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DESIGN AND DEVELOPMENT OF HYDRAULIC POWERED COCONUT WATER EXTRACTION MACHINE

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Abstract - *Tender Coconut Water is considered one of the healthiest drinks naturally available. But, most of the existing methodologies involve a lot of physical labor and a lot of complexities as the final product is an edible product which limits its availability. The aim of the project is to design a methodology and to fabricate a Coconut water extraction machine that is safe, hygienic, and easy to operate. The model developed is a lever-operated hydraulic system that requires lesser exertion and better productivity than manual operation. All the parts which come in contact with the product is a food-grade material. The accomplished outcomes are increased productivity, reduced time per operation in contrast with the conventional method. This machine can be used in small and medium-scale industries to extract Coconut Water on a large scale.*

***Key Words*: Hydraulic System, Piercing Tool, Coconut Placer,**

1. INTRODUCTION

The coconut palm (cocos nucifera) is found all over the globe, where it has mingled into the lives of local people. It provides almost all the requirements of humans such as food, drink, firewood, medicines, domestic utensils etc. Because of these reasons, it has been called the "Tree of heaven" and "Tree of Life". [1]

Water from tender coconut is a common refreshing drink and has been used as an excellent isotonic in several tropical countries. It is not only a thirst-quenching liquid, but also a mineral drink, which is beneficial to human health. [2]

A common problem that many people are facing in a developing country like India is punching and splitting the tender coconut. Present tools and trends used are unsafe as well as the risk of injury is high. From past years the tender coconut is being opened and cut by completely manual effort by using a hard knife. The tools used are unsafe, messy and need skill and training. Some machines for paring coconut are available, but until now no household tool exists to punch hole in tender coconut and split it open safely. [3]

A market study was carried out to understand the different mechanisms employed in various organizations for this operation. The market study was very helpful in understanding about the mechanisms and machines being used in India as well as abroad.

MARKET STUDY KEY FINDINGS

- Very Tedious process
- Mostly manually operated using machetes
- No proper work cleanliness
- Hygiene issue
- No proper storage and handling of the product

The aim of this project is to design and develop a mechanization for coconut water extraction, with the main criteria being improved productivity along with reduced effort of labor, time and thereby increasing the profits.

1.1. PROBLEM DEFINITION

The aim of this project is to design and develop a mechanization for coconut water extraction, with the main criteria being improved productivity along with reduced effort of labor, time and thereby increasing the profits. This report involves a basic survey of different mechanisms used for the purpose defined above and finding a solution to the problem, proposing new design, doing a feasibility study of design and fabrication of the machine.

1.2. HYDRAULIC SYSTEM

Hydraulic is a technology involving mechanical properties and use of liquids. In its fluid power applications, hydraulics is used for the Generation, Control, and Transmission of power by the use of pressurized liquids. The basis for all hydraulic systems is expressed by Pascal's law which states that the pressure exerted anywhere upon an enclosed liquid is transmitted undiminished, in all directions, to the interior of the container. This principle allows large forces to be generated with relatively little effort.

The simplest hydraulic circuit consists of a Reservoir, Pump, Pressure Relief Valve, Directional Control Valve, Actuator, Connectors and Lines.

2. METHODOLOGY & DESIGN ANALYSIS

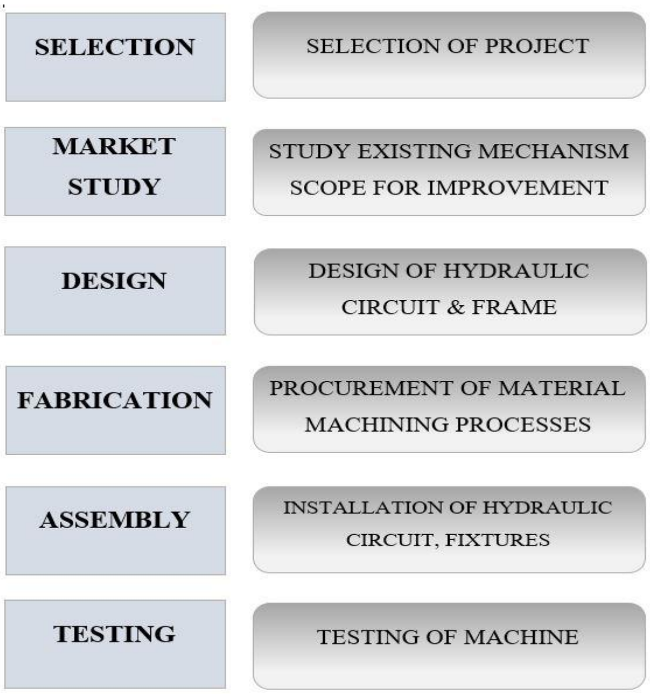
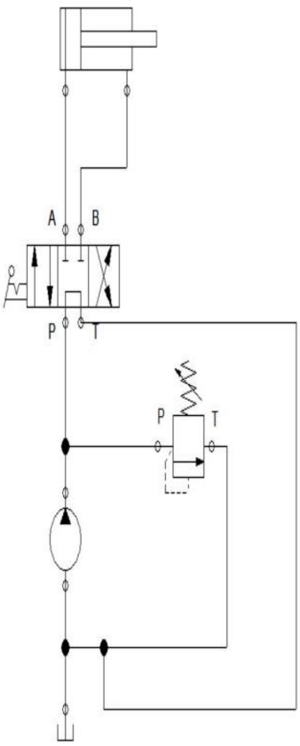


Fig - 1: Stages

2.1 HYDRAULIC CIRCUIT



Number	Description
1	Tank
1	Fixed displacement pump
1	4/3-way hand-lever valve with bypass position
1	Double acting cylinder
1	Pressure relief valve

Fig - 2: Hydraulic Circuit Diagram

2.1.1 HYDRAULIC CIRCUIT CONNECTIONS

The connection of the hydraulic circuit is as follows:

1. The tank is filled with hydraulic oil.
2. A gear pump is coupled to an electric motor.
3. The delivery port is connected to the 4/3 directional control valve.
4. A pressure relief valve is connected in-between the DCV and pump.
5. Port '1' of the double actuating cylinder is connected to Port 'A' of the DCV and Port '2' of the cylinder is connected to Port 'B' of the DCV.
6. The pressure line and Tank line are connected respectively.
7. There are 3 positions in this particular DCV
   a. Position 1-Pressure port and port 'A' and Tank port and port 'B' is directly connected. Forward stroke of the cylinder piston.
   b. Position 2- No movement of the piston, the oil pumped is directed back to the tank. (Neutral Position)
   c. Position 3- Pressure port and port 'A' and Tank port and port 'B' is inter-connected. Reverse stroke of the cylinder piston.
8. Tank port of DCV, Pressure relief valve are directed back to tank through hoses.

2.2 DESIGN ANALYSIS

The proposed model is a basic hydraulic machine with a pierce tool and a fixture to hold the coconut. This machine is lever-operated. This machine requires constant supply of electric power. Once power is supplied to the electric motor, the pump coupled to the motor starts its operation and the whole operation is carried out with the aid of hydraulic circuit. The DCV is controlled by the operator.

This Coconut water extraction machine consists of two main parts, one is the hydraulic system and the other is the frame onto which the hydraulic circuit is mounted and the fixture to hold the coconut. The piercing action takes place with the help of a tool which is made up of Stainless Steel and is fixed onto the collection plate. A ram is fixed onto the shaft of the cylinder rod. A hose pipe is used to take out the coconut water from the collection plate.

2.2.1 DESIGN LAYOUT

The following design layout portrays the fundamental interconnection methodology between the Hydraulic system which is coupled with the power generation.

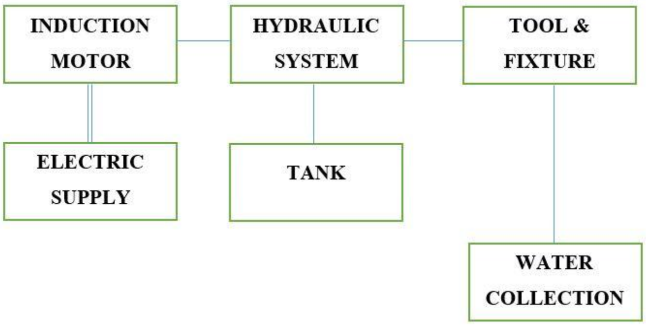


Fig - 3: Design Layout

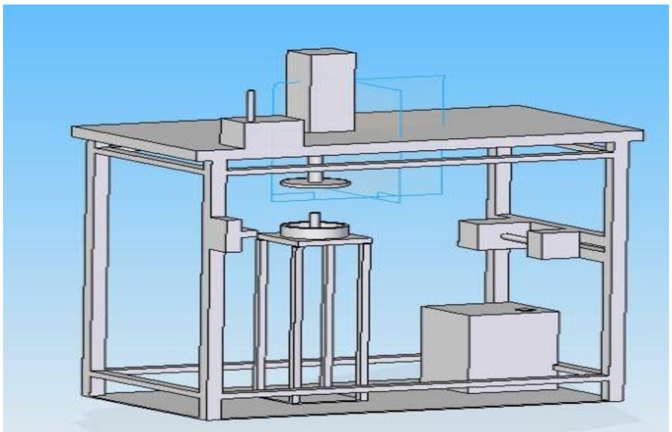


Fig – 4: 3D CAD model of the machine

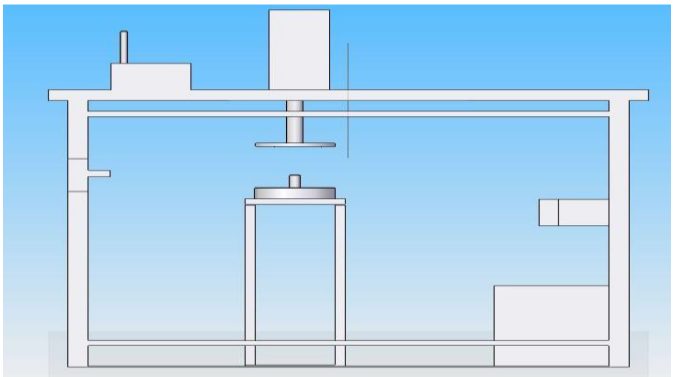


Fig – 5: Front view

2.3 DESIGN CALCULATIONS

A trial of was conducted on 15 coconuts of various sizes. The area is calculated using the formula of circle($A = \pi r^2$) but as the coconut is not a perfect circle, we have assumed a generalized reduction of 30%. The force required for punching is calculated using Universal testing machine. For punching, the force varied from 630N to 1532N. The mean of the calculated forces was found as 1093.67N, and the average of calculated pressure in Pascal was found to be 17299Pa.

Sl.no	Weight of Tender Coconut(Kg)	Diameter(mm)	Area(mm²)	Measured Resistive Force(N)	Calculated Pressure(Pa)
1	2.5	375	77273.44	1287	16655.14
2	1.75	349	66929.65	1156	17271.87
3	2	352	68085.25	1328	19504.96
4	1.5	323	57328.79	1130	19710.87
5	1.75	373	76451.39	1045	13668.82
6	1.5	319	55917.67	1139	20369.23
7	0.95	286	44946.90	630	14016.54
8	1	267	39173.31	780	19911.52
9	1.5	339	63149.09	876	13871.93
10	1.2	296	48144.99	765	15889.50
11	3.5	407	91024.13	1532	16830.70
12	2	368	74415.49	1179	15843.48
13	2.5	335	61667.64	1200	19459.15
14	1.8	287	45261.77	985	21762.30
15	3	412	93274.33	1373	14720.02

The components were chosen on basis of the required parameters, availability of refurbished components, cost of the components.

Mathematical expressions used for the above table:

1. $A = \pi(d/2)^2 - (0.3 * \pi(d/2)^2)$ (As the coconut is not a perfect circle, we assumed the area to be 70% of the general area of a circle)
2. $P = F/A * 10^6$(The pressure was calculated using standard N/mm^2(MPa), and later converted the value to Pascal for ease of expression)

Design for frame bending (Punching operation)

σ_y of Mild steel = 380 N/mm^2

τ_y of Mild steel = 165 N/mm^2

$\sigma_{max} = B_{max} * D_{max}$

I_N

$B_{max} = FL$

4

$B_{max} = (1093.5*125)/4 = 34171.5$N-mm

D_{max} ➔ Distance of the outer fiber from the neutral axis=h/2

D_{max}= 1.5 inch mild steel rectangular pipe ➔ 38.4/2=17.2mm

$I_N = b*h^3$ (38.4mm is the breadth of the pipe and height
12 is 3 feet which translates to 915mm)

$I_N = 38.4*915^3 - 36.4*915^3 = 127*10^6$ mm^4

12 12

$\sigma_{max} = 34171.5*17.2 = 0.00462$ $N/mm^2 << \sigma_{allowable}$

$127*10^6$

$\sigma_{max}+\sigma_{operation}=0.00462+0.03 N/mm^2 << \sigma_{allowable}$

Therefore the design is safe during the operation

2.4 SELECTION OF HYDRAULIC COMPONENTS

1) **Selection of hydraulic cylinder**: The selection of the cylinder was based on the required travel length in order to have a successful piercing of the coconut. In general, the husk of coconut would be around 3-6 cms. So based on this assumption, we concluded the required stroke length of the cylinder should not be less than 10cms (100 mm).

   Bore diameter : 32 mm ➔3.2 cm
   Area of the cylinder : $\frac{\pi * d^2}{4}$
   Area of the cylinder = $\frac{3.2^2 * \pi}{4}$ = 8.04 cm^2
   Stroke = 125 mm➔ 12.5 cm
   Speed of cylinder ➔ 25 mm/sec ➔2.5cm/ sec

   Flow required for one stroke = Area * Stroke
   Flow required for one stroke = 8.04 * 12.5 = 100.5 cm^3 / stroke

   Q = A * V
   Where Q : Flow rate
   A : Area of the cylinder
   V : Speed of the cylinder

   Q = A * V
   Q = 8.04cm^2 * 2.5cm/sec = 20.1 cm^3/sec
   To calculate flow rate per minute, Q is multiplied with 60(1 minute➔ 60 seconds)
   Q = 20.1 * 60 = 1206 cm^3/min➔1.206LPM
   1.206 * 2 = 2.412LPM for both forward and return stroke

2) **Selection of Hydraulic Pump**: The pressure induced during operation of piercing is approximately 4 bar.

   Calculation of Flow rate:

   Displacement: 12cc/rev
   Though the maximum rated speed of the Gear pump is 3000RPM, the max speed of the chosen electric motor is 1425RPM. Therefore,

   Flow rate = $\frac{\text{Displacement} * \text{speed}}{1000}$
   Flow rate = $\frac{12 * 1425}{1000}$
   Flow rate of the pump = 17.1 Litre/min

   Disclaimer: Though the required flow rate is comparatively lower than the flow rate of the pump, the hydraulic pump was selected based on the cost and availability of the components in the market.

3) **Selection of Directional control valve**: A 4/3 lever operated directional control valve is chosen for the application; In the neutral position, the fluid is directed back to the tank.

4) **Selection of Hydraulic hoses**: Pipes, hoses and fittings are very important parts in a hydraulic system. The fluid flows through the pipes, hose and fittings. It carries the fluid from the reservoir through the operating components and back to the reservoir. Return line flow velocity is different from pressurized line flow velocity in a hydraulic system.

   The velocity specified for the return line is to reduce the back pressure. Generally, suction flow velocity is chosen 1.5 m/s and return line velocity is chosen 2 m/s.

   A nomograph is used for calculating the required hose size

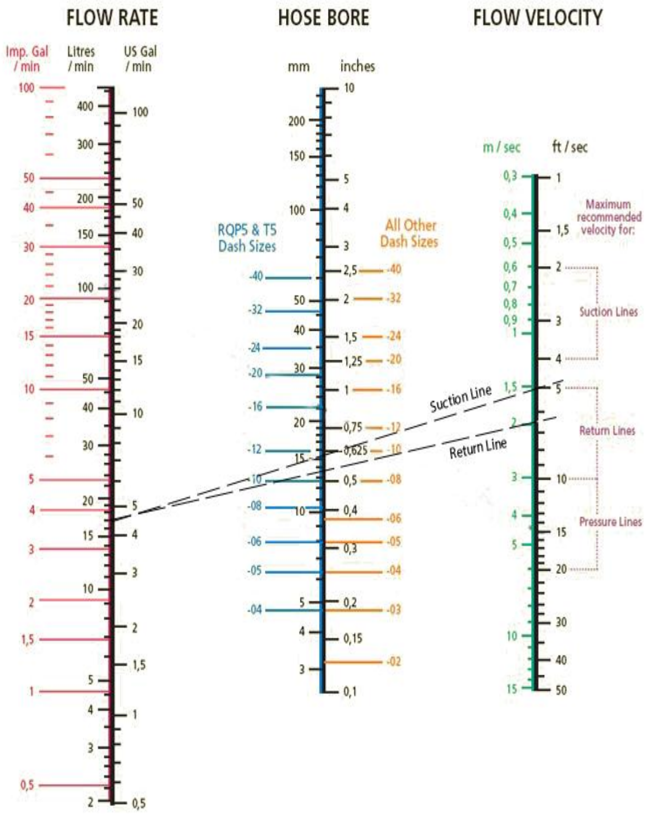


Fig – 6: Nomograph

Based on availability, Internal Diameter of 14mm and 12mm is chosen for Suction and Return line respectively.

5) **Selection of Electric motor** :

   Power = $\frac{\text{Pressure} * \text{Flow}}{612 * \eta}$

η : Efficiency is rated at 80%

P = 20 bar * 17.1 LPM

612 * 0.8

P = 0.69KW

1KW = 1.34HP

P= 0.69KW * 1.34 → 0.92HP

Therefore, based on the above calculations, a 1 HP electric motor with 1425RPM was selected for the application.

2.5 FABRICATION

Frame: The frame is fabricated using Mild Steel pipes of 1.5inch width and 2mm thickness. The supports are made of pipes of 1/2 inch and 1mm thickness. The vertical height is approximately 3 feet. The horizontal width is 1.4 feet(42cm) on top and 1.9 feet(57cm). Electric arc welding is used to join each side of the frame with each other. The legs are inclined a bit outwards for better support.

Coupling:

Fig – 7: Coupling

This coupling is used to couple AC induction motor to hydraulic gear pump. It is used to transfer energy from the motor to the pump. A MS Rod of 65mm length is used. The outer diameter of the rod is 25mm and the inner diameter is of 25mm and 16mm at the motor and pump side respectively. The holes for fastening are drilled using taps. Grub Screws are used to fasten the coupling.

A coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both.

Tool:

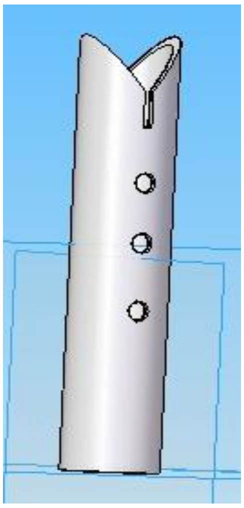


Fig – 8: 3D model of the tool

As the tool comes in direct contact with the edible product, it is necessary to design the tool using a food grade material, after a detailed study of various materials, we concluded to use Stainless steel 316 for the application.

This tool is a hollow pipe, and it is placed in the bowl vertically in the coconut placer and this tool consists small holes in it through-out its length, so that the water from the coconut water would get collected it the coconut placer, which in turn is connected to a storage tank. After various trials with various shapes of the tool, we decided on going ahead with a dual pointed tool, as it would provide a deeper cut and the residue of the husk can be removed easily. The tool was rigidly fastened on the circular plate using cotter pins.

The length of the tool is 110 mm, with a diameter of 22mm.

Coconut Placer:

Coconut placer is there in the shape of bowl. In this coconut placer we are going to place the coconut horizontally, any size of coconut can have accommodated very easily and this coconut placer is made up of aluminum for hygiene purpose. The diameter is 270 mm with a height of 65mm. A strainer is placed at the bottom of the bowl which is of 100mm diameter.

2.6 WORKING PRINCIPLE

In this coconut water extraction process, water from the tender coconut is extracted using a piercing tool which is actuated using hydraulic power. Firstly, the coconut is placed on the coconut placer space, in second stage force is applied on the coconut with the help of a ram using the hydraulic power which in turn exerts force on the coconut against the tool, which is meant to be for the piercing. As the pressure on the coconut increases piercing tool inserts into the coconut causing the water flow from the coconut through the tool itself as it has a hollow configuration, so the fresh water from the coconut is extracted from the coconut to the is collected in the container onto which the tool is placed and which in turn is connected to a storage container. The tool is double pointed and has a rectangular slot for easy removal of the husk residue. The tool has 6 holes on its lateral surface through which the coconut water gets collected in the container. The coconut placer is equipped with a filter/strainer through which the coconut water flows to the storage.

3. CONCLUSIONS

The main aim of the project was to extract the coconut water effortlessly and we have succeeded in it. This machine uses hydraulic power to pierce the coconut, so the operator has to only actuate the lever to perform the operation. The time required to extract the water has greatly reduced. As the tool is made up of food grade stainless steel and no human contact, the hygiene of the liquid is maintained and reduced chances of accidents. Anyone can operate the machine without any special skill that is required to extract the water. With some modifications in the machine, it can be used for mass production of packaged coconut water with necessary processing techniques. Thus, this project successfully achieved its primary objective of reducing the risk and increasing the productivity. Time required for the whole operation is 3-5 seconds whereas the conventional method takes around 10-20 seconds based on the skill of the worker.

3.1 SUGGESTIONS FOR FUTURE WORK

The whole system can be automated using necessary material handling systems, rotary drives, a machete (hydraulic or pneumatic powered) to increase the usage of the machine.

A storage tank can be used to store the coconut water when extraction is done on a mass scale. The fixture can have a minimum of 4 slots to reduce the time taken for the process where each of the operation like Piercing, Splitting can occur simultaneously.

The lever operated DCVs can be replaced with Solenoid actuated DCVs in order to automate the process with minimal human interaction.

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BIOGRAPHIES

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