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OPTIMIZATION OF LPG TANKS DEDICATED TO THE CONVERSION OF RENAULT SYMBOL TO BI-FUEL

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ملـــخص:

يعمل غاز البترول المسال كوقود رئيسي للنقل على مستوى العالم، حيث يعمل على تشغيل مجموعة متنوعة من المركبات مثل السيارات والشاحنات والحافلات والرافعات الشوكية والسفن البحرية والطائرات. في عام 1983، تم وضع لوائح قانونية لاستغلال واستخدام غاز البترول المسال كوقود للسيارات في الجزائر.

كان استخدام غاز البترول المسال في المركبات، بما في ذلك طرازات السيارات الشهيرة مثل رينو سيمبول، نقطة محورية في جهود الجزائر. تتضمن أنظمة تحويل غاز البترول المسال في هذه السيارات.

الهدف من هذه الدراسة هو معالجة العيوب وتحسين خزان وقود غاز البترول المسال بحيث يكون مناسبا لسيارة رينو سيمبول.

استخدمنا برنامج صوليد ووركس في هذه الدراسة من أجل الحصول على خزان بمواصفات وخصائص تتوافق مع سيارة رينو سيمبول.

الكلمات المفتاحية:

سيارة رينو سيمبول، وقود غاز البترول المسال، المحاكاة، طقم تحويل وقود غاز البترول المسال، خزانات وقود غاز البترول المسال، الخزان المسطح، خزان ثنائي الأسطوانة، الجزائر، برنامج صوليد وركس.

ABSTARCT:

LPG serves as the main fuel for transportation globally, powering a variety of vehicles such as cars, trucks, buses, forklifts, sea vessels and airplanes. In 1983, legal regulations were established for the exploitation and use of liquefied petroleum gas as a fuel for cars in Algeria. The utilization of LPG in vehicles, including popular car models like the Renault Symbol, has been a focal point of Algeria's efforts. LPG conversion systems in these cars incorporate.

The aim of this study is to address the disadvantages and improve the LPG fuel tank so that it is suitable for Renault symbol.

We used the SolidWorks program in this study in order to obtain a tank with specifications and characteristics that correspond to the Renault symbol car.

Key Words:

CAR OF RENAULT SYMBOL, LPG fuel, Simulation, LPG conversion kit, LPG fuel tanks, flat tank, optimization, two-cylinder tank, Algeria, program SOLIDWORKS.

Résumé:

Le GPL sert de carburant principal pour le transport à l'échelle mondiale, alimentant une variété de véhicules tels que des voitures, des camions, des autobus, des chariots élévateurs, des navires et des avions. En 1983, des réglementations légales ont été établies pour l'exploitation et l'utilisation du gaz de pétrole liquéfié comme carburant pour les voitures en Algérie.

L'utilisation du GPL dans les véhicules, y compris les modèles de voitures populaires tels que le symbole Renault, a été au centre des efforts de l'Algérie. Les systèmes de conversion au GPL de ces voitures comprennent.

Le but de cette étude est de remédier aux défauts et d'améliorer le réservoir de carburant GPL afin qu'il soit adapté au symbole Renault.

Nous avons utilisé le programme SolidWorks dans cette étude afin d'obtenir un réservoir avec des spécifications et des caractéristiques qui correspondent à la voiture Renault symbol.

Mots Clés :

Carburant au gaz de pétrole liquéfié, simulation, kit de conversion de carburant GPL, réservoirs de carburant au gaz de pétrole liquéfié, réservoir plat, réservoir à deux cylindres, Algérie, Logiciel SOLIDWORKS.

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الحمد لله الذي بنعمته تتم الصالحات

الحمد لله الذي وفقنا لتثمين هذه الخطوة في مسيرتنا لطلب العلم بمذكرتنا هذه، ثمرة الجهد و النجاح

أمي التي فضلها سبق إنجازاتي، أنت جمهوري الوفي الدائم

إلى تاج فخر طالما حملته على رأسي، أبي، لك كامل الشكر والعرفان

إخوتي من بهم أكبر و عليهم أعتمد إليكم يا نعم السند

إليكن يا من بكن تحلو الحياة، يا قرة العينين و كامل الفؤاد، إخواتي

لمن لم تقصر لا بكلمة ولا بفعل في سبيل تشجيعي، ابنة أختي "بوحفص إسماء"

إلى أخوة الجامعة، من قضيت برفقتهم أجمل الأيام و عشت معهم أحلى الذكريات فكانوا أسعد الناس بنجاحي

إلى كل من سهر، بذل و ساهم في سبيل وصولي إلى هنا، و تبقى قائمتي مفتوحة فلا تسعني الورقة، ولا تسعفني الكلمات ...

إليكم جميعا أهدي تخرجي

إهداء

الحمد لله وكفى والصلاة والسلام على الحبيب
المصطفى وأهله ومن وفى
الحمد لله الذي وفقني لتثمين هذه الخطوة في
مسيرتي الدراسية بمذكرتنا هذه ثمرة الجهد والنجاح
بفضله تعالى مهداة إلى الوالدين الكريمين حفظهما الله
.وأدامهما نورا لدربي
إلى العائلة الكريمة كل باسمه التي كانت سندا لي ولا
تزال من إخوة وأخوات، إلى كل الزملاء والأصدقاء ذكورا
وإناثا ممن تشرفت بصداقتهم طوال مسيرتي الدراسية
إلى كل من ذكرنا في دعاءه
أهديكم فرحة تخرجي هاته والتي لا تسع الكلمات
لذكرها دمتم سندا وفخرا لي
أخوكم في الله لالي عبد الكريم
جامعة قاصدي مرباح ورقلة

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General Introduction

In recent years, the need for mobility has been growing rapidly due to a growing world population and expanding economies, particularly in regions such as Africa, Latin America, and Asia. This increased mobility has led to a higher demand for vehicles, including two and three-wheelers, cars, trucks, and more, requiring greater energy consumption. However, this surge in gasoline and diesel consumption has resulted in adverse effects on the environment, contributing to climate change and air pollution, which pose significant threats to public health worldwide [1].

To address these challenges, the adoption of alternative fuels, such as Liquefied Petroleum Gas (LPG), has emerged as a crucial solution to mitigate the negative impact of traditional petroleum fuels. LPG, a clean-burning fuel composed of propane and butane, offers tailored energy solutions to meet local needs in both developed and developing countries. LPG serves various purposes, including heating and transportation, and has gained popularity as a low-cost transport fuel in many nations. Its affordability enables individuals living in rural areas with limited access to public transportation to manage their fuel expenses effectively.

Recognizing the health and environmental benefits of LPG in improving air quality and mitigating climate change, as well as its practical and cost advantages over conventional and other alternative fuels, governments worldwide have actively promoted its use. Algeria, boasting the largest reserves of liquefied petroleum gas estimated at 4.5 trillion cubic meters, has undertaken significant efforts in recent years to utilize LPG as an alternative vehicle fuel. By reducing the consumption of gasoline and diesel, which have detrimental environmental impacts and higher costs compared to gas, Algeria aims to minimize harm to the environment and promote sustainable practices.

The historical significance of LPG as a fuel dates back to the early 1900s when it was first used for automobiles. However, it wasn't until the 1950s that LPG gained widespread adoption in transportation due to advancements in storage and transportation technologies, enabling safe and efficient utilization. Today, LPG serves as a major fuel for transportation globally, powering a diverse range of vehicles such as cars, trucks, buses, forklifts, marine vessels, and aircraft.

The utilization of LPG in vehicles, including popular car models like the Renault Symbol, has been a focal point of Algeria's efforts. LPG conversion systems in these cars incorporate various key safety features, ensuring the protection of the LPG storage tank located either in the trunk or underneath the rear of the car. These tanks are designed to withstand pressures several times higher than their normal operating conditions and offer safeguards against accidental damage, including rear-end collisions, which are risks also associated with conventional gasoline or diesel tanks.

One of the primary advantages of LPG as a transportation fuel is its cleaner-burning nature, resulting in lower emissions compared to gasoline or diesel, it is also less likely to cause engine knock, which can damage the engine and reduce fuel efficiency. Furthermore, LPG offers enhanced fuel efficiency, translating into potential cost savings for users. The economic and environmental benefits of LPG have contributed to its growing popularity as a transportation fuel, and this trend is expected to continue in the years to come.

Beside these advantages, installing an LPG tank in the car trunk has certain disadvantages to consider:

- **Reduced trunk space and accessibility:** The LPG tank occupies space that would typically be used for the trunk, making it less accessible for storing items. This can be inconvenient, especially for vehicles that require frequent access to the trunk. It is also a significant drawback if the vehicle is frequently used for transporting goods or luggage.
- **Weight distribution:** Placing a heavy LPG tank in the rear box can affect the vehicle's weight distribution. This imbalance may result in handling issues, reduced stability, and increased braking distances. It is crucial to ensure proper weight distribution to maintain safe driving conditions.
- **Rear-end collision vulnerability:** The LPG tank located in the rear box is susceptible to damage in the event of a rear-end collision. Just like gasoline or diesel tanks, the LPG tank may be at risk of rupture or other damage, potentially leading to fuel leakage or safety hazards.
- **Risk to damage LPG multivalve unit:** Placing goods or luggage in the vicinity of the LPG multivalve unit box can pose a risk of damage. It is crucial to ensure that the multivalve box remains adequately protected to prevent potential accidents.

In this dissertation, our aim is to address and mitigate some of the aforementioned disadvantages by optimizing the LPG tank installation. To achieve this, the dissertation is structured as follows:

A first chapter "Literature review" provides an introduction to LPG, covering its history, composition, characteristics, and an overview of conversion kits and their components. By exploring literature, we gain a comprehensive understanding of the current state of LPG technology and its application in vehicle conversions.

The second chapter "LPG tanks" focus on LPG tanks available types, their manufacturing processes, associated accessories, and installation methods. By examining the existing knowledge and best practices in tank design, we lay the groundwork for developing an improved LPG tank solution.

In the third and last chapter "Conception of an optimized LPG tank" we present our conceptual design for an optimized LPG tank dedicated to the Renault Symbol, while also considering its compatibility with other similar vehicles such as Dong Feng Mini-Trucks. We explore innovative approaches, taking into account factors like size, integration with the vehicle and multivalve protection. The goal is to propose an optimized LPG tank solution that addresses the disadvantages associated with conventional installations.

A conclusion at the end summarizes our work and provides recommendations for future research and development in this field. By structuring the dissertation in this manner, we provide a comprehensive exploration of LPG, its tanks, and the proposed solution. This work aims to contribute to the optimization of LPG tank installations, ultimately enhancing the safety and functionality of bi-fuel conversions for various vehicles.

Chapter I
Literature Review

I.1 Introduction

Vehicles typically run on "classic" fuels such as gasoline and diesel. There are also some fuels that can be used in internal combustion engines, in the name of alternative fuels. The most common are gaseous fuels, such as LPG fuel.

I.2 Definition

Liquefied Petroleum Gas (LPG) is a hydrocarbon gaseous fuel extracted from crude oil or natural gas. At normal temperature, LPG exists in the form of gas, but it will be liquefied under moderate pressure, so it is called liquefied petroleum gas [6].

Autogas is an acronym for Automotive Liquefied Petroleum Gas (LPG) liquefied gas used as fuel for motor vehicles, in Algeria is known by its commercial name “Sirghaz”.

LPG is the general term for hydrocarbon mixtures that transform from gas to liquid when compressed or cooled at moderate pressure. The chemical composition of liquefied petroleum gas varies, but it usually consists mainly of propane and butane (regular butane and isobutene). LPG is generally a 30% to 99% propane mixture. In some countries, the mixture changes depending on the time of year as the physical properties of the two gases vary slightly depending on the ambient temperature [1].

I.3 History

The LPG industry did not start until about 1904, more than 40 years after the start of North American crude oil and natural gas production around 1860 [2].

Moreover, if we look at the beginning of its use as a fuel in the car, it passed through historical stations:

- 1921: The LPG fuel appears for the first time in the United States of America, in the state of Michigan on a fleet of transporter trucks.
- 1969: French legislation authorizes propane as a fuel. Only for forklifts and small machines intended for the transport of goods not exceeding two meters in length. Prohibition for these to use the road network or to evolve in agglomeration.
- 1978: Volvo develops an engine powered by liquefied petroleum gas and equips a 245 station wagon, which will be tested, for 10,000 km. The project is abandoned during a study on methanol.
- 1978: The GPLc is authorized in France, in single-fuel only. Mercedes-Benz announces the manufacture of a gas turbine developing 115 hp, consuming between 8.3 and 10 liters depending on the operating cycle.
- 1980: Renault engages in the development of LPG vehicles with the R4 Van and the R5 Company.
- 1985: The LPG fuel is authorized in France in dual-fuel. Its price is aligned with that of diesel fuel.
- 1987: 590,000 vehicles running on LPG are registered in the Netherlands, including 130,000 trucks.
- 1988: 1380 service stations distribute LPG in France on the road and motorway network.
- 1989: In Tokyo, the fleet of taxis using dual-fuel LPG reaches 250,000 vehicles.
- 1994: 1,100,000 vehicles running on LPG are registered in Italy.
- 1995: In France, the LPG fuel car fleet barely reaches 30,000 units, represented mainly by company fleets. The number of gas stations distributing LPG fuel drops to 700.
- 1996: In January, the French government eases the taxation of the LPG fuel. The litter goes from 4.70 F to 2.55 F. Renault offers for the first time in its catalogue, two models: a 1.2l Clio and a 1.4l Express.

At the same time, a draft law on air provides for numerous tax advantages related to this new fuel (exemption from the vignette and the gray card). The Air Act recognizes LPG as a clean fuel [3].

- Late 90's: the emergence of high-pressure direct injection on new diesel engines.
- 2000: marketing of the first hybrid vehicle, the Toyota Prius.

- 2001: establishment of European approval for manufacturers of LPG vehicles (directive 70/156, amended for LPG) [4].

In Algeria, the history of using LPG as a transportation fuel has passed through these stages:

- In 1978: The beginnings of study and experimentation of liquefied petroleum gas.
- 1983: Establishing legal regulations for the exploitation and use of LPG as a fuel for cars.
- 1985: Development of an action plan for the introduction of LPG as a fuel for cars in terms of distribution and installation.
- 1995: The opening of the activity of converting cars from the gasoline to LPG system.
- 1997: The field of distribution of LPG was opened to the private sector.
- 2016/2018: Numbers of measures have been taken to encourage the use of LPG as fuel, including raising the price of gasoline and diesel, fixing the price of liquefied petroleum gas, and taking a set of financial, tax and even legal measures to direct the consumer towards LPG [5].

I.4 Composition and characteristics

The main components of LPG are propane and butane; mainly a mixture of 40% of propane and 60% of butane

- Propane - C_3H_8 is a saturated hydrocarbon with an energy value of 46 $MJ.kg^{-1}$ and calorific value of 11.070 $kJ.kg^{-1}$ [4].

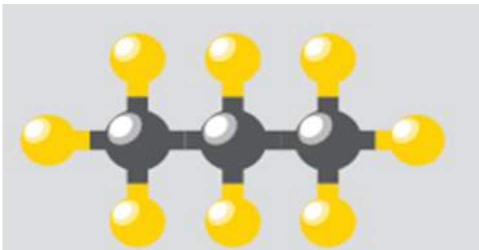

Figure I.1: *Propane C_3H_8 structure [6].*

- Butane - C_4H_{10} is highly inflammable and easily liquefiable gas with an energy value of 45 $MJ.kg^{-1}$ and calorific value of 10,920 $kJ.kg^{-1}$ [4].Butane consists of four carbon atoms and ten hydrogen atoms and has two isomers, n-butane and iso-butane (n-butane and iso-butane) have the same chemical formula (C_4H_{10}), but their atomic space Different arrangements have different properties, for example, n-butane has a boiling point of -0.5°C, while iso-butane has a boiling point of -12.8°C. Due to their material and combustion properties, both liquid gases are suitable for many possible applications. When used as fuel for vehicles with internal combustion engines, the liquid gas is also known as LPG [6].

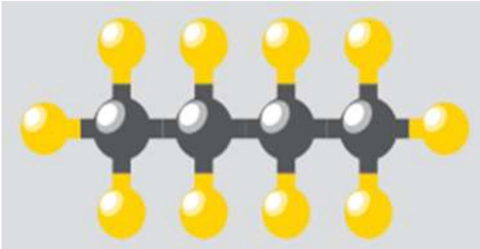

Figure I.2: *n-Butane C_4H_{10} structure [6].*

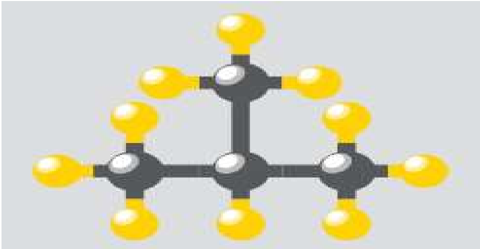

Figure I.3: *iso-Butane C_4H_{10} structure [6].*

LPG characteristics are the followings:

- LPG is a gasoline-like fuel. It has an energy value of 45 MJ/kg and a density of 0.55kg/L. LPG is heavier than air when gaseous and lighter than water when liquid [7].
- LPG is not harmful when considering its impacts on human health; however, it is unbreathable and has mildly toxic consequences. The propane-butane combination is colorless and odorless. Additional components (Ethyl Mercaptan) are required to detect LPG leakage [7].
- When compared to gasoline or diesel, autogas has the potential to significantly reduce NOx and hydrocarbon emissions, and it contains very few harmful metal compounds. Due to the reduced amount of sulfide in it when using a LPG fuel engine, wear and tear is also reduced.
- The higher the octane number of LPG, the smoother the operation and the elimination of vibrations. These two elements allow for a large boost in the life of an LPG-powered engine, achieving lifetime comparable to diesel engines. Because LPG combustion is nearly complete, there is much less deposit in the engine compared to gasoline. The engine does not become unclean, and its service life is increased. Engine oil, on the other hand, keeps its lubricating characteristics for a longer period than gasoline.

Table I-1: *Characteristics of LPG fuel [].*

Characteristics	Butane	Propane	LPG
Chemical formula	C4H10	C3H8	Mix. of mainly 40% C3H8 and 60% C4H10
Burning velocity (cm/sec)	32 in air	32 in air	32 in air
Molecular weight	58	44	50
Specific weight (Kg/l)	0.580	0.510	0.54
Boiling point (°C)	-0.5	-43	-0.5–43
Lower heating value (Kcal/Kg)	10920	11070	10997
Fire point (°C)	490 atm	510 atm	~500 atm
Ignition limits (% of volume)	1.5–8.5	2.1–9.5	1.5–9.5

I.5 LPG in transportation

I.5.1 Worldwide

The use of LPG in the transport sector has grown steadily over the past decade, reaching almost 8% of total global LPG demand. New figures from the 2021 WLPGA Global Statistical Review show that more than 29 million vehicles worldwide use LPG as their primary fuel, an increase of 1.6 million from 2019 [8].

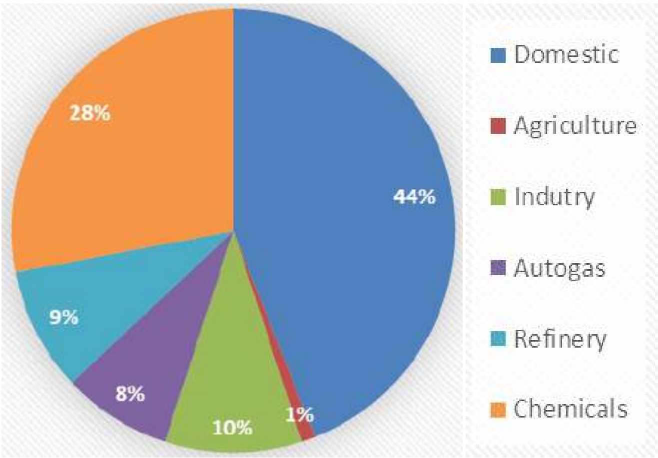

Figure I.4: *LPG consumption by sector in 2020 [8].*

More than 24 million tons of LPG was consumed worldwide as a transport fuel in 2020. A decrease of 2.8 million tons compared to 2019. However, this percentage reduction in demand is lower than the reduction achieved, recorded by gasoline in 2020.

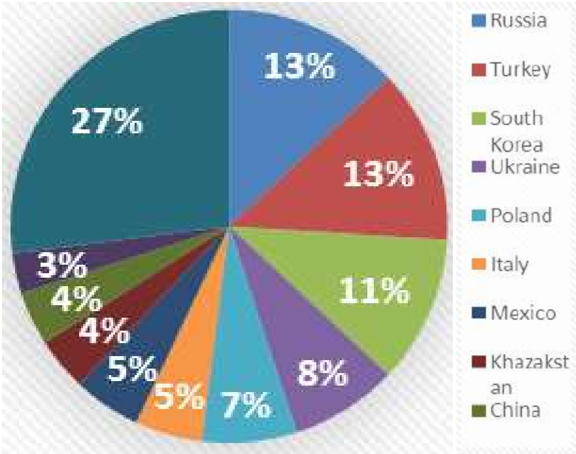

Figure I.5: *Autogas Demand in 2021 by country [8].*

The pie chart in figure I.5 depicts the top 10 Autogas consumption countries. In 2020, the top ten nations will account for 73% of global Autogas demand. Russia is the largest Autogas market in terms of volume, with 3.22 million tones of demand in 2020 and 3.0 million vehicles. Turkey has the largest Autogas fleet, with 4.65 million vehicles now on the road, suggesting that LPG fuels more than 40% of private cars [8].

Recently, some nations in Southern and Eastern Europe have seen significant rise in Autogas consumption. In Greece, for example, Autogas was first introduced in the 1980s, but its use was initially restricted to taxis. In the aftermath of the financial and economic crisis, the government imposed a steep increase in excise rates on gasoline and diesel that was more than that imposed on Autogas in order to earn additional tax money, making Autogas the cheapest fuel alternative for Greek motorists. Since then, the Greek Autogas industry has grown rapidly [8].

Similarly, Spain has a very tiny Autogas market, but it is fast developing because of a significant tax incentive and several national and local programs to encourage the use of the fuel for environmental reasons. In 2020, the number of Autogas vehicles reached about 100,000, a 20% increase over 2019 [8].

Autogas is appropriate for all vehicle categories, including buses and large cargo trucks, vans, passenger automobiles, and even two and three wheelers. While passenger cars make up the majority of the Autogas market in Europe, LPG is becoming an increasingly popular option in North America for fleets of trucks, buses, and delivery vans. Two and three wheelers powered by Autogas are prevalent in India and Bangladesh[8].

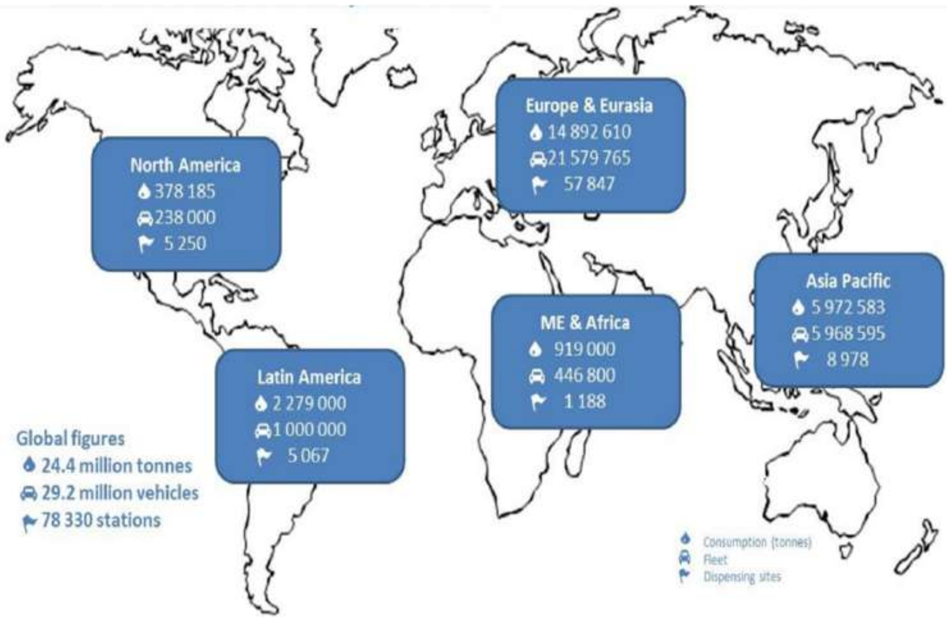

Figure I.6: *Statistical review of global LPG – 2021 (WLPGA/Argus Media) [8].*

I.5.2 In Algeria

Because of Algeria's enormous supplies of liquefied petroleum gas and it's environmentally beneficial properties; Algeria has worked out a program in the few last years (between 2018 and 2021) that includes the conversion of 500 thousand cars to the LPG fuel system as the table I-2 shows. During the same period, it has also increased the number of stations that are available on LPG fuel from 30% in 2018 to 75% in 2021 [5].

Table I-2: *Converted cars per year [5].*

The year	Number of cars converted
2018	100000
2019	120000
2020	130000
2021	150000
Total	**500000**

Algeria's financial crisis, which began in 2014, has contributed to this, as well as the subsequent rationalization of consumption, a new pricing policy was also adopted including raising fuel prices except for LPG [5].

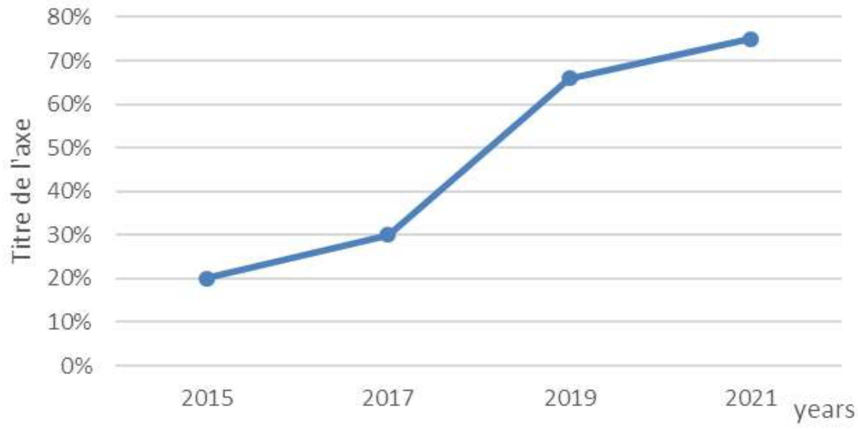

Figure I.7: *Number of gas stations that LPG is available in Algeria [5].*

Also the horizons 2030 program aims to convert 1.1 million cars by 2030 by raising the National Stock of cars operating on the LPG fuel system to 30% of gasoline-powered cars and increase the number of stations operating with LPG fuel [5].

I.6 LPG conversion kit

Vehicle LPG systems are utilized for alternate fueling. The liquefied petroleum gas (propane-butane) is compressed to approximately 10 bar (down to 3 bar in winter) and flows out of the tank via a multi-valve and a pressure line (plastic or copper) before being delivered to the engine compartment via a solenoid and a reduction. The reducer (vaporizer) lowers the gas pressure to around 1.5 bar in order to convert the liquid to gas. This change necessitates heating the reducer with engine coolant. The gas is then routed through a volatile phase filter to injectors with outlets close to petrol injectors. When autogas fuelling is activated, the injectors feed the gas in time with theoretical petrol injection. The procedure is overseen.

The process is synchronized with petrol fueling, which is regulated by the ECU, ensuring consistent system control over engine operating conditions, fume emission levels, and optimum catalytic conversion. Such gas injection control is based on the optimized algorithms of the most recent petrol ECU units, including those with OBD diagnostic capabilities, and does not cause any conflict between the fuel delivery systems.

The main components of an LPG conversion kit are (as shown in figure I.8): the controller, injectors, reducer, tank and some other pieces.

1- Controller, 2- Gas injectors, 3- Solenoid valve, 4- Reducer,
5- Gas filter, 6- Pressure sensor, 7- Fuel switch, 8-Tank.

Figure I.8: *An LPG conversion kit [9].*

I.6.1 The controller

The controller is the LPG-injection system's central processing unit. It connects to the car's conventional gasoline controller and emulates the signals sent by the gasoline controller to regulate the LPG injectors. It also constantly examines information from three sensors to ensure optimal operating conditions. Depending on the LPG pressure levels, it automatically deactivates the petrol injectors and activates the LPG injectors.

Figure I.9: *The Controller.*

While installing it:

- Controller should be mounted to fixed elements that are not exposed to extreme temperatures or moisture, with the connector socket pointing downwards.

- All electrical cables should be insulated and laid so that they do not interfere with other vehicle components or come into contact with moving parts or hot elements.
- Controller supply lines should be connected directly to the battery.
- All electrical connections should be soldered and well insulated [9].

I.6.2 LPG injectors

LPG injectors are used to inject LPG into the intake manifold and are controlled by an electric current via a solenoid. The size of the injector is determined by the engine capacity, and each cylinder has its own injector. [10].

Figure I.10: *LPG injectors [19].*

Special attention must be made to the rail's alignment in relation to the order of the injectors and must be linked to that inlet duct with its corresponding hose, as the system injects the fuel based on the original ECU's injection time reading.

To keep the car soundproof, the injector rail should be attached to the intake manifold or another component that moves with the engine, rather than to the vehicle body, which would increase the sonority of the injector assembly [11].

I.6.3 Solenoid valve

When the vehicle is in Petrol mode, the solenoid valve is used to cut off the flow of LPG. It is installed between the Tank and the Reducer and is likewise controlled by an electric current [10].

Figure I.11: *Solenoid valve [19].*

Installation is carried out in a location that allows for easy filter change and as close to the reducer as it can be [9].

I.6.4 Reducer

The reducer is the first critical component in ensuring proper LPG system operation across the whole load range. Its primary function is to maintain the pressure in the LPG intake system (reducer, injector) and convert the liquefied gas to vapour (adiabatic expansion), resulting in a fast drop in gas temperature [9].

Figure I.12: *The reducer [19].*

I.6.5 LPG Filter

The purpose of an LPG fuel filter is to remove dirt and foreign substances from the fuel, and it can only be replaced as a whole. Filter maintenance is crucial to the proper operation of the fuel system, and it must be replaced on a regular basis.

Figure I.13: *LPG fuel filter [19].*

I.6.6 Pressure sensor

The pressure sensor functions as a safety feature, cutting off the LPG supply and allowing the engine to run in petrol mode.

A pressure sensor is used to measure the injection pressure, and it automatically regulates the pressure in the LPG fuel line based on the pressure supplied by the fuel pump. The LPG fuel pump is a diaphragm pump that circulates LPG via the fuel system. The pump must have a maximum pressure of 6 bar. [10]

Figure I.14: *The pressure sensor [09].*

The pressure sensor should be fitted on the gas tube between the LPG fuel filter and the LPG injector. [12]

I.6.7 Fuel switch

Pressure switches are simply sensors that respond to variations in fluid pressure and perform on/off operations on flow based on pre-programmed switching points. They provide critical safety functionality in power, oil, and gas applications such as liquid transfer and pump systems for LPG.

Figure I.15: *Gas/petrol switch and indicator of fuel [11].*

I.6.8 Tank

In cars, the LPG tank is shaped as an annular or cylindrical tank in the luggage area.LPG is stored as a liquid in the fuel tank. When the tank is full and the temperature is 27°C, the approximate pressure in the tank is 16.5 bar [13].

Figure I.16: *Toroidal and cylindrical LPG tanks [19].*

Chapter II
LPG Fuel Storage System

II.1 Introduction

Storage fuel tanks used in the automotive industry have technologically advanced components, and their design considers super shapes design variables, specific structural parameters, and precise geometrical conditions of linkage. In this chapter we will focus on LPG tanks: their types, manufacturing, installation, safety, accessories…

II.2 Liquefied petroleum gas fuel tanks

All LPG systems are supplied with an LPG tank affixed to the vehicle, usually in the boot or underneath. Under pressure, the LPG is held in the tank as a liquid. The tank is completely sealed, and there are safety features in place to prevent over-pressurising or over-filling. To allow for liquid expansion (LPG liquid expands at temperatures many times higher than water), it can only be filled to 80% of its capacity.

II.2.1 Types of LPG fuel tanks:

There are numerous tank sizes and configurations available, generally; there are two forms of LPG tank: cylindrical and toroidal (doughnut) tanks.

II.2.1.1 *Cylindrical tanks*

Cylindrical tanks can be used in vehicles that do not allow for the installation of toroidal tanks (no usual spare wheel recess, for example, Honda CRV - spare wheel on the door), as well as if the vehicle owner desires to have both a spare wheel and a gas tank. They are fitted as chassis components within the vehicle frame's area [14].

Cylindrical tanks are mounted using a mounting frame and bolt connections. The required connection strength is ensured by installation of mounting frames as well as bands, the strength of which is confirmed through relevant tests conducted by the tank manufacturer.

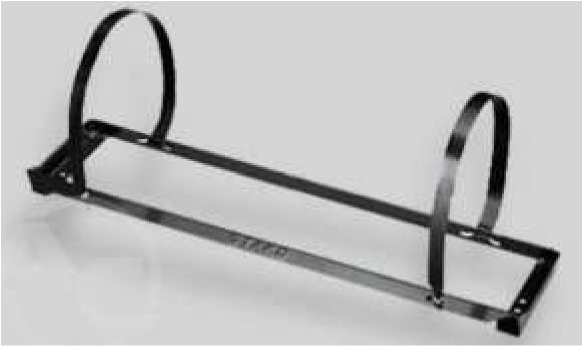

Figure II.1: *A frame for a cylindrical LPG tank [12].*

The tank should be positioned perpendicular to the vehicle's longitudinal axis, leaving 10 cm between the tank and the back seat. There is no need to leave the 10 cm space if the tank is mounted in the boot, which is divided from the rear seat by a divider, and there is no risk of contact between the tank and the back seat [12].

Figure II.2: *A fitted LPG tank [12].*

II.2.1.2 *Toroidal tanks*

A Toroidal tank type dedicated for LPG fuel storage is also known as doughnut tank. The storage fuel tanks, made from various types of steel or aluminum alloys, are used in the automotive industry for safely storing LPG.

A Toroidal storage tank is a complex geometrical product that can be considered as a shell in the form of the surface of revolution with the wall thickness very small in comparison with its other dimensions. The dimension of the tank selected for the car is based on the area of the spare tire of a vehicle [15].

Figure II.3: *A Fitted toroidal tank [12].*

Toroidal tanks should be mounted to metal vehicle elements with the included parts (Figure II.3).Orifices in the bodywork must be cut to allow for the routing of the gas tubes, ventilation of the gas tight housing (the inside of the torus), and installation of the fitting bolts. Under the tank, a plastic support should be installed. Gas tubes and the wire harness are installed once the tank has been placed. All mounted bolts and screws should be protected against corrosion (Figure II.4) [12].

Figure II.4: *The view from underneath of the vehicle after installation of the tank [12].*

II.2.2 Manufacturing

II.2.2.1 *The material*

Steel used to construct storage tanks is classified into two types: carbon steel and stainless steel. Carbon steel is favoured over stainless steel whenever possible since it is much less expensive. Low-carbon steel, sometimes known as mild steel, has between 0.05% and 0.15% carbon; as a result, it is very pliable and can be bent, rolled, and welded into desired shapes. Because of its flexibility, carbon steel plates are easily formed into the basic "disc and donut" assemblies used to construct many finished storage tanks [16].

II.2.2.2 *Steps of manufacturing*

The first stage is to gather a large quantity of metal sheeting in various forms and sizes for the LPG tanks. Sheeting for this particular manufacturing is made up of a variety of disks and flat sheets, which are kept and sorted before usage. To begin the procedure, steel disks are placed in a 500-ton special press and shaped into the hemispherical ends of the tanks. A competent person manipulates the sheets, controls the press, and inspects each piece to guarantee it was pressed correctly.

Figure II.5: *Forming a half-tank by means of a pressing machine [16].*

Once pressed into a donut shape, the parts are then stored ready for the next part of the process. The next part of the process is to mount the end caps into another special machine to trim them down, this machine works similar to a large can opener with a sharp metal disk that trims off a strip of the tank part as it spins.

For more cylindrical tanks, sheet metal is passed through a series of presses and rollers to make bands of metal into which valve pieces are set. Valves are also included within the rings to allow LPG to be filled and drawn from the tanks once complete. Information plates are also welded into place on parts as required [16].

Figure II.6: *Cylindrical tanks under manufacturing [16].*

When the major components of the LPG tanks are complete, the next step is to join them together. Each half of the tank is placed in yet another machine and then the spot-welded top holds the two parts together. Once done, the tanks are then transferred to another lathe-like welding machine for further welding; this machine works independently and creates a very strong weld between the parts of the tank.

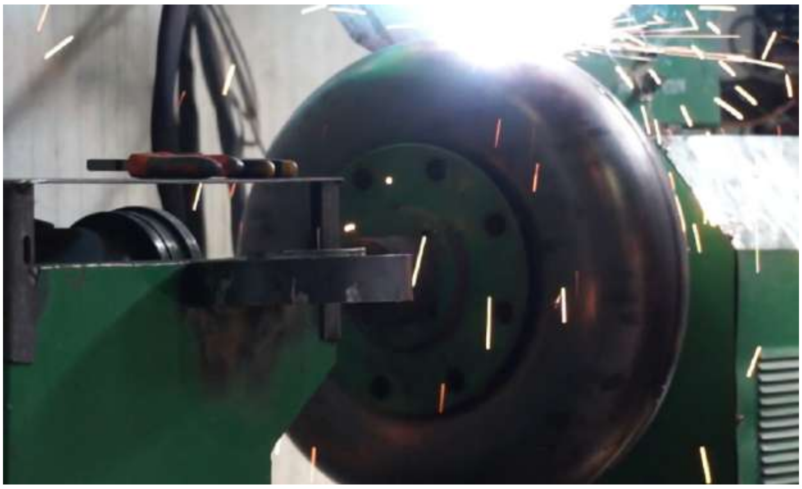

Figure II.7: *Welding the parts of a toroidal tank [16].*

This machine is quite adaptable, as it may be used to weld tanks of all forms and sizes. A qualified person is present at all stages of the welding process to monitor the operation and intervene or rectify as needed [16].

With the main tanks completed, the next step is to cover the tanks. The tanks are suspended from the hooks, placed in a ready-made large coating machine and heated / cleaned for a period of time. Once finished, the tanks are removed from the machine and left to cool.

Figure II.8: *Coating the tanks [16].*

II.2.3 Experimental burst tests

It is critical to assure safety when constructing an LPG tank; hence a flame exposure test is performed. To check the gas filling status by combining the tank and the gas valve, the LPG and the water density are compared; for example, approximately 80% of the water is loaded into a 72-liter tank to confirm the actual capacity of 72 litters, and then the LPG is fully charged into the container. The LPG tank container is heated from the outside during the flame exposure test to assess the tank's pressure. As the flame progresses and a certain period of time passes, the pressure in the tank container rises, and the fusible (lead) associated with the flame rises as well [17].

II.3 Tank accessories

II.3.1 LPG multi valve

II.3.1.1 *Components*

LPG tanks come with a standard connector where a multi-valve will be installed. Its function is to control the inlet/outlet of LPG from/to the tank. Furthermore, when 80% of the level is reached, it blocks the filling. If the pipeline is accidentally broken, it also stops the outlet. It also allows checking the LPG level with a gauge and sending the information to the switch and level indicator while driving [11].

Figure II.9: *A multivalve [18].*

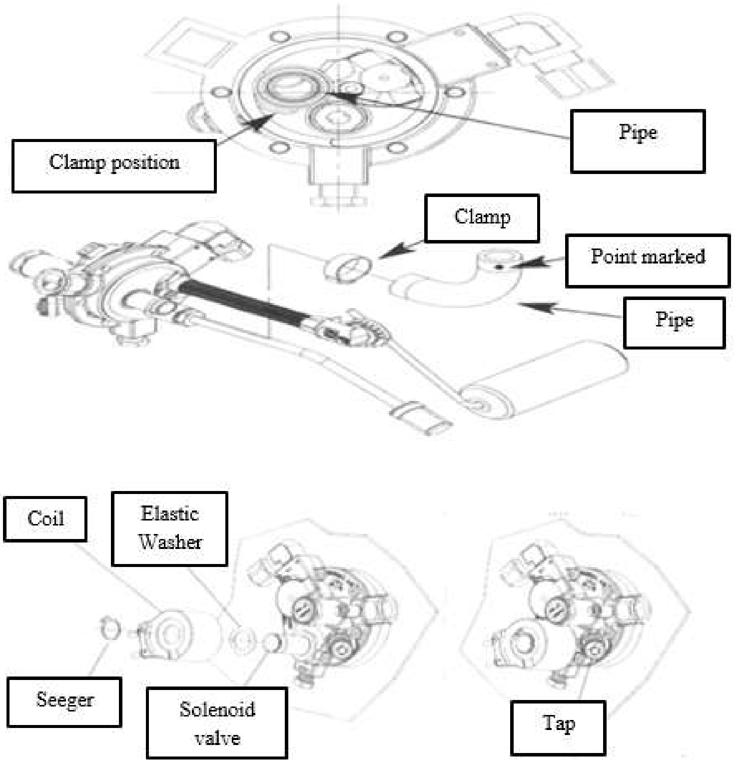

Figure II.10: *Multi-valve components [18].*

II.3.1.2 *Functions*

The multi-valve has the main safety functions in order to protect:

- **Pressure relief valve (PRV):**

The pressure relief valve, which includes a retaining spring, facilitates the release of LPG in the vapour phase from the tank in the event of an overpressure (20 bar), preventing the tank from exploding [].

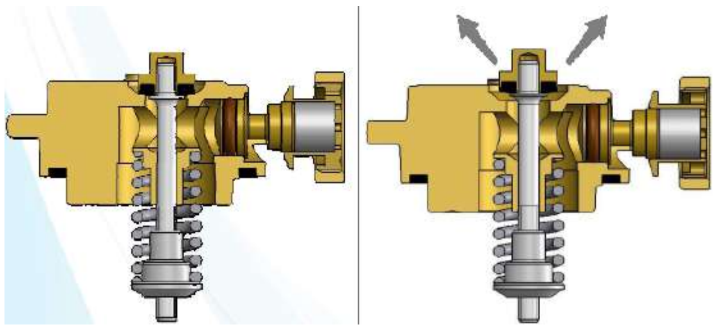

Figure II.11: *The release of overpressure [21].*

- **Thermofuse**

In the event of a fire; the thermofuse element that melts at a predetermined temperature of 120 °C, enables the opening of a large hole in the valve body for the rapid release of gas from the tank, preventing the tank from exploding [19].

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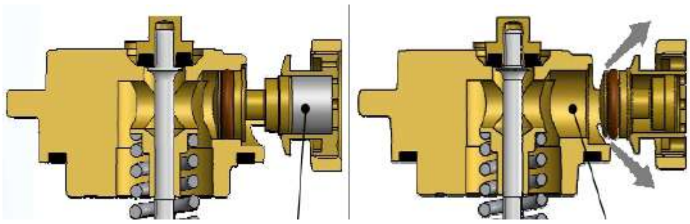

Figure II.12: *Thethermofuse [20].*

- **Excess flow valve**

The withdrawal circuit's excess flow valve is situated upstream of the solenoid valve and is designed to stop the flow of LPG in the event that the LPG pipe is accidentally broken. A residual flow is permitted following its intervention to enable for the automatic resetting of the valve [20].

- **Manuel valve**

The manual valve is intended to maintain the solenoid valve and intercepts the outlet gas circuit upstream of the solenoid valve in case of maintenance of the system.

Figure II.13: *Themanual valve [20].*

- **80% fill limiter system**

The 80% fill limiter uses a float, a rod, and a unique mechanism with a rotating cam to close the filling valve when 80% of the tank capacity is achieved.

- **Entry pipe fitting**

This fitting is used to join the copper pipe coming from the filling point to the multivalve.

Figure II.14: *The inlet [20].*

- **Outlet pipe fitting :**

  Fitting for a copper line at the multivalve outlet where LPG is sent to the engine.

Figure II.15: *The outlet [20].*

- **Shut-off solenoid valve**

When the engine is off or running on gasoline and the electric supply to the solenoid is turned off, a spring inside the solenoid valve keeps the moving core in the closed position. When the engine is switched to LPG, however, the electric supply to the solenoid is turned on, and the solenoid generates a magnetic field that attracts the plunger, allowing the opening of the valve [20].

- **Electronic level indicator**

  The level indicator should be chosen according to the adopted ECU system.

Figure II.16: *The level indicator [20].*

II.3.1.3 *Installation*

Before installing the multivalve, the safety valve rubber pipe must be installed. It is recommended to secure the pipe using the special "click" clamp, hooking it so that the area it occupies is incorporated in the multivalve rear profile and does not interfere with the multivalve introduction in the ring-nut.

The pipe ought to be installed so that, after the multi valve assembly, its intake (marked with a point) in the gaseous phase is turned upwards (Figure II.10) [18].

While assembling the tank and its multivalve, the six screws must be tight as shown in figure II.11. A dynamometric wrench should be used to obtain the tightening torque.

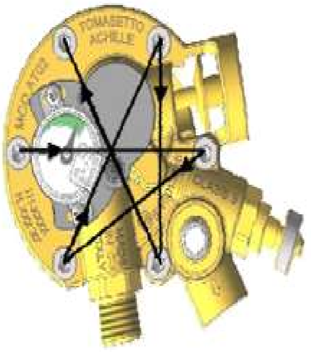

Figure II.17: *Operation sequence for screws fixing [21].*

After the multivalve have been installed and after having introduced some litres of gas (around 10 or more, on particularly big tanks), the multivalve good working and the total absence of leaks must be check by using soapy water or leak-detecting liquid, by sprinkling all the fittings and orifices of the multi valve. The correct operating verification of automatic filling level limiter is done by rotating the tank and checking the level sensor's correct indication (Figure II.12).

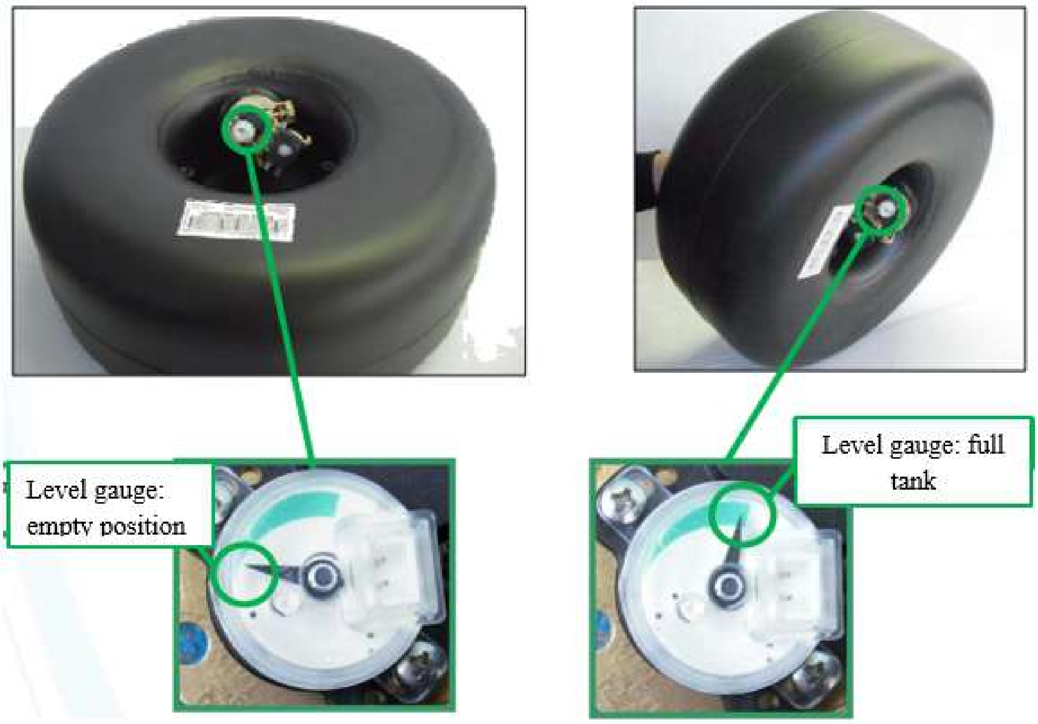

Figure II.18: *80% system check [21].*

II.3.2 Gas pipe

The gas pipe is an essential part of the kit. It is constructed of a sturdy copper tube that transports gas (in liquid form) from the LPG tank to the engine compartment. To prevent leaks, this pipe must be highly reliable, and the installer must be careful not to route it too close to the exhaust system or around any electrical components that could create a fire.

In order to install the gas pipe, all pipes connected to tanks or the rest of the equipment must have "curls" to prevent breakage in the event of displacement due to an accident. Those "curls" should be as close to the connection's ends as possible. The "curl" will have a diameter of no less than 50 mm, a minimum of one turn, and a gap between turns of no less than 2 mm. The "curls" omegas, and curves must be formed in such a way that, in the event of deformation of the vehicle due to hits on the front or side nearest to the "curls," they tend to lengthen, preventing constriction or breakage; with gasoline leaking, this would cause the "curls" to break. [11].

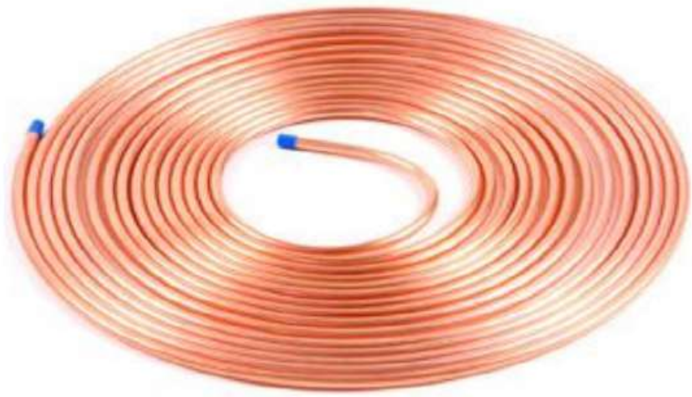

Figure II.19: *The gas pipe [13].*

The fixing of the piping under the chassis must be made with the clamps provided in the kit, and the clamps must be placed at least every 300 mm, avoiding at the same time the proximity to the mobile parts of the vehicle or contact with sharp edged parts of the vehicle body, and keeping distance from exhaust pipes and catalytic converters [11].

II.3.3 The venting pipes

The role of ventilation pipes is to ensure a constant air flow when the car is moving.They must be installed near the vapour box, and special care must be taken to avoid venting discharge on the combustion gas outlet, and the location of the venting pipes must not allow partial or total valve obscuration due to mud accumulation or mud guards. Hoses will be connected to the mouthpieces and to the vapour box [11].

Figure II.20: *Venting system [11].*

II.4 LPG tank test

LPG tanks must be periodically retested every five years and totally replaced after fifteen years of its production according to the Algerian legislation. During the inspection, the tank is pressure tested to a 1.5 times the service pressure, and checked for leaks. If the tank meets the standards, it must be marked with a new date.

When dismantling the LPG tank to test it or for any possible maintenance operations, the tank must be totally empty before loosening the six screws, keeping any LPG leftovers in the tank in mind.

Chapter III
Conception of an Optimized LPG Tank

III.1 Introduction

As man always works on inventing things according to his need and discovering easy ways to facilitate his life with complete ease in various fields; ourwork in this chapter is to find solutions and address the problems raised earlier in the general introduction concerning the LPG tank.

III.2 Inconvenient of placing an LPG tank inside the trunk

The storage of liquefied petroleum gas (LPG) for vehicles depends on a tank of cylindrical or annular shape only, which is characterized by conditions and characteristics according to the type of vehicle. Their installation in the trunk of the car or in the spare wheel placement has some disadvantages:

- The cylindrical tank for LPG fuel takes up a considerable volume of the car trunk, as well as the inability to take out the spare wheel and insert it into its assigned position.
- In the presence of the toroidal tank, it forces us to dispense with the spare wheel, which takes the position of the wheel.
- The position of the multi-valve is unsafe, especially relative to the cylindrical tank, where it is prone to breakage.

To address these disadvantages, some manufacturers have developed alternative storage solutions for LPG, such as:

- Under-floor tanks: These tanks are installed under the vehicle, which frees up space in the trunk and allows the spare wheel to be retained.

- Towing tanks: These tanks are mounted on a trailer and towed behind the vehicle. This is a good option for vehicles that do not have enough space for an under-floor tank.

III.3 Conception

III.3.1 Flat tank

The major concept that we believe can address these drawbacks is to modify the tank so that its shape is suitable for the automobile trunk's proportions.

The multivalve can also be installed on the tank's underbelly, which is accessible from underneath the car. This will result in more usable space in the trunk (things may be placed on the tank without any issues), and as the multivalve is accessible from underneath the car, there won't be a requirement for a venting system.

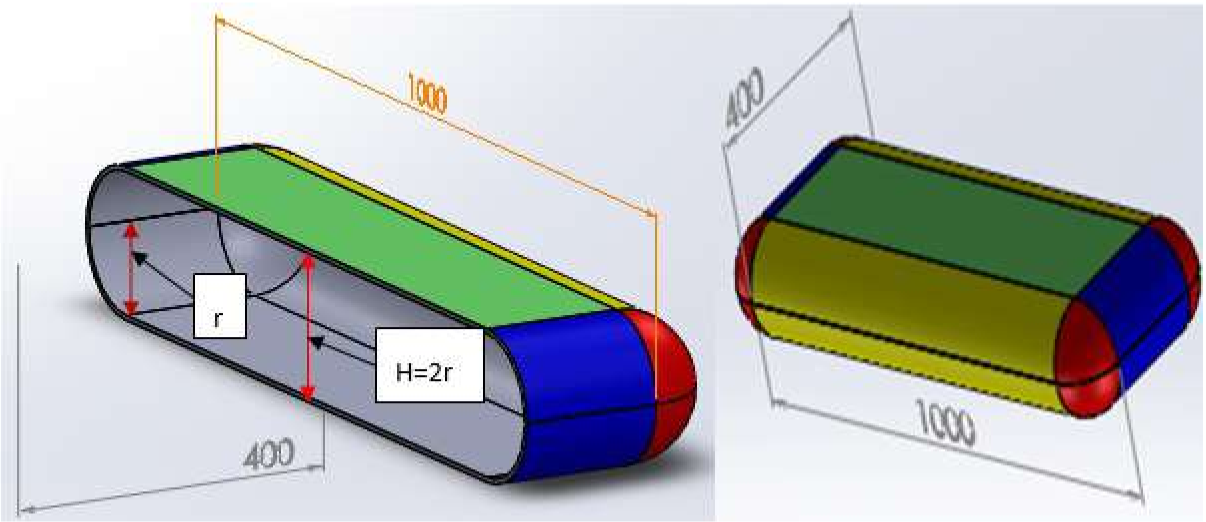

Figure III.1: *The typical shape of the tank.*

III.3.1.1 *Tank dimensions*

In order to get a tank of a size similar to the cylindrical tanks usually installed on the Renault Symbol, we have taken the volume equal to 60 litres.

Figure III.2: *Dimensions of the Renault Symbol trunk.*

As the Figure III.2 shows, a length of 1020mm is available, so the optimized tank should have 1000 mm length. We have taken in mind that the tank must fit in its place smoothly when installing or repairing. In the other hand, and to allow to the spare wheel to be taken out from its position and put it back easily; the width of the tank should not exceed 400mm.

It is clear from the Figure III.1 that the size V of the tank is formed of a long cylinder (blue and yellow parts), a cuboid (the green part) and a sphere (red). The total size is calculated as follows:

1. **Cylinder**

V_C: The total volume of cylinders:

$$V_C = V_Y + V_B \qquad \text{III.1}$$

$\boldsymbol{V_Y}$: Represents the volume of the yellow cylinder shown in the *Figure III.3*

$$V_Y = \pi * r^2 * a \qquad \text{III.2}$$

$\boldsymbol{V_B}$: Represents the volume of the blue cylinder shown in the *Figure III.4*

$$V_B = \pi * r^2 * b \qquad \text{III.3}$$

So the total volume

$$V_C = (\pi * r^2) * (a + b) \qquad \text{III.4}$$

2. **Cuboid**

$$V_{Cu} = (L - 2r) * (W - 2r) * 2r \qquad \text{III.5}$$

$$a = L - 2r ; b = W - 2r \qquad \text{III.6}$$

$$V_{Cu} = a * b * 2r \qquad \text{III.7}$$

3. Sphere

$$V_S = \frac{4}{3} * \pi * r^3 \qquad \text{III.8}$$

The total size is then:

$$V = V_C + V_{Cu} + V_S \qquad \text{III.9}$$

$$V = \left(\frac{4\pi r^3}{3}\right) + \left(\pi(1400 - 4r)r^2\right) + (4(500 - r)(400 - 2r)r) \qquad \text{III.10}$$

$$\left(\frac{4\pi r^3}{3}\right) + \left(\pi(1400 - 4r)r^2\right) + (4(500 - r)(400 - (2r))r) - V = 0 \qquad \text{III.11}$$

Leading us to solve the following equation:

$$\left(\frac{4\pi r^3}{3}\right) + \left(\pi(1400 - 4r)r^2\right) + (4(500 - r)(400 - 2r)r) - 60000000 = 0 \qquad \text{III.12}$$

Using an online equation solver (dcode.fr); we have found that this third-order equation accepts the following three roots:

$$r_1 = -3757.89 \ ; r_2 = 86.5622 \ ; \ r_3 = 488.506$$

As r is a dimension and represents the radius of the cylindrical part, it can't be negative, so the chosen value of r is equal to$86{,}5mm$.

We took the value of r equal to:$r = 90mm$

$$H = 2 * r = 2 * 90 = 180mm$$

III.3.1.2 *Test simulation*

In order to ensure the reliability of the LPG fuel tank, the company responsible for its manufacture tests it under a pressure of 30bars. From this point of view, we simulate the reliability of our conception through the SolidWorks program by applying a pressure of 35 bars to the interior of the tank. Figures III.3 and 4 shows the results of deformation and stress.

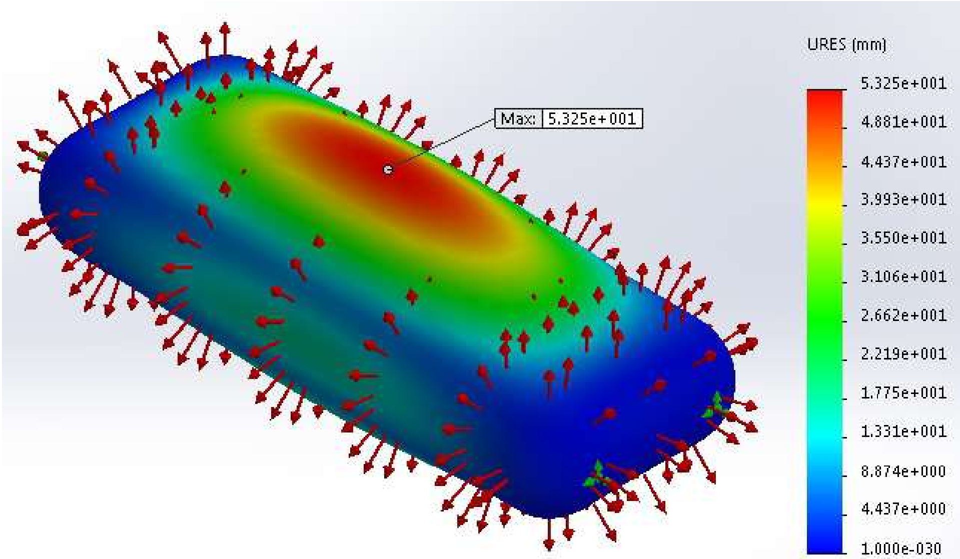

Figure III.5: *Deformation under a pressure of 35 bars.*

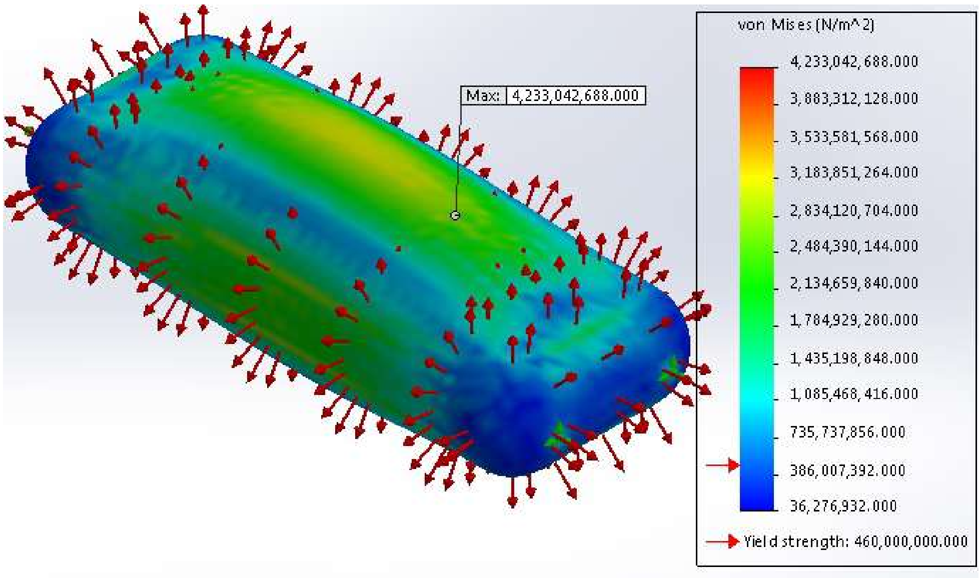

Figure III.6: *Stress distribution under a pressure of 35 bars.*

By applying 35 bars of pressure, we observe that the two ends of the tank were not been deformed, on the contrary, there was a bulge at the flat surfaces of the tank recording a deformation up to53 mm. On the other hand the stress has reached $4233\ N/mm^2$ while the yield strength is only$460 N/mm^2$.

As the tank will not resist, and the deformation is so high, we have implemented a design improvement. Within the tank, we have installed two robust columns strategically positioned to provide additional support. These columns are specifically engineered to bear the load and counteract the forces exerted on the tank, thereby enhancing its resistance.

Re-simulation leads us to the following results where a reduction of stress and deformation is recoded.

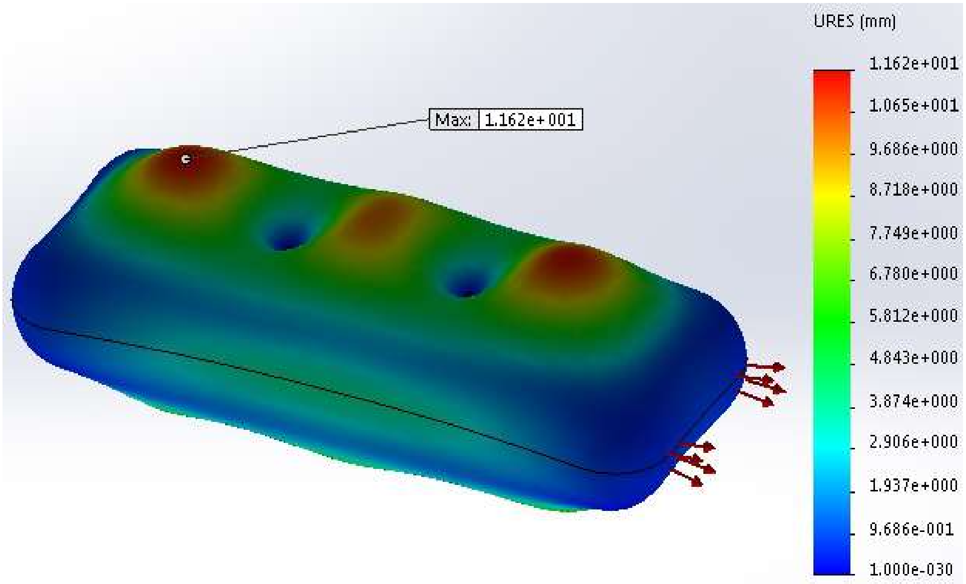

Figure III.7: *Deformation with two columns inside.*

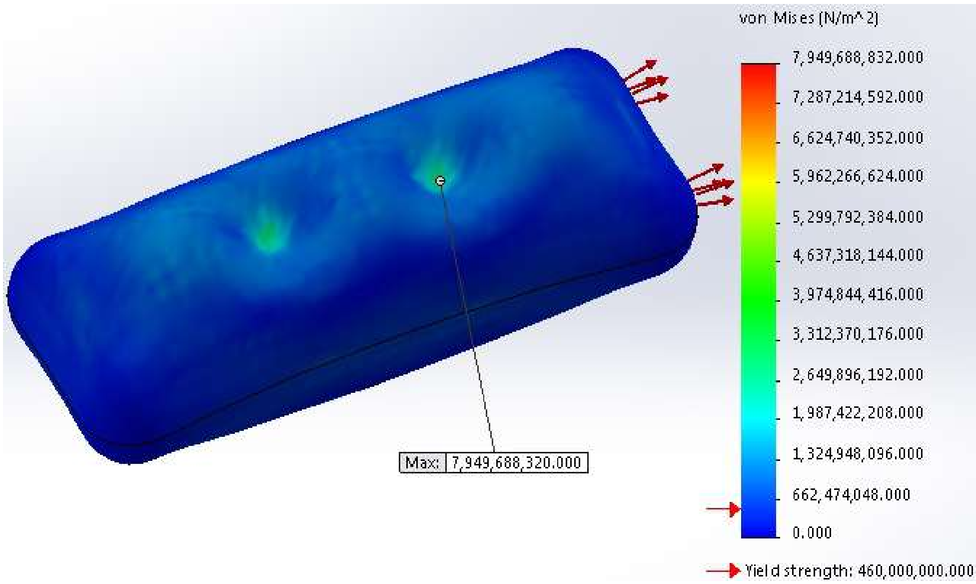

Figure III.8: *Stress distribution with two columns inside.*

We can see that even with two columns inside the tank, a maximum deformation up to 11mm is recorded and stress has get greater than before reaching more than $7kN/mm^2$ on the fixing points of the installed columns.

Therefore, we have installed more columns, figures III.7 to 10 shows deformation and stress for tanks with three and four columns inside.

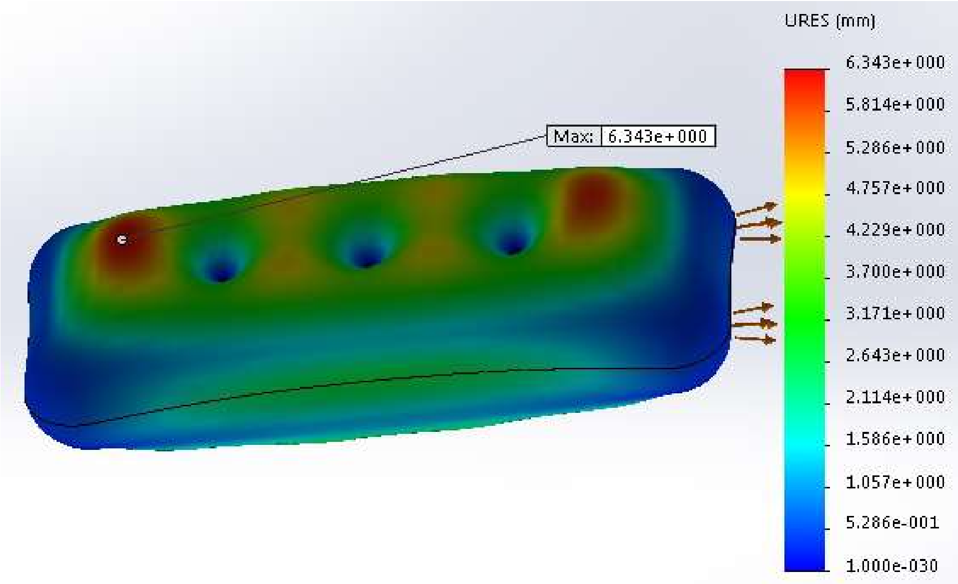

Figure III.9: *Deformation with three columns inside.*

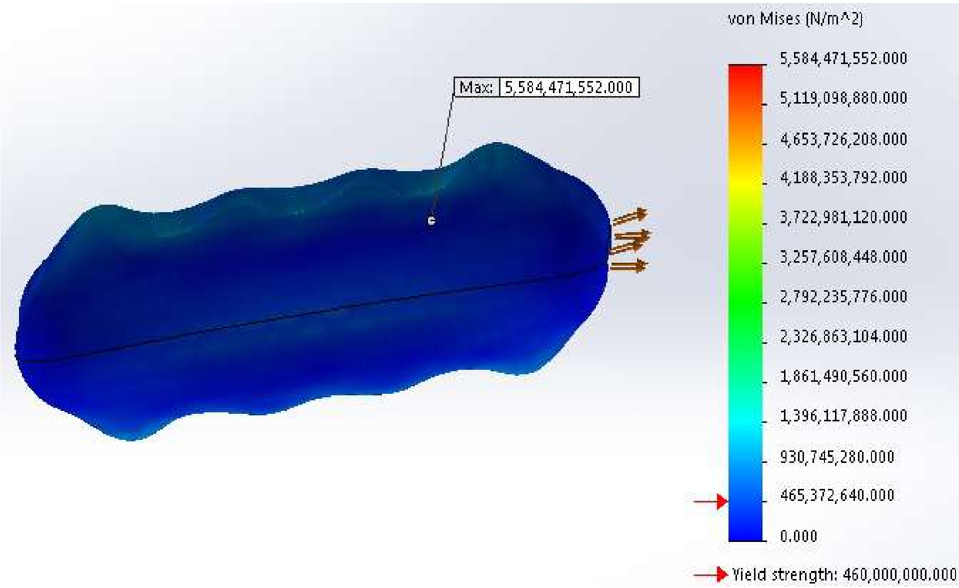

Figure III.10: *Stress distribution with three columns inside.*

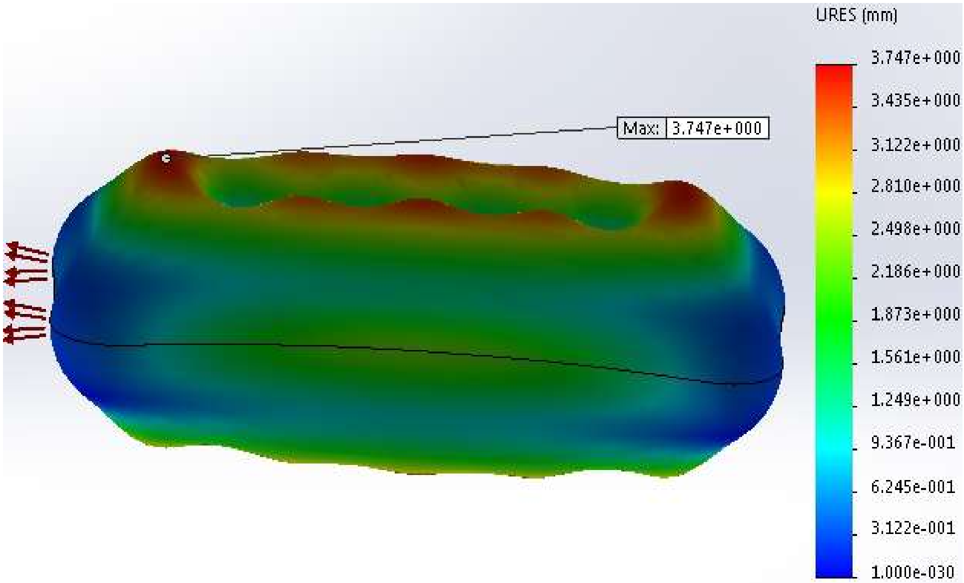

Figure III.11: *Deformation with four columns inside.*

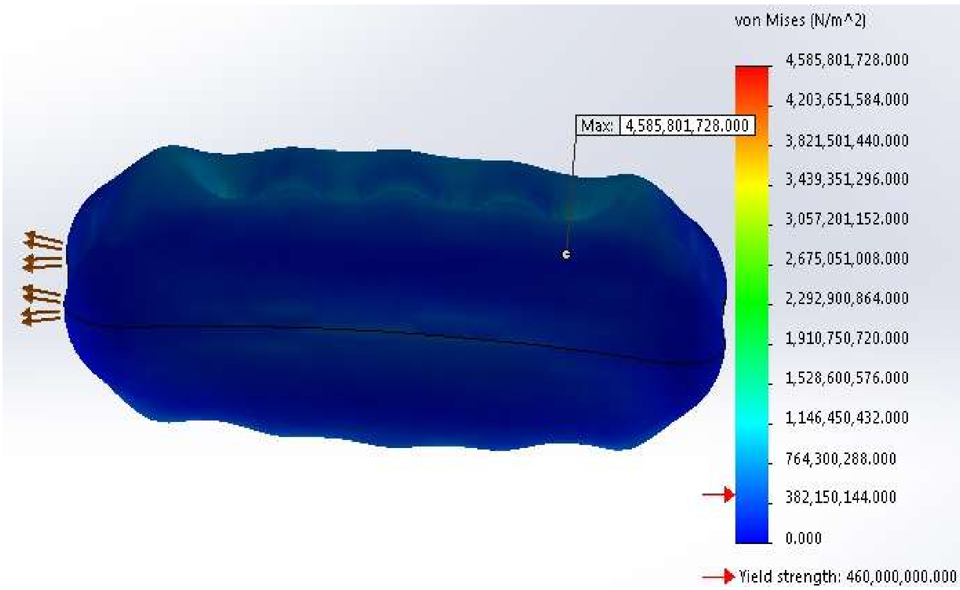

Figure III.12: *Stress distribution with four columns inside.*

We can see that the deformation is reduced to less than$3.8mm$; even if we consider this value of deformation acceptable, stress was reduced to only$4585N/mm^2$, which is always higher than resistance limit, as result; this conception is unfortunately unable to ensure its reliability.

Therefore, we have opted for another solution where we propose to use two cylindrical tanks each one of 30 liters and having the multi-valve installed on the side.

III.3.2 Two-cylinder tank

As we will see in the coming results, the deformation and stress distribution is quasi uniform for the cylindrical shape, this is why propose to replace the 60 liters cylindrical tank by two others of 30 liters each, with the multi-valves placed on the end side of each one.

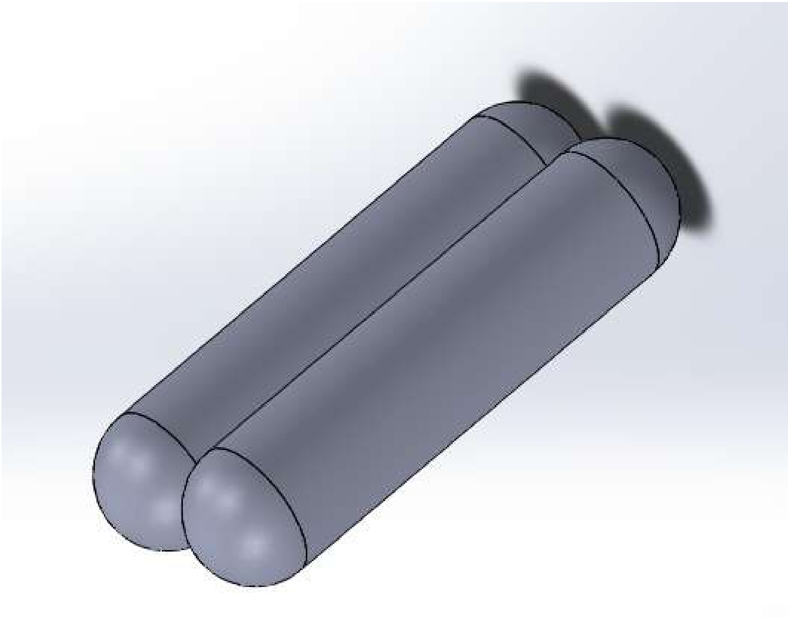

Figure III.13: *Two-cylinder LPG fuel tank.*

III.3.2.1 *Tank dimensions*

As the multi-valve will be placed on the end side of the tank, the length of this one is taken equal to 900mm, letting 120mm as space for the multi-valve. With a volume of 30 liters each tank, the radius of the cylinder will be than:

$$V_c = 30000000mm^3 \qquad \text{III.13}$$

$$V_c = \pi * r^2 * L \qquad \text{III.14}$$

$$30 * 10^6 = \pi * r^2 * 900 \qquad \text{III.15}$$

$$r = \sqrt{\frac{30 * 10^6}{\pi * 900}} \qquad \text{III.16}$$

$$r = 103mm$$

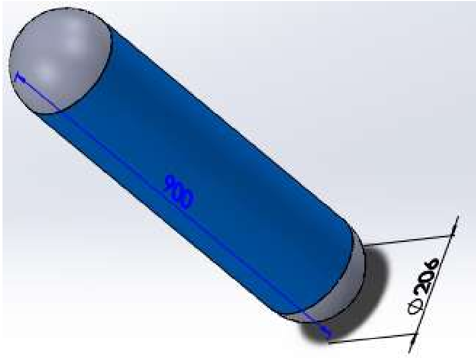

Figure III.14: *30 liters cylinder LPG tank dimensions.*

III.3.2.2 *Test simulation*

Simulation lead to acceptable results as shown in figures II.13 and 14, where the maximum deformation was less than $6.8 \times 10^{-5} mm$ and a maximum stress of less than $3.06 N/mm^2$ which is very low than the yield strength ($460/mm^2$).

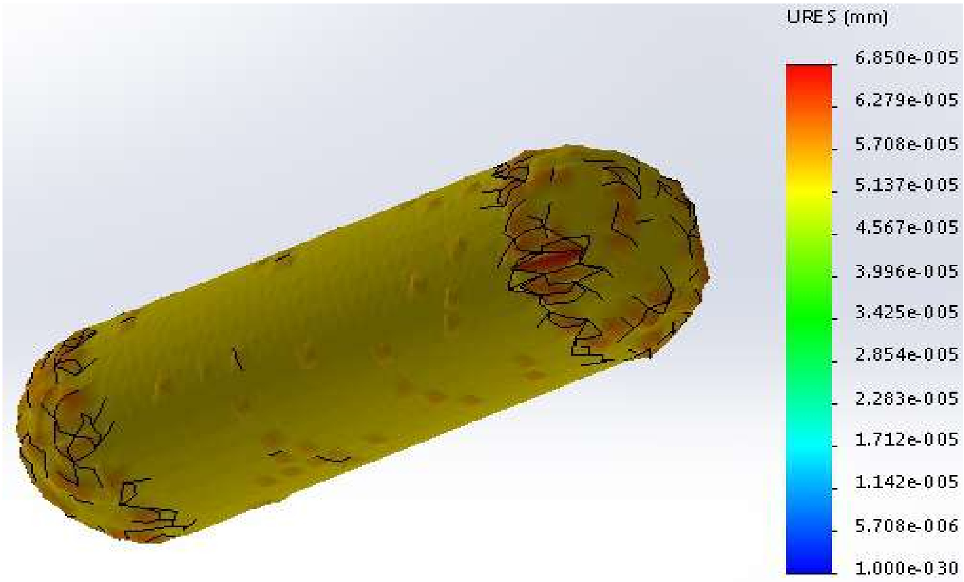

Figure III.15: *30 liters cylinder LPG tank deformation under 35 bars of pressure.*

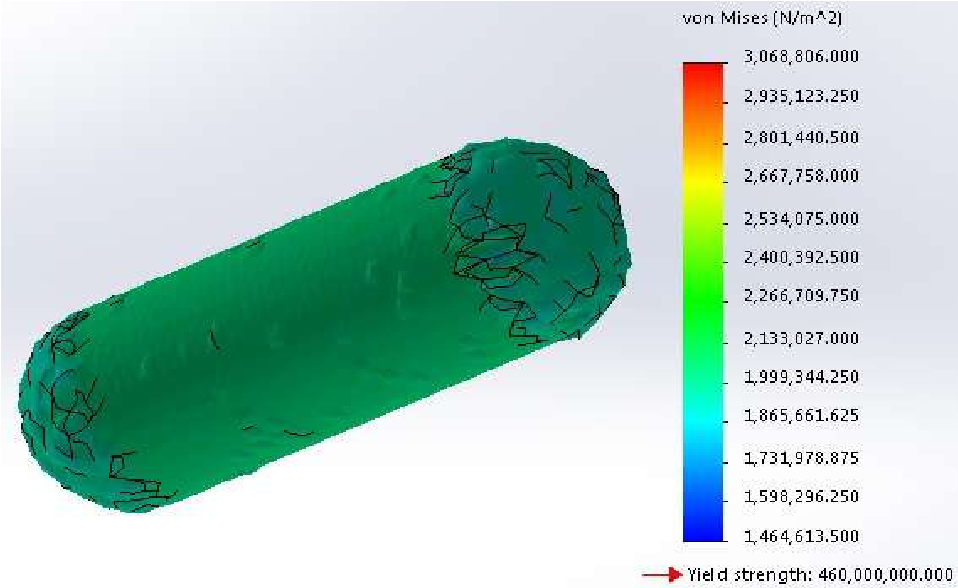

Figure III.16: *30 liters cylinder LPG tank stress distribution.*

III.4 Conclusion

In this chapter, we have proposed at first a tank of “flat” shape which has fail the test under 35 bars of pressure, so we proposed another conception replacing the one cylindrical tank of 60 liters by two others of 30 liters with the multi-valves placed on the end side of each one. According to results of simulation, we can say that this conception is marked successful.

Conclusion

Based on the above-studied in the three chapters on the study of LPG fuel, it was adopted as an alternative resource to fossil energy, which is considered a cause of environmental degradation.

The use of LPG in vehicles, including popular car models such as Renault symbol, is a focal point of Algeria's efforts. The LPG conversion systems of these cars have several key safety features, ensuring the protection of the LPG storage tank located either in the trunk of the car or under the back of the car.

After studying and inspecting the cylindrical and annular tank in order to reach the ideal and appropriate shape, based on what we discussed in the last chapter. We proposed a different geometric model in terms of shape and experimented with it using the solid works system.

Among its advantages:

- Maintain the same storage capacity as before (60 liters).
- It takes up a small amount of car bag space.
- The multi-position installation is either parallel to the rear seat or placed on the base of the car bag.
- It is considered safer than an annular and cylindrical tank due to the presence of a multi-valve under the car and protected by an Iron Guard, so that the gas is discharged immediately after a gas leak.
- This model is intended for the Renault symbol and can also be generalized to the rest of the cars if the conditions are met.
- Finally, based on the content of the subject of the message, the idea remains just a suggestion in the hope of applying it in the future prospects.

References

[01] World LPG Association, "A Global Roadmap for Autogas," no. December, 2019, [Online]. Available: https: //www.wlpga.org/wp-content/uploads/2019/04/WLPGA-AUTOGAS-ROADMAP-March-2019-1.pdf

[02] G. E. Totten, S. R. Westbrook, and R. J. Shah, Fuels and Lubricants Handbook: Technology, Properties, Performance, and Testing. 2003. doi: 10.1520/mnl37wcd-eb.

[03] L. Gpl and L. Gnv, "Le GPLc".

[04] E. Eetp, E. Emission, and T. Programme, "GPL Carburant : un carburant propre d ' aujourd ' hui et pour demain," pp. 1–51, 2004.

[05] Hamachwalid,Talbiriad, towards clean energies as a strategic choice for sustainability -Case Study Liquefied petroleum gas (GPL) in Algeria,14/06/2019

[06] J. Adolf, C. Balzer, A. Joedicke, and U. Schabla, "Shell LPG Study," pp. 1–15, 2015, [Online]. Available: http: //s05.static-shell.com/content/dam/shell-new/local/country/deu/downloads/pdf/shell-lpg-study-english-summary.pdf

[07] F. Synák, K. Čulík, V. Rievaj, and J. Gaňa, "Liquefied petroleum gas as an alternative fuel," Transp. Res. Procedia, vol. 40, pp. 527–534, 2019, doi: 10.1016/j.trpro.2019.07.076.

[08] A. S. A. To, I. Lpg, U. S. E. For, B. On, L. Learned, and S. Markets, "Guide To New Markets," no. December, 2021.

[09] "Installation guidelines for LPG systems by AC S . A.," pp. 1–16.

[10] N. Mustaffa, M. M. Tukiman, M. Fawzi, and S. A. Osman, "Conversion of a gasoline engine into an LPG-fuelled engine," ARPN J. Eng. Appl. Sci., vol. 11, no. 14, pp. 8568–8572, 2016.

[11] "Sequential Gas Injection System Installer's Manual".

[12] A. C. S. Akcyjna, "Installation manual for lpg systems designed for direct petrol injection engines programming manual for stag 400 dpi controller (also available in the diagnostic software and at www.ac.com.pl) Manufacturer : Table of contents PART ONE – installation of t," pp. 1–44, 2012.

[13] R. Atatra, S. Qaimary, W. Abu-ayyash, and A. Sabbah, "Palestine Polytechnic University College of Engineering Investigating the Performance and Emission of the Gasoline and LPG Dual-Fuel Engine," 2018.

[14] CMSMirage sp. z o.o. - www.cmsmirage.pl (no date) About Autogas we know everything, Elpigaz. Available at: https: //www.elpigaz.com/en/cylindrical-tanks/ (Accessed: 03 June 2023).

[15] M. Ţălu and Ş. Ţălu, "3D Geometrical Solutions for Toroidal LPG Fuel Tanks Used in Automotive Industry," Proc. 2018 Int. Conf. Comput. Model. Simul. Algorithm (CMSA 2018), vol. 151, no. July, 2018, doi: 10.2991/cmsa-18.2018.44.

[16] Person (2022) Here's how common LPG tanks are made from sheets of metal, InterestingEngineering. Available at: https: //interestingengineering.com/video/how-lpg-tanks-are-made (Accessed: 03 June 2023).

[17] S.-K. Choi and D.-S. Baik, “Analytical Approach on Fuel Tank Design for LPG Vehicle,” Asia-pacific J. Converg. Res. Interchang., vol. 6, no. 6, pp. 55–63, 2020, doi: 10.21742/apjcri.2020.06.06.

[18] LPG Shop (no date) 360mm cylinder 30° multivalve BRC Europa 2, LPG Shop. Available at: https: //lpgshop.co.uk/360mm-cylinder-30-multivalve-brc-europa-2/ (Accessed: 03 June 2023).

[19] T. A. Spa, “LPG MULTIVALVE AT 02”.

[20] “Tomasetto Multivalve Model AT 02”.