam pressure (manometric, at 15.6 °C) (kgf/cm$^2$) | 6.51 | 0.82 |
| Thermal value (kcal/kg) | 11070 | 10920 |

As it can be seen from Table 1, while using LPG gas more attention has to be paid than other gases due to its property [11]. The physical properties of propane and butane gases are shown in Table 2 [12].

The physical properties of propane and butane gases can display the differences based on the country of the production. In Table 2, the data in Turkey have been considered [12].

### 2.2. Structure of LPG tank model

As it can be seen in Figs. 1 and 2, 81 each model tanks have been produced. The thickness variations forming at deep traction layer of tube body have been shown in Figs. 2 and 3. These thickness region values have been measured by ultrasonic probe for each tube having a thickness of 2.8 and 3 mm and the measured values are given in Tables 3 and 4 [13].

It has been determined that the data and variations obtained from the wall thickness measurements of the produced tanks are not below the computation results made by design formula given by standard.

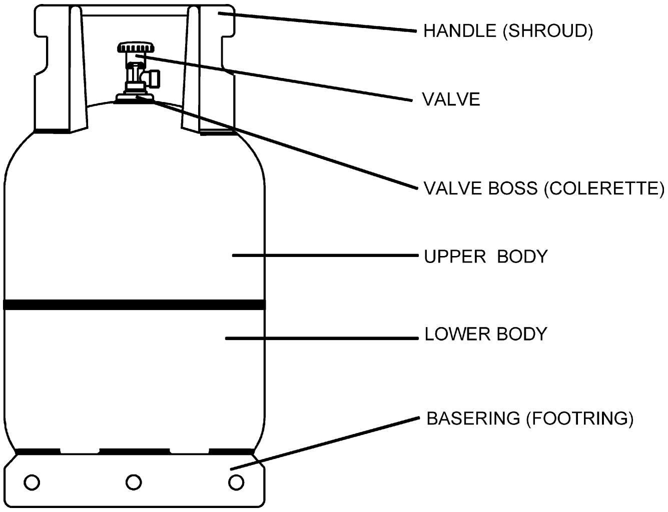


Fig. 1. Scheme of the LPG tank.

Table 3
The thickness value measurements received over the cartridge

| Region | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| The thickness value measurements (mm) | 3.2 | 3.01 | 2.88 | 2.81 | 2.74 | 2.74 | 2.91 | 2.92 | 2.94 | 2.85 |

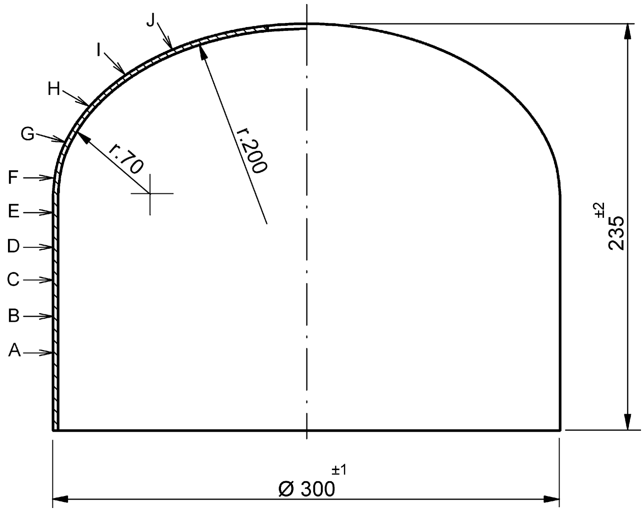


Fig. 2. The thickness data of the tanks produced by 3 mm sheet.

### 2.3. Material and properties

The material to be selected for the tanks to be used in burst experiment is the sheet material named as semi finished as flat steel and used in hot rolled welded tanks. Material is low alloy carbon steel. It is convenient to cold formalization and it has a high welding capacity. The mechanical and chemical properties of LPG tank material used in experimental study are given in Tables 5 and 6[14].

The mechanical and chemical properties of the material alternatives to be selected are identified in above mentioned tables. In the study, the selected steel material named P265NB 1.0423 is defined as BS2 quality sheet in NF A36-21 standard. Material is the roll sheet material which has a D region produced by rolling and subjected to normalization heat treatment.

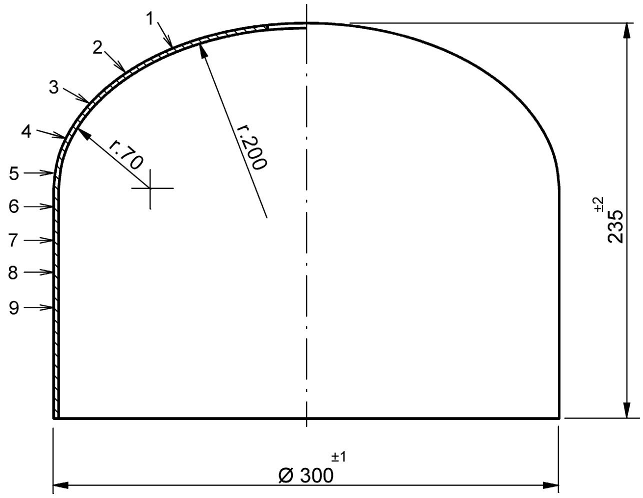


Fig. 3. The thickness data of the tanks produced by 2.8 mm sheet.

### 2.4. LPG tank production

The tank body has been produced from two symmetrical parts by deep drawing treatment. The end pieces jointed by MIG welding method have formed the medium part of tank. Weld measurements (in mm) are shown in Figs. 4 and 5. In the

Table 4
Comparison of thickness measurement values received over sheets and bodies

| Thickness regions | Sheet thickness (mm) | Body thickness (mm) | Variation (mm) |
|---|---|---|---|
| A region | | | |
| 1 | 2.79 | 2.58 | 0.21 |
| 2 | 2.79 | 2.60 | 0.19 |
| 3 | 2.77 | 2.53 | 0.24 |
| 4 | 2.78 | 2.62 | 0.16 |
| 5 | 2.79 | 2.68 | 0.11 |
| 6 | 2.79 | 2.54 | 0.25 |
| 7 | 2.78 | 2.63 | 0.15 |
| 8 | 2.76 | 2.83 | −0.07 |
| 9 | 2.77 | 3.07 | −0.30 |
| B region | | | |
| 1 | 2.78 | 2.52 | 0.26 |
| 2 | 2.79 | 2.64 | 0.15 |
| 3 | 2.76 | 2.67 | 0.09 |
| 4 | 2.76 | 2.68 | 0.08 |
| 5 | 2.78 | 2.57 | 0.21 |
| 6 | 2.77 | 2.59 | 0.18 |
| 7 | 2.78 | 2.71 | 0.07 |
| 8 | 2.78 | 3.00 | −0.22 |
| 9 | 2.79 | 3.02 | −0.23 |
| C region | | | |
| 1 | 2.77 | 2.53 | 0.24 |
| 2 | 2.79 | 2.51 | 0.28 |
| 3 | 2.78 | 2.60 | 0.18 |
| 4 | 2.75 | 2.69 | 0.06 |
| 5 | 2.76 | 2.69 | 0.07 |
| 6 | 2.73 | 2.58 | 0.15 |
| 7 | 2.74 | 2.57 | 0.17 |
| 8 | 2.75 | 2.69 | 0.06 |
| 9 | 2.73 | 3.05 | −0.32 |
| D region | | | |
| 1 | 2.77 | 2.55 | 0.22 |
| 2 | 2.74 | 2.61 | 0.13 |
| 3 | 2.77 | 2.60 | 0.17 |
| 4 | 2.76 | 2.69 | 0.07 |
| 5 | 2.75 | 2.76 | −0.01 |
| 6 | 2.76 | 2.61 | 0.15 |
| 7 | 2.74 | 2.62 | 0.12 |
| 8 | 2.73 | 2.79 | −0.06 |
| 9 | 2.75 | 3.02 | −0.27 |

Table 5
Mechanical properties of LPG tank material

| Steel | | Upper yield strength, Rm (N/mm$^2$ min.) | Tensile strength, Rm (N/mm$^2$ min.-max.) | Elongation after fracture for product A, thickness *t* in mm | | Normalizing temperature (for guidance) (°C) |
|---|---|---|---|---|---|---|
| Name | Number | | | $t < 3$ (Lo = 80 mm) (%min.) | $3 \leq t \leq 5$ (Lo = 5.65 So) (%min.) | |
| P265NB | 1.0423 | 265 | 410–500 | 24 | 32 | 890–930 |

Table 6
Chemical properties of LPG tank material

| Steel grade | | C max. | Si max. | Mn min. | P max. | S max. | Al min. | N max. | Nb max. | Ti max. |
|---|---|---|---|---|---|---|---|---|---|---|
| Name | Number | | | | | | | | | |
| P265NB | 1.0423 | 0.19 | 0.25 | 0.40 | 0.025 | 0.015 | 0.020 | 0.009 | 0.050 | 0.03 |

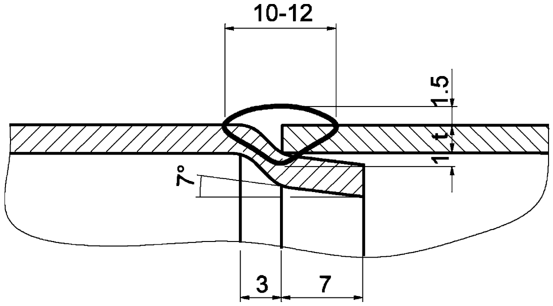


Fig. 4. Weld of the joggle joint form.

collaret, chassis and guard welding treatments of the tanks subjected to burst experiment of the study, metal-inert-gas (MIG) welding method was applied by the use of selected welding parameters as shown in Table 7. Two demounted parts which have been MIG welded come to main welding operation named as assembly treatment. With main welding treatment two half pieces are joined. The method of joining is the submerged submerged, arc-welding (SAW) welding method the tanks that will be subject to burst experiment have been assembled by selecting suitable welding parameters. The minimum wall thickness of the LPG tank are calculated according to EN 1442:1998; part 7.2.3.2 standard which can resist both fire and 30 bar pressure values.

## 2.5. Experimental study

Checking of the compliance with necessary criteria at the end of burst of the random selected tube samples among tanks subjected to heat treatment is performed by burst experiment. Manometer, burst experiment cabin, weight and tube constitute the basis of the experiment mechanism as shown in Figs. 6 and 7.

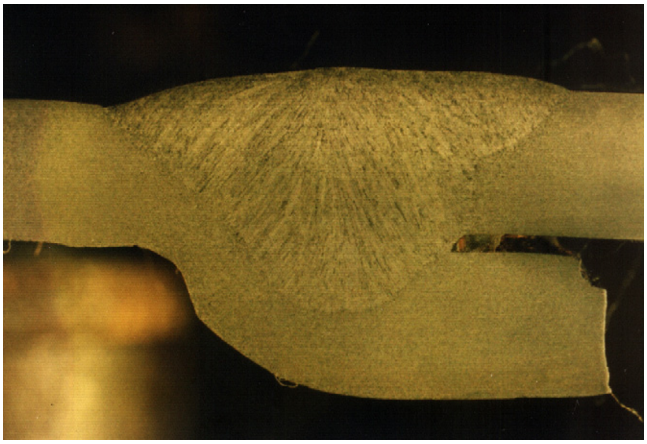


Fig. 5. Macro examination of circumferential main weld.

Fig. 6. Overview of burst experiment.

Table 7
Welding procedure and parameters

| Welding procedure | Welding material | | Welding parameter | | |
|---|---|---|---|---|---|
| | Name | Size, Ø (mm) | Current (A) | Voltage (V) | Speed (mm/s) |
| SAW (submerged-arc-welding) | S1 (EN 756) | 3.2 | 430–450 | 28–30 | 17 |

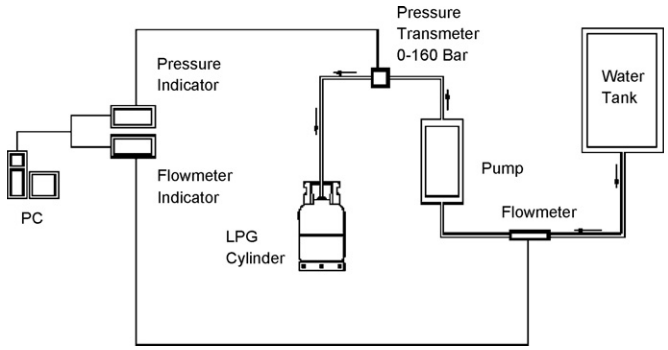


Fig. 7. Schematic experiment mechanism.

Before starting the experiment the randomly selected sample to be placed in experiment cabin is weighed empty. The sample is weighed again by filling water inside and the difference gives the water volume of the tube ($V_{\text{first}}$). After assembling the sample tank to the pressure pipes inside the burst experiment cabin, the cabin is closed. By opening the vanes of pressure and water pumps the experiment is started. After the burst of the tank the vanes of pressure and water pumps are closed and the experiment is finalized. During the experiment, the pressure value of the tube during the burst is read from the indicator of manometer. After removing the burst sample tank from experiment cabin, the torn and perforated parts are closed and the volume is measured by filling with water ($V_{\text{final}}$). %Volume increase of the sample tube burst by expansion is calculated by the below formula.

$$\%\,\text{expansion amount by volume} = \%\,\Delta V = \frac{V_{\text{final}} - V_{\text{first}}}{V_{\text{first}}} \times 100.$$

### 2.6. The required conditions at experiment result

The measured burst pressure ($P_{\text{b}}$) should never be less than 9/4th of the calculated pressure ($P_{\text{c}}$) and 50 bars.

The ratio of tanks expansion by volume to the first volume should be equal or bigger than the values mentioned below: If the length of the tank (the length of the body that includes the vane muff) is greater than the diameter ($D$) of the body subject to pressure, it is 20% and if the tube length (the length of body that includes the vane muff) is equal to diameter or less, it is 17%. At the tear occurred in the end of the experiment, the points taken into consideration are:

- Burst experiment should not cause any break up at tube.
- The edges of main tear should not be radial, but they should form an angle to the plane forming the tube diameter and it should display cross section shrinkage along its thickness.
- Tear should not reveal a visible defect (i.e., lamination, etc.) in the structure of metal.

### 2.7. The experiment results

The experiment study has been applied to LPG tanks of min 26.2 l water capacities and with 300 mm diameter. A total of 81 burst experiments have been concluded and 38 each of them are produced from sheet material with 2.8 mm nominal thickness, 43 each are tanks produced from 3 mm nominal thickness sheet. In the experiment parameters, tube body sheet thicknesses (2.8 and 3 mm) were entered by taking two materials of different thickness. The burst values table of the tanks with different thickness and the formed figures are shown in Tables 8 and 9.

Another important aspect to be handled during the tube production is the deep drawing process. The each tube's (total of 81 experiments) deep drawing was established in single layer. The variation intervals of rolled sheets were given in Figs. 2 and 3. The point to be noted is that the decrease in the wall thickness should below the minimum wall thickness at design. At the experiments, fluctuations in the amount of pressure and expansion by volume values are a function of time. The compression of tank is performed by water in the experiments and the flow of water is being constant. The tank is supplied with water at equal time and equal amount and the time parameter does not display variation. This situation only shows the relationship of pressure and expansion by volume. The reason of similarity of the graphics in burst and drawing experiments are originating from the pressure and force, expansion by volume percentage and the elongation percentage being in same character. Namely, the force in the drawing experiment has been replaced by pressure in burst experiment and the elongation percentage in the drawing experiment has been replaced by expansion percentage again in burst experiment.

At the tanks produced with 2.8 mm thickness, the internal volume value received prior to burst experiment, in other words water capacity, does not display a wide clearance. For 26.2 l tube this value is only 0.2 l. Therefore, the figures formed at the conclusion of this experiment have to be reliable.

On tanks produced from 3 mm thickness sheets, the volume values vary between 26.3 and 26.55 l and the clearance difference value is being realized with 0.25 l. As in the tanks produced by the use of 2.8 mm sheets the figures of the burst experiment have to be reliable. The purpose of taking 81 each tanks prepared for experiments in tank basis is the alteration of the burst figures in a suitable manner and being able to make easy comparison of the results formed by the thickness decrease. The tanks produced from both sheet metal of 2.8 and 3 mm have been realized at the same production conditions and have been heat treated at the same temperature. A different parameter error will not affect the experiment results in this way. Heat treatment temperature interval displays a variation between 890 and 939 °C which is mentioned in standards. The purpose of the normalization which is a heat treatment is to bring the initial state of the defective material micro structure due to deep drawing and welding processes and establishment of recovery of internal structure irregularities. The normalization temperature directly affects the burst results. As it can be seen in the burst experiment graphics of the burst experiment shown in Fig. 8, the material displays plastic behavior after certain flow point and after this moment stationary form variation is constituted in the structure. Until the flow point, the curve of the graphic continues linearly and the material displays an apparent elasticity at flow point.

Table 8
Burst experiment results for material of 2.8 mm thickness

| Test number | Before test, volumetric capacity of cylinder $V_{\mathrm{first}}$ (l) | During bursting, volumetric capacity of cylinder $V_{\mathrm{final}}$ (l) | After test, volumetric variation $V_{\mathrm{first}} - V_{\mathrm{final}}$ (l) | Volumetric expansion (%) | During bursting, measured pressure $P_{\mathrm{b}}$ (bar) | Crack location |
|---|---|---|---|---|---|---|
| 1 | 26.40 | 36.87 | 10.47 | 39.65 | 121.38 | Main welding |
| 2 | 26.25 | 36.49 | 10.24 | 39.01 | 121.41 | Body |
| 3 | 26.35 | 35.99 | 9.64 | 36.59 | 120.86 | Body |
| 4 | 26.30 | 37.52 | 11.22 | 42.65 | 121.38 | Main welding |
| 5 | 26.25 | 35.94 | 9.69 | 36.91 | 118.92 | Body |
| 6 | 26.25 | 35.90 | 9.65 | 36.74 | 121.36 | Body |
| 7 | 26.35 | 37.47 | 11.12 | 42.20 | 121.46 | Body |
| 8 | 26.35 | 36.72 | 10.37 | 39.34 | 120.45 | Body |
| 9 | 26.35 | 36.09 | 9.74 | 36.98 | 118.33 | Body |
| 10 | 26.30 | 36.75 | 10.45 | 39.71 | 122.92 | Body |
| 11 | 26.35 | 35.68 | 9.33 | 35.41 | 116.79 | Body |
| 12 | 26.30 | 35.79 | 9.49 | 36.09 | 118.01 | Body |
| 13 | 26.25 | 36.83 | 10.58 | 40.32 | 120.73 | Body |
| 14 | 26.25 | 36.64 | 10.39 | 39.56 | 118.94 | Main welding |
| 15 | 26.30 | 35.89 | 9.59 | 36.45 | 118.15 | Main welding |
| 16 | 26.25 | 36.38 | 10.13 | 38.60 | 118.65 | Body |
| 17 | 26.30 | 35.58 | 9.28 | 35.29 | 117.29 | Body |
| 18 | 26.25 | 35.69 | 9.44 | 35.97 | 119.54 | Body |
| 19 | 26.25 | 35.22 | 8.97 | 34.17 | 115.44 | Body |
| 20 | 26.30 | 35.90 | 9.60 | 36.49 | 115.84 | Body |
| 21 | 26.35 | 36.13 | 9.78 | 37.11 | 116.73 | Body |
| 22 | 26.25 | 34.34 | 8.09 | 30.83 | 114.27 | Main welding |
| 23 | 26.25 | 37.22 | 10.97 | 41.79 | 117.79 | Body |
| 24 | 26.25 | 34.81 | 8.56 | 32.62 | 116.98 | Body |
| 25 | 26.30 | 36.66 | 10.36 | 39.40 | 120.80 | Body |
| 26 | 26.30 | 36.39 | 10.09 | 38.36 | 120.05 | Body |
| 27 | 26.35 | 35.39 | 9.04 | 34.31 | 117.62 | Main welding |
| 28 | 26.30 | 34.11 | 7.81 | 29.68 | 116.41 | Body |
| 29 | 26.25 | 36.39 | 10.14 | 38.62 | 118.67 | Body |
| 30 | 26.25 | 36.47 | 10.22 | 38.91 | 120.14 | Body |
| 31 | 26.25 | 35.16 | 8.91 | 33.95 | 120.01 | Main welding |
| 32 | 26.30 | 36.05 | 9.75 | 37.05 | 120.43 | Body |
| 33 | 26.30 | 36.33 | 10.03 | 38.15 | 119.35 | Body |
| 34 | 26.30 | 35.17 | 8.87 | 33.71 | 118,34 | Body |
| 35 | 26.35 | 35.40 | 9.05 | 34.33 | 119.28 | Body |
| 36 | 26.30 | 34.70 | 8.40 | 31.95 | 116.53 | Body |
| 37 | 26.30 | 33.66 | 7.36 | 27.97 | 117.23 | Body |
| 38 | 26.20 | 35.89 | 9.69 | 36.98 | 123.15 | Body |

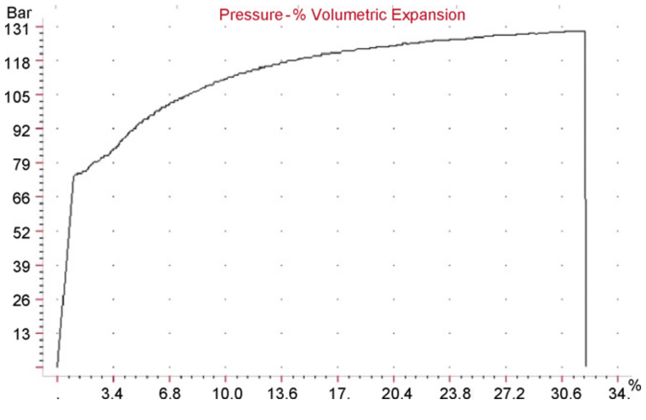


Fig. 8. Number 1 burst experiment graphic for 3 mm sheet.

The tears occurring at tanks after the burst experiment constitute a plane that vertically intersects with the circumference axis. The stress accumulation at the butted section refines the material at that section and it reaches the burst pressure value at the beginning of the tear. The length of the tear displays a variation with respect to the maximum pressure value at the moment of burst both for the tear formed at main welding and for tear formed at right above the main welding. The tear formed at the tube after the burst experiment is shown in Fig. 9.

At the burst tank palletizing or bending cannot be observed. The tear forms an angle within the circumferential welding plane and does not display any shrapnel effect. At the tear rims no internally or externally stranded places have formed. The tear has continued uniformly at the progress plane.

The appearance of bursted tanks was examined after completion of the paint process. The same tube has undergone heat treatment operation as in the other tanks and it has been determined that the sanding, zinc plating and painting operations

Table 9
Burst experiment results for material of 3 mm thickness

| Test number | Before test, volumetric capacity of cylinder $V_{\text{first}}$ (l) | During bursting, volumetric capacity of cylinder $V_{\text{final}}$ (l) | After test, volumetric variation $V_{\text{final}} - V_{\text{first}}$ (l) | Volumetric expansion% | During bursting, measured pressure $P_b$ (bar) | Crack location |
|---|---|---|---|---|---|---|
| 1 | 26.30 | 34.73 | 8.43 | 32.05 | 129.11 | Body |
| 2 | 26.30 | 34.15 | 7.85 | 29.84 | 126.26 | Body |
| 3 | 26.40 | 32.79 | 6.39 | 24.22 | 129.17 | Main welding |
| 4 | 26.50 | 35.42 | 8.92 | 33.68 | 128.08 | Body |
| 5 | 26.45 | 33.88 | 7.43 | 28.08 | 129.02 | Body |
| 6 | 26.45 | 33.72 | 7.27 | 27.49 | 126.58 | Body |
| 7 | 26.30 | 33.57 | 7.27 | 27.62 | 124.73 | Body |
| 8 | 26.45 | 33.36 | 6.91 | 26.11 | 127.45 | Body |
| 9 | 26.55 | 33.41 | 6.86 | 25.82 | 125.03 | Body |
| 10 | 26.35 | 33.08 | 6.73 | 25.54 | 126.05 | Body |
| 11 | 26.50 | 34.32 | 7.82 | 29.51 | 125.42 | Body |
| 12 | 26.45 | 35.08 | 8.63 | 32.62 | 129.73 | Body |
| 13 | 26.35 | 36.31 | 9.96 | 37.80 | 125.54 | Body |
| 14 | 26.30 | 34.58 | 8.28 | 31.46 | 127.92 | Body |
| 15 | 26.35 | 33.78 | 7.43 | 28.19 | 126.74 | Main welding |
| 16 | 26.35 | 34.54 | 8.19 | 31.09 | 129.60 | Body |
| 17 | 26.45 | 34.24 | 7.79 | 29.47 | 121.26 | Body |
| 18 | 26.40 | 32.58 | 6.18 | 23.42 | 119.37 | Main welding |
| 19 | 26.40 | 33.00 | 6.60 | 25.00 | 122.58 | Main welding |
| 20 | 26.35 | 34.74 | 8.39 | 31.84 | 128.14 | Body |
| 21 | 26.40 | 35.08 | 8.68 | 32.89 | 131.65 | Body |
| 22 | 26.50 | 32.78 | 6.28 | 23.71 | 121.26 | Main welding |
| 23 | 26.30 | 31.96 | 5.66 | 21.52 | 124.15 | Main welding |
| 24 | 26.30 | 35.32 | 9.02 | 34.30 | 130.88 | Body |
| 25 | 26.40 | 34.21 | 7.81 | 29.57 | 125.71 | Body |
| 26 | 26.40 | 33.50 | 7.10 | 26.89 | 127.77 | Body |
| 27 | 26.30 | 31.86 | 5.56 | 21.13 | 116.38 | Main welding |
| 28 | 26.45 | 33.94 | 7.49 | 28.33 | 117.87 | Main welding |
| 29 | 26.45 | 33.57 | 7.12 | 26.92 | 123.05 | Body |
| 30 | 26.30 | 34.05 | 7.75 | 29.46 | 126.64 | Body |
| 31 | 26.35 | 33.54 | 7.19 | 27.30 | 123.63 | Body |
| 32 | 26.40 | 34.52 | 8.12 | 30.76 | 123.73 | Body |
| 33 | 26.30 | 34.29 | 7.99 | 30.40 | 132.11 | Body |
| 34 | 26.35 | 34.68 | 8.33 | 31.62 | 131.79 | Body |
| 35 | 26.35 | 33.44 | 7.09 | 26.91 | 121.29 | Body |
| 36 | 26.45 | 32.06 | 5.61 | 21.19 | 123.65 | Body |
| 37 | 26.35 | 33.66 | 7.31 | 27.72 | 126.76 | Body |
| 38 | 26.45 | 35.19 | 8.74 | 33.06 | 126.69 | Body |
| 39 | 26.35 | 34.54 | 8.19 | 31.10 | 126.30 | Body |
| 40 | 26.50 | 33.03 | 6.53 | 24.64 | 124.55 | Main welding |
| 41 | 26.45 | 34.89 | 8.44 | 31.91 | 122.75 | Body |
| 42 | 26.40 | 34.95 | 8.55 | 32.38 | 125.21 | Body |
| 43 | 26.50 | 35.50 | 9.00 | 33.95 | 125.48 | Body |

applied on tube do not have any effect on the burst experiment parameters. Each burst experiment (total of 81 experiments) performed has been applied to the cylinders cooled at a suitable medium after the heat treatment in the oven. From the point of explosion place all the tanks have the same region and its position shows spreading vertical to the main welding operation.

## 3. Discussion

A general evaluation of the experiment results based on the tanks produced by 2.8 mm sheet material is given below.

- The water capacity of the tanks does not have any effect on expansion by volume at change interval.
- When the volume increase drops, the amount of expansion due to formula also drops.
- When the volume increase drops, the burst pressure drops.
- The tanks with Ø 300 mm diameters are generally torn from the body and explode.
- The expansion by volume has been limited with 0.2 l due to the production of the tanks between 26.2 and 26.4 l narrow interval and this value has not created an effective impact on the burst results.
- Expansion by volume amount has displayed a wide distribution interval that varies between 27.92% and 42.65%.
- The maximum measured burst pressure has been 123.15 bar and the minimum burst pressure has been 114.27 bar. A wide pressure interval has not been formed.

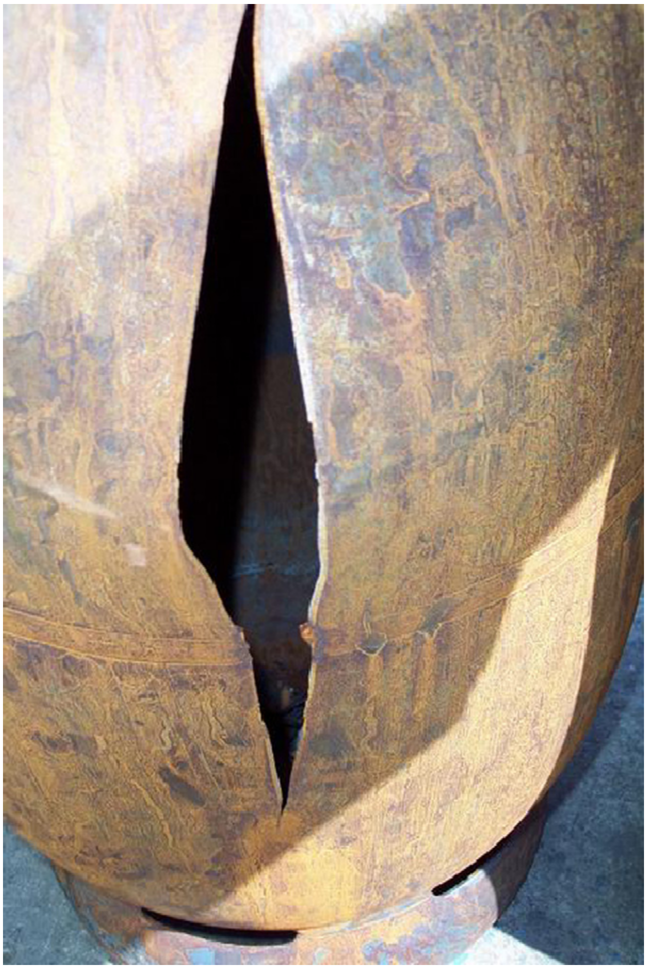


Fig. 9. The appearance of the tear on the burst tank.

- The expansion by volume does not have a direct effect on the burst pressure. The increase in the amount of expansion and burst amount has not shown an appearance proportionally.

The following results are given when the tanks are produced by 3 mm sheet material.

- The water capacities of tanks vary between 26.3 and 26.5 l. As in the tanks produced from 2.8 mm sheet material, the volume variation interval arising from 0.25 l production of these tanks did not affect the burst results.
- The tear location of the tanks has generally been realized at the body.
- The expansion by volume amount has displayed a wide distribution interval between 21.13% and 37.8%. In all the tanks, the value of 20%, which is the minimum value of expansion by volume, has been exceeded.
- All the tanks produced according to related standards and subjected to experiment are successful. (According to the burst experiment conditions.)
- The lowest and highest burst pressure values of the tanks are 116.38 and 132.11 bar.
- The tank with the experiment number 27 and produced from 3 mm sheet has displayed the lowest percentage of expansion by volume and it has exploded at the highest burst pressure value of 116.38 bar. Expansion amount values and burst pressure values has shown non-linear variation interval at these tanks.
- The increase of sheet iron thickness has brought a compatible pressure and expansion relationship along with itself.

The common results for sheets 2.8 and 3 mm thicknesses.

- The decrease in sheet thickness has brought an increase in expansion by volume along with itself.
- The increase in sheet thickness has brought an increase in burst pressure value along with itself.
- The tanks produced by 2.8 mm sheet and subjected to experiment had an average expansion value of 36.8% and average burst pressure value of 118.99 bar.
- The tanks produced by 3 mm sheet and subjected to experiment had an average expansion value of 28.8% and average burst pressure value of 125.74 bar.
- By decreasing the material thickness greater expansion values at lower burst pressure values have been observed. Therefore, together with the increase in thickness, increase in pressure and decrease in expansion are taking place.
- As the outer diameter value is constant in the tank, the decrease in sheet thickness has increased the constant internal volume and the stationary deformation in material.
- The tank burst data obtained on the tanks selected by both sheet thicknesses have been successful.
- At the tears from main welding has effected at the moment of an air vent along circumferential welding on the tube sheet and forced the material to tear down.

## 4. Finite element analysis

Making radical changes in production system generally can cause high costs. By foreseeing this earning from this cost, the modifications have been made and the process has been recovered. FEM has been frequently used in the recovery of the production process in recent years. In this way, the result of the modification to be done can be simulated in computer medium.

The LPG tanks subjected to the burst test have also been analyzed by the use of the finite element method. The purpose of FEM analysis in this study is inclined to estimate the burst pressure and amount of expansion by volume prior to the burst. As a method “Explicit non-linear analysis” method has been used. The reason of preferring this method is the request of simulation of refraction and breaking that occur during the event. In the FEM analysis performed, as the tank handled is symmetrical only one half has been modeled as a surface. Taking the CAD model as a basis, the region under the influence of the tube chassis, welding line has been modeled as three different parts and FEM network has been constituted as shown in Fig. 10. For the rest of the model, freedom of 6 degree shell type of elements has been used. The establishment of CAD model has been real-

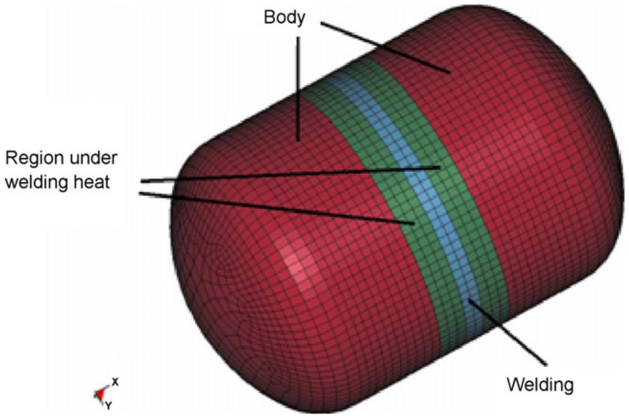
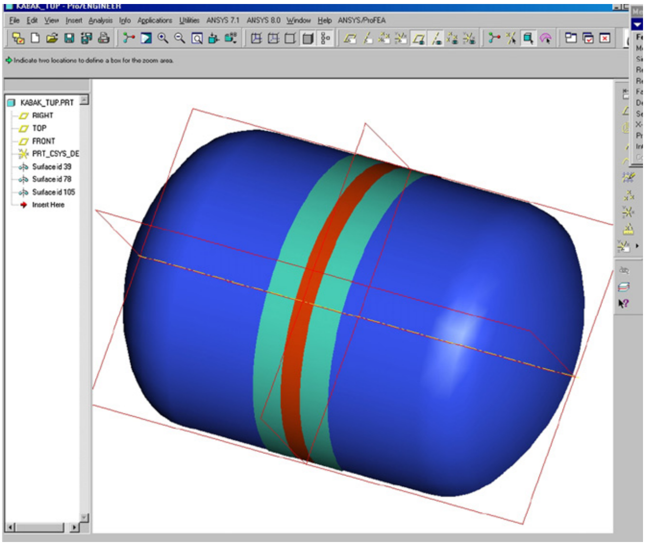


Fig. 10. Picture of LS—Pre Post.

ized by Pro/Engineer$^{TM}$ software as shown in Fig. 11 and the FEM model with ANSYS$^{TM}$ software as shown in Fig. 12. For problem solving ANSYS/LS-Dyna software has been used.

At the nodal points of the elements in the symmetry axis symmetrical boundary conditions have been given. For modeling the internal pressure load, a pressure has been applied to elements with a curve that is dependent on time from internally to externally suitable to burst experiment. Based on the constituted pressure–time graphic test character it is in linearly increasing nature as shown in Fig. 13. For establishing this pressure graphics the internal pressure values recorded at the experiment have been taken as a basis. The analysis has continued until the refraction of the element in the structure has been obtained.

As a material model “Isotope Bi-Linear plastic” material model has been used. As refraction-breaking criteria the failure strain has been taken as a basis. The elements are being perished after a certain elongation limit. The necessary data for this model have been obtained from the coupons received from tanks and from drawing experiments as shown in Table 10. The drawing experiment results of the sample received from the welding line have been used as necessary material parameters for the region



Indicate two locations to define a box for the zoom area.

Fig. 11. Pro/Engineer$^{TM}$ model.

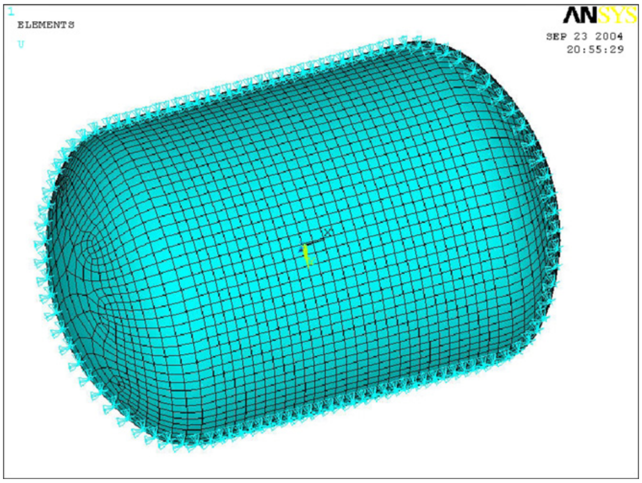


Fig. 12. ANSYS$^{TM}$ model.

under the welding line and heat influence. The data obtained from the drawing experiment of the body have been used for the body material parameters.

The finite elements model includes a total of 2292 shell element and 2343 nodal points. The prepared finite elements model has been analyzed with ANSYS/LS-DYNA software. For analysis, a Pentium IV 2.8 processor and IGB dynamic memory PC have been used. The simulation results and experiment results display a harmony with each other. The plastic deformation prior to tear and the form variation can be expressly seen in the simulation model in Fig. 14. The tank is torn around the welding region similar to the physical experiment.

Physical experiment and simulation results have been compared by taking two important magnitudes as basis. The first of these two magnitudes is burst pressure (internal pressure). The experiment pressure measured during physical experiment and foreseen by standards is the pressure of the liquid inside the LPG tube during the experiment; it is not possible to directly obtain this magnitude in the FEM model. Instead of this determination of internal pressure by the use of pressure loading graphic has been preferred. The FEM simulation burst pressure value states the internal pressure value at the moment that the breaking is first observed.

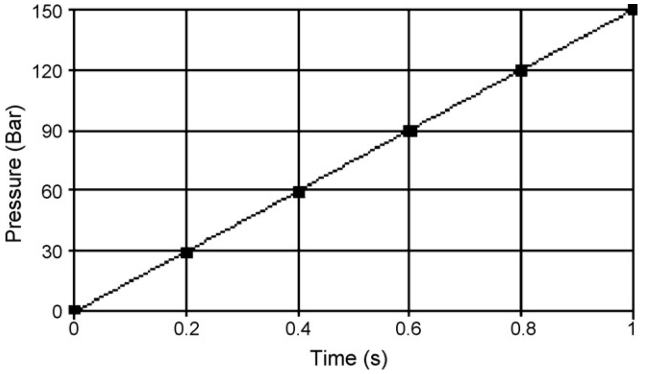


Fig. 13. Variation of the loading pressure with respect to time.

Table 10
The used bi-linear cinematic material model parameters

| Isotrop non-linear plastic model | Elastic module (MPa) | Density (kg/m$^3$) | Poison rate | Yield stress (MPa) | Tangent module (MPa) | Elongation after fracture |
|---|---|---|---|---|---|---|
| Body | 172000 | 7860 | 0.3 | 343 | 1580 | 0.296 |
| Welding | 172000 | 7860 | 0.3 | 245 | 920 | 0.22 |

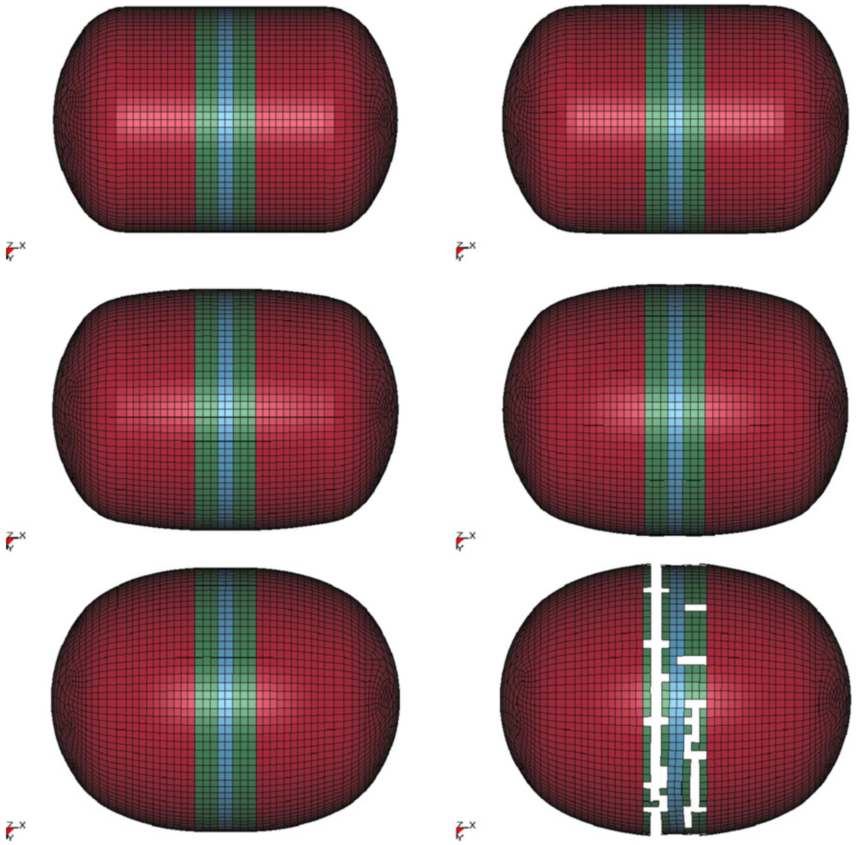


Fig. 14. Transformation of the shape and expansion at LPG tube with 2.8 mm wall thickness.

Table 11
Comparison of the simulation and test results

| Cylinder wall thickness (mm) | Average experimental burst pressure (bar) | FEM simulation burst pressure (bar) | %Fault |
|---|---|---|---|
| 2.8 | 118.99 | 111.75 | −6.08 |
| 3 | 125.74 | 118.8 | −5.52 |

## 5. Comparison of the experimental and FEM results

As it can be seen from Table 11, the physical experiment results and simulation results are very close values to each other. Error ratio is within the acceptable limits and this ratio can be reduced by the use of more detailed material model and comprehensive experiment data.

Nevertheless, in general simulation model behaves more definitely than the real structure. This situation is a general conclusion arising from the analyses made by FEM. It has been observed that it is a reliable method that can yield correct results to be used towards decreasing the LPG tube burst tests.

## 6. Conclusions

The experiment results indicate that the manufacturers may be able to perform their production by selecting thinner sheet thickness provided that they have established the control wall thickness decrease at deep drawing phase and they develop their technologies with respect to this. The matching of the experiment and FEM results has indicated that the FEM studies can be used effectively for testing of cylinders. In the studies that can be performed in the future, the sheet thickness can be taken as 2.5 mm at tanks with sheet thickness of 300 mm outer diameter measure and that have a 26.21 capacity by volume. This will bring the cost decrease of the tank along with itself.

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