School of Mechanical, Chemical and Materials Engineering

Designing and Prototyping of a Device to Extract Phytochemicals from Alive Plants a Research Partially Funded by ASTU

By

Getaw Ayay (MSc in Mechanical Design)

Address: getawayay421@gmail.com or 0920 00 49 33

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Abbreviation

A	Area	Δd	Change in Diameter
D	Diameter	σ_e	Endurance Limit
d	Diameter	τ_e	Endurance Limit in Shear
D_i	Internal diameter	σ_H	Hoop Stress
D_o	External diameter	τ	Induced Shear Stress
d_R	Diameter of the reservoir	σ_b	Induced Stress in Bending
E	Modulus of elasticity	K_a	Load Factor for Reverse Axial Loading
F	Force	τ_{max}	Maximum Shear
GPA	Giga Pascal	K_{sz}	Size factor
H	Stroke length	K_{sur}	Surface Finish Factor
I	Area Moment of Inertia	σ_w	Working Stress
L	Height of reservoir	σ_y	Yield Stress
M	Bending Moment	δ	Deflection
mm	Millimeter		
Mpa	Mega Pascal		
n	Factor of Safety Amount of Gas in Moles		
N	Newton, number of active coils, Numbers of stroke in plunger		
P	Pressure		
p	Pitch		
Pa	Pascal		
P_{Ar}	Partial pressure of Argon		
PEF	Pulsed Electric Field		
P_i	Internal pressure		
P_N	Partial pressure of nitrogen		
P_o	External pressure		
P_O	Partial pressure of oxygen		
P_{others}	Partial pressure of others		
P_{tot}	Total pressure		
P_{tur}	Turgor pressure		
R	universal gas constant		
T	temperature		
t	thickness		
v	Poison Ratio		
V	volume		
y	Deflection		

Abstract

Phytochemicals are any of various biologically active compounds found in plants which are extracted for different purposes. The current quality of the extracted chemicals are reduced during the process due to the contamination of the useful chemicals with unwanted part of the plant, dusts and machine related chemicals. The objective of the research is to design, manufacture and test phytochemicals extractor from alive plants. It is achieved by applying the standard methods of designing mechanical systems. These are literature review, selecting a best mechanism among different alternatives, mathematical modeling and technical analysis, preparing manufacturing process, manufacturing of each part, buying standard parts, assembling and testing. A simple and small system (Plant Milker) has been designed, manufactured and tested that can extract phytochemicals from plants without cutting it using pressure difference. The quality and quantity of phytochemicals are improved because firstly the fluid has collected within chemically neutral confined system; secondly there is no wastage during collecting and removal of byproducts and lastly production time will be increased. In addition, a huge amount of money can be saved since initial investment cost, industry running cost and energy cost are eliminated.

Keywords: Designing and Prototyping of Phytochemicals Extractor, Alive Plants (without cutting the plants), Improvement of quality and quantity of the Phytochemicals, Plant Milker, pressure difference

1. Introduction

Plants play many great roles in our world for different application. Some of the importance of plants are in medicine, food, textiles, perfumes, manufacturing, cosmetic products etc. These functions of plants are taken from different parts of the plant using different processes and techniques. All processes and techniques are done after cutting the parts of the plant or the whole plant from the source.

Supercritical fluid extraction, solvent extraction, etc. are applied first by cutting the plants and processed it in different stages. This process demands more time, money and energy to grow or replant and process it. The negative effects of these methods are more visible if the plants need more time to grow and to give the required product. In order to minimize the wastage of time and money in these methods, it is possible to take the phytochemicals directly from alive plants. So that the device extracts the required phytochemicals directly from the plant in such a way that health professionals had a trend of taking blood from animals.

Extraction of the phytochemicals using this new device is better than the current available devices and techniques from the following perspectives.

1. It needs less Initial installment cost since material handling equipment like transportation of raw and waste materials, conveying equipment, cutting, milling, grinding, filtering, etc. machines do not required.
2. The quality of the phytochemicals will be improved since there is no contamination with mechanical parts, systems, storages during transportation, conveying, cutting, grinding, filtering, heating, evaporating, distilling, drying and cooling processes.
3. Production time will be shortened because many processes like cutting, transporting, storing, grinding, heat treating are not applied in the process.

1.1. Statement of the Problem

Plants are one of the sources of phytochemicals that are used for different purposes such as drugs, foods, and perfumes. These chemicals are taken from leaves, stems, roots, seeds, flowers, fruits, etc. The demands for the aforementioned chemicals are high in this century and we can predict that there will be a very high demand in the future. Currently these chemicals are taken from plants by cutting some parts or all the parts of the plant. After the plant is cut partially or completely, it needs more time and money to recover its parts or to replant again. However, if there is a way to take the required chemicals without cutting the plants, it is possible to save time and money and also it can increase productivity and quality. The trend to take chemical from plants is cutting and processing it in different stages.

The extraction of the phytochemical is carried by incorporating electric field and vacuum creation. The purpose of electric field is to disturb the normal activities of the plant and to widen the porosity of the plant-chemical transporting vessels. The electric field is applied with a limiting value in order to protect permanent damage on the plant. At the same time, the phytochemicals are attracted using vacuum sucker created by a small pump using hollow needles.

1.2. Significance of the Study

The result of this study is important to introduce a new way to extract phytochemicals from alive plants. This will improve the efficiency of drug, perfume and food production industries. These industries increase their productivity by reducing the different stages of production, minimizing and eliminating by-products and materials handling equipment. Cost of drying, storage, and shipment of by-products are economically limiting factors. On top of that they will reduce the production cost since they will not use mega processing machines and material handling equipment. In addition, the energy required to drive the mega machine will also be saved. The quality of the phytochemicals also improved since it will not pass through different production processes, i.e. if the production process is reduced the contamination and leakage from the machinery into the phytochemicals will be eliminated. In general, both the quality and quantity of phytochemicals production will be significantly improved.

1.3. Objectives

General Objectives

The general objective of the research is to design, manufacture and test a simple and small phytochemicals extractor from alive plants to improve the quantity and quality of production of phytochemicals.

Specific Objectives

The study was focus on;

- Designing and manufacturing of the different components of the device. The subsystems (components) of the device that was designed are connecting mechanism between the plant and the extractor, extractor itself, power unit and storage system of the pure extract chemicals.
- After that the device was tested for its functionality.

1.4. Scope of the Research

This study was focused on designing, manufacturing, assembling and testing the functionality of the system. The plant vessels for chemical transportation was taken from existing study. All the funds except designing cost was covered by the Adama Science and Technology University.

The types of plants that are expected to give the phytochemicals are like ye-etan zaf (Boswellia), Kinchip (Finger euphorbia), Kulkual (Candelabra euphorbia or Tree euphorbia), Shola (Ficus sycomorus), Qimbo (Calotropis procera), Yegoma zaf (Ficus elastic), Eret (Aloe vera), and the like (these names are local and Vernacular names respectively). They have a similar character of vessels that are used to transport water and minerals through them. The device extracts the required phytochemicals from plants and then used for the expected purpose or it will be processed to get the required chemical composition.

2. Literature Review

Extraction of chemicals from plants has been being carried out using different methods for different purposes. These methods are traditional extraction, conventional extraction and Novel extraction. Traditional extraction methods have been being exercised in our country in different ways for medication, cosmetics, foods, washing purposes.

2.1. Conventional Extraction Methods

Solid-liquid extraction methods used for the extraction of phytochemicals from plants include maceration, infusion and Soxhlet extraction. These extraction processes involve firstly the diffusion of the solvent into the plants cells, solubilisation of the phytochemical compounds within the plant matrix and finally diffusion of the phytochemical-rich solvent out of the plant cells. This section will also cover the extraction of essential oils from plants using steam and hydro-distillation.

2.1.1. Maceration

Macerations are produced by steeping the plant material in a liquid, which is generally an organic solvent, at room temperature. For this extraction process the plant material is soaked in the solvent in a closed container. The solution can be stirred to increase the rate of extraction of the phytochemicals from the plant material. After extraction is complete the plant material is separated from the solvent by filtration. The plant material can then undergo another extraction step by adding fresh solvent to the material and letting it soak. This step can be repeated several times to ensure complete extraction of phytochemicals from the plant material, however it is a very time and solvent consuming process. Maceration can take from hours to days for a single extraction, and can take weeks for repeated maceration of the plant material (Seidel, 2006). Although it is time consuming it is a useful extraction method for heat labile compounds as it is carried out at room temperature.

2.1.2. Infusions

Infusion is a similar process to maceration but the extraction is carried out at a set temperature (normally higher than room temperature and up to 100 °C) for a set period of time (from minutes to hours) and water is generally used as the extraction solvent. As for maceration, after extraction is complete the mixture is filtered. Traditionally, infusions were made by using boiling water as the extracting solvent, for example, making a cup of tea. Following immersion in boiling water the plant material was left to steep and finally filtered to remove the plant material from the extract.

2.1.3. Soxhlet Extraction

Soxhlet extraction has been used for many years in the extraction of phytochemicals from plants, and is often used as a reference for evaluating other solid-liquid extraction methods or new non-conventional extraction methods (Wang and Weller, 2006). In a Soxhlet extraction system the plant material is put in a thimble-holder, which has perforated sides and bottom so liquid can fall through. There is a collection flask below the thimble and a reflux condenser above it. Heat is applied to the flask containing solvent; the solvent evaporates and travels to the condenser. Condensed solvent then falls into the thimble containing the plant material, when it reaches a certain level it is unloaded back into the solvent flask. The solute is separated from the solvent by distillation, as the solute is left in the flask and fresh solvent passes into the plant material. This procedure is repeated until complete extraction of plant material is achieved (Wang and Weller, 2006). Solvent and particle size will need to be selected depending on the phytochemicals which need to be extracted.

2.1.4. Steam and Hydro-Distillation

Steam and hydrodistillation are extraction techniques used to extract water-insoluble volatile constituents from various matrices, including the extraction of essential oils from plants and are widely used in the perfume industry for extraction of essential oils. For steam distillation the steam is percolated through the plant material. The steam dissolves the essential oil in the plant material and then enters a condenser. The mixture of condensed water and oil is collected and finally separated by decanting. For hydrodistillation the only difference is that the plant material is submerged in the water, which is then heated until it boils. The extraction conditions can be optimised by modifying the distillation time and temperature. The conditions may also need to be modified depending on the material being extracted, for example, for the extraction of tough material (roots or bark) glycerol may be added to the water to assist extraction (Seidel, 2006).

2.1.5. Factors Affecting Conventional Extraction Methods

The efficiency of the solid-liquid extraction methods are affected by factors such as solvent type, ratio of solvent to plant material, temperature, time and structure of the matrix (e.g. particle size, plant organ).

Solvent: The factors that need to be considered when choosing the solvent or solvent system for extraction of phytochemicals are safety of the solvent and potential for formation or extraction of undesirable compounds and finally solubility of the target compounds (Seidel, 2006).

In recent years, organic solvents (e.g. methanol) have been used to extract phytochemicals from plant material (Naczk and Shahidi, 2004). These extraction procedures were efficient and resulted in high yields of phytochemicals, but the solvents may be harmful to human health if ingested and therefore would not be desirable for inclusion in a food or beverage.

Temperature:Many studies have investigated the effect of temperature on the extraction of polyphenolics from plant material (Joubert, 1990; Price and Spitzer, 1994; Labbe, Tremblay and Bazinet, 2006; Lim and Murtijaya, 2007). In general, a higher extraction temperature causes an increase in the rate of diffusion of the soluble plant phytochemicals into the extraction solvent, thereby reducing extraction time. An increase in temperature can cause an increase in the concentration of some phytochemicals, which is possibly due to an increase in the solubility of many of these bioactive compounds, or to the breakdown of cellular constituents resulting in the release of the phytochemicals (Lim and Murtijaya, 2007). In addition an increase in the extraction temperature may also inhibit enzymatic activities thus resulting in an increase in the yield of the bioactive compounds. Marete, Jacquier and O'Riordan (2009) reported that extraction temperature of 70 °C and above resulted in a significant increase of total phenols from feverfew due to inactivation of polyphenol oxidase.

Time: The time given to the extraction of phytochemicals from plant material by a food manufacturer may be a compromise between complete extraction of these components and having an extraction process which is both time and cost effective. The time it takes for extraction of phytochemicals will vary depending on the plant species to be extracted, the particle size of the material and the plant organ. For example, the extraction of phytochemicals from leafy material will be faster than the extraction from harder material such as roots or bark (Whitehead, 2005). To produce extracts high in desirable and low in undesirable compounds, the extraction kinetics of both the wanted and unwanted compounds may need to be studied.

Particle size: Plant material can undergo grinding or milling before extraction to reduce the particle size. The smaller the particle size of the material the shorter the path that the solvent has to travel, which decreases the time for maximum phytochemical content to be extracted (Shi et al., 2005). Also, grinding or milling the plant material to reduce the particle size damages the plant cells which can also lead to increased extraction of phytochemical compounds. For example, Fonseca, Rushing, Thomas, Riley and Rajapakse (2006) explained the suitability of using finely ground samples for the maximum extraction yield of parthenolide in feverfew, which may be localised in trichomes, in small oil glands or may be bound in other tissues. The disadvantage of grinding or milling the plant before extraction is that plant material of small particle size may block filters quicker than bigger particles and this could possibly result in wastage of the extract and extended extraction times (Whitehead, 2005).

2.2. Novel Extraction Techniques for Phytochemicals

2.2.1. Pressurized Solvents

As the name suggests, pressurized solvents apply pressure to a solvent system, which affects the target molecule's specificity and speed. By applying certain pressure and temperature conditions, the physicochemical properties of the solvents, including density, diffusivity, viscosity and dielectric constant, can be controlled. By using high pressures and temperatures the extraction of phytochemicals is generally enhanced and the environmentally friendly solvents such as water can obtain similar physicochemical properties as organic solvents. Another advantage may be that through the high pressures used, the cellular matrix is more penetrable.

The two techniques that fall under this category are:

1. Supercritical fluid extraction, which is called supercritical CO_2 extraction (SC-CO_2) when carbon dioxide is used. Supercritical fluid extractions are taking place above the critical temperature and critical pressure of the applied solvent. The critical temperature is the highest temperature at which an increase in pressure can convert a gas to a liquid phase and the critical pressure is the highest pressure at which a liquid can be converted into a gas by an increase in temperature.
2. Pressurized liquid extraction (PLE) or when 100% water is used, this technique is called subcritical water extraction (SWE) or superheated water extraction (Pronyk and Mazza 2009). Pressurized liquid extraction is another technique that has potential to be used in the extraction of phytochemicals. It is a technique that makes use of pressurized fluids. Other names for the technique are accelerated solvent extraction, pressurized solvent extraction and subcritical solvent extraction. Any solvent that is normally applied in extractions can be used. Most applications are in the development of analytical methods and the extraction of many groups of phytochemicals has been optimized using organic solvents: capsaicinoids from peppers (Barbero et al., 2006), polyphenols from apples (Alonso-Salces et al., 2001), carotenoids from microalgae (Rodriguez-Meizoso et al., 2008) and polyacetylenes from carrots (Pferschy-Wenzig et al., 2009).

2.2.2. Enzyme Assisted Extraction

Exogenous enzymes can be added, in order to enhance the extraction of phytochemical compounds. The exact effect of enzymes is still somewhat unclear though. The leading theory suggests that the enzymes degrade the cell walls partially, which enhances porosity and pore size and therefore increases extractability of polyphenols. Another theory is that phytochemicals are chemically bound to a cell structure and can be released by adding exogenous enzymes (Landbo and Meyer, 2001). The composition of cell walls depends on the source, but cell walls mainly consist of polysaccaharides, such as cellulose and pectins. Therefore, for extraction purposes, many applications of cellulases and pectinases have been reported.

2.2.3. Non-Thermal Processing Assisted Extraction

Plant phytochemicals are usually entrapped in insoluble cell structures, such as vacuoles or lipoprotein bilayers, which offer significant diffusional resistance to the extraction. Furthermore, the ability of some phytochemicals to form hydrogen bounds with bulk constituents of the cell matrix additionally limits the yield of the extraction process. To overcome diffusion limitations a pre-treatment that will allow larger solute-solvent contact area, that is, release of intracellular compounds into the appropriate solvent, can be used. Let us see two emerging technologies that increase the plant material porosity by cell disruption: ultrasound and pulsed electric fields (PEF).

2.2.4. Ultrasound

Ultrasound is a technique in which sound waves that are higher in frequency than the human hearing (ca. 16 kHz) are applied to a medium. The lowest frequency generally applied is 20 kHz. If the ultrasound is strong enough, bubbles are formed in the liquid. Eventually the formed bubbles cannot take up the energy any longer and will collapse; this implosion is called 'cavitation'. This collapse generates the energy for chemical reactions by a change in temperature and pressure within the bubble. Extremely high temperatures of 5000 °C and pressures of 1000 bars have been measured. When a solid matrix is present, it is affected by mechanical forces surrounding the bubble (Luque-Garcia and Luque de Castro, 2003). Ultrasound can result in a higher swelling of the plant material that increases extraction (Vinatoru, 2001). The choice of solvent is important, since solvent properties, including vapour pressure, surface tension, viscosity and density play important roles in cavitational activity (Xu et al., 2007).

2.2.5. Pulsed Electric Fields

Pulsed electric fields (PEF) utilize the influence of a strong electrical field on material located between two electrodes, which lead to cell membrane disruption, thus increasing cell permeability. The exact mechanism of this occurrence is still under debate, but the most accepted theory is the electromechanical model developed by Zimmermann et al. (1974). In essence, cells are highly complicated structures that consist of an intracellular space, which is filled with different organelles and is surrounded by a cell membrane. The cell membrane separates the intracellular and extracellular space and is essentially electroneutral (equivalent to a capacitor in electrical circuits), while free charges of opposite polarities are present on both sides of the membrane. This creates a naturally occurring transmembrane potential. When an external electrical field is applied the additional transmembrane potential is formed, which increases attraction between opposite charges on both sides of the membranes and compresses the membrane. If the stress on the membrane is large enough pore formation occurs. Depending on the treatment applied (electric field strength, pulse duration, number of pulses) the pore formation can be reversible or irreversible; in the latter case cells are destroyed.

According to Angersbach et al. (2000), the pore formation is reversible only if the formed pores are small in comparison to the membrane area (low intensity treatment), while if the field strength is large enough irreversible breakdown occurs. The critical field strength where electroporation occurs depends on cell diameter and it typically is in the range of 1–2 kV/cm for plant cells (diameter 40–200 μm) and 12–20 kV/cm for microorganisms (diameter 1–10 μm) (Heinz et al., 2002; Soliva-Fortuny et al., 2009). In the case of plant tissues the cell wall perforation by PEF can potentially lead to higher extractability of cell contents. According to Vorobiev, E. and Lebovka, N. (2010) the electroporation of plant cells and extraction of materials from solid foods typically require 0.1–5 kV/cm field strengths and pulses of 10–000 μs. The reason for higher extractability could be two-fold:

1. By applying a severe treatment irreversible permeabilisation leads to release of bioactive compounds that were previously enclosed in cells, i.e. the extraction can be enhanced due to a decrease in diffusional resistance; and
2. By applying moderate treatment conditions electroporation is reversible and the viability of cell is preserved. In this case PEF induces a stress reaction in the plant tissue, which leads to additional synthesis of secondary metabolites. The majority of bioactive compounds, like polyphenols, are secondary cell metabolites.

3. Research Methodology

Designing and prototyping of the new chemical extractor is carried out by following the standard methods of designing mechanical systems. These standard research methodologies are listed out as follows.

1. Literature Review: in this stage, previously studied papers and available extracting mechanisms and devices will be reviewed. In addition, plant physiology in chemical transportation and plant vessels will be reviewed.
2. Selecting a best mechanism among different alternatives: This is achieved;
    a. Firstly, by formal need analysis of the problem
    b. Secondly, by bringing a system analysis of the different parts that compose the mechanism
    c. Thirdly, by interconnecting the function of the different parts for one purpose
    d. Finally selecting the best mechanism using prioritizing criteria
3. Technical Analysis: The geometry analysis, force analysis and strength analysis of the different parts and components of the selected mechanism will be designed in detail by considering different internal and external effects on the mechanism and system.
4. Manufacturing Process: The steps and process of manufacturing of each part will be studied under this stage. In addition, assembly procedures, disassembly procedures and maintenance procedures will be studied. After completing these, each part is manufactured, assembled and tested.
5. Cost analysis: Finally, the total cost of the chemical extractor is calculated that will be expended for all aspects of designing, manufacturing, assembling and testing of the device.
6. Manufacturing, Assembling and Testing the Extractor: each part is manufactured by following and applying the proposed steps. Then after each part will bring together and assembled. Finally it will be tested to check how much it meets the expected function. The test will be carried out using phytochemical producing plants that such as Ficus elastica or Rubber Plant.

4. Results and Discussion

4.1. Preliminary Synthesis

Many important chemicals are taken from plants using different methods. The methods that has been used are by cutting the plants. A system is needed to extract chemicals from plants without cutting it. This system will depend on human force and small amount of electric energy. The technical name of this system is **Plant Milker**. Using this system a mixture of chemicals are extracted in the form of fluid which will be used for different purposes or for further processing.

4.1.1. Synthesis and Development of Alternative Solution

After a brain storming and reviewing of literatures the following possible alternative ways of extractions are developed.

1. The first way of extraction is carried out by cutting the plant in very small amount. When oozing is happening receive it using bucket type material. (Solution A)
2. Syringe type mechanism which will suck the mixtures of chemicals by creating vacuum. This mechanism can be brought in two ways. The first way is sucking phytochemicals using only vacuum however, the second mechanism is incorporating small amount of electric signals in addition to the vacuum sucker in order to disturb the permeability of the plants. (Solution B)
3. The third extracting method is to make artificial plant which has a power to take chemicals from plants than the natural plants. The artificial plant has similarity with the natural plant in the way where the chemicals are extracted and transported. (Solution C)

Among the above alternatives one of the best ways of extraction should be selected using appropriate design and manufacturing criteria. These criteria are like possibility to design and manufacture the system using the current available knowledge and technologies, ease of operation, waste minimization and clean of extracted chemicals, and power availability. Using the following weightage it is possible to select one of the best acceptable methods of extraction of the chemicals. The values are 1, 2, 3, 4 and 5. Maximum value is 5 and minimum value is 1.

Table4-1 Evaluation of the Alternative Solution

Criteria	**(Solution A)**	**Solution B**	**Solution C**	**Remark**
Easy to design	4.0	4.0	3.0	
Easy to manufacture	5.0	4.5	2.5	
Operation	3.5	4.0	5.0	
Availabilities of technology	5.0	5.0	2.5	

Current knowledge	5.0	5.0	3.5	
Waste reduction	3.0	4.5	5.0	
Cleanness	3.0	4.5	5.0	
Power availability	5.0	3.5	3.5	
Average	4.2	4.4	3.8	

According to the above result alternative solution B is selected. Hence, its alternative structures are going to be developed.

4.1.2. Synthesis and Development of Alternative Basic Structures

The selected system sucks the fluid from plants by creating pressure difference. The vacuum pressure created in the sucker is much greater than pressure in the plant which tries to hold its fluid. To create a vacuum pressure and sucks the fluid the following basic structures are needed. These are power source, vacuum creator, reservoir and means of attachment between the system and the plant which is shown diagrammatically below.

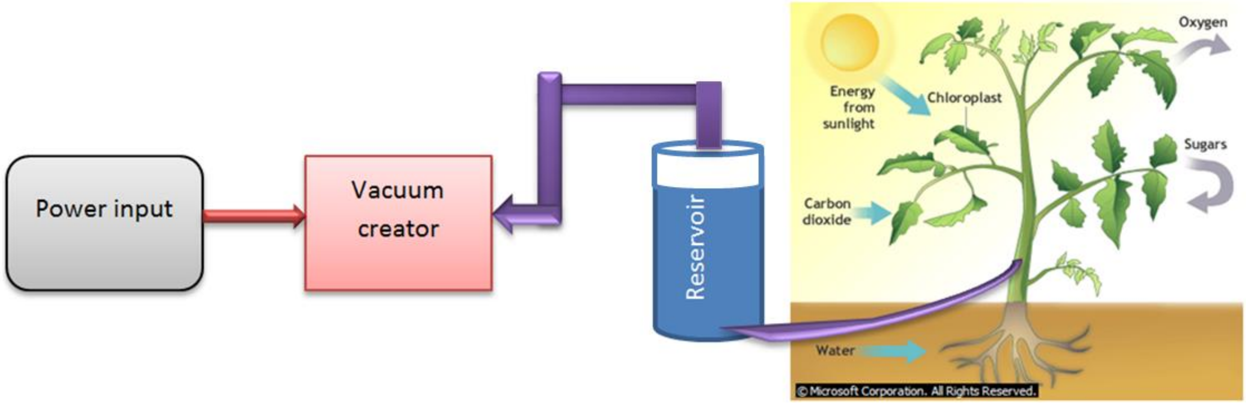


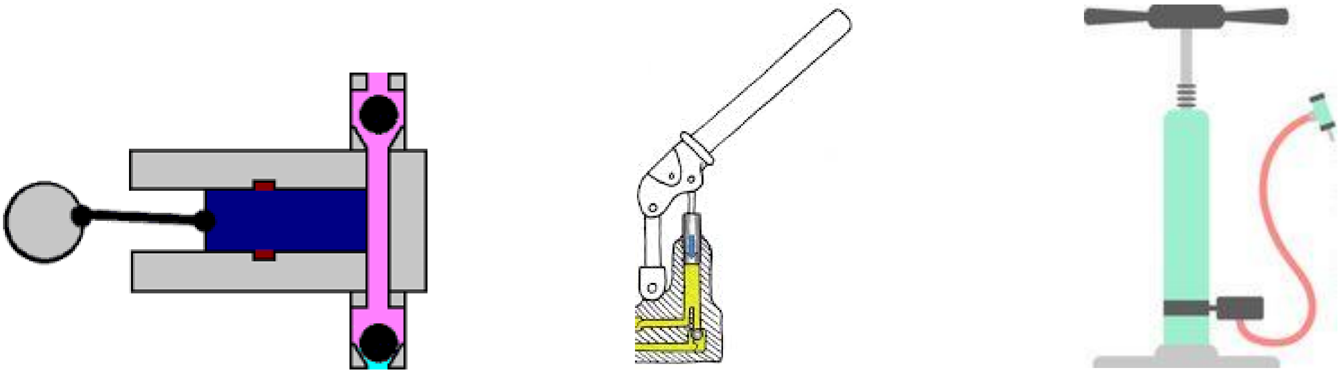
Figure 4-1 Basic Structure of Chemical Extractor

Power Input: There are three options of applying power to the vacuum creator. These are manual (either hand or foot), electric (using battery or solar source) and hybrid (both manual and electric). It is obvious that, it is nicely accepted if the source of power is hybrid. This is because, if electric source is available motor will be used and when power is gone manual force will be applied. The electric sources are either solar energy or direct power supply from electric power distributors. In order to use these sources of powers motor, solar panels, heavy batteries and electric appliances should be incorporated. Most of the working places are jungles which are not simple to pass through it by holding the above and additional devices. The vacuum creator is not required to have a big flow rate instead to get a pressure difference. Therefore, it is advisable to use manual source of power.

Vacuum Creator: It is used to create a pressure difference between the reservoir and the plant system. It is obvious that plants have their own pressure to hold their fluids. In order to suck out these fluids the value of vacuum pressure must be greater than the plant holding pressure. In addition to this, the sucking flow rate is very small due to the slow natural flow rate of fluids in the plants. Therefore, it is wise to use a vacuum creator that can create higher pressure difference with small flow rate. This will be achieved using positive displacement pumps. This category of pump has characteristics of low capacity, creates high pressure, used for high fluid viscosity and needs lower power. The positive displacement pump uses reciprocating mechanism.

Reservoir: it is used to store extracted fluids from plants. The fluid flows into it since it is under vacuum pressure. It has no special futures except pressure gauge and joints with hoses. The hoses are used as a media to transport fluid and air. The hose between the plants and reservoir can either single or networked.

The following alternatives are developed for the combinations of manual power input and vacuum creator. Among these alternatives the third one is selected because it can be easily supported with feet and operated with hand.



Alternative 1 Alternative 2 Alternative 3

Figure 4-2 Alternative basic structure of power input and vacuum creator [44]

Functional Analysis

The functional tree of the extractor is shown below

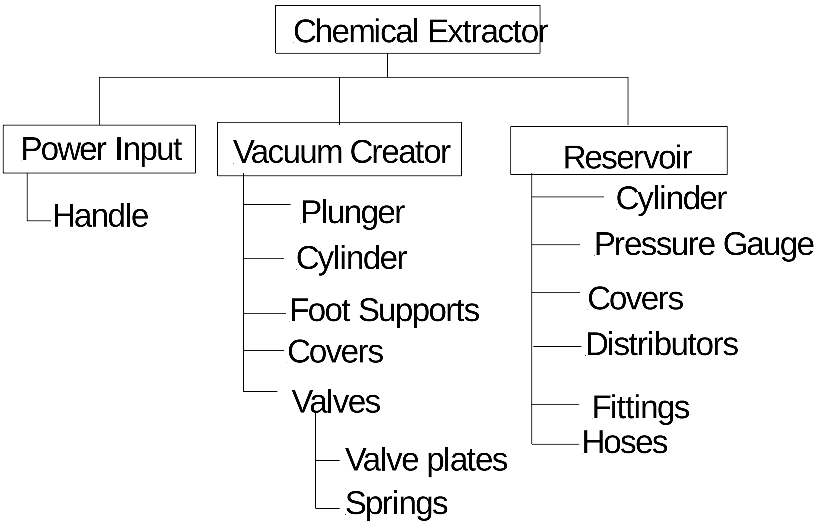


Figure 4-3 Means Tree of chemical extractor

4.2. Detail synthesis and Analysis

4.2.1. Working Principle

The chemical extractor works on the principle of pressure difference. When the power input (handle) is moving up together with the plunger, vacuum pressure is created inside the cylinder. During this time the air inside the reservoir is sucked into the cylinder which in turn creates vacuum inside the reservoir. When handle is moving down air inside the cylinder flows out. This upward and downward motion is repeated until air inside the reservoir becomes almost empty.

Hence, the fluid flows into the reservoir through the hoses. The fluid will be stored in a bigger tank when the reservoir becomes fully filled.

4.2.2. Geometry Synthesis

The system is interconnected with each other by a pressure. The pressure is created by a force on a given cross-sectional area that is why geometry and force analysis will be carried out at once. The important parameters that are inputs to the geometry and force analyses are applied human force which is between 100N and 300N [42], handle, diameter of plunger, pressure created inside the cylinder, volume of the reservoir, total vacuum pressure required to suck the fluid from plants, Partial pressure of air mixtures with dry air is a mixture of nitrogen, oxygen, carbon dioxide and more (Air is a mixture of gases - 78% nitrogen and 21% oxygen - with traces of water vapor, carbon dioxide, argon, and various other components), atmospheric pressure at sea level is 101.325 KPa (0.101225MPa) and hydrostatic or turgor Pressure of plants that exudate fluids ranges from 6 bars (0.6MPa) at a growing root cell (over three times that in a car tyre) to 15–20 bars (1.5–2.0MPa) at the epidermal cells in a leaf. Compare these with pressure in animal systems; high blood pressure might only be 0.03 bars (0.003MPa). Thus plants operate at high pressures that are essential to the way they interact with their environment [13].

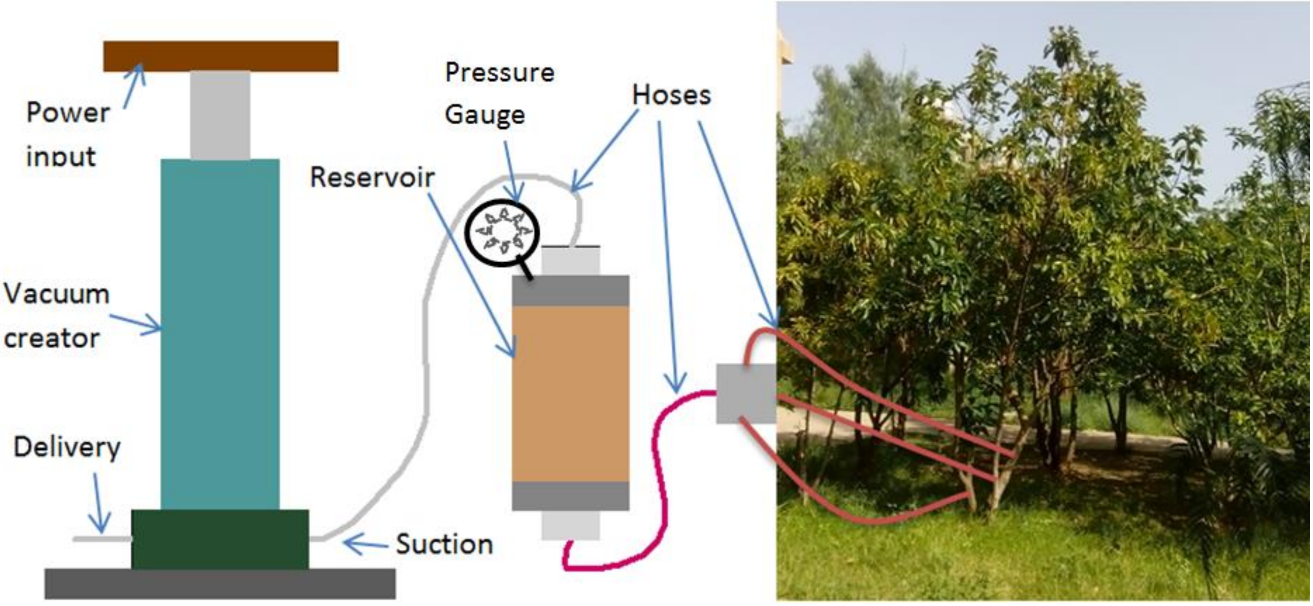


Figure 4-4 Simple schematic diagram of the fluid extractor

The above parameters will be related with mathematical equations. First the turgor pressure should be greater than the vacuum pressure inside the reservoir. The vacuum pressure is equals to the sum of the partial pressure of the atmospheric air remain inside the reservoir. Mathematically,

$$\text{turgor pressure} > \text{total pressure inside the reservoir} = \text{sum of partial pressure of air inside reservoir}$$

$$P_{tur} > P_{tot} = P_N + P_O + P_{Ar} + P_{others}$$

It is estimated that the pressure created inside the reservoir is almost zero since the air is flows out with repeated reciprocation of the plunger. The sucking capacity of the vacuum pressure has a direct relationship with volume of the reservoir. The partial pressure of each element in the reservoir is analyzed by applying ideal gas law.

$$P_{tur} > P_{tot} = P_N + P_{O_2} + P_{Ar} + P_{others} = \left(\frac{nRT}{V}\right)_N + \left(\frac{nRT}{V}\right)_{O_2} + \left(\frac{nRT}{V}\right)_{Ar} + \left(\frac{nRT}{V}\right)_{others} \qquad \text{------------------ 4-1}$$

Where P-is pressure, T-is temperature, V-is volume, n-is amount of gas in moles and R-is universal gas constant.

Second, the cylinder vacuum pressure has a direct relationship with the applied human hand force and inversely proportional to the area of the plunger. The forces applied on the plunger are atmospheric pressure, inside vacuum pressure and human hand force.

$$\text{human force } F = (\text{outside pressure on the plunger} + \text{insiden pressure on the plunger}) \times \text{Area of plunger}$$

The maximum inside and outside pressure on the plunger is atmospheric pressure.

$$F = 2PA = 2 \times P \times \pi \frac{d^2}{4} = \frac{\pi}{2} P \times d^2 \Rightarrow d = \sqrt{\frac{2F}{\pi P}}, P = 101325\,Pa, F = [100 - 300]N$$

$$d = \sqrt{\frac{2F}{\pi P}} = 2.507\sqrt{F}\ mm \text{ -- 4-2}$$

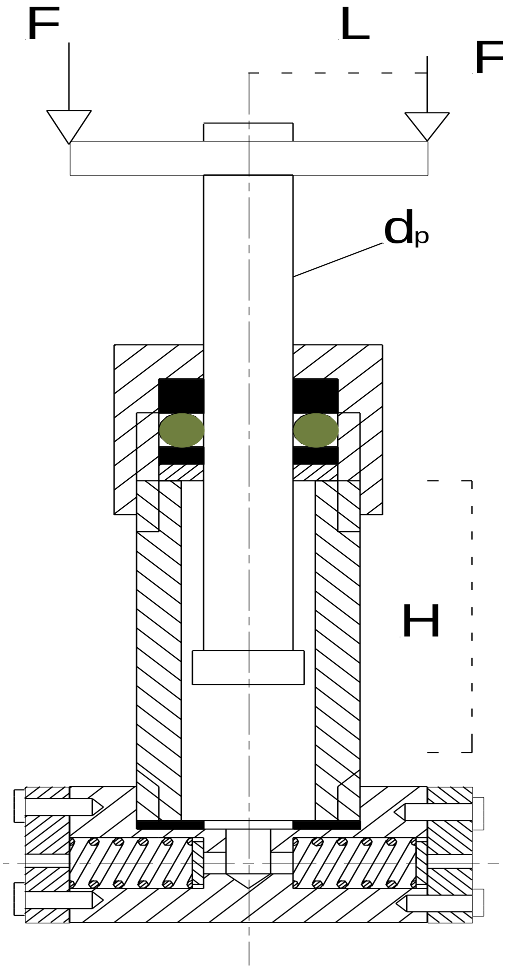


Figure 4-5 Hand Pump sectional view

As it is shown in figure 4-3 the horizontal axis is force applied in N and the vertical axis is diameter of plunger in mm. The applied force is known which is between 100 N and 300 N. The corresponding diameter of plunger is between 25 mm and 44 mm. The selection of the diameter needs critical thinking because at the lowest diameter the minimum force should be applied in the same manner, for the largest diameter the maximum force should be applied otherwise it will become difficult to operate the largest diameter with the minimum force. However, there is a good condition when the diameter is lowest and force is the maximum. Therefore, the diameter should be 25 mm.

The next task is determining the stroke length of the plunger. This length has a relationship with volume of reservoir and number of stroke of the plunger. Mathematically it can be defined that the product of volume of the plunger and numbers of stroke are equal to the volume of the reservoir.

$$\text{Volume of Plunger} \times \text{Number of Stroke} = \text{Volume of Reservoir}$$

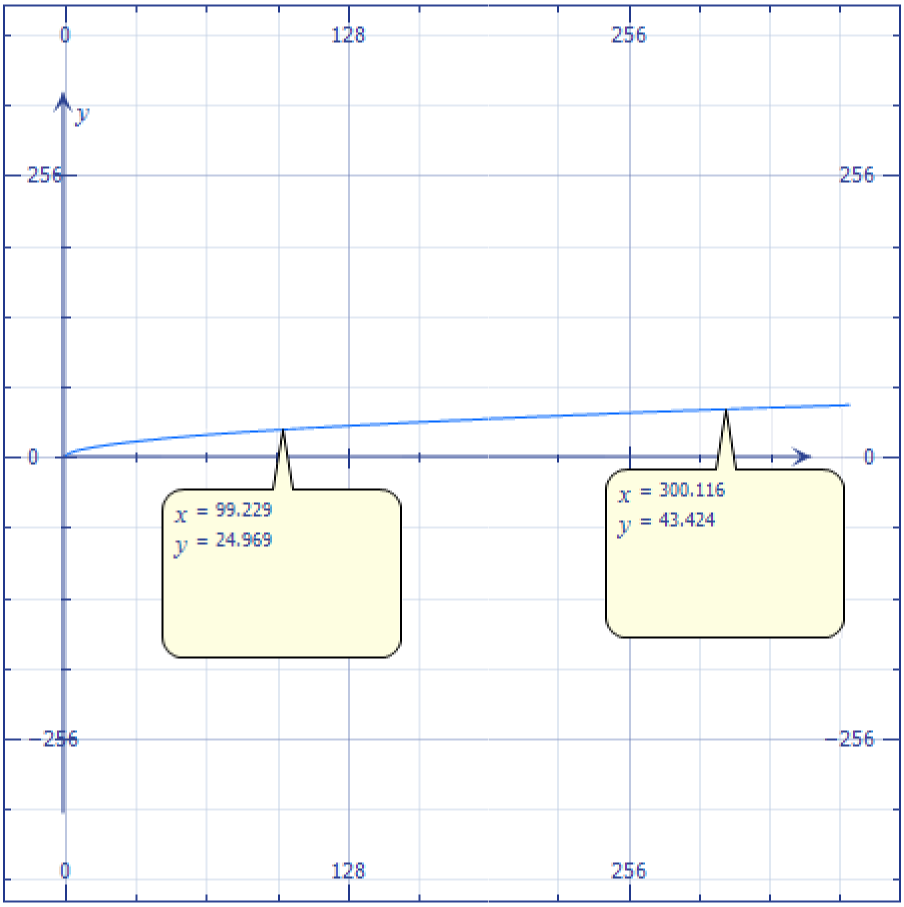


Figure 4-6 Horizontal Axis Force Applied in N and the Vertical Axis Diameter of Plunger in mm

$$V_P \times n = V_R \Rightarrow \frac{\pi d^2}{4} H \times n = \frac{\pi d_R^{\ 2}}{4} L \Rightarrow d^2 H \times n = d_R^{\ 2} L \text{ --- 4-3}$$

The diameter of the plunger d is determined (25 mm), the stroke length H has a maximum possible length of 500 mm (equivalent to forearm), and (the number of stroke n, the diameter of the reservoir d_R and height of reservoir L) are unknowns. The unknowns are not easy to determine so that a critical estimation is needed. The reservoir may be estimated by considering stability to stand upright, simplicity and comfort-ability to transport by humans. Hence the maximum height and diameter of the reservoir are 300 mm and 200 mm respectively. With this assumption a maximum volume of the reservoir becomes 14.137 liters which is not suitable to transport and suck up. Therefore, the dimensions should be very small. Since this project is to introduce a new device that can take fluid from alive plants, an appropriate dimension can be decided. Therefore, the stroke length of the plunger is 400 mm; the diameter of the reservoir d_R is 200 mm and height of reservoir L 65 mm. The number of stroke n of the plunger becomes 11.

$$d = 25\,mm, H = 400\,mm, n = 11, d_R = 200\,mm \text{ and } L = 65\,mm$$

4.2.3. Force Analysis

The forces in the handle come from human hands which has a maximum of 300 N. The length of the handle should be equals the average human shoulder width which is 400 mm [18]. This implies that L becomes 200 mm.

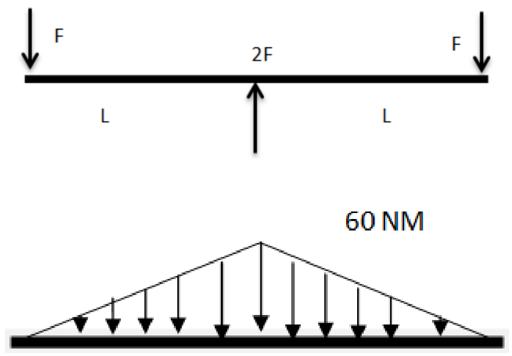


Figure 4-7 Shear Force and Bending Moment Diagram of Handle

The forces in the plunger are human hand, atmospheric pressure and inside vacuum pressure. There are two conditions for the plunger, i.e. when it is moving up and down.

$$\text{The resultant cyclic force} = 2F + 2AP = 2 \times 300N + 2 \times \pi 25^2 \times 101325 N/m^2 = 997.902N$$

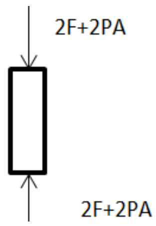


Figure 4-8 Free Body Diagram of Plunger

$$\text{Total Force} = 2 \times F + 2 \times P \times A = 2(300N + 101325\frac{N}{m^2} \times \pi \times (25 \times 10^{-3} m)^2 = 2(300 + 198.951)N = 997.902N$$

A 997.902 N compressive load is applied on the plunger.

The cylinder of the pump is under internal and external pressure. The maximum value of the external pressure P_o is atmospheric pressure and the internal pressure P_i has maximum of atmospheric pressure and minimum value of zero pressure.

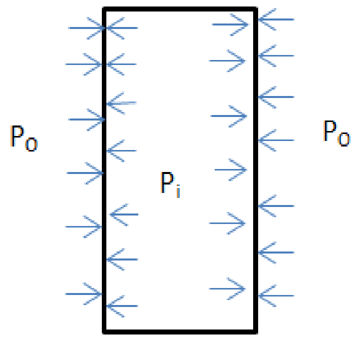


Figure 4-9 Free Body Diagram of Cylinder

The cylinder cover is under internal and external pressure. The internal pressure has maximum of atmospheric pressure and minimum value of zero pressure whereas the external pressure is subjected to atmospheric pressure.

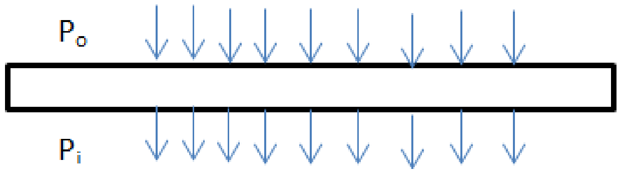


Figure 4-10 Free Body Diagram of Cylinder Cover

$$\text{Force F} = (P_0 + P_{i)}\ A = (P_0 + 0)\ A = P_0\ A = 101325 \times \pi/4 \times 0.027^2 = 58.014\,N$$

The cylinder of the reservoir is under internal and external pressure. The internal pressure has maximum of atmospheric pressure and minimum value of zero pressure whereas the external pressure is subjected to atmospheric pressure.

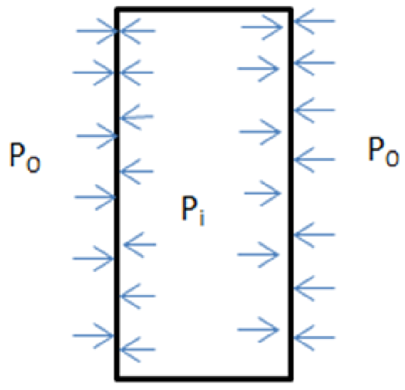


Figure 4-11 Free Body Diagram of the Cylinder of the Reservoir

The cylinder cover of the reservoir is under internal and external pressure. The internal pressure has maximum of atmospheric pressure and minimum value of zero pressure whereas the external pressure is subjected to atmospheric pressure.

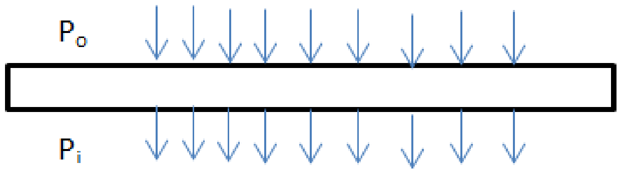


Figure 4-12 Free Body Diagram of Cylinder Cover of the Reservoir

$$\text{Force } F = (P_0 + P_{i)}\ A = (P_0 + 0)\ A = P_0\ A = 101325 \times \pi/4 \times 0.2^2 = 3183.219\,N$$

4.2.4. Strength Analysis

The handle in figure 4.4 is under a maximum bending moment of 60 Nm. It can be produced either from circular or rectangular cross section. Since it is used by hand it should be comfortable so that circular cross section is preferred. The extractor is used in outdoor that is subjected to environment. Hence the material should have good corrosion resistant. Stainless steel with modulus of elasticity 200 GPA, yield strength of 380 MPa and density 7800 Kg/m^3 is selected with a factor of safety of 2. The working stress becomes;

$$\text{working stress} = \frac{\text{endurance limit}}{\text{factor of safet}} \rightarrow \sigma_w = \frac{\sigma_e}{n} \rightarrow \sigma_e = 0.8\sigma_y \text{ for stainless steel}$$

$$\rightarrow \sigma_w = \frac{0.8\sigma_y}{2} = \frac{0.8 \times 380 \text{ MPa}}{2} = 152 \text{ MPa}$$

$$\text{The induced stress in bending } \sigma_b = \sigma_w = \frac{My}{I} \rightarrow 152 \text{ MPa} = \frac{60{,}000 \text{ Nmm} \times \frac{d}{2}}{\pi \frac{d^4}{64}}$$

$$\rightarrow d \cong 15.9 \text{ mm}$$

The 15.9 mm diameter is for solid handle. It is possible to reduce the weight by making it hollow.

It is not enough to consider only the strength. The deflection should be analyzed. The 1/360 of the length of the handle is allowed, hence;

$$\text{deflection } \delta = \frac{L}{360} = \frac{PL^3}{3EI} = \frac{PL^3 \frac{d}{2}}{3E \times \pi/64 \times d^4} = \frac{PL^3 \frac{d_o}{2}}{3E \times \pi/64((d_o)^4 - (d_i)^4)}$$

Using the above relationship the diameter of the handle becomes 42 mm. The weight can be reduced by making the handle hollow. The equivalent section modulus can be achieved by making the internal and external diameter of the handle 40 mm and 50 mm respectively. Based on the above results, the decision is given to the deflection.

D_i=40 mm and D_o=50 mm

The plunger in figure 4.5 is under a cyclic axial force of 997.902N which are created during suction and delivery of air. It should be constructed from corrosive resistant materials (stainless steel) since the device is operated in the open air. The working stress is 152 MPa which was analyzed in the handle design.

$$\text{The induced stress in axial } \sigma_a = \sigma_w = \frac{F}{A} = \frac{997.902N}{\pi \times ((25mm)^2 - (d_i)^2)} = 152Mpa$$

$$\rightarrow d_i = 24.958 \text{ mm}$$

Using seamless tube standard from table the internal diameter is preferably becomes 21 mm. The design of the plunge is should be analyzed using both strength and deflection. Hence its deflection becomes;

$$\text{deflection } \delta = \frac{FL}{AE} = \frac{600N \times 600mm}{\pi \times ((25mm)^2 - (21)^2) \times 200{,}000N/mm^2} = 0.00099 \text{ mm}$$

This deflection is acceptable and the plunger is under safe conditions with internal and external diameter of 21 mm and 25 mm respectively.

The pin for handle plunger connector in figure 4.11 is under a shear load of 600N which is shared into two, i.e. 300N. It should be manufactured from corrosive resistant materials (stainless steel) since the device is operated in the open air. The working stress is 152 MPa which was analyzed in the handle design with 2 factor of safety.

$$\text{The induced shear stress } \tau = \frac{F}{A} = \frac{4F}{\pi d^2} = \frac{4 \times 300 \text{ N}}{\pi \times d^2} = 152MPa \rightarrow d = 1.585 \text{ mm}$$

The diameter of the pin is 1.585 mm which is very small hence it should be increased to 5 mm.

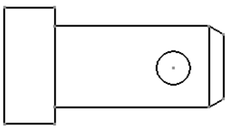


Figure 4-13 Pin for Handle Plunger Connector

The length of the pin is, equal to the sum diameter of plunger, thickness of plunger handle connector and cotter diameter, 34 mm.

The handle plunger connector in figure 4.12 is under a shear load of 600N which is shared into two, i.e. 300N. It should be manufactured from corrosive resistant materials (stainless steel) since the device is operated in the open air. The working stress is 152 MPa which was analyzed in the handle design with 2 factor of safety.

The length and thickness of the dimension is designated by L and t respectively.

$$\text{The induced shear stress } \tau = \frac{F}{A} = \frac{F}{Lt} = \frac{300 \text{ N}}{Lt} = 152MPa$$

$$\rightarrow Lt = 1.974 \text{ mm}^2$$

Based on the above formula the length becomes 0.987 mm for a thickness of 2 mm. The connector has 5 mm hole hence the length should be greater than 5 mm. Therefore, a 15 mm length is selected.

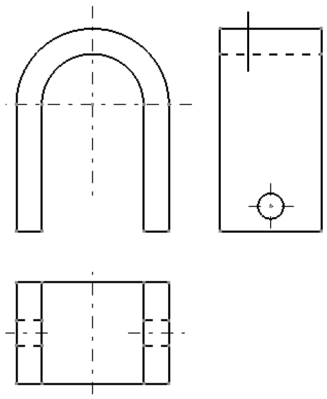


Figure 4-14 Handle Plunger Connector

The cylinder in figure 4.6 is under internal and external pressure of 305577.491 Pa and 101325 Pa respectively and the internal diameter of the cylinder is 25 mm. The cylinder is manufactured from seamless tube made of steel which has yield strength of 620 MPa. The working stress with 2 factor of safety becomes:

$$\text{working stress} = \frac{\text{endurance limit}}{\text{factor of safet}} \rightarrow \sigma_w = \frac{\sigma_e}{n} \rightarrow \sigma_e = 0.8\sigma_y \text{ for steel}$$

$$\text{working stress} = \frac{\text{endurance limit}}{\text{factor of safet}} \rightarrow \sigma_w = \frac{0.8 \times 620\text{MPa}}{2} = 248\text{MPa}$$

The pressure created inside the cylinder is low so the pressure vessel is categorized under thin pressure vessel. The design depends on circumferential or hoop stress, i.e.

$$\sigma_H = \frac{(p_i - p_o)d}{2t} \rightarrow \sigma_H = \frac{(305577.491 - 101325)\frac{N}{mm^2} \times 25mm}{2 \times 10^6 \times t} = \frac{248N}{mm^2}$$

$$\rightarrow t = 0.0103 \text{ mm}$$

The cylinder should be also designed by considering the deflection along longitudinal axis.

$$\text{Change in length } \Delta L = \frac{(P_i\text{-}P_o)d[1\text{-}2v]L}{4tE} = \frac{(305577.491\text{-}101325) \times 25 \times [1\text{-}2 \times 0.3] \times 600}{4 \times 0.0103 \times 200000} \text{mm}$$

$$= 0.149 \text{ mm}$$

Using standard seamless tube table the next thickness of the cylinder becomes 1 mm which results a 0.0015 mm axial deflection.

$$\text{The change in diameter } \Delta d = \frac{(P_i\text{-}P_o)d^2[1\text{-}2v]}{4tE} = \frac{(0.305577.491\text{-}0.101325) \times 25^2[1\text{-}2 \times 0.3]}{4 \times 1 \times 200000} \text{mm}$$

$$= 0.000064\text{mm}$$

Based on the 25 mm internal diameter and 1 mm thickness of the cylinder, it is in safe conditions.

Design of springs

Step 1: The springs are compressive type of springs that is used to open or close the suction or discharge valves. The force that pushes these springs are the internal pressure created inside the cylinder. Hence, the springs have a capacity to return the valves to its closed positions.

Step 2: Gathered information: The maximum pressure applied on the valves is P=305577.491 Pa

Step 3: Problem statement: Designing of a spring which is capable of compressed by 305577.491 Pa pressure force

Step 4: Determining the shape of a spring that is compatible with the valve, valve seat and valve cover. The type of spring is ground closed end because it is stable and suitable for the valve.

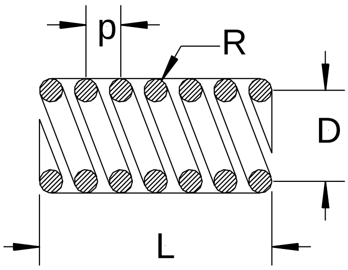


Figure 4-15 Sectional view of a compressive spring

Since the spring is axially loaded, it is subjected to shearing and twisting; its total effect is shearing.

Step 5: Material selection and working stress: The material should have resistance to corrosion and wear, good elastic nature, low coefficient of friction and relatively low cost and weight.

Common spring wires with the highest strengths are ASTMA228 (music wire) and ASTMA401 (oil-tempered chrome silicon). Wires having slightly lower tensile strength and with surface equality suitable for static applications are ASTMA313 type 302 (stainless steel), ASTMA230 (oil-tempered carbon valve-spring-quality steel), and ASTMA232 (oil-tempered chrome vanadium). For most fatigue applications ASTMA227 (hard-drawn carbon steel) and ASTMA229 (oil-tempered carbon steel) are available at lower strength levels [3]. Hence ASTMA230 (oil-tempered carbon valve-spring-quality steel) is selected [Appendix A-3].

The allowable shear stress of the ASTMA230 (oil-tempered carbon valve-spring-quality steel) is 525MPa for light service.

The spring is under fatigue load so that the endurance limit should be calculated as follows;

$$\tau_{ea} = \tau_e \times k_a \times k_{sur} \times k_{sz}$$

k_a =0.8 load factor for reverse axial loading

k_{sur} = surface finish factor = 0.75 for machined with ultimate strength of 1120Mpa

k_{sz} = Size factor=1 since nominal diameter is less than 10 mm

$$\tau_e = 0.8\tau_{all} \text{ for carbon steel=0.8×525=420Mpa}$$

$$\tau_{ea} = 420 \times 0.8 \times 0.75 \times 1 = 252\text{MPa}$$

$$\text{Working stress} = \frac{\text{Endurance limit stress}}{\text{Factor of safety}} \quad \tau_w = \frac{\tau_{ea}}{n} = \frac{252}{2} = 126MPa$$

Step 6: Detailed stress analysis: The spring is pushed by a pressure of 305577.491 Pa force. The magnitude of the force applied on the spring is equal to the product of pressure and inside diameter of the cylinder for the strength purpose.

$F = PA$ Where p is the pressure in the cylinder (305577.491 Pa) and A is the net area of the valve head

$$A = \frac{\pi}{4}(D_i^{\ 2})$$

Where D_i is the outside diameter of the valve head and the available valve head diameter in the market is D =10 mm.

$$A = \frac{\pi}{4}(10^2) = 78.54\text{mm}^2 = 78.54 \times 10^{-6}\text{m}^2$$

The force becomes, $F = 305577.491\text{Pa} \times 78.54 \times 10^{-6}\text{m}^2 = 24\text{N}$

The maximum shear stress in the spring is found by using, $\tau_{max} = \frac{8FD}{\pi d^3} + \frac{4F}{\pi d^2}$

Where D and d are mean and wire diameters of the compression spring. Substituting the working shear stress and the force in the above equation;

$$126 \times 10^6 = \frac{8 \times 24 \times D}{\pi d^3} + \frac{4 \times 24}{\pi d^2} = \frac{61.115D}{d^3} + \frac{30.558}{d^2}$$

The minimum and maximum standard wire diameter of the oil-tempered carbon valve-spring is between 1.3mm and 6.35 mm [3]. Hence, the smallest values are selected to meet the space requirement.

D=7.7 mm and d=1.3mm

The outside diameter of the spring becomes; D_o=D+d=7.7+1.3=9 mm

The spring index is becomes, $C = \frac{D}{d} = \frac{7.7}{1.3} = 5.9$

The maximum induced shear stress in the spring is equal to;

$$\tau_{max} = \frac{8FD}{\pi d^3} + \frac{4F}{\pi d^2} = \frac{8 \times 24N \times 7.7 \times 10^{-3} m}{\pi \times (1.3 \times 10^{-3} m)^3} + \frac{4 \times 24N}{\pi \times (1.3 \times 10^{-3} m)^2} = 29.654MPa$$

The maximum induced stress is less than the endurance limit of the spring; this implies that the design is safe.

Now let us check the stability of the spring. The spring is fabricated from steel, so that the following criteria should be fulfilled for steel [4].

$$L < 2.63 \frac{D}{\alpha}$$

Where α is the end condition constant, since the spring end condition is spring supported between flat parallel surfaces (fixed ends) is 0.5. Therefore, the free length becomes,

$$L < 2.63 \times \frac{7.7mm}{0.5} = 40.502mm$$

A very small amount of length is preferred to make compact and strong to prevent buckling of the spring. But there should be enough space free length of the spring to have free movement of fluid. Hence, its preferred free length is 20 mm.

$$L=20 \text{ mm}$$

The free length for closed end and ground spring is found by using the following formula;

$$L = P \times N + 2d \rightarrow 20mm = P \times N + 2 \times 1.3mm$$

Where p is the pitch and N is the number of active coils. Since none of these two (P or N) parameters are unknown they can be analyzed by iteration.

Table 4-2 Iteration of spring N and p

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
P(mm)	17.400	8.700	5.800	4.350	3.480	2.900	2.486	2.175	1.933	1.740	1.582	1.450	1.338	1.243	1.160	1.088	1.024	0.967

The pitch should greater than the wire diameter of the spring (1.3mm). The pitch is advisable to make 2.486 mm and the corresponding numbers of active coils are 7. The total number of coils is found by using the following equation.

$$N_t = \frac{L - 2d}{P} + 2 = \frac{20mm - 2 \times 1.3mm}{2.486mm} + 2 = 9$$

Solid length of the spring is calculated as follows, $L_s = N_t \times d = 5 \times 1.3mm = 11.7mm$

The maximum deflection of the spring should be advisable as small as possible to prevent the back flow of the air, which in turn reduces the effectiveness of the vacuum creator. So that the maximum deflection of the spring is equals to the difference between the free length and solid length of the spring.

$$\delta = L - L_s = 20 - 11.7 = 8.3mm$$

Design of Valve

Step 1: The valve is used to control the air inside the cylinder. It should withstand a pressure force of 305577.491 Pa and be wear resistant.

Step 2: Gathered information: The maximum pressure applied on the valve is P=305577.491 Pa and its outer diameter should be less than the inside diameter of the valve seat.

Step 3: Problem statement: Designing of a valve that is capable of resisting 305577.491 Pa pressure force, which is applied intermittently.

Step 4: Determining the shape of the valve, which is compatible with the valve seat and spring.

The following shape is chosen because it is simple to manufacturing, compact in size and compatible to the valve seat and the spring.

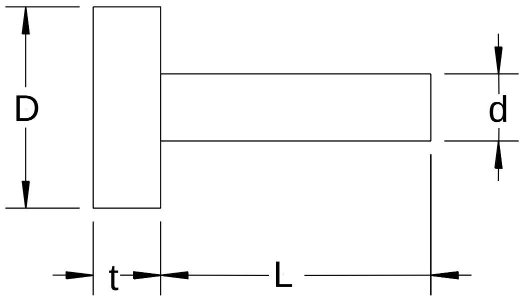


Figure 4-16 Inlet and Exit Valve

The diameter (d) of valve is equal to the inside diameter of the spring. The length of the valve is less than the length of the spring. In addition, the diameter (D) of the valve is approximately equals to the outer diameter of the spring.

$$d = \text{mean diameter - wire diameter} = 7.7 - 1.3 = 6.4\text{mm}$$

$$L = \text{length of the spring - deflection of the spring} = 20 - 8.3 = 11.7\text{mm and}$$

$$D \cong \textit{outside}\ \text{diameter of the spring} = 9\text{mm}$$

The head of the valve is under shearing stress.

Step 5: Material selection and working stress: The material should have resistance to corrosion and wear, has low coefficient of friction and relatively low cost and weight. Aluminum alloy is the best material for corrosion resistance but it is highly affected by wear. Since the valve is always in sliding motion it should be manufactured from the wear resistant material. The plain carbon steel, Alloy steel and carbon steel have excellent resistance to wear and moderate resistance to corrosion. Therefore, carbon steel is selected since it is the cheapest of all and suitable for machining [AppendixA-2]. To make the system compact in size and light in weight, the factor of safety should be minimum which is 2.

Working stress= the yield stress ╱ factor of safety

However, the valve is subjected to reverse axial loading. We know that for reversed axial loading correction factor ka=0.8. The endurance limit for reversed axial load;

$$\tau_{ea} = \tau_e \times k_a \times k_{sur} \times k_{sz}$$

k_{sur} = surface finish factor =0.89 for machined with ultimate strength of 435Mpa

k_{sz} = Size factor=0.9 since nominal diameter is greater than 7.65mm

τ_e =0.8 τ y for carbon steel=0.8×217=173.6Mpa

τ_{ea} =173.6×0.8×0.89×0.9=111.243Mpa

$$\text{Working stress} = \frac{\text{Endurance limit stress}}{\text{Factor of safety}} \quad \tau_w = \frac{\tau_{ea}}{n} = \frac{111.243}{2} = 55.621 MPa$$

Step 6: Detailed stress analysis: The valve head is under shearing due to a pressure of 305577.491 Pa force. The magnitude of the force that is applied on the cover is equal to the product of pressure inside the cylinder and the area of the valve head in contact with the pressurized fluid. The maximum force applied on the valve for strength purpose is 24N force:

$$\tau = \frac{F}{A}, \text{ but } A = \pi(d)t, \ A = \frac{F}{\tau} = \frac{24\text{N}}{55.621 \times 10^6 \text{ N/m}^2} = 4.315 \times 10^{-7}\text{ m}^2 = 0.4315\text{mm}^2$$

$$t = \frac{A}{\pi d} = \frac{0.4315\text{mm}^2}{\pi \times 6.4\text{mm}} = 0.02146\text{mm}$$

The thickness of the valve head is very small so that it is advisable to maximize its thickness to prevent bending and deflecting from normal shape to 2 mm.

The cylinder cover of the pump in figure 4.7 is under internal and external pressure of 305577.491 MPa and 101325 MPa respectively. The cover will fail under shear due to the pressure. The diameter of the cylinder is 25 mm. It should be manufactured from corrosive resistant materials (stainless steel) since the device is operated in the open air. The working stress is 240 MPa which was analyzed in the handle design.

$$\text{The induced stress in Shear } \tau = \tau_w = \frac{F}{A} = \frac{(P_i + P_o)\pi {d_R}^2/4}{\pi d_R t} = 152\text{Mpa}$$

$$= \frac{(0.305577491 + 0.101325) \times 25}{4t}\text{mm} = 152 \rightarrow t = 0.0167 \text{ mm}$$

Since there are attachments on the cover it should be strong hence its thickness is preferred to be 2 mm.

$$t = 2 \text{ mm}$$

The bolt (4 in numbers) for cylinder cover in figure 4.14 is under a tensile load of 600N which is shared into 4, i.e. 150N. It should be manufactured from corrosive resistant materials (stainless steel) since the device is operated in the open air. The working stress is 152 MPa which was analyzed in the handle design with 2 factor of safety.

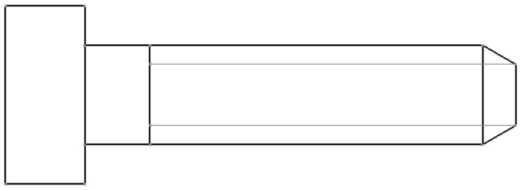


Figure 4-17 Bolt for Cylinder Cover

$$\text{The induced tensile stress } \sigma = \frac{F}{A} = \frac{4F}{\pi d^2} = \frac{4 \times 150\ N}{\pi \times d^2} = 152\text{MPa} \rightarrow d = 1.121\ mm$$

The diameter of the bolt is 1.121 mm which is very small hence it should be increased to 5 mm. The length of the bolt is equal to the sum of 71.5mm.

The cylinder of the reservoir in figure 4.8 is under internal and external pressure of 0 MPa and 101325 MPa respectively. The diameter and height of the reservoir are 200 mm and 65 mm respectively. The cylinder is manufactured from Polypropylene (PP) which has yield strength of 30 MPa, modulus of elasticity of 1 GPa and a density of 0.9 Mg/m^3. The working stress with 2 factor of safety becomes:

$$\text{working stress} = \frac{\text{endurance limit}}{\text{factor of safet}} \rightarrow \sigma_w = \frac{\sigma_e}{n} \rightarrow \sigma_e = 0.8\sigma_y \text{ for steel}$$

$$\text{working stress} = \frac{\text{endurance limit}}{\text{factor of safet}} \rightarrow \sigma_w = \frac{0.8 \times 30\text{MPa}}{2} = 12\ \text{MPa}$$

The pressure created inside the cylinder is low so the pressure vessel is categorized under thin pressure vessel. The design depends on circumferential or hoop stress, i.e.

$$\sigma_H = \frac{(-p_i + p_o)d}{2t} \rightarrow \sigma_H = (0.101325 - 0)\text{N/mm}^2 \frac{200\text{mm}}{2 \times t} = 12\frac{N}{\text{mm}^2} \rightarrow t = 0.8444\text{mm}$$

The cylinder should be also designed by considering the deflection along longitudinal axis.

$$\text{Change in length } \Delta L = \frac{(-P_i + P_o)d[1-2v]L}{4tE} = \frac{(0.101325-0)\times 200 \times [1-2\times 0.3]\times 65}{4\times 0.844\times 1000}\text{mm} = 0.156\ \text{mm}$$

Using standard seamless tube table the next thickness of the cylinder becomes 2 mm which results a 0.078 mm axial deflection.

$$\text{The change in diameter } \Delta d = \frac{(-P_i + P_o)d^2[1-2v]}{4tE} = \frac{(0.101325-0) \times 200^2[1-2\times 0.3]}{4\times 2\times 1000}\text{mm} =$$

$$= 0.20265\ \text{mm}$$

Based on the 200 mm internal diameter and 2 mm thickness of the cylinder it is in safe conditions.

The cylinder cover of the reservoir in figure 4.9 is under internal and external pressure of 0 MPa and 101325 MPa respectively. The cover will fail under shear due to the pressure. The diameter of the reservoir is 200 mm. It should be manufactured from corrosive resistant materials (stainless steel) since the device is operated in the open air. The working stress is 240 MPa which was analyzed in the plunger design.

$$\text{The induced stress in Shear } \tau = \tau_w = \frac{F}{A} = \frac{(P_i + P_o)\pi {d_R}^2/4}{\pi d_R t} = 240\text{Mpa}$$

$$= \frac{(0 + 0.101325) \times 200}{4t}\text{mm} = 240 \rightarrow t = 0.02111 \text{ mm}$$

Since there are attachments on the cover it should be strong hence its thickness is preferred to be 2 mm.

$$t = 2 \text{ mm}$$

The bolt (4 in numbers) for Reservoir cover in figure is not under load because the reservoir is under very low pressure. Hence it is advisable to use the same bolts as the cylinder cover. The diameter of the bolts becomes 5 mm. The length of the bolt is equal to the sum of 83 mm.

The Axe Tip (Sucking Tip) is used to suck the fluid from the alive plant. There is no load applied on the sucking tip. Its size depends on the thickness of the bark of the plant. The resin will be taken by different types sucker. The sucker shapes and feature will become one of the main issue in the extraction of fluids from alive plants. For the time being, it is designed and applied the following shapes.

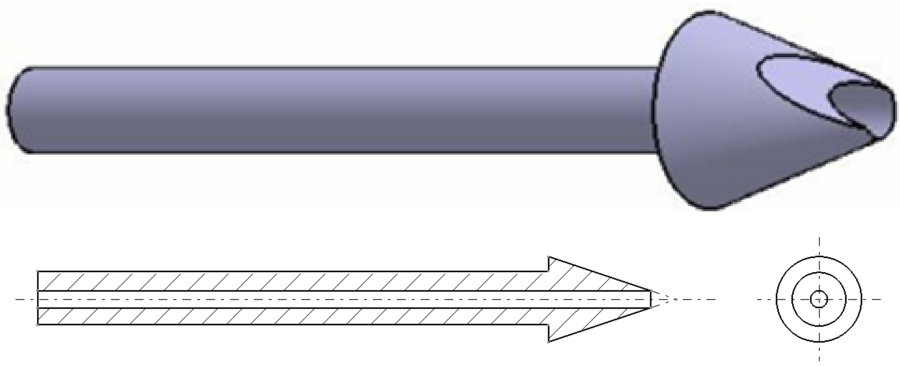


Figure 4-18 Sucking Tip

4.3. *Manufacturing Process*

There are two types of components incorporated in the extractor. These are standard finished parts which will be bought from market and parts that will be manufactured locally. The standard parts are bolt for handle and plunger connector, bolt for cylinder covers, pneumatic hoses, biocompatible hoses, nuts, washers, pressure gauge, fluid distributor, belt, etc. The locally manufactured parts are handle, plunger, handle plunger connector, cylinder covers, gasket, cylinder, reservoir, reservoir covers, gridded sucking tip, fixing tool, slide adjustor, valve head, spring, etc.

The handle, plunger and cylinder are prepared from seamless tubes. First the tubes should be bought from market using the designed diameters and thicknesses and then cut it using specified dimensions using hacksaw machine. The grooves on the plunder and cylinder will be made using lathe machine.

The handle plunger connector, cylinder covers and reservoir covers are manufactured from 2 mm thick plate. However, all have different features. The handle plunger connector is prepared from 108.54 mm length, 15 mm and 2 mm thickness. The two holes are made by drilling the plate 5 mm hollow. The bend is made by a radius of 25 mm at midpoint. The cylinder covers have square of 57 mm and 2 mm thickness. The outer cover has four holes (5 mm diameter) which are symmetrical about the center. The holes are made by drilling. The inner cover has four holes (5 mm diameter) which are symmetrical about the center and one central hole of 25 mm. All the holes are made by using driller.

The plunger cup is prepared from 30 mm diameter aluminum bar which is faced and turned using the dimension by a lathe machine.

The valves are also prepared from aluminum bar which is turned and faced using the dimension by a lathe machined. The spring will be manufactured locally using threaded rod which has the same diameter pitch with the spring using a lathe machine. The wire and the threaded rod are fixed together in the chuck and then by holding one end of the wire it is possible make a spring.

4.4. Assembly, Disassembly and Maintenance Procedures

The assembly, disassembly and maintenance procedures are list below.

Assembly and Disassembly Procedures

There are two systems in the extractor. These are vacuum creator and reservoir. The vacuum creator has handle, plunger, cylinder and valves. Hence the main and other components are assembled together as follows.

> Step1: Assemble the handle and the plunger by using bolt, nut, and handle and plunger. And then insert the plunger cup into the lower end of the plunger and fix it by gasket maker
>
> Step2: Insert spring-valve-Gasket in the inlet hole, at the same time, insert Gasket-valve and then spring from the exit hole of valves and cylinder holder. Align holes of the covers and then tight using the bolts and nuts.
>
> Step3: The cylinder should be attached to the valve and cylinder holder. Finally insert the handle into the cylinder.

The reservoir has cylinder, covers, pressure gauge, hose attachments. These components are assembled as follows:

Step 1: Fix the pressure gauge holder, fluid hose connector and air hose connector on the top cover of the cylinder.

Step 2: Align the holes top bottom covers and tight using bolts and nuts.

Step 3: Connect the vacuum creator and the reservoir using a hose.

Step 4: Connect the reservoir and the gridded sucker tip using a hose.

In order to test the system, cut the tree using an axe that has same dimension as the gridded sucker, and insert and fix the sucker tip into the tree. And then move up and down the handle of the vacuum creator. Fluid will be start flowing into the reservoir. Otherwise, there may be leakage in the system.

The system is very simple and compact. Its disassembly procedures are opposite to the assembly procedures.

Maintenance Procedures

The system may stop sucking fluid. This will be due to leakages in the head of the plunder, valves, valve covers, hose between vacuum creator and reservoir, hose between reservoir and sucking tip or in the reservoir covers. The specific point of leakage can be found by separating and testing the vacuum creator, hoses, fittings, and reservoir individually. Appropriate gaskets will be replaced based on the requirement.

4.5. Cost Analysis

The budget required for manufacturing and assembling of the plant milker is estimated below based on the current market condition. The estimation is done for a well-equipped workshop and its purpose is dedicated only for manufacturing. The cost is analyzed by considering that the raw material is available in the store which is nearest to the workshop. In addition, it is analyzed for mass production.

The total manufacturing cost is analyzed using the following formula;

$$Manufacturing\ cost = machining\ cost + material\ cost + factory\ expenses$$

$$machining\ cost = (Ro + Rm)\left(\frac{T_{su}}{Q} + T_{ot} + T_{no}\right) = 36675.917$$

Where R_o is the operators rate, R_m is the machine rate, T_o is Total operation time, T_{su} is Tools, work piece and machine set up time, T_{no} is Preparing work piece, tools, dimension measuring and checkups, centering, marking, cleaning and others non operation time and Q is batch size.

$$Manufacturing\ cost = 36675.917 + 3489.0 + factory\ expenses$$
$$= 40164.917 + factory\ expenses$$

The details of raw material cost and machining costs are shown in Appendix [E] and Appendix [F].

4.6. Tests and Results

The system was tested for its functionality in two stages. The first stage was testing the system after assembling it. This test was carried in order to get the amount of vacuum pressure created inside the reservoir before it is tested for the real application by closing the sucking tip. During the test, more than 240 millibar vacuum pressure was created inside the reservoir for lose hose fittings see figure 7.1. The vacuum pressure can be more than 240 millibar if the hoses are fitted leakage free.

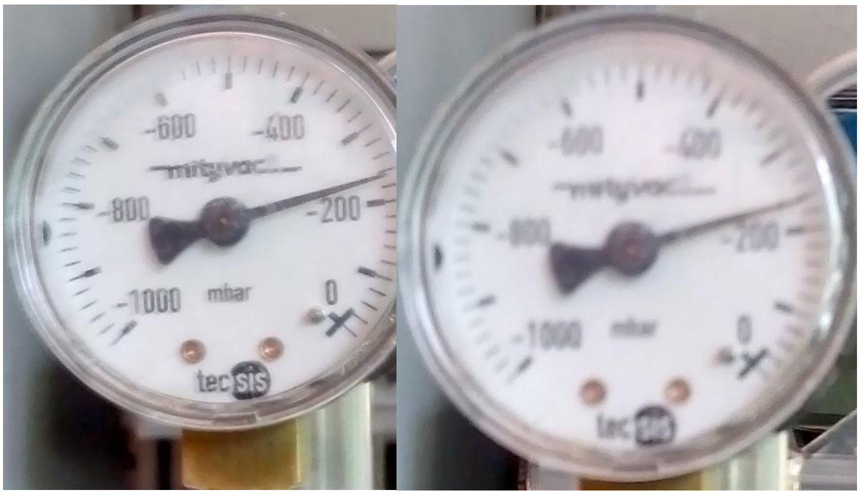


Figure 4-19 Recorded Pressure during Assembly Test

The second stage was tested in the real alive plant. During the test the phytochemicals was flow into the hose. The actual test incorporates the following parts and devices. These are two transparent hoses, vacuum creator, sucking tip, pressure gauge, belt, reservoir, hammer, large needle and axe. The vacuum creator and reservoir are connected using one hose. The reservoir and the sucking tip are connected using another hose. The pressure gauge is inserted on top of the reservoir. When the handle moves up and down the air inside the reservoir discharged into the atmosphere. Hence, a vacuum is developed inside the reservoir. The fluid, exude from injured plants, sucked into the reservoir due to the pressure difference.

Figure 4-20 Extraction of Phytochemicals using Long Hose

The extraction of chemicals depends on the rate of vacuum creation, length of the hose (from sucking tip to reservoir) and the way how the sucking tip is attached into the plant. The actual test was conducted in two conditions of the hose length (short and long) and two conditions of the way how the sucking tip is attached into the plant. In the short and long hose testing, first it was tested using the longer hose (2640 mm) see figure 7.2**.** During the test the fluid was flew through the hose but it couldn’t reach to the reservoir. This is because the amount of fluid which comes from the plant was not enough to fill the volume of the hose. Hence, it needs more time to fill the volume of the hose and then to drop into the reservoir. However, for the shorter hose (220mm) phytochemicals was dropped into the reservoir easily see figure 7.3. This implies that the length of the hose between the reservoir and sucking tip should be short. The amount of chemicals collected depends on the natural tendency of the plant to give its fluids.

Figure 4-21 Extraction of Phytochemicals using Short Hose

The other test was carried for two conditions of the way how the sucking tip is attached into the plant. The first test was made by cutting the plant using an axe in an inclined way on the outer part of the plant (see figure 7.4). The sucking tip was placed at the bottom end of the injured part.

Figure 4-22 Extraction of Phytochemicals from a Cut in an inclined way Using an Axe

As we can see in figure 7.4, the phytochemicals overflow out of the way made by the axe. This leads to wastage due to contamination with different things like dusts and barks.

The second test was made using needle. The needle was inserted into the alive plant by hitting using a hammer. When the needle was removed, the phytochemicals started to exude from the plant and the sucking tip inserted into the hole see figure 7.5.

Figure 4-23 Extraction of Phytochemicals from Holes Made by Large Needle

As we can see in figure 7.5, the fluid comes out from the plant only along the hole. When it is sucked, all the fluid will enter into the reservoir. The wastage and contamination will be eliminated. Hence both the quality and quantity of phytochemicals will be improved.

Results and Discussion

The purpose of the test was carried to check the functionality of the system. During the test the phytochemicals was entered freely into the reservoir. The chemicals that was collected have no the chance to contaminate with dusts. Because the sucking tip, hose and reservoir are clean and the phytochemicals flows through a confined system.

Figure 4-24 Clean Phytochemicals Extracted Using the New System

Figure 7.6 shows sample collected phytochemicals from Ficus elastica also called the rubber bush or rubber tree. As it is seen on the photo, it is clean and free from any contaminate. The quality and quantity of phytochemicals is definitely improved.

The quality is improved because there is no contamination with machine related chemicals, soils, dusts and barks. In addition the natural chemical composition will not be changed because there is no high temperature, high pressure and high electric fields applied during extraction.

The production quantity will be improved due to elimination of wastage during disposal of by-products and minimizing wastages during extraction processes. In addition, the exude time will be maximized because the fluid will not settled and make clotting layer on the injured parts of the plant. This will contribute to collect more phytochemicals. The replanting time will be eliminated which is a good news for the plant that needs more time to grow and give the required phytochemicals.

The purpose of this research is not only to improve quality and quantity but also to introduce a new system in the production of phytochemicals. The system minimizes the production steps which reduce initial investment cost, machine running cost and save huge amount of energy. The initial investment costs are designing, manufacturing, assembling, transporting, installing from small to mega machines that have be being used in the current industries. The machine running costs are the operation related costs. The mega machineries need a huge amount of energy to drive properly. These costs will be saved if the production system is changed. All these costs are headache to the current industries. This is due to a knowledge gap in the phytochemical extraction. In order to mitigate it, we have to apply the new way of extraction which is free from cutting, transporting, milling, heating, pressurizing, evaporating, cooling, etc.

Conclusion

In this research a simple and representative system have designed, prototyped and tested. The real test result is promising since clean phytochemical has collected. The quality of phytochemicals is improved because the fluid has collected within chemically neutral confined system, i.e., the fluid has no the chance to contaminate with dusts, barks and machine related chemicals. The natural chemical composition will be collected without any change which magnifies the quality of phytochemicals. The quantity of phytochemicals is also increased because there is no wastage during collection of raw materials and removal of byproducts.

The other main aim is to change the current mega phytochemicals manufacturing industry into a simple and none moving system. By applying the new system, a huge amount of money can be saved since initial investment cost, industry running cost and energy cost are eliminated. In addition, the replanting time will be minimized which increases the production time since there is no partial or complete cutting of the plant in the new system.

Recommendation

The system is revolutionary in the production of foods, medicines, perfumes, and other raw phytochemicals from alive plants. It will become hot issues in the near future in order to improve the efficiency of the extractor and the quality of extracted phytochemicals. The researcher recommends industries, universities, governments and researchers to apply this extraction method and to do further researches in the improvement of the system, analysis of chemical composition of the phytochemicals, and improvement of attaching mechanism of the sucking tip and the plant. Finally, this research paper can be used as a reference for mechanical engineering courses like strength of materials, machine element, mechanism of machinery, machine design projects, senior projects, etc.

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A. Appendix

Table A-1 Indian Standard designation of steel according to IS: 1570 (Part I)-1978 (Reaffirmed 1993). [31]

Indian standard designation (Minimum)	*Tensil strength N/mm² N/mm²*	*Yield stress (Minimum) elongation*	*Minimum percentage*	*Uses as per IS : 1871 (Part I)–1987 (Reaffirmed 1993)*
Fe 290	290	170	27	It is used for plain drawn or enamelled parts, tubes for oil well casing, steam, water and air passage, cycle, motor cycle and automobile tubes, rivet bars and wire.
Fe E 220	290	220	27	
Fe 310	310	180	26	These steels are used for locomotive carriages and car structures, screw stock and other general engineering purposes.
Fe E 230	310	230	26	
Fe 330	330	200	26	
Fe E 250	330	250	26	
Fe 360	360	220	25	It is used for chemical pressure vessels and other general engineering purposes.
Fe E 270	360	270	25	
Fe 410	410	250	23	It is used for bridges and building construction, railway rolling stock, screw spikes, oil well casing, tube piles, and other general engineering purposes.
Fe E 310	410	310	23	
Fe 490	490	290	21	It is used for mines, forgings for marine engines, sheet piling and machine parts.
Fe E 370	490	370	21	
Fe 540	540	320	20	It is used for locomotive, carriage, wagon and tramway axles, arches for mines, bolts, seamless and welded tubes.
Fe E 400	540	400	20	
Fe 620	620	380	15	It is used for tramway axles and seamless tubes.
Fe E 460	620	460	15	
Fe 690	690	410	12	It is used for locomotive, carriage and wagon wheels and tyres, arches for mines, seamless oil well casing and drill tubes, and machine parts for heavy loading.
Fe E 520	690	520	12	
Fe 770	770	460	10	It is used for locomotive, carriage and wagon wheels and tyres, and machine parts for heavy loading.
Fe E 580	770	580	10	
Fe 870	870	520	8	It is used for locomotive, carriage and wagon wheels and tyres.
Fe E 650	870	650	8	

Appendix A

Table A-2 Characteristic of materials [31]

Designation	Description	e%	Mn%	Si%	Mo%	Cu%	σy Mpa	Relative cost
40c - 8	Plain carbon steel	0.4	0.8	_	_	_	320	medium
35Mn^{2} - Mo28	Alloy -steel	0.35	0.2	_	0.28	_	600	high
0.6Cu-0.3Mn-5Si	Al-alloy	_	0.3	-5	_	0.6	63	highest
Galvanized C-18	Carbon steel	0.18	-	-	-	-	217	lowest

Appendix B

Table A-3 Characteristics of Spring Materials [31]

Material	*Allowable shear stress (τ) MPa*			*Modulus of rigidity (G) kN/m²*	*Modulus of elasticity (E) kN/mm²*
	Severe service	*Average service*	*Light service*		
1. Carbon steel					
(*a*) Upto to 2.125 mm dia.	420	525	651		
(*b*) 2.125 to 4.625 mm	385	483	595		
(*c*) 4.625 to 8.00 mm	336	420	525		
(*d*) 8.00 to 13.25 mm	294	364	455		
(*e*) 13.25 to 24.25 mm	252	315	392	80	210
(*f*) 24.25 to 38.00 mm	224	280	350		
2. Music wire	392	490	612		
3. Oil tempered wire	336	420	525		
4. Hard-drawn spring wire	280	350	437.5		
5. Stainless-steel wire	280	350	437.5	70	196
6. Monel metal	196	245	306	44	105
7. Phosphor bronze	196	245	306	44	105
8. Brass	140	175	219	35	100

Appendix C

Table A-4 Physical Properties of Metal

Metal	*Density (kg/m³)*	*Melting point (°C)*	*Thermal conductivity (W/m°C)*	*Coefficient of linear expansion at 20°C (μm/m/°C)*
Aluminium	2700	660	220	23.0
Brass	8450	950	130	16.7
Bronze	8730	1040	67	17.3
Cast iron	7250	1300	54.5	9.0
Copper	8900	1083	393.5	16.7
Lead	11 400	327	33.5	29.1
Monel metal	8600	1350	25.2	14.0
Nickel	8900	1453	63.2	12.8
Silver	10 500	960	420	18.9
Steel	7850	1510	50.2	11.1
Tin	7400	232	67	21.4
Tungsten	19 300	3410	201	4.5
Zinc	7200	419	113	33.0
Cobalt	8850	1490	69.2	12.4
Molybdenum	10 200	2650	13	4.8
Vanadium	6000	1750	—	7.75

Appendix D

Table A-5 Raw Materials Costs

S. No	Part name	Material	Dimension in mm	Qty.	Raw material cost birr/pc	Subtotal cost in birr
1.	Pump outlet & inlet valve cover	Stainless steel	Ø52x31.5x2	2	1.2	2.4
2.	Pump Outlet & inlet valve spring	Music wire	Ø10x20x2.22	2	2.0	4.0
3.	Pump Outlet & inlet valve head	Stainless steel	Ø8.2x7.59	2	2.0	4.0
4.	Pump outlet & inlet valve head gasket	Rubber	Ø8.2x2	2	10.0	20.0
5.	Pump outlet & Inlet cover gasket	Asbestos	52x31.5x1	2	2.0	4.0
6.	Pump Inlet valve hose connector	Stainless steel	Ø8x19.5	1	5.0	5.0
7.	Pump Stud	Stainless steel	Ø5x75	4	7.5	30.0
8.	Pump valve holder	Stainless steel	61x51x31.5	1	51.0	51.0
9.	Pump O-ring	Rubber		2	12.0	24.0
10.	Pump Plunder cup	Stainless steel	Ø23.67x20	1	25.0	25.0
11.	Pump Cylinder	Stainless steel	Ø27x490x2	1	104.20	104.20
12.	Pump Plunger	Stainless steel	Ø25x520x2	1	102.10	102.10
13.	Pump Pin	Stainless steel	Ø8x37	1	20.0	20.0
14.	Handle	Stainless steel	Ø50x400x5	1	106.2	106.2
15.	Handle plunger connector	Stainless steel	Ø54x15x65.38	1	18.0	18.0
16.	Reservoir Bottom & Top gasket	Asbestos	Ø200x1	2	400.0	800.0
17.	Nut for Reservoir discharge hose connector	Stainless steel	M9	1	30.0	30.0
18.	Reservoir discharge hose connector	Stainless steel	Ø14.5x35	1	5.0	5.0
19.	Nut for Pressure gauge holder	Stainless steel	M9	1	30.0	30.0
20.	Pressure gauge holder	Stainless steel	Ø20x27	1	5.0	5.0
21.	Vacuum pressure gauge		Pc	1	1500.0	1500.0
22.	Sucking-tip hose connector	Stainless steel	Ø14.5x35	1	5.0	5.0
23.	Nut for Sucking-tip hose connector	Stainless steel	M9	1	30.0	30.0
24.	Top & Bottom reservoir cover	Stainless steel	224x224x2	2	30.2	60.40
25.	Nut for stud	Stainless steel	M5	4	20.0	80.0
26.	Reservoir	Polypropylene	Ø200x65x2	1	200.0	200.0
27.	Stud for reservoir cover	Stainless steel	M5x78	4	8.0	32.0
28.	Sucking-tip	Stainless steel	Ø10X100	1	33.34	33.34
29.	Needle	Stainless steel	Ø15X200	2	66.68	133.36
30.	Hose	PVC	2.5 meter	2	12.5	25.0
Total Raw Material Cost						3489.0

Appendix E

Table A-6 Machining Cost

S. No	Part name	Material	Dimension in mm	Qty.	Operations	Time in min. T_o	T_{su}	T_{no}	Machining cost All Product
1.	Pump outlet & inlet valve cover	Stainless steel	Ø52x31.5x2	2	Cutting	5	5	30	250.000
				2	Drilling	100	10	40	1450.000
				2	Grinding	30	0	15	270.000
				2	Filing and Finishing	10	5	10	93.750
2.	Pump Outlet & inlet valve spring	Music wire	Ø10x20x2.22	2	Cutting	4	0	20	100.000
				2	Spiraling	5	20	15	335.000
				2	Grinding	10	0	10	120.000

				2	Finishing	5	0	8	54.167
3.	Pump Outlet & inlet valve head	Stainless steel	Ø8.2x7.59	2	Cutting	10	8	30	293.333
				2	Facing	30	10	30	725.833
				2	Turning	60	15	30	1088.750
				2	Chamfering	20	15	30	642.083
				2	Polishing	15	10	20	446.667
4.	Pump outlet & inlet valve head gasket	Rubber	Ø8.2x2	2	Cutting	10	20	15	145.833
				2	Holing	25	30	10	208.333
5.	Pump Inlet & outlet cover gasket	Asbestos	52x31.5x1	2	Cutting	10	20	15	145.833
				2	Holing	25	30	10	208.333
6.	Pump Inlet valve-hose connector	Stainless steel	Ø8x19.5	1	Cutting	10	7	25	140.000
				1	Facing	25	10	30	362.917
				1	Turning	50	20	30	558.333
				1	Drilling	45	25	30	500.000
				1	Chamfering	15	20	30	362.917
				1	Threading	35	20	30	474.583
				1	Polishing	10	10	20	223.333
7.	Stud for Pump cover	Stainless steel	Ø5x75	4	cutting	20	8	30	693.333
				4	Grinding	50	10	20	870.000
				4	Filing	20	0	15	291.667
8.	Pump valve holder	Stainless steel	61x51x31.5	1	Cutting	40	10	20	233.333
				1	Milling	120	15	30	893.750
				1	Drilling	120	25	40	925.000
				1	Threading	100	30	30	893.333
				1	Chamfering	20	5	20	251.250
				1	Finishing	20	10	15	251.250
9.	Pump Plunder cup	Stainless steel	Ø23.67x20	1	Cutting	15	7	30	173.333
				1	Turning	45	15	30	502.500
				1	Facing	25	13	25	351.750
				1	Drilling	25	10	30	325.000
				1	Chamfering	15	10	20	251.250
				1	Polishing	10	7	15	178.667
10.	Pump Cylinder	Stainless steel	Ø27x490x2	1	Cutting	20	8	30	193.333
				1	Grooving	25	7	20	290.333
				1	Threading	40	10	20	390.833
				1	Chamfering	10	7	20	206.583
				1	Polishing	15	8	20	240.083
11.	Pump Plunger	Stainless steel	Ø25x520x2	1	Cutting	20	8	30	193.333
				1	Grooving	50	7	20	429.917
				1	Chamfering	10	7	20	206.583
				1	Polishing	15	8	20	240.083
13.	Handle	Stainless steel	Ø50x400x5	1	Cutting	10	7	30	156.667
				1	Grinding	20	0	20	120.000
				1	Finishing	5	0	20	52.083
14.	Handle plunger connector	Stainless steel	Ø54x15x65.38	1	Cutting	5	7	20	106.667
				1	Drilling	20	8	30	290.000
				1	Grinding	15	0	20	105.000
				1	Finishing	10	0	15	52.083
15.	Reservoir Bottom & Top gasket	Asbestos	Ø200x1	2	Cutting	10	20	15	145.833
				2	Holing	25	30	10	208.333
16.	Inlet & Outlet	Stainless	Ø14.5x35	2	Cutting	10	7	25	256.667

	Reservoir-hose connector	steel		2	Facing	25	10	30	670.000
				2	Turning	40	20	30	893.333
				2	Drilling	45	25	30	875.000
				2	Chamfering	15	20	30	614.167
				2	Threading	40	20	30	893.333
				2	Polishing	10	10	20	390.833
17.	Pressure gauge holder	Stainless steel	Ø20x27	1	Cutting	10	7	25	140.000
				1	Facing	25	10	30	362.917
				1	Turning	40	20	30	502.500
				1	Drilling	45	25	30	500.000
				1	Chamfering	15	20	30	362.917
				1	Threading	40	20	30	502.500
				1	Polishing	10	10	20	223.333
18.	Top & bottom reservoir cover	Stainless steel	224x224x2	2	Cutting	5	5	30	250.000
				2	Drilling	140	10	40	1850.000
				2	Grinding	30	0	15	270.000
				2	Filing and Finishing	10	5	10	93.750
19.	Reservoir	Polypropylen e	Ø200x65x2	1	Cutting	15	7	30	173.333
				1	Grinding	20	0	25	135.000
				1	Finishing	10	0	20	62.500
20.	Stud for Pump cover	Stainless steel	Ø5x75	4	cutting	20	8	30	693.333
				4	Grinding	50	10	20	870.000
				4	Filing	20	0	15	291.667
21.	Sucking-tip	Stainless steel	$Ø10X100$	1	Cutting	15	7	30	173.333
				1	Turning	40	20	25	474.583
				1	Facing	20	15	20	307.083
				1	Drilling	40	15	20	375.000
				1	Tapering	25	20	20	362.917
				1	Chamfering	20	15	15	279.167
				1	Polishing	15	7	10	178.667
22.	Needle	Stainless steel	$Ø15X200$	2	Cutting	15	7	30	323.333
				2	Turning	40	10	25	781.667
				2	Facing	20	10	20	502.500
				2	Tapering	30	15	15	586.250
				2	Chamfering	25	12	10	457.833
23.	Hose	PVC		2	Cutting	5	0	15	83.333
Total Machining Cost									**36675.917**

Appendix F

Table A-7 Machine Rate (Source: Vision International Consultants)

Machine Name	Rate in Birr	Remark
Milling	225.00	
Lathe	235.00	
Power Hacksaw	100.00	
Drilling	100.00	
Grinding	200.00	
Shearing Machine	80.00	

Appendix G

Table A-8 Total Project Budget

S. No	Activities	Unit Price in Birr	Total Price in Birr	Remark
1	Material Purchasing	Lump Sum	36950.0	
2	Manufacturing	Lump Sum	46800.0	
3	Communication	Lump Sum	2000.0	
4	Assembling and testing	Lump Sum	3100.0	
5	Printing and Binding	Lump Sum	1500.0	
6	Transportation	Lump Sum	0.0	
7	Per Diems	Lump Sum	6300.0	
8	Contingency	5% of total	4782.5	
Total			101432.5	

Appendix H

Photo 1 Some Photos during test

Appendix I

Photo 2 Traditional Harvesting Methods of Ficus Elastica or Rubber Plant [45]

Appendix J