Improvement of Liquefied Petroleum Gas (LPG) Bottles Loading Capacity at the Gas Filling Centres in Cameroon

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Name of the Author (s):

Theodore Tchotang[1],
Nasser Yimen[2],
Bienvenu Kenmeugne[3]

[1,2,3]*Department of Industrial and Mechanical Engineering, National Advanced School of Engineering/ University of Yaoundé I, Cameroon*

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ABSTRACT

The study done on this paper focuses on "improving the loading capacity of LPG bottles of the gas filling centres in Cameroon". It came at a time when the demand for LPG bottles is growing. The absence, failure, and efficiency of the gas filling centres have a direct influence to the economy of Cameroon, whereas the filling of these bottles is a key element in the production chain. The loading operation to the trucks is an important task in the gas filling centres. The objective of this paper is to design a palletizer to reduce the loading time of LPG bottles and to ensure the safety of the workers. To achieve this goal, the adopted methodology begins with a functional analysis of a palletizing unit, followed by the choice of components and then sizing these different components. The LPG bottles under study have a diameter of 290 mm and a height of 600 mm. The classic process of palletization retained has many advantages in particular a high speed and its flexibility. The loading capacity of the palletizer is 14 bottles per minute. The unit is consist of 2 pneumatic cylinders of 300 mm and 700 mm length, 80 mm and 160 mm as rod diameters respectively. It also consists of 2 chain conveyors having 0.18kW and 0.55kW as engine power. This work had improved the performance of the studied filling centres by 36.81%..

Keywords:
Design, Filling, Loading time, LPG, Palletization, Sizing

I. INTRODUCTION

Liquefied Petroleum Gas (LPG) is a necessity product used both in households and in companies. According to the statistics published by the Ministry of Energy and Water 16.8% of Cameroonians have access to domestic gas which is for a consumption of nearly 75,000 tons in 2013. This consumption is increasing by 5 to 10% per year and is expected to reach 200,000 tons by 2022. All of this consumption comes from the gas filling centres. Faced with this increase in consumption which is a real challenge for Cameroon, the centres must equip with reliable and efficient equipment. After the bottles being filled they are loaded into trucks for distribution, however, the labour involved is painful for the workers as it requires a lot of physical effort. In addition, the repetitive nature of this task can easily lead to musculoskeletal conditions when done for eight (8) hours a day. Thus, to facilitate this labour of loading while gaining efficiency we asked ourselves this question, what impact would this improvement have on the truck loading times? To face this question, it is therefore important to set up a palletizing unit for LPG bottles in the gas filling centres in order to meet the challenge in the production. The main objective of this paper is to design a palletizer to reduce the loading time of LPG bottles in trucks and also to ensure the safety of workers and the bottles. The structure of the work includes the generalities on the constituent elements of a palletizing unit as well as a study of the various palletizing processes, then the design methodology, and finally the presentation of the results.

II. MATERIALS

The Components of the LPG bottle palletizer

The palletizing process of LPG cylinders requires several materials, the first is the gas cylinder which is composed of several elements. The cap; this is the protection device of the tap, possibly allowing the bottle to be transported. The colour of the cap which is excluded from the standard, should no longer be considered for the identification of gas or risk. A faucet; it is designed to be operated by hand, never with a spanner. Finally, the warhead it is part of the bottle which is the link between the neck and the cylindrical portion of the body. The colour of the warhead of a gas cylinder is defined by the European standard NF-EN 1089-3 according to the main risk associated with the contents of the bottle. There are several types of bottles depending on the dimensional characteristics thereof. These characteristics are the height and the diameter of the bottle. As part of this work, the diameter of the bottles is 290 mm and the height of 600 mm.

The second material is the jack which is a device for printing a linear or angular displacement to a movable item. It transforms the energy of a fluid under pressure into mechanical energy (movement with effort). According to (Philippe TAILLARD, 1998), its classification considers the nature of the fluid. Pneumatic cylinder uses compressed air of 2 to 10 bar for current usage, it is very simple to use and used in automated systems too. Hydraulic cylinder uses pressurized fluid up to 350 bars, compared to the pneumatic cylinder, it is more expensive and develops much greater strength and the shaft speeds are more precise. Electric Cylinders uses electrical energy and is mainly used in domestic applications. Pneumatic cylinders are the most used cylinders for industrial automation systems.

The third material is the conveyor which allows the continuous movement of products from one point to another. There are several types of conveyors as stated below: belt conveyor is characterized by the type of conveyor belt used (materials, texture, thickness) and by the position of the motorisation group (central or end). Belt conveyor notched; the notches of the band allow its displacement of a precise value, without fear of sliding as possible with a smooth belt. Chain Conveyor; it transports mesh pallets and similar products longitudinally and crosswise. This optimized handling system guarantees quality transport and minimum noise emission. Pilgrim Conveyor; it is a system where the product advances step by step. The mechanism describes a rectangle mounting and lifting the product / advance with the product / lowering and laying the product and return empty. Roller Conveyor; it is used for transporting or accumulating products long enough not to fall between two rollers. Packages to be transported must also be flat-bottomed and rigid. Worm Conveyor; the screw conveyor is a material transport system using the principle of the Archimedean screw. Chain conveyors are better suited for transporting LPG cylinders because of its many advantages.

The Palletizing Process

Palletizing is the action of loading products on a pallet. According to (Jacques THIBAULT, 1998), palletizing is grouping or stacking packages or (unit loads) on pallets or other supports for handling, transport and storage operations. This task must be particularly done carefully because the stack must be stable enough to withstand transport by fork-lift trucks. Several palletizer systems have been developed since the appearance of the pallet more than a century ago. In a palletizer, the products are first pushed against each other until forming a layer for the pallet, then this layer is pushed on the pallet in one movement. In recent decades, robotic systems have become increasingly diverse. The peculiarity of this system is that it does not drag the products forward but that it grabs and lift them then place them on the pallet in one movement. The choice of the type of palletizer is to be carried out among the four major types of palletizer, these are classic palletizer, articulated arm robot, gantry robot and standard palletizer. This choice is made according to the objectives to be achieved.

The choice for the type of palletizer requires a careful analysis of the process to automate as a whole. At the end of the study, the appropriate palletizing solution will be different depending on the situation. The central points that need to be considered include the capacity, flexibility, clutter, user-friendliness, life service and maintainability. Based on our need, the method that seems best suited in the context of the study is the classic process of palletizing. Indeed, it has many advantages in addition to its high speed and flexibility, moreover, it is easy to install and has a long service life.

With regard to the choice of components, according to the studies conducted by (NJIKAM Moise, 2016), the main criteria for selection are the distance, the wanted effort, and the required speed. The choice made is focused on pneumatic cylinders because they are the most used cylinders for industrial automation systems. In addition, the main criteria for choosing a conveyor are the service life, the quality of transmission, the efficiency and the flexibility of the accessories installation. Chain conveyors are better suited for transporting LPG cylinders as they have many advantages, including good transmission quality and minimal noise emission.

The Table 1, below shows the advantages and disadvantages of the different types of palletizers. It makes it possible to choose the palletizer adapted for this work according to the objectives to be achieved, the integration, the operation, and the cost. By presenting more advantages from the point of view of the objectives and operation, it indicates that the classic palletizer is the most suitable for palletization for this work.

Table 1: Advantages and disadvantages of the types of palletizers

Types of Palletizers	Classic Palletizer	Robot with articulated arm	Robot Gantry	Standard Palletizer
Objectives to be obtained				
Speed / Capacity	+ +	+/-	-	+ +
Flexibility (pallet sizes)	+ +	+/-	-	+ +
Quality of stacking	+ +	+/-	-	+ +
Integration				
Use of space	+	+/-	+	+/-
Power performance	-	+ +	+/-	-
Level of training for the operator	+	-	-	+/-
Operation				
Maintenance	+	+ +	+ +	+/-
Duration of service	++	-	+/-	+ +
Accessibility	+	+/-	-	+/-
Costs Purchase				
Purchase	+/-	+/-	+/-	+/-
Installation	+/-	+/-	+	+
Exploitation (energy)	+	-	+/-	+
Maintenance	+	+/-	-	+
Spare parts	+	-	-	+

Therefore: – is the less advantageous, +/- more or less advantageous and + advantageous

III. METHOD OF SIZING

Sizing of Pneumatic Cylinders

According to the research of (Philippe THAILLARD, 2002), the procedure to be followed for the sizing of the pneumatic cylinders consists of four stages. It begins with the development of the specifications which is to fix the load *C* to move, the stroke C_2 of the cylinder, the required action time *t,* and the mass moved *md*. These specifications are developed according to the objectives to be achieved. After the elaboration of the specifications, then the preselection of a model. It is the choice in the range of a manufacturer of the model of cylinder adapted to the need. The catalog of (Parker HANNINFIN, 2011) presents some ranges of cylinders and the sizes. Also, determination of the diameter of the cylinder respecting the specifications. Then it is necessary to check the damping by calculating the kinetic energy of the cylinder at the end of the stock, if this energy is lower than the allowable energy of the range of cylinder chosen, then the sizing is valid otherwise it will be necessary to increase the diameter or to change the damping mode. The Eq. (1) below is used to determine the necessary diameter.

$$F_{sp}\frac{\pi}{4} \times D^2 \times p \times t_c \dots\dots\dots\dots\dots.. (1)$$

$$F_{sp} \geq C \Rightarrow D \geq \sqrt{\frac{4\times C}{\pi\times p\times t_c}}$$

Whereas *D* is the diameter of the piston (cm), *p* is the supply pressure (Pa), t_c is the load factor, F_{sp} is the thrust strength (daN) and *C* is the load to be moved (daN).

Given the instability of the rod, which is subjected to a normal compressive strength, tends to bend and deform in a perpendicular direction to the compression axis (passage of a state of compression to a state of bending), it is necessary to size the rod in buckling.

For the bucking sizing of the rod, we used the Euler formula Eq. (2) below.

$$F_e = \frac{\pi^2 \times EI}{L_f} \dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2)$$

$$C \leq F_e \Rightarrow C \leq \frac{\pi^2\times EI}{L_f^2} \Rightarrow L_f \leq \sqrt{\frac{\pi^2\times EI}{C}}$$

Whereas *E* is the Youngs modulus (Mpa), F_e is the critical bucking load (N), *I* is the quadratic moment (mm^4), and L_f is the buckling length (mm).

This allowed us to determine the buckling length L_f of the rod. The checking of damping is done by using the Eq. (3) below.

$$E_v = \frac{1}{2} m_d V^2 \quad \dots\dots\dots\dots\dots\dots\dots\dots.. \quad (3)$$

Whereas E_v is the absorptive kinetic energy (J), m_d is the displaced mass (kg) and *V* is the displacement speed in (m/s).

Sizing of Chain Conveyors

The various stages of chain conveyor sizing begin with the determination of the length of the conveyor, this depends on the number of bottles to be transported. Then the choice of the type of string which depends solely on the pitch of the string. Finally, the determination of drive strength, drive power, motor power, and gear and bearing sizing. Table (2) below presents the elements of choice for the chain.

Table 2: Choice of the type of chain

Symbol	Steps (mm)	Width (mm)	Diameter (mm)	Mass (kg)
08A	12.70	7.95	3.96	0.45
10A	15.87	9.53	5.08	1.00
12A	19.05	12.70	5.94	1.90
18A	25.04	15.88	7.92	2.60
06B	9.52	5.72	3.28	0.40
08B	12.70	7.75	4.45	0.75
10B	15.87	9.65	5.08	1.20
12B	19.05	11.68	5.72	1.65
16B	25.04	17.02	8.27	2.95

The Parking effort according to the studies of (Arber FABER, 2013) is given by Eq. (4).

$$F = 9{,}8L[(M_{tr} + 2M_K)(\mu_1 + D_1) + M_{tr}(\mu_2 + D_2)] \dots.. (4)$$

Whereas M_{tr} is the mass transported (kg/m), M_k is the mass of the chain (kg/m of length) for a given width, *L* is the length of the conveyor (m), μ_1 is the friction coefficient between the chain and its support, μ_2 is the friction coefficient between the chain and its bottle, $D_1 = 0{,}2$ is the starting coefficient in absence of progressive starting and $D_2 = 0{,}2$ is the starting coefficient at full speed accumulation.

The driving power is given by the Eq. (5) below.

$$P_e = F \times V_e \quad \dots\dots\dots\dots\dots \quad (5)$$

Whereas F is the driving strength (N), V_e is the driving speed (m/s) and P_e is the driving power (W).
The power of the motor is given by Eq. (6) below.

$$P_m = \frac{P_e}{\eta_{bearing}^2 \times \eta_{gearing}} \quad \dots\dots\dots\dots\dots \quad (6)$$

Whereas P_m is the power of the motor (W), $\eta_{gearing}$ is the gearing output, $\eta_{bearing}$ is the bearing output.

The calculation of the shaft and the bearings.

It is necessary to determine the ideal bending moment. According to (J Goulet and J-P. Boutin, 1996), it is given by the Eq. (7) below:

$$M_{if} = \sqrt{M_f^2 + M_t^2} \quad \dots\dots\dots\dots\dots \quad (7)$$

Whereas M_{if} ideal bending moment (N.m), M_f is the bending moment (N.m), M_t is the twisting moment (N.m).

Then it is necessary to determine the diameter of the shaft with the conditions of resistance and rigidity.

Calculation of the diameter of the shaft.

The Eqs. (8) and (9) are the conditions of the resistance and rigidity respectively. They are to determine the diameter of the suitable shaft. Knowing the couple (twisting or bending) that the shaft must support, we therefore determine its diameter using the two equations below.

$$(M_t/GI_0) < \theta_{limit} \quad \dots\dots\dots\dots\dots \quad (8)$$

$$(KM_{if}/I_0) * \rho < R_{pe} \quad \dots\dots\dots\dots\dots \quad (9)$$

Whereas M_{if} is the ideal bending moment (N.m), M_f is the bending moment (N.m), M_t is the twisting moment (N.m), θ_{limit} is the twisting angle (rad/m), R_{pe} is the practical resistance Mpa, I_0 is the quadratic polar moment (m^4), k is the coefficient, ρ is the radius (m) and G is the coulomb modulus (MPa).

Concerning the bearings, according to research of (Fridolin TEMGOUA, 2013), the life span is obtained by using the Eq. (10) below.

$$L_h = \frac{10^6}{60N} \times L_2 = \frac{10^6}{60N}\left(\frac{C_d}{P}\right)^n \quad \dots\dots\dots\dots\dots \quad (10)$$

Whereas N is the rotational speed (tr/min), C_d is the dynamic load (N), P is the equivalent load (N), L_2 is the live span in billions of lathes and L_h is the live span. n is the coefficient equal to 3 for the ball bearings and $\frac{1}{3}$ for the cylinder bearing.

Sizing of the Gearing

The sizing of the gears is done by determining the number of teeth of the different transmission wheels as well as their module. To do this, it is necessary to determine the transmission ratio of the gears, then fix the number of teeth of the motor pinion knowing that its minimum value is 13; then calculate the modulus of the wheel using the Eq. (11).

$$m \geq 2{,}34\sqrt{\frac{F_t}{kR_{pe}}} \quad \dots\dots\dots\dots\dots \quad (11)$$

Whereas F_t is the tangential effort (N), m is the wheel modulus, R_{pe} is the practical resistance (MPa) and k is the coefficient.

Finally, to determine the different diameters of the driving and driven gears by using the Eq. (12) drawn from the research of (Abdellatif BEN HAMADOU, 2010).

$$d_i = m \times Z_i \text{ et } \quad r_{i/j} = \eta_{gearing} \times \eta_{bearing}^2 \times \frac{C_j}{C_i} = \frac{N_i}{N_j} = \frac{d_j}{d_i} = \frac{Z_j}{Z_i} \quad \dots\dots\dots\dots\dots \quad (12)$$

Whereas $d_i and\ d_j$ are diameters of the wheels i and j (m), $N_i\ and\ N_j$ are the rotation speeds of the wheels i and j (tr/min). $Z_i and\ Z_j$ are the teeth number of the wheels i and j, $r_{i/j}$ is the transmission ratio between wheel i and j. and $C_i and\ C_j$ are the couples of the wheel i and j (N.m). $\eta_{gearing}$ is the gearing output and $\eta_{bearing}$ is the bearing output and m is the wheel modulus.

Impact of the unit on the bottle loading capacity

The loading capacity of the filling center is imposed by the rate of the carousel which is 14 bottles per minute. To determine the impact of the palletizing unit on this capacity, it will be necessary to make a comparative study between the loading capacity before and after the establishment of the palletizing unit. Before the installation of the unit, the loading capacity is determined experimentally. Following the recording of the loading time of a few trucks in the filling center, the results are recorded in the Table 3 below. It should be noted that during the loading, there was no equipment failure and the carousel worked with 14 rockers.

Table 3: Truck Loading Time at the Filling Center

Numbers of bottles of trucks	Loading time	Carousel capacity	Output
120	16 minutes	224	53,57%
210	25 minutes	350	60,00%
300	30 minutes	420	71,43%
400	40 minutes	560	71,43%
500	60 minutes	840	59,52%

After the installation of the palletization unit, this capacity was determined by the capacity of the carousel which is of 14 bottles per minute.

The output of the center before the installation of the palletization unit is determined by making the average of the relationship between the loading capacity and that of the carousel. This is summarized in the Eq. (13) below:

$$r = average\left(\frac{C_{av}}{C_{ca}}\right) \quad \dots\dots\dots\dots\dots \quad (13)$$

Whereas c_{av} is the loading capacity before the installation of the unit, c_{ca} is the carousel capacity, and r is the output of the centre before the installation of the unit.

It should be noted that the loading capacity after the installation of the unit is that of the carousel. The palletization unit allowed the center to reach its maximum capacity of an output of 100 %, the improvement is thus obtained using Eq. (14) below:

$$r_{am} = 100\% - r \quad \dots\dots\dots\dots\dots \quad (14)$$

Whereas r_{am} is the output of improvement, and r is the output of the centre before installation of the unit.

IV. RESULTS AND DISCUSSION

Sizing of components

The loading capacity of the palletizer found is 14 bottles per minute. Calculations of the sizes of the cylinders as well as the powers of the conveyor motors using Eqs. (1) to (6) give the values confined in Table 4 below. The speed and the other characteristics of the conveyors were obtained using the Eqs. (7) to (12). These values are obtained for a bottle conveyor moving a load of 14 bottles and a pallet conveyor moving a pallet of 35 bottles weighing 12.5 kg. The handling cylinder is responsible for pushing a row of 7 bottles. The clamping cylinder clamps the remaining 7 bottles onto the bottle conveyor when the handling cylinder loads 7 bottles into the pallet. The palletizing unit of LPG bottles improves the filling centers efficiency by 36.81%. This yield is obtained using Eqs. (13) and (14).

Table 4: Characteristics of the Cylinder Rods and Motors

	Cylinders		Motors	
	Clamping Cylinder	Manipulator	Bottles Conveyor Motors	Motor Conveyor Pallets
Diameter of rod	80 mm	160 mm	-	-
Length of rod	300 mm	700 mm	-	-
Power	-	-	0.18 kW	0.55 kW

The Synoptic of Operation

The palletizing unit will consist of 2 pneumatic cylinders having 300 mm and 700 mm rod length as well as 80 mm and 160 mm as rod diameter and 2 chain conveyors having 0.18 kW and 0.55 kW as power of the motor. engine. The bottles are first conveyed to the station by the bottle conveyor, then they are loaded in rows in the pallets via a manipulator jack. During loading, the stopper cylinder blocks the other bottles in order to avoid overloads on the thrust cylinder. The loaded pallet is discharged to the outlet by the pallet conveyor. The operation of the synoptic diagram can be seen in Fig.1 below.

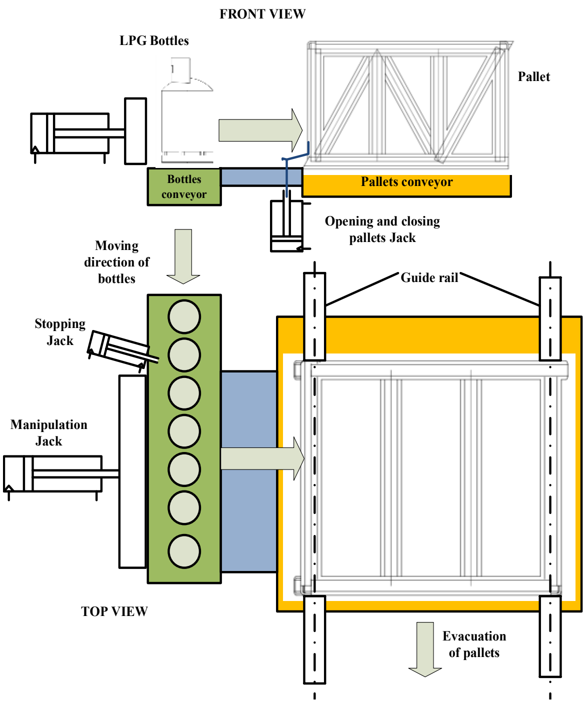

Figure 1: Operating diagram of the palletizing unit

Impact of the Unit on the Bottle Loading Capacity

It was noted in this study that the palletization of products is a painful job. The operator must constantly turn, bend and sometimes even stretch to the maximum while handling products that can weigh several kilos. Fig.2 below shows the impact of the unit on the loading capacity of the center. This is a response to the concern for ergonomics that is a solution to the problem of aging business personnel.

It should be observed in Fig. 2 above that, there is a significant improvement in the loading capacity of the filling center. Indeed, this figure shows the former loading capacity of the filling center (in green) and after the installation of the palletizing unit (in blue). For example, the filling center that loaded 300 bottles in 30 minutes managed to load 420 after the installation of the palletizing unit. The palletizing unit of the LPG bottles thus improves the filling center's efficiency by 36.81%. This improvement is justified by the fact that machines can perform repetitive tasks much faster than humans. Of course, we could use several people, but they would interfere with each other very quickly. In addition, unlike machines, men get tired and their ability decreases during the workday and unlike humans, machines can work both day and night.

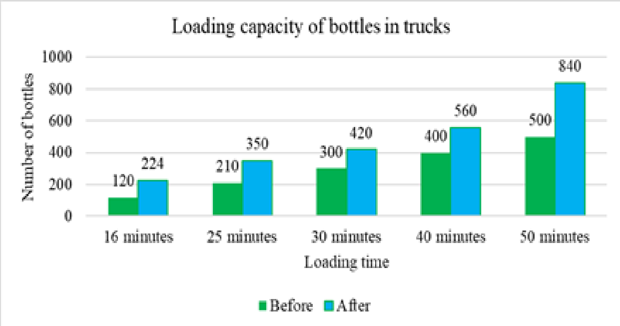

Figure 2: Impact of the palletization unit on the loading capacity of the bottles in the trucks

V. CONCLUSION

The work presented here was focused on "the improvement of the LPG bottle loading capacity at the gas filling centers in Cameroon". The objective of this work was to carry out a detailed study aiming at proposing a palletizing unit for LPG bottles to improve the loading capacity of gas bottles in trucks. To carry out this work, several steps were necessary to be known and to become acquainted with the different methods of palletization. A functional analysis of the unit to be set up was conducted in order to identify technological solutions, and the choose and sizing of the components chosen was done. The LPG bottle palletizing unit determined improved the performance of the filling center by 36.81%. This improvement can be seen in the performance of the center as well as in the safety of the workers.

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