Design and Fabrication of a Human-Powered Vacuum System for Milking Carabaos and Cows

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Abstract

The use of electric milking devices is used in several developing countries. It is expensive, high maintenance, and has high electric consumption. Small-scale farmers cannot accommodate these variables. Therefore, the researchers design a human-powered vacuum system for Milking Carabaos and Cows, which the farmers can utilize. This research intends to fill the market gap between the electric milking device and the traditional hand milking technique. Moreover, to yield more milk in a short period compared to hand milking. The system showed a slight difference concerning the milk output volume compared to using an electric milking device under the working pressure of 40-50 kPa. Comparisons between the designed prototype and different milking processes were tested, and therefore, the objectives of this study were attained.

Keywords
Human-powered vacuum, design, and fabrication

1. Introduction

Extracting milk has provided the needs of many people. Also, these domesticated animals like Carabaos and Cows were used in doing this. Through the advancement of technology, mechanical devices were used to nurture milk (Swart, Blignaut, and Jooste, 2018). These devices were also utilized for mass production and the progress of the study of pasteurization. Thus, milking machines were highly favored compared to the traditional hand milking technique. It was preferred due to the demands of yielding milk effectively.

The Philippines is an agricultural country, use of these animals, especially the carabaos and cows, were widely utilized. (Bondoc, 2018). These animals were used for farming and to supply their by-products, especially their milk. The production of extracting milk of carabaos and cows is different depending on many factors. But the usual yield range would be 4-7 liters of milk per session. Farmers used this for their utilization and sometimes sell for profit. There is also nourishment advantages comparing the milk of carabaos to cows (Que, 2018).

Having a milking machine have its advantages and disadvantages. A farmer in the Philippines owns an average of three cows or carabaos. Most of them resort to manual hand milking instead of the milking machines readily available in the market, for they do not find milking machines practical due to their high cost. Manual hand milking is an outdated technique that is deemed inefficient. The researchers made a system in which milking would be more efficient but still cost-effective at the same time by solely utilizing human power and no other energy resources.

1.1 Objectives
The study focuses on developing an alternative and more affordable human-powered vacuum system for the milking machine that will be used by the farmers who own carabaos or cows to increase output milk production. The specific objectives are: (1) to create a pump mechanism that will provide enough vacuum pressure for the milking machine to yield milk from the carabao or cow being tested. Next is to develop a prototype that will cost cheaper in value than the electric milking machine. Lastly, to compare the data acquired with the human-powered milking machine to be an electric milking machine for the carabaos and cows.

This machine would help the farmer in yielding milk to the carabao or cow. Also, this would decrease the workload upon milking the animal. It eradicates the dependency on electricity in milking the animal. Finally, the portability and compatibility of the device to both cows and carabaos are observed in the design.

Moreover, the cost of the system will be placed below the price range of the electric milking machine, around Php 25,000 – 60,000. A significant part of the system is the source of the vacuum, which was replaced. But the part that is in contact with the animal will not be changed or altered. The system will be in a vacuum range of 40-50 kPa. Five to six carabaos would use the milking device. In between, the farmer will rest for 10-15 minutes before operating the machine again. Philippine Carabao Center wants the device to be fully mechanized since not all farmers have access to electricity. The study does not include the effect of human posture, biomechanics, and ergonomics while using the device.

2. Literature Review
2.1. Components of Human-Powered Milking Device
The human-powered milking device is composed of the following components observed and researched in connection with the electric milking machine. The materials used in making the device were also indicated for fabrication purposes. The schematic diagram of the device can be seen in Figure 1. The main components of the device are vacuum pump, pulsator, cluster, claw piece, vacuum gauge, vacuum accumulator, double-acting, reciprocating pump, check valve, and ball valve. While materials used in making the device are mild steel and polypropylene.

The vacuum pump makes the primary source of the vacuum. It moves the air from a sealed container and moves the gases by mechanical action (Conlon, 2018). The pulsator is a device that acts as a divider that passes through a machine; this is like a valve that opens and closes the liners in the teat every second. The pulsator is the central part of the system that acts as a massager for the teat to prevent swelling (Reitsima et al., 1981).

A cluster is a set of equipment of the milking device that consists of a claw and four fully assembled cups. Correctly, setting the cluster will give efficient results that will increase milking efficiency and improve the animal's health (Reitsima et al., 1981). The claw piece is where the milk pools as it is removed in the teats of the carabao. It is where the four liners intersect to provide each one with an equal amount of vacuum (Pressure Gauges Information., n.d.).

The vacuum gauge is a device used to measure the pressure in an air pump or vacuum pump. A vacuum is a space in which gas pressure is lower than the atmospheric pressure (Pressure Gauges Information., n.d.). A vacuum accumulator is used to maintain a vacuum pressure level if the vacuum source fails because of an unexpected event or one of the components leaks. A double-acting reciprocating pump is used for the source of the vacuum pressure for the milking system. This type of pump has two processes that work simultaneously for each stroke of the piston head. The suction and discharge are done simultaneously; it has two discharge sides and two suction sides. This reciprocating pump gives a continuous vacuum pressure because of its nature (Mishra, 2018).

There are two valves used in the system. First is the check valve. It has two ports, so it has two openings, one for input and one for output. This valve only allows a fluid (gas or liquid) to flow in a one-way direction (Limited, 2018). Second is the ball valve; it has a pivoting ball inside of its casing to control the flow of the fluid (gas or liquid). The valve opens when the ball's hole inside the valve or its handle is perpendicular to its casing.

Mild steel is a type of carbon steel that contains a low amount of carbon, unlike any other steel. Mild steel does not have many different elements, so it is not categorized as alloy steel. It typically contains about 0.05% to 0.25% carbon (Google, n.d.) Polypropylene is made from a combination of propylene monomers. Its characteristics make it an ideal material for various objects such as car bumpers, medical tools, and utensils. Polypropylene has a high melting point, can resist stress, and is durable (Staff, 2018).

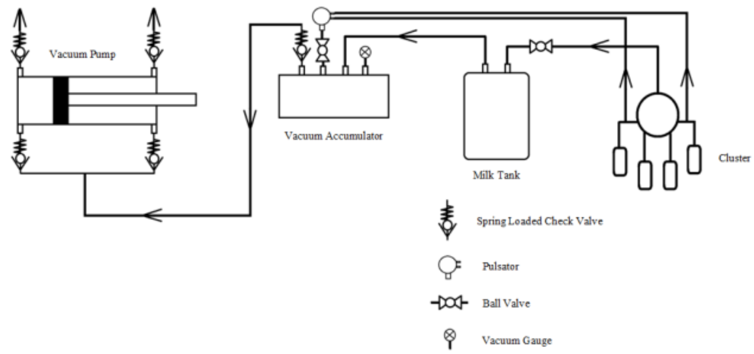

Figure 1. Schematic Diagram

2.2. Parameters Considered in Yielding Milk

The researchers applied the following principles to understand further each component in yielding milk effectively, such as force, mass, area of the vacuum accumulator and the reciprocating pump, torque, force analysis, and volume of the right cylinder.

Different forces are acting on the device itself. This is the force acquired when the air is displaced inside the reciprocating pump creating a vacuum pressure. The mass is equivalent to the force acting on the piston and lever to estimate how heavy it is to operate the machine. The area of the vacuum accumulator was used to determine the volume of the air inside. At the same time, the area formula for the reciprocating pump was used to determine the needed area for calculating the force inside the pump. The torque is defined as the tendency of a force to rotate at an object on a certain axis. For a class two lever arm, the load is between the fulcrum and the effort force by the user.

Force analysis in a hand-powered reciprocating pump, the force to lift the pump's piston during the upward stroke is equal to the summation of forces acting upon it. The volume formula of the right circular cylinder was used to obtain the necessary dimension for the reciprocating pump and vacuum accumulator, as shown in Equation 1.

$$(1) \quad F_t = F_p + F_{vp} + F_l$$

2.3. Conditions for Milking the Carabao

The milking machine has various things to consider to safely and adequately extract milk from a carabao or a cow, such as a vacuum, pulsation, and food grade. One factor for efficient milk extraction from the carabao is the vacuum pressure in the milking device. The adequate pressure is 40-50 kPa to yield milk from the animal without the cluster falling off the teat and harming the animal, causing mastitis. The vacuum pressure is essential for the animal's well-being that affects the overall milk production of the carabao or cow.

Another factor for efficient milk extraction from the carabao and cow is the pulsation inside the teat cup liner. Using a pulsator automatically switches the vacuum pressure to atmospheric pressure. This causes a massaging feeling in the teat of the carabao that prevents harming the animal from over-exposure from the vacuum pressure.

Food grade is any material that is suitable for human consumption. The milk that comes into contact within the milking device should be made from food-grade materials to prevent microorganisms from getting in the milk and ensure that the carabaos don't have any infections during the milking process (UIUC, n.d.).

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3. Methods

3.1. Identification of the Market Gap and Attributes of the Milking Machine

Electric milking machines are costly, have high maintenance costs, and have high electricity consumption. The prototype filled the price gap in the milking industry that farmers can also use without electricity.

3.2. Presentation and Approval from the Philippine Carabao Center

The topic was commissioned by the PCC. Although the idea came from them, the concept and the approach the group still needed approval from the PCC to avoid misunderstanding. Dr. Cyril Baltazar is our primary contact person. The researchers initially presented their approach to him then to PCC president Dr. Arnel Barrios.

3.3. Data Gathering and Background Research at Philippine Carabao Center

The electric type milking machine was examined, and each component was studied to modify the existing system further. Further studies are needed for a better understanding of the mechanics of milking machines.

3.4. Design of Milking Machine

The design of the human-powered milking machine was based on the requirements that the PCC gave, which provided sufficient vacuum pressure to extract milk from the carabao without harming the animal. The researchers used Sketch Up and AutoCAD to construct the 3D model of the milking device. Sketch Up and AutoCAD is software that was used to create 2D or 3D model designs.

3.4. Design of Vacuum Pump

The vacuum source was a double-acting reciprocating pump that gave a vacuum pressure for each stroke of its piston head. The material that was used to make the pump and its piston was mild steel. The suction and discharge outlets were fitted with a check valve that made airflow only in one direction, as shown in Figure 2.

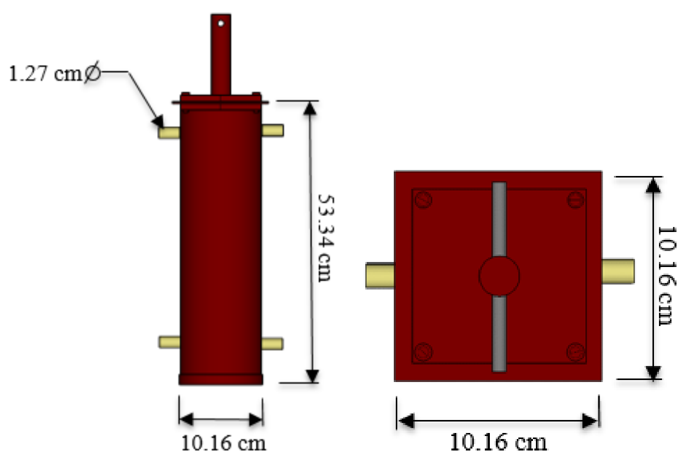

Figure 2. Front and top view of the Reciprocating Pump

3.4. Design of Vacuum Accumulator

The accumulator is a right circular cylinder that has four openings on its sides. The openings are for the input of the vacuum, the output to the milk tank, the pulsator, and the vacuum gauge. The material used to make the vacuum accumulator was mild steel, as shown in Figure 3.

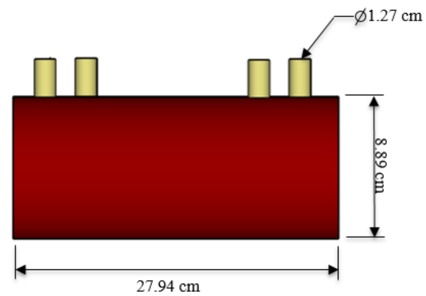

Figure 3. Side view of the vacuum accumulator

3.5. Connection of various valves

The valves used for the prototype are correctly connected to the system to prevent vacuum leaks, leading to loss of pressure inside the whole system. Ball valves are used as a switch that is manually closed or opened whenever the desired vacuum pressure is achieved. Check valves were also used to act as an automatic switch for the airflow in the system.

3.6. Stand of the Cluster

After every milking session, the stand was used to support the milking cluster to prevent it from falling to the ground. It has an adjustable height and was made from lightweight and durable material.

3.7. Frame, Lever, and the Handle of the System

The frame is the one to hold all the components together and supports the lever of the vacuum pump. The material that was used for the structure was an angle bar to have durability and lightweight. It was also fitted with four wheels, each with a lock to ensure the device does not move when operating, as shown in Figure 4.

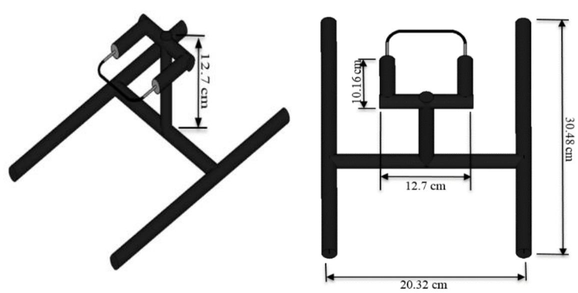

Figure 4. Isometric and Top view of the Cluster stand

3.8. Set-up for the Whole system of the machine

The connections for the actual prototype were based on this 3D model. They were appropriately used to designate each component to its rightful place, as shown in Figure 5.

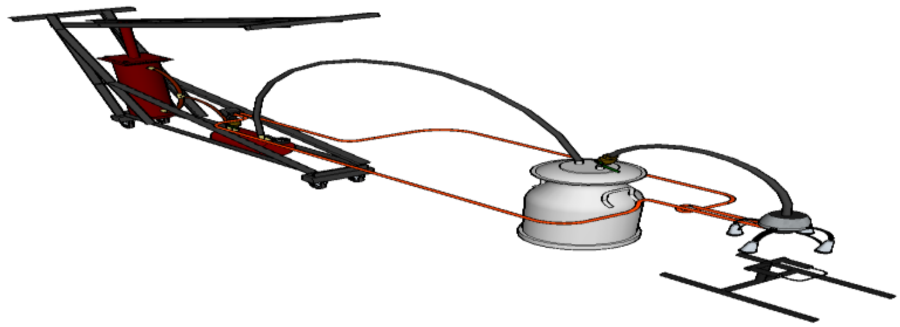

Figure 5. Isometric view of the whole system

3.9. Fabrication of the Prototype

The human-powered milking device was modified from the electric type that has a human-powered pumping system. All parts that would touch and have contact with the animal were not altered. The machine was based on the machine available at the Philippine Carabao Center.

3.10. Testing, Evaluation, and Fine Tuning of the Milking Machine

The actual milking process was done at the Philippine Carabao Center (PCC) in Nueva Ecija. The researchers first determined if the pressure range of 40-50 kPa can be maintained to properly yield milk from the animal when subjected to the device and assessed the animal to ensure that it was perfectly healthy to avoid complications during the performance milking procedure. The portable milking device was connected to the teat of the animal. The lever was used to operate the vacuum pump.

4. Results and Discussion

Table 1 shows the average strokes and the time required to obtain enough vacuum for the cups to stick to the teats (50 kPa vacuum pressure), with a 20-liter milk tank and a stroke of 96.52 cm for the entire length.

Table 1. A summary of the number of strokes and the time to reach the desired vacuum pressure.

Length of Stroke	Trials	No. of strokes	Time (sec)
96.52 cm	Trial 1	30	21
	Trial 2	28	22
	Trial 3	29	23
	Trial 4	28	22
	Average	28.75	22

Table 2 shows the milk yield of each of the two five-minute trials and the milk yield in the overall time of 10 minutes using the Human-Powered Milking Device on the cow.

Table 2. Milk yield from the cow after each five-minute trial

Trial	Time (min)	Milk Yield (liters)
1	5	1.9
2	5	2.3
Total	10	4.2

Table 3 shows the range of vacuum pressure that can be obtained using the human-powered vacuum pump for each minute of the two five-minute trials.

Table 3. The vacuum pressure range for each minute of the two five-minute trials

Trial	Time (min)	Vacuum Pressure Range

Trial 1	1st min	50.8-47.4
	2nd min	50.8-47.4
	3rd min	47.4-40.6
	4th min	44.0-40.6
	5th min	44.0-37.3
Trial 2	1st min	50.8-44.0
	2nd min	47.4-44.0
	3rd min	44.0-37.3
	4th min	47.4-40.6
	5th min	47.4-40.6

Table 4 shows the milk yield of each of the two five-minute trials and the total milk yield within the overall time of 10 minutes using the Human-Powered Milking Device on the carabao.

Table 4. Milk yield from the carabao after each five-minute trial

Trial	Time (min)	Milk Yield (liters)
1	5	0.12
2	5	0.13
Total	10	0.25

Table 5 shows the range of vacuum pressure that can be obtained using the human-powered vacuum pump for each minute of the two 5-minute trials.

Table 5. The vacuum pressure range for each minute of the two five-minute trials

Trial	Time (min)	Vacuum Pressure Range
Trial 1	1st min	50.8-47.4
	2nd min	50.8-40.6
	3rd min	44.0-40.6
	4th min	44.0-40.6
	5th min	40.6-37.3
Trial 2	1st min	50.8-44.0
	2nd min	50.8-40.6
	3rd min	47.4-40.6
	4th min	44.0-37.3
	5th min	40.6-37.3

4.1. Data for the carabao using the Electric Milking Machine

The milk yield of the 10-minute trial using the Electric Milking Device on the carabao is 0.275. The vacuum pressure that the Electric Milking Device can produce for the 10-minute trial is 45 kPa.

4.2. Comparison of the Performance of the Human-Powered Milking Machine to the Manual Hand Milking

Data that was compared would come from first-hand experiences of farmers within the scope of the PCC outreach and cooperative programs.

According to their experience, for a veteran milker, a regular milking session for a cow would be 20-25 minutes for six to seven liters of milk. In comparison, the prototype achieved the amount of milk of 4.2 liters in 10 minutes. With time as the unit of measure for human labor required, this device has lessened the milking time. It is mainly due to the benefit of using a claw and cluster assembly that works on all four teats simultaneously compared to using two human hands each for one teat.

4.3. Comparison of the Data acquired in the Philippine Carabao Center (PCC)

Table 6 shows the data acquired in the Philippine Carabao Center using the human-powered milking machine and electric milking machine to yield milk from the carabao in 10 minutes.

Table 6. Comparison of the Data Acquired in the Philippine Carabao Center (PCC)

Elements	Human-Powered Milking Machine	Electric Milking Machine
Milk Yield (Liters) in 10 minutes	0.25	0.275
Vacuum pressure Range (kpa)	40-50	45
Nature of milking	Single Cluster	Single Cluster
Pulsation rate	60 clicks per minute	60 clicks per minute
Milk Tank Capacity (Liters)	20	20
Size of Cluster	Standard Size	Standard Size
Attachment of Cluster	From the sides of the animal	From the sides of the animal

4.4. Cost Comparison Between the Human-Powered Milking Machine and the Electric milking machine

Table 7 shows the total cost of the human-powered vacuum system, including the milking cluster, milk tank, and pulsator. The total price is used to compare the value of the prototype to the existing milking machines available in the market.

Table 7. The total cost of the Human-Powered Milking Machine

Parts	Price (Php)
Milking Cluster	2,500
Milk Tank 20 Liters	3,000
Pulsator	1,600
Human-powered Vacuum system (Prototyping Cost)	11,230
Total	**18,330**

Table 8 shows the different prices of the electric milking machines in the industry. These prices were used for the cost comparison with the human-powered milking machine. We can see that these prices are a lot higher. These prices also do not include shipping and taxes, which contribute to the overall cost of the device.

Table 8. Costs of different Milking Machines

Milking Machines Sold in the Market	Price (Php)
Vevor Milking Machine 550W Electric milking	25,000
Arjun Pump Ind. Vacuum Milking Machine	27,000
Electricity Cow Milking Machine LEO Machinery	43,000
Melasty Cow Milking Machine Portable Electric	63,000
Human-Powered Milking Machine	**18,330**

5. Conclusion

The study concluded that the system is safe to work with both carabaos and cows. It showed that a human produces enough energy that can sustain a pressure ranging from 40-50 kPa vacuum under an operating time of 10 minutes. Adjustments to the pump and vacuum sealing were made, leading to better pump milking time. Fine-tuning of the prototype helped in maintaining the sustained pressure measured at the system accumulator. Moreover, the addition of lubricant to parts in contact assured smooth flow of operation of the machine. Attaching the cluster through the sides of the animal was found to be the safest and most efficient way in milking the animal since it can easily access its four teats, wherein each cup of the cluster was fitted well. The materials utilized in this system were chosen for their availability, cost, and ease of manufacturing, making it cheaper than the commercial milking machine available in the market. It was also found out that factors such as environment, milk-let down, food, and routine of milking contribute to the amount of milk yielded by the animal. Comparison with the automatic milking machine results in a slight difference in milk yield volume when using the prototype. The prototype is better than the traditional hand milking in terms of work, time, and efficiency. A single person can operate it, and when the user uses a vacuum pressure of 45-50 kPa, the time for the milking session can be lessened. Improvements in the design can be achieved if a pneumatic check is used wherein less air leakage from the pump can be attained. Designing a smaller frame or choosing lighter materials for the whole system is recommended for ease of transport. A pedal mechanism instead of a pumping system can decrease the workload of the user. Designing a new cluster system is also recommended to prevent leakage. Lastly, the application of ergonomics will significantly aid in the design.

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