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Research Article

Development of hydraulic system for internal emergency shut-off valves for Liquefied Petroleum Gas (LPG) storage vessel

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Abstract: The aim of the present study is to solve the problems of rising cost and increased plant down-time associated with the maintenance and servicing of the Redwood hydraulic power unit (HPU) installed at the Pipelines and Products Marketing Company (PPMG) LPG plants by developing an HPU that can be used as a cost effective and easy-to-maintain alternative to the complex Redwood HPU. The HPU developed was tested with a Whessoe-Varec internal Emergency Shut-off Valves (ESV) and it successfully opened the valve. The maximum pump flow rate of the developed HPU was determined by experiment to be litres per minute (with an overall efficiency of as compared with the Redwood HPU which has a maximum flow rate of and overall efficiency of The Cost Effectiveness Analysis (C.E.A) shows that the developed HPU is 89.5 % cheaper in terms of cost of procurement than the Redwood HPU.

Keywords: Hydraulic power unit; emergency shut-off valve; cost effectiveness analysis; liquified petroleum gas; pump flow rate

1. Introduction

Pipelines and Products Marketing Company (PPMC) Ltd, a subsidiary of Nigerian National Petroleum Corporation (NNPC), is a state-owned company saddled with the responsibility of storage and supply of petroleum products across the nation. Liquefied Petroleum Gas (LPG) plants are designed specifically for the storage and supply of LPG (cooking gas). In line with the opinion of Angeli and Chatzinikolaou (1995), the frequent failure of the installed imported Redwood Hydraulic Power Unit (HPU) and the lack of specialised personnel to carry-out maintenance services and repairs have made the operation of the LPG plants difficult and thereby resulting in loss of revenue from the sale of cooking gas, creation of artificial scarcity of the product across the nation, and causing an increase in the prices of the commodity to the end users. In addition, huge financial resources are spent on ordering of parts from overseas with the accompanying increased plant shutdown time due to long periods of response time.

This research focused on the development of a new HPU that can serve as a local substitute for the imported Redwood HPU installed at NNPC-PPMC LPG Plants in Nigeria. The locally fabricated HPU will boost the development of the Nigerian local content policy in the field of hydraulic technology. LPG is the general name given for propane, butane and mixtures of the two and it is obtained from crude oil in petroleum-processing plants. It is a fuel that is widely used for domestic, agricultural, and industrial purposes (Tarim, 2014). LPG may be stored in pressure vessels (PV) (Bhavana et al., 2017) which includes above-ground storage vessels (Leem & Huh, 2011), mounded storage facility kept above ground (Jose & Sudhakara, 2015), and in underground caverns (McGuire & White, 2000).

A hydraulic circuit is a system comprising an interconnected set of discrete components that transport liquid. The purpose of this system is to control where fluid flows (as in a network of tubes of coolant in a thermodynamic system) or to control fluid pressure (as

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in hydraulic amplifiers) (Navya & Pradeep, 2013). The hydraulic system consists of a reservoir from where the oil is pressurised by means of pump to the various pipelines through hoses (Janbandhu et al. 2016).

According to Reddy et al. (2014) and Lahari et al. (2014), the HPU is an integral power supply unit which applies fluid pressure that drives motors, cylinders, and other complementary parts of a hydraulic system. Rajput, (2013) asserted that power is transmitted with the help of a fluid in a hydraulic system. In the view of Lahari et al. (2014), some of the important factors that influence a hydraulic power unit performance are pressure limits, power capacity, and reservoir volume. In addition, its physical characteristics, including size, power supply, and pumping strength are also significant considerations. NNPC (1995) stated that HPU should be located in a well-ventilated area to ensure efficient heat dissipation.

In a related research, Tic and Lovrec (2012) worked on the use of simulation techniques to design a hydraulic tank. The research focused on the design of a 400 litre hydraulic tank using different software simulation models. They concluded that the use of CFD simulation tools helped in understanding fluid flow in stationary hydraulic tank; and that small cost-effective modifications could make a great difference on hydraulic unit long-term operation, reliability and maintenance costs.

Also, Kulkarni et al. (2015) investigated the enhancement of the performance of the hydraulic power pack by increasing heat dissipation; it was concluded that the total heat transfer rate had been improved by changing the material of the tank from mild steel to aluminium.

Furthermore, Gangwar et al. (2014) studied the modelling of closed-circuit hydraulic energy-regenerative system for hydrostatic transmission using hydraulic accumulator. The paper discussed the introduction of closed-loop hydrostatic transmission and used a hydraulic accumulator as the energy storage system fabricated in a novel configuration to recover the kinetic energy without any reversion of the fluid flow.

In the opinion of Vukovic and Murrenhoff (2015), to ensure competitiveness of hydraulic systems with their electromechanical counterparts, it is necessary to develop more energy and cost efficient architectures. The lack of specialised personnel demands new methodologies for the design, operation and maintenance of hydraulic systems for transmission and control (Angeli and Chatzinikolaou, 1995). Based on these reasons, the present study troubleshoots the installed Redwood HPU and then designs a new HPU that is less expensive and easier to maintain.

2. Materials and methods

The processes involved in carrying out this work are discussed as follows:

2.1. Design considerations

In the design of the HPU, the following factors are discussed:

2.1.1. Space available for installation

The hydraulic power unit was placed in a small area (7m^2) that is well ventilated with all hydraulic components mounted on top of the reservoir tank for compactness. Since the reservoir top is to be used for mounting equipment, attention was paid to the construction of the support for the reservoir tank.

2.1.2. Design configuration

A rectangular and non-pressurised hydraulic reservoir tank with extensions (supports) that hold the tank 5 cm off the floor (to allow air flow around the tank for ventilation) was considered. This will aid heat dissipation (cooling) of the hydraulic fluid inside the tank by transferring the generated heat from the tank's surface to the surroundings.

2.1.3. Reservoir sizing

The general rule for reservoir sizing is pump gallons per minute or litres per minute 3 or 5. In this design, a sizing factor of 5 was adopted while a pump flow rate of was assumed. Also, the reservoir was sized for a 25 % overcapacity to provide a reserve against unexpected demands; and a 25 % air cushion for effective heat dissipation.

2.1.4. Economic considerations

The material for the reservoir tank construction is mild steel because it is readily available, cost effective, and can be easily machined. This hydraulic power unit was designed to operate for 8 - 10 hours a day. The overall cost of the machine is less than the foreign assembled power unit. The maintenance and production losses associated with the shutdown of the HPU are minimised because every component part was sourced locally and time wastage on importation of service parts is eliminated.

2.1.5. Power source

An electric motor was used as the primary driver of the pump because of the availability of an electric power supply within the NNPC-PPMC facility.

2.1.6. Pressure and flow requirements

This design requires a hydraulic system with a design pressure of 50 bars and a positive displacement gear pump of 4 litres per minute with an assumed mechanical efficiency of 90 %. Also, leakage and friction losses were neglected at the initial stage.

2.1.7. Environmental conditions

This HPU is designed to operate in Ilorin where daily temperatures range between 29°C and 37°C and the working temperature of the system ranges between 45 °C and 65°C.A simple filter arrangement comprising of a magnet for trapping metallic particles from the gears in the pump and rust from pipelines and a sieve cloth wrapped over the suction and return lines in the system is required.

2.1.8. Design calculations

The following design calculations were made for:

(i). The reservoir tank volume

Considering a pump flow rate of , a tank sizing factor of 5, a hydraulic reservoir overcapacity of 25 % and an air cushion of 25 % for cooling. The volume of the required hydraulic fluid (was calculated using equation (1). It is expressed as: (Kulkarni et al., 2015)

$$V_{fl} = S_F \times Q \qquad (1)$$

Where S_F is the sizing factor.

The hydraulic reserve capacity (R_c) in cm^3 was calculated using equation (2). It is expressed as: (Kulkarni et al., 2015)

$$R_c = O_c \times V_{fl} \qquad (2)$$

Where O_C is the overcapacity value in %.

The air cushion (V_A) in % required for effective heat dissipation was calculated using equation (3).

$$V_A = A_{Cus} \times V_{fl} \qquad (3)$$

Where A_{CUS} is the air cushion for heat dissipation

The total tank capacity (T_{tc}) in m^3 was calculated using equation (4).

$$T_{tc} = V_{fl} + R_c + V_A \qquad (4)$$

Therefore, the tank should be able to contain of hydraulic fluid.

The volume of tank (V_{tk}) is given by equation (5)

$$V_{tk} = L_{tk} \times W_{tk} \times H_{tk} (5), V_{tk} = T_{tc} \quad (6)$$

For (0.20 *m*) tank length (L_{tk}), from equation (5) the height of the tank, $H_{tk} = 0.30\ m$

(ii) The reservoir tank weight

The reservoir fluid used is hydraulic oil with a specific gravity, S. G of 0.884 but for the design test, water, with S. G of 1, was used for the load analysis. The maximum operating volume of the reservoir tank is 0.03m^3 and a tolerance value of 5 % was added. The individual weight of various items used in both the construction and assembly of the tank were measured and added together to get the minimum calculated weight of the HPU as shown in Table 1. This formed the basis for the calculation of the load analysis.

The tolerance mass of the fabricated reservoir tank (in kg was calculated using equation . It is expressed as: (NNPC, 1993)

$$T_m = T_o \times M_{cw} \qquad (7)$$

$$T_m = 0.05 \times 39.10$$

$$T_m = 1.96\ kg$$

The design mass of the reservoir tank (D_m) was calculated using equation (9). It is expressed as: (NNPC, 1993)

Table 1: Minimum calculated weights

Minimum calculated weights,	
Items	Mass kg
Pump/motor	12.90
Rectangular hydraulic reservoir	13.70
Reservoir lid	10.00
Pressure relieve valve (PRV) and pipe fittings/Accessories	1.74
NPT gate valve	0.50
Filling cup/cap	0.05
Oil level gauge	0.01
Pressure Gauge	0.20
Total mass = 39.10 kg	

$$D_m = T_m + M_{cw} \quad (8)$$

$D_W = 1.96 + 39.10 \approx 41.06$ kg

The mass of the fluid in the reservoir tank was calculated using equation (9)

$$\rho = M \times v \quad (9)$$

Maximum operating volume $\approx 0.03\text{m}^3$

The hydraulic fluid to be used is Total Azolla ZS 68 grade oil with S. G of 0.884

$$M = 884 \times 0.030000 = 26.52kg$$

Following NNPC, 1993, the operating mass (O_m) of the reservoir tank is given by equation (10)

$$O_m = D_m + M \quad (10)$$

$$O_m = 41.06 + 26.52 = 67.58kg$$

The reservoir tank self-weight (*Tsw*) was calculated using equation (11). It is expressed as: (NNPC, 1993).

$$Tsw = O_m \times 9.81 \quad (11)$$

$$T_{sw} = 67.58 \times 9.81 = 402.80\ N$$

The reservoir tank self-weight per width was calculated using equation (12). It is expressed as: (NNPC, 1993)

$$T_{ksw/_w} = T_{sw}/W \quad (12)$$

$$T_{ksw/_w} = \frac{402.8}{0.5} = 805.60\ (N/m)$$

From equation (9), the mass of the test fluid (water) in the reservoir tank is:

$$M = 1000 \times 0.03 = 30.00\ kg$$

The reservoir tank test mass T_{TM} was calculated using equation (13). It is expressed as: (NNPC, 1993)

$$T_{Tm} = D_m + M \quad (13)$$

$$T_{Tm} = 41.06 + 30.00 = 71.06\ kg$$

The reservoir tank test weight, T_{TW}, in Newton can be calculated using equation (14).

$$T_{TW} = T_{Tm} \times 9.81 \quad (14)$$

$$T_{TW} = 71.06 \times 9.81 = 697.10\ N$$

The reservoir tank test weight per width was calculated using equation (15). It is expressed as: (NNPC, 1993)

$$T_{kTw/_W} = {}^{T_{TW}}/_{W} \quad (15)$$

$$T_{kTw/_W} = \frac{679.1}{0.5} = 1.40\ kN/m$$

The reservoir tank as shown in Figure 1 rests on two supports spaced 50 cm apart.

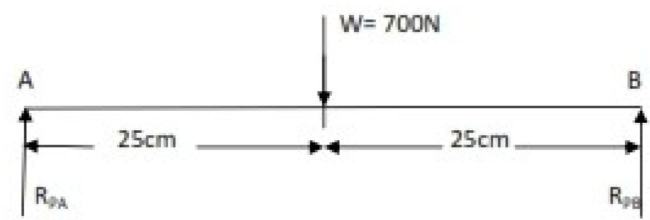

Figure 1: Load analysis diagram

The total load on the reservoir as shown in Figure 1 is 700 N and the reaction R_{PB} and R_{PA} is 350N

(iii) The electric motor and pump

The motor power required to drive the pump (P_{hp}) can be obtained using equation. It is expressed as: ("Parker Hannifin Corporation," 2018).

$$P_{hp} = \frac{Q_{gpm} \times P_{psi}}{1714 \times E_M} \quad (16)$$

Considering a positive displacement pump with a flow rate of 4 *lpm* , mechanical efficiency of 90 %, and a design pressure of 50 bar, from equation (16), the motor horsepower required to drive the pump is 0.5 *hp*.

Therefore, an electric motor of 0.5 hp was selected.

2.2. Materials selection

The following materials were selected and used in the fabrication of the locally develop HPU. These materials and their properties are discussed below.

2.2.1. Mild steel for the reservoir tank and lid

A 4 mm thick mild steel sheet was selected for the hydraulic reservoir tank and tank lid. Mild steel has a carbon content of 0.16 - 0.29 % and is grouped under carbon steels. Its low price (compared to other carbon steels) and multipurpose application in many engineering construction make it a very economical engineering material. It is relatively ductile and malleable. It has a density of 7850 kg/m^3 and Young's modulus of 206.5 GPa. Due to these properties and its availability, machineability and good strength quality, it was used in the construction of reservoir tank and tank lid. Table 2 shows the technical data for mild steel.

Table 2: Mechanical properties of mild steel

Mechanical Properties of Mild Steel	
Max Stress	400 - 560 N/mm^2
Yield Stress	300 - 440 N/mm^2 Min
0.2% Proof Stress	280 - 420 N/mm^2 Min
Elongation	10 – 14 % Min

Source: (Adetoro, 2013).

2.2.2. Total Azolla ZS 68 grade oil for the hydraulic fluid

The hydraulic fluid is the medium that transfers power in the system or the machinery. For the operation of the locally developed HPU, Total Azolla ZS 68 grade hydraulic oil was selected as the working medium. Table 3 shows the technical data for the hydraulic oil.

Table 3: Total Azolla ZS 68 grade hydraulic oil properties

Typical characteristics	Methods	Units	Value
Appearance	Internal	-	Clear Liquid
Density at 15°C	ISO 3675	kg/m^3	880
Kinematic viscosity at 40°C	ISO 3104	mm^2/sec	68.0
Kinematic viscosity at 100°C	ISO 3104	mm^2/sec	8.7
Viscosity index	ISO 2909	-	100
Cleveland Flash point	ISO 2592	°C	242
Pour point	ISO 3016	°C	-21°C
Filterability 0.8µ without water	NF E 48 - 690	Index (IF)	1.01
Filterability 0.8µ water	NF E 48 - 691	Index (IF)	1.5

Source: (Total Lubrifiants, 2011)

2.2.3. Seipee 3-phase, 0.5 hp electric motor

The electric motor delivers the electric power supply that drives the hydraulic pump to create flow. The specifications are 0.5 hp, 4 P, 440 V, 50 Hz, Frame-B3, and rpm- 1380. The electric motor was selected based on design calculation and cost.

Table 4: Specification for hydraulic pump

Name of Component	Hydraulic Pump	Unit
Type : Internal gear fixed displacement		
Maximum flow rate	4	Lpm
Displacement	2.66	cm^3/rev
Continuous maximum pressure	75	Bar
Maximum speed	1380	Rpm

Source: (NNPC, 1995)

2.2.4. Hydraulic pump

A positive displacement gear pump was selected due to long life, low maintenance cost and high performance (Egbe, 2013). Table 4 shows the specification for the hydraulic pump.

2.3. Parts fabrication sequences

The parts fabrication sequences for the hydraulic power unit being constructed are the reservoir tank and lid, the electric control panel, the general assembly of the whole process.

a) Hydraulic reservoir tank and lid

The fabrication sequence for the hydraulic reservoir tank and lid as represented in Table 5 shows the various processes.

b) Electric control panel

The electric control panel houses the power control mechanism of the HPU. Table 6 shows the fabrication sequence for the electric control panel.

c) General assembly of the hydraulic power unit

Table 7 shows the fabrication sequence for the general assembly of the HPU.

2.4. Cost analysis

The cost analysis for the locally developed HPU involved costing of the project (material and labour costs), price comparison between the estimated cost of the locally developed HPU and other competitors, and the cost-

Table 5: Fabrication sequence for the hydraulic reservoir tank and lid

Sn	Sequence	Tools / Instrument
1	Marking of parts on Grade 8 (4mm) metal sheet: 2 pieces of 318 mm x 308 mm for left and right sides of tank. 2 pieces of 234 mm x 500 mm for the back and front sides of tank. 1 piece of 308 mm x 500 mm for the base of tank. 1 piece of 337 mm x 566 mm for reservoir lid 1 piece of 245 mm x 426 mm for support for control panel (Grade 20).	Measuring tape, metal square, marker, puncher and hammer
2	Cutting and 45 ^{o}mitring of marked out parts: 30 mm from the upper end of the four sides of the tank are mitered at an angle of 45^{o}	Stationary hydraulic guillotine cutting machine (Machine No: 6202/6, Capacity: 10.0 x .25ms, and Manufacturer: Pearson machine Tools Co Ltd, Newcastle – Upon – Tyne, England)
3	Flame cutting of positions for filling cap and bell-housing on reservoir lid	Oxy-Acetylene
4	Bending of metal sheet: Left and right sides of tank Back and front sides of tank Reservoir lid	Stationary hydraulic bending machine (Machine No: 667004/2, Capacity: 12′13″ x 155 Ton, and Manufacturer: Pearson Machine Tools Co Ltd, Newcastle – Upon-Tyne England)
5	Welding of formed parts	3 Phase, 9KW FEMAS Electric arc welding machine (Model: S250F, Machine No: 667004/2, Manufacturer: FEMAS, Milan-Italy, Year of Manufacture: 1976), and some electrodes
6	Boring or drilling of holes on reservoir tank and lid: Ø 13 mm on back side of tank (1 no) Ø 8 mm on front side of tank (2 nos) Ø 10 mm on top of tank (6 nos) Ø 10 mm on top of lid (8 nos) Ø 7 mm on for Bell-house mount on top of lid (8 nos) Ø 5 mm on Support stand on top of lid (8 nos)	Measuring tape, marker, puncher, hammer, Fobco $1^{1}/_{4}$″ Drilling machine (Manufacturer: F. O. Brian & Co Ltd, Wadlincote Burton-On Trent, England) with a 10 mm diameter drill bit
7	Grinding of weld spots	Electric grinding machine (Manufacturer: Bosch)
8	Inspection	Measuring tape, and vernier caliper
9	Painting	90 litre gasoline air compressor spraying machine – 14CFM, 3hp (Manufacturer: SGS) with a 1.4 mm nozzle central cup gravity-type with 400 cc spraying gun.

Table 6: Fabrication sequence for the electric control panel

Sn	Sequence	Tools / Instrument
1	Procurement and preparation of control panel box	A piece of clean cloth, and ABB (Asea Brown Boveri) metallic box with an attached cover
2	Drilling of the box and DIN rail	Measuring tape, metal square, maker, puncher, hammer, and electric hand drilling machine (Model: Raider 13 mm) and a 3 mm diameter drill bit
3	Placement of DIN rail inside control panel box	Screw driver, and screws
4	Placement of connectors, contactor, and connector clamps on DIN rail	Screw driver, and screws
5	Placement of pilot lamps and power control selector switch on the control panel cover	Screw driver, and screws
6	Colour coding of the wires	Cable lug and wire crimper
7	General wiring of control panel circuit	Phillip's screw driver

Table 7: Fabrication sequence for the general assembly of the HPU

Sn	Sequence	Tools / Instrument
1	Mounting of the electric motor and hydraulic pump on the tank lid	A piece of clean cloth, oil gasket, 8 mm Allen key screws, 10 mm Allen key screws, 13 mm Hex screws, 10 mm and 13 mm spanners.
2	Mounting of electric control panel on the stand frame on the top of the tank lid	Screw driver, 5 mm screws and bolts
3	Placement of the oil level gauge on the hydraulic tank	Screw driver, 8 mm screws, and bolts
4	Connection of various components of the hydraulic circuit (check valve, pressure relief valve, pressure switch, pressure gauge, and Shut-off valve)	Teflon thread tape, and pipe wrench, ¼ inch pipe fittings and couplings, high pressure hoses, clips, and screw driver.

effectiveness analysis which determined whether the value of locally developed HPU justified its cost.

2.4.1 Materials and estimated labour cost

The cost of materials for this project came to a total of ₦120, 000 (One Hundred and Twenty Thousand Naira). The materials were mostly sourced from local vendors both in Ilorin and Lagos. This project was worked on twice a week for five hours on average and began June 3rd, 2017. The project was completed for initial testing by August 28th, 2017 making the total build time about twelve weeks. Total hours put into this project is estimated at around 120. The average basic monthly salary for a worker in Nigeria is Sixty-thousand Naira (₦60, 000). This translates to ₦2,500 per day or ₦312.5 per hour (8 hours of work per day for 24 days in a month). Therefore, the labor cost amounts to ₦37,500 for the 120 hours spent in production of the locally developed HPU. The total cost of this project came to One Hundred and Fifty-Seven Thousand, Five Hundred Naira Only (₦157,500). Table 8 shows the parts list (cost sheet) for the locally developed HPU.

2.4.2. Total estimated cost vs. competition

The material and labour cost estimated was ₦157, 500 (One Hundred and Fifty-Seven Thousand, Five

Table 8: Cost sheet for the locally developed HPU

Reservoir Frame & Lid	Quantity	Description	UnitPrice ₦	Total ₦
Gauge 8 Sheet Metal (4mm)	1	1010 mm x 760 mm	2500	2500`
Gauge 8 Sheet Metal (4mm)	1	335 mm x 570 mm	500	500
Gauge 20 Sheet Metal (1mm)	1	300 mm x 400 mm	100	100
Filling cap	1	1 1/4 " Diameter	500	500
Hardware				
Bell-house Mount Bolts	4	13 mm Allen Screw and Bolts	25	100
Tank Lid Bolts	6	13 mm Hex Screw and Nut	20	120
Drain Plug	1	17 mm Hex Screw and Nut	20	20
Electric Motor Mount Bolts	4	13 mm Hex Screw	20	80
Pump Mount Bolts	4	8 mm Allen Screw	20	80
Fluid Transfer				
Electric Motor	1	Seipee ZKF 71B 4	15000	15000
Hydraulic Pump	1	4 lpm	5000	5000
Nipple	9	1/4 " Male to 1/4 " Male	300	2700
Elbow	1	1/4 " Male to 1/4 " Female		
Elbow	2	1/4 " Female	300	600
90^{o} Barb				
Socket	5	1/4 " Female to Female	300	1500
Tee	3	1/4 " Male	300	900
Tee	1	1/4 " Female	300	300
Tee	3	(1) 1/4 " Male to (2) 1/4 " Female NPT Stainless Steel	1500	4500
Lock Nut	2	1/4 "	100	200
R2 Hose	1	4 ' SAE 100R2	1000	1000
Check Valve (Non – Return Valve)	1	1/4 " NPT Black	1500	1500
Instruments & Control				
Pressure Switch	1	Danfoss KP 37 Type	18000	20000
Oil Level Gauge	1	20 Litres Tank Gauge	2000	2000
Oil Pressure Gauge	1	1/4 " 0 - 200 psi Wet	1500	1500
Pressure Relieve Valve	1	Yuken Pressure Relief Valve	15000	15000
Flow Regulator	1	1/4 " Parker F400S-11DW, 5000 PSI, NPT Black	1500	1500
Flow Meter	1		10000	10000
Electric Control Panel				

Enclosure	1	ABB Metallic Box (175 mm x 175 mm x 140 mm)	1000	1000
Three – Phase Contactor	1	Schneider LC1D50AM7 Magnetic Contactor Ac 220V DIN Rail	3000	3000
Indicator Lights	2	28mm Diameter LED Pilot Panel Indicator Signal Warning light 220 – 240V	500	1000
Power Selector Switch	1	28mm Diameter	1000	1000
Terminal Blocks	2	Phoenix DOK 1, 5 – 2D, 3-Level, 5 Contacts w. ground	500	1000
Terminal Blocks	4	Dinkle 45A, 600V, 8 mm Thickness, ULVDE RoHS (1- Level)	250	1000
Screw Terminal Blocks Ground	2	Entrele Terminal Block M6/8.P Anchor Stop Clamp 6 mm Wide DIN	100	200
Hanger	1	DIN Rail	100	100
Miscellaneous Expenses				20000
Estimated Labour Cost	120 hrs	Labour cost in line with the wages being paid to NNPC-PPMC contract staff	₦312.5/hr	37500
		Total		157500

Hundred Naira Only) which was about $437. Compare this cost to that of a used Lincoln 7 Gallon, 1hp, 1735 rpm, 3 Phase, 230/460 V, and 60 Hz HPU which sells for $290 with a shipping cost to Nigeria of $1800 from "ebay" (an online shopping platform). Without the final transportation cost to deliver it to its final destination (from Lagos to Ilorin), it can be seen that the total cost is $2100 and going by an exchange rate of ₦360/$, it costs approximately Seven Hundred and Fifty-Six Thousand Naira (₦756, 000). This Lincoln hydraulic power unit neither has a pressure switch nor a pressure relief valve. The originally installed Redwood HPU cost around One Million, Five Hundred Thousand Naira (₦1,500, 000).

2.4.3. Cost-effectiveness analysis (C.E.A.)

Cost-effectiveness analysis is a tool used to compare the cost and effectiveness of two or more alternatives. Cost-effectiveness involves more than determining cost, it also involves assignment of a value to the outcome. The goal of cost-effectiveness analysis was to determine whether the value of an intervention justified its cost. The cost-effectiveness (₦/kg) was calculated using equation (17) which can be expressed as:

$$C.E = {}^{C_P}/_{O_D} \tag{17}$$

Where

$C.E$ = Cost effectiveness

E_p= Cost of production of HPU, and

O_D= Daily output of LPG sold

The average daily output of LPG sold in the PPMC LPG Plant Ilorin is 500 Cylinders of 12.5 kg capacity which translated to 6250 kg.

3. Experimental procedure to measure pump flow rate

The experimental set up comprised a reservoir hydraulic pump, pipelines, pressure relief valves, vent valve, flow meter, pressure gauge, and a variable flow control valve. The pump was connected to a parallel configuration of a flow meter and a pressure relief valve with a dead-headed pressure gauge as shown in Figure 2.The circuit

Figure 2: Actual setup for experiment

was assembled using hoses fixed with quick connects attached to permanently fixed valves and gauges on the test specimen. The pressure relief valve was initially set to 200 psi and decreased in random steps until the pressure relief valve was fully open. System pressure and flow rate were recorded for each change in the set pressure of the relief valve.

From the experiment carried out, the maximum flow rate of the pump was established and used to determine the overall performance of the locally developed HPU. The hydraulic pump volumetric efficiency, which can be expressed as the ratio of actual flow rate to theoretical flow rate, was calculated using equation (18). It is expressed as:

$$\eta_V = \frac{Q_{act}}{Q_{th}} x\ 100 \quad \text{(Brendan, 2015)} \quad (18)$$

Efficiency of gear pump = 90%, Pump flow rate, $Q = 4.0\ lpm\ Q_{th} = 3.6\ lpm\ Q_{lpm} = 0.5686\ gpm$

therefore, $\eta_V = 59.7\%$, Working pressure = $50\ bar = 725\ psi$

The power of the motor required to drive the pump was calculated using equation. It is given by (Pratik et al., 2013) as

$$P_{hp} = \frac{Q_{gpm} \times P_{psi}}{1714} \quad (19)$$

Therefore, from equation (18), the power required to drive the motor is $0.24\ hpor\ 0.179\ kW$

The mechanical efficiency of the motor was calculated using equation (20) . It is given by Pratik et al. (2013) as:

$$\eta_M = \frac{N_{(act)}}{N_{(rt)}} \quad (20)$$

$$N_{(act)} = \eta_M \times N_{(rt)} \quad (21)$$

$\eta_M = 71\%$ (according to the name plate on motor), $N_{(rt)} = 1400\ rpm$

From equation $N_{(rt)} = 1400\ rpm$

The pump displacement was calculated using equation (22). It is expressed by Pratik et al.(2013) as,

$$PD_{CI} = \frac{Q_{gpm} \times 231}{N_{rpm}} \quad (22)$$

The torque was obtained as $15.92\ ft - lb\ or\ 1.79\ Nm$ using equation (22). It is expressed as: (Pratik et al., 2013)

$$T_{(ft-lb)} = \frac{P_{hp} \times 63025}{N_{rpm}} \quad (23)$$

The overall efficiency of the motor was obtained from equation (24) as expressed by Brendan (2015):

$$\eta_o = \eta_M \times \eta_V \quad (24)$$

4. Results and discussion

4.1. Cost effectiveness of the developed HPU

Table 9 shows the cost effectiveness (CE) of the two HPUs with the least cost effectiveness of Twenty-Five Naira, Twenty Kobo per kilogram (₦25.20/kg) from the cost-effectiveness analysis (C.E.A), the locally developed HPU, was 89.5 % less in price than the Redwood HPU.

Table 9: Cost effectiveness of the HPUs

S/N	HPU	Cost of Procurement (N)	Measured Daily Output(kg)	CE (N / kg)
1	Locally Produced	157, 500	6250	25.20
2	Redwood	1, 500, 000	6250	206.89

4.2. Testing of locally developed HPU

The locally developed HPU tested on a Whessoe-Varec internal hydraulically operated ESV. It produced a maximum pressure of 60 bars that successfully pressurised the hydraulic lines and opened the ESV. When the pressure in the line, reached 30 bars, one pole in the contactor opened and the power supply to the motor/pump was cut off and the electric motor/pump was idling. Also, when the pressure in the line dropped to 20 bars, the other pole in the contactor closed and power was supplied to the motor/pump once again and the pump/motor began to pump hydraulic fluid to the lines in order to maintain the working pressure of 30 bars (which is the pressure required to open the hydraulic internal ESV) for effective product transfer to and from the storage vessels.

4.3. Experimental result and performance evaluation

Table 10 shows pressure versus flow as relief valve is opened with the corresponding calculated fluid power. The fluid pressure in the circuit was limited to the set pressure of the relief valve. As the relief valve pressure decreased, more fluid flowed over the relief valve while less fluid flowed through the circuit. The fluid power (FP) at the flow meter was also calculated and it was clear that as the relief valve of the system opened, the fluid power of the system decreased due to the imposed restriction in the path the fluid is to take

Table 10: Pressure versus flow as relief valve is opened with the corresponding calculated fluid power

PRV setting (psi)	200	190	180	170	165	Relief valve open
Pressure(psi)	52	47	45	44	43	Relief valve open
Flow, Q (lpm)	1.580	1.550	1.510	1.470	1.460	1.460
Flow, Q (gpm)	0.4174	0.4095	0.3989	0.3884	0.3857	0.3857
FP (hp)	0.0127	0.0112	0.0105	0.0100	0.0097	0.0097

Table 11 shows the flow rate over the relief valve. The flow rates of fluid flowing through the hydraulic system and the corresponding flow rate of fluid flowing through the pressure relief valve at a specific PRV setting were also recorded and calculated. As less fluid flowed through the system, more fluid flowed over the relief valve.

Table 11: Flow rate over the relief valve

$Q_{(gauge)}$	1.710	1.575	1.460	1.100	0.710
$Q_{(rv)}$	0.440	0.575	0.690	1.050	1.440

Table 12 shows the calculated parameters for performance evaluation of the HPU. The values of the parameters for determining the performance of the locally developed HPU were calculated and it was found that the overall efficiency of the locally developed HPU was 42.4 %.

Table 12: Calculated parameters for performance evaluation of the HPU

S/N	Parameter	Value	Unit
1	Efficiency of gear pump, η	90	%
2	Design flow rate of pump, Q	4	lpm
3	Theoretical flow rate, Q_T	3.6	lpm
4	Actual flow rate , Q_A	2.15	lpm
5	Working pressure, P	50	bar
6	Volumetric efficiency of the pump, η_v	59.7	%
7	Power required to drive the motor (P_{hp})	0.24	hp
8	Maximum speed of the motor, $N_{(Max)}$	950	rpm
9	Pump displacement at 950 rpm PD_{CI}	0.138	C u in/rev
10	Pump displacement at 950 rpm PD_{CC}	2.26	cm^3/rev
11	Motor torque, $T_{(ft\text{-}lb)}$ at 950 rpm	15.92	$ft-lb$
12	Motor torque, $T(_{Nm})$ at 950 rpm	1.79	Nm
13	Overall efficiency, η_o	42.4	%

5. Conclusion and recommendation

At the end of the design, construction, and evaluation of the HPU, the following conclusions were drawn:

The cause of failure in the Redwood HPU was mainly the accumulator which might be as a result of either the contamination of the hydraulic oil (as a result of damaged hydraulic filters) or the deterioration of the material used due to ageing.

In terms of performance, the locally developed HPU, when tested with a Whessoe-Varec internal emergency shut-off valve (ESV) (Model no: 6139 2", Serial no: 2510), successfully opened the valve and therefore can serve as a substitute for the imported Redwood HPU.

The developed HPU, having the least cost effectiveness of ₦25.20 per kilogram and 89.5 % cheaper than the Redwood HPU, will save several hundreds of thousands of Naira when compared to the amount spent in the maintenance of its foreign counterpart.

The locally constructed HPU had a maximum pump flow rate of 2.15 and an overall efficiency of 42.4 % as compared with the Redwood HPU which had a maximum pump flow rate of 3.06 and an overall efficiency of 60 %.

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