Design of a Controlled Atmospheric Storage Facility for Climacteric Fruits

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Abstract*— *The work focused on designing a Controlled Atmospheric Storage facility for climacteric fruits. Climacteric fruits are those fruits that continue to ripen after being maturely harvested e.g. tomatoes, bananas, papaya, guava, fig, apple, apricot, and plum. Sweet William or Veredia bananas from Chipinge (Zimbabwe) were used for experiments in the design. The researchers noted that Zimbabwean small scale fruits producers, vendors, and retailers do not have adequate storage facilities to store their produce. This inadequacy has led to rapid postharvest losses of about 30 – 40 %.

The design project aimed at controlling atmospheric gases, humidity and temperature during storage of bananas as these are the parameters that accelerate deterioration if not controlled. The design had to include a swing term air filtering technology to separate or absorb oxygen from the compressed atmospheric air (about 78% N_2, 21% O_2, and 0.03% CO_2) using Erythorbic acid inside the absorption tanks. The remaining gas composition constitute more of N_2 (78%) and CO_2 (0.03%) which are needed to delay ripening process. The design in the form of a metal box had to include an air tight environment; the door incorporated was air tight so as to prevent the entrance and exit of gases. It also had to include temperature detectors e.g. Thermocouples detect the temperature inside the storage. A fan that runs automatically when the door is opened was incorporated, so as to drive away any gases that might have gained entrance into the storage. An additional fan to maintain the optimum temperatures inside the storage and control the internal humidity was also added. The design had to include foam rubber between the double walls so as maintain the optimum temperature inside the box when water is allowed to flow on the foam rubber through the coolant inlet funnel. Ethylene absorbers (activated carbon impregnated with potassium permanganate) were included inside the storage for them to adsorb the produced ethylene gas by the fruits. Silica gel also added to adsorb the produced moisture which can be a media for microbial flora.

***Keywords*— climacteric fruits,swing term air filtering technology,autocalytic ripening, phytomones, presure swing adsorption (PSA), vacuum pressure swing adsorption (VPSA), thermocouple.**

I. INTRODUCTION

All fruits are perishable, which makes postharvest handling crucial to reduce loses. On average, 15-55% losses in fruit produce can be experienced in the developing world [20]. For example, 30% distribution losses have been reported for Sunspun fruit distributers in Harare owing to poor selection of improper packing material and physical damage to the produce [29]. The reduction of postharvest losses of perishables is of major importance when striving for improved food security in developing countries [22]. Most climacteric fruits spend a lot of time on the shelves and end up in landfills as wastes [20]. They are packaged in corrugated boxes, wooden crates or refrigerated which do not adequately protect the produce from deteriorating. As a result growers and those engaged in the food handling chain suffer major financial loses [52].

Fruit processing industries, supermarkets, farmers and local vendors suffer postharvest losses of climacteric fruits daily. Researches and experiments have been done by scientists to delay fruit ripening so that farmers, retailers and fruit processors will have flexibility in marketing their produce and ensure consumers of “fresh-from-the-garden” [27].

Atmospheric gases, humidity and temperature are all parameters that accelerate the deterioration of climacteric fruits if not controlled. In Zimbabwe small scale producers, vendors and retailers do not have adequate storage facilities to control these parameters and this leads to rapid spoilage of 30% of produce in the primary packaging. The inability to control these parameters during fruits storage contribute to the decaying of the fruits which results in postharvest loses of climacteric fruits in the local and industrial market leading to financial loses.

The primary goal of fresh produce merchandising is to deliver products to the consumer at such a point in the ripening scale that it will achieve ripening stage at the time of eating. This course is extremely difficult to achieve. Controlled atmosphere (CA) storage involves maintaining an atmospheric composition that is different from air composition, which is 78% N2, 21% O2, and 0.03% CO2). Generally, O2 levels below 8% and CO2 levels above 1% are used [57]. Gaseous nitrogen is used in controlled and modified atmosphere fruits and vegetables storage and packaging to maintain the quality of fresh products by retarding oxygen-dependent ripening and decay processes [22].

Atmosphere modification should be considered as a supplement to maintenance of optimum ranges of temperature and relative humidity for each commodity in preserving quality and safety of fresh fruits and vegetables [57]. Ethylene, a plant hormone plays an important role in ripening processes for climacteric fruits [8]. However, its action is inhibited by elevated CO2 atmospheres [8]. Optimum atmospheric composition retard chlorophyll loss (green colour), biosynthesis of carotenoids (yellow and orange colours) and anthocyanins (red and blue colours), and biosynthesis and oxidation of phenolic compounds (brown colour) [52]. Controlled atmospheres slow down the activity of cell wall degrading enzymes involved in softening of fruit peels [5]. Low O2 and/or high CO2 atmospheres influence flavour profiles by reducing loss of acidity, starch to sugar conversion, sugar interconversions, and biosynthesis of flavour volatiles [22].

When produce is kept in an optimum atmosphere, there is retention of ascorbic acid and other vitamins, resulting in better nutritional quality. The design of this controlled atmospheric storage can be very important as the quality and shelf life of climacteric fruits can be heightened.

II. LITERATURE REVIEW

Fruit ripening and ethylene

Ripening is the process by which fruits attain their desirable flavour, quality, colour, palatable nature and other textural properties. Ripening is associated with change in composition i.e. conversion of starch to sugar . An important factor for climacteric ripening is the natural plant hormone ethylene (C_2H4), which is produced by the fruit itself and released as a gas into the surrounding atmosphere. The released ethylene accelerates the ripening and senescence processes, making the climacteric fruit react very strongly to it (autocatalytic ripening) [5]. Ethylene is a phytohormone that controls or influences many aspects of plant growth and development [1]. Many of the developmental processes controlled by ethylene, such as senescence, organ abscission and fruit ripening, are critically important to agriculture [34]. For example, climacteric fruits, such as tomato, banana and apple, require an increase in ethylene biosynthesis at maturity in order to ripen.

Ethylene is a phytohormone that controls or influences many aspects of plant growth and development . Many of the developmental processes controlled by ethylene, such as senescence, organ abscission and fruit ripening, are critically important to agriculture. For example, climacteric fruits, such as tomato, banana and apple, require an increase in ethylene biosynthesis at maturity in order to ripen [5]

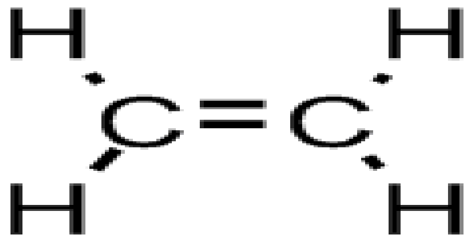

Fig.1: structure of ethylene (Bunce 1994)[8]

Ethylene is also produced from combustion of organic compounds, both in natural processes (e.g. forest fires) and as a result of human activity (fossil fuel combustion, processing of natural gas).The atmosphere contains less than 0.005ppb of ethylene [8]. The optimum composition of the ethylene in a storage facility depends on the type of climacteric fruit [5].In general, a fruit becomes sweeter, less green and softer as it ripens. Though the acidity as well as sweetness rises during ripening, the fruit still tastes sweeter [15].

As shown in table 1 below, ethylene increases rapidly but differently in the case of climacteric fruits.

Table.1: Ethylene internal concentration (µL/L) (Berk 2009)[5]

Fruit	Ethylene (*µL/L)*
Apple	25 – 2500
Avocado	28.9 -74.2
Banana	0,05 -2.1
Passion fruit	466-530
Tomato	3.6 -29.8

Climacteric fruit produce much larger quantities of ethylene, although the internal ethylene concentrations vary significantly between fruit types. For most climacteric fruit a sharp increase in internal ethylene concentration precedes or is coincident with a dramatic increase in respiration rate. The increasing ethylene concentration triggers the increase in respiration rate (metabolic activity) and attendant biochemical and physiological transformations that occur during ripening [1]. Ethylene production in climacteric fruit is described as an 'autocatalytic' process i.e. exposure to an initial small concentration of ethylene causes the fruit to produce greater quantities of ethylene until a peak concentration is achieved. Exposing immature climacteric fruit to ethylene can trigger this autocatalytic response, causing premature ripening and result in fruit with poor eating quality [8].

Ripening and respiration

Ripening is a term applied to fruit that describes the transition from physiological maturity to senescence (ageing and death of the plant tissues). It is a developmental stage evolved to facilitate reproduction by preparing the seed-bearing organ for detachment from the plant [1].

Ripening is the start of significant biochemical and physiological transformations, such as changes in skin colour, internal flesh softening, aroma development and sweetening. Ripening generally begins after fruit has reached maximum size and is physiologically mature [23]. At physiological maturity fruit have accumulated a range of complex molecules in the form of carbohydrates, proteins, lipids and organic acids [15].

Once detached (harvested) from the plant the fruit continues as a living organism but can no longer draw on water and nutrient from the plant to supply its energy needs and complete the ripening processes. The fruit remains metabolically active and respiration now relies on these accumulated complex molecules [5].

Respiration is a process of oxidative breakdown (catabolism) of complex molecules into simpler molecules, yielding energy, water, carbon dioxide and simpler molecules needed for other cellular biochemical reactions required for ripening [23]. The respiration rate per unit of fruit weight is (as a general rule) highest in immature fruit, with the respiration rate declining with age. Thus respiration rate of fruit is an indicator of overall metabolic activity level, progression of ripening and potential storage life of the fruit i.e. a low respiration rate means that the energy reserves will take longer to be consumed and the fruit can be stored for longer [23].

Pressure driven adsorption processes

Oxygen or nitrogen production by an adsorption process is driven by the ability of process specific molecular sieve to preferentially adsorb the non-desired molecules at a feed pressure that is higher than the subsequent pressure during the desorption step. The pressure differential may be the result of compressing the air feed to high pressure when nitrogen is the desired product in a process known as pressure swing adsorption (PSA) (Air Products 2002).

PSA process is cyclical in nature, undergoing a sequence of steps such as adsorption, purge, equalization, evacuation, and re-pressurization. Eventually, the process will reach a cyclical steady state or CSS where the composition profiles within the vessels are constant at a given stage in the adsorption step. Each bed in a PSA accepts air feed for a short period of time, on the order of 10 seconds. This might lead one to conclude that the response times are short. The key issue here is that it takes many cycles for the composition and temperature profiles to reach CSS, on the order of hours. Varying demands for product flow require the unit to rapidly vary between maximum and minimum production while maintaining purity. Variations in the speed of opening of even one of the valves can cause significant disturbances to the process.

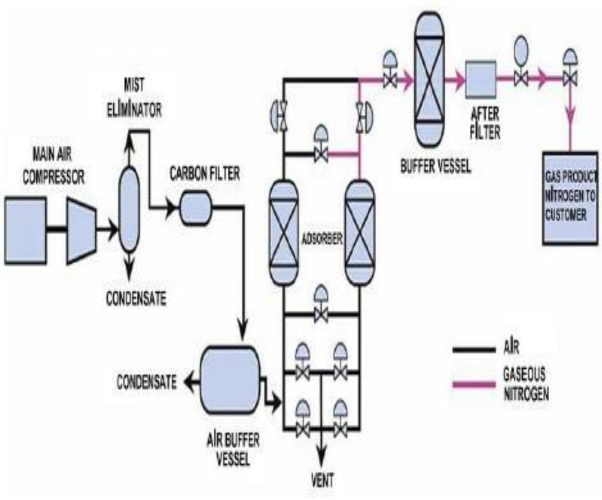

Fig.2: Nitrogen PSA production process (Beh & Webley, 2003)

Vacuum Pressure Swing Adsorption (VPSA)

The Vacuum Pressures Swing Adsorption (VPSA) process is a variation on the Pressures Swing Adsorption (PSA) process, which is more applicable for certain applications. VPSA uses a feed blower instead of an air compressor to supply air to the system and the purified gas is collected using a vacuum blower to desorb the adsorber vessels. Although power savings are clear with this system, they are typically cost effective only for plants requiring very large oxygen producing capacities .

Each VPSA system includes a rotary-lobe feed air blower, vacuum blower (two bed systems only), one or two adsorbent vessels, an oxygen surge tank, switching valves and computer controls. In the single-bed system, the blower draws in air, compresses it and sends it to the adsorbent vessel to remove impurities, leaving 90 to 94 percent pure oxygen as the product. The adsorbent is then regenerated as the blower removes gas by reducing the pressure inside the vessel. Since oxygen is not produced during regeneration, the system includes a low-pressure surge tank to allow for continuous oxygen supply. The two-bed system uses a similar adsorption process cycle that relies on swings in pressure from above one atmosphere to below atmospheric pressure (vacuum) to cycle each bed sequentially from adsorption to desorption. One bed is always adsorbing impurities to separate oxygen from air, while the other bed regenerates ..

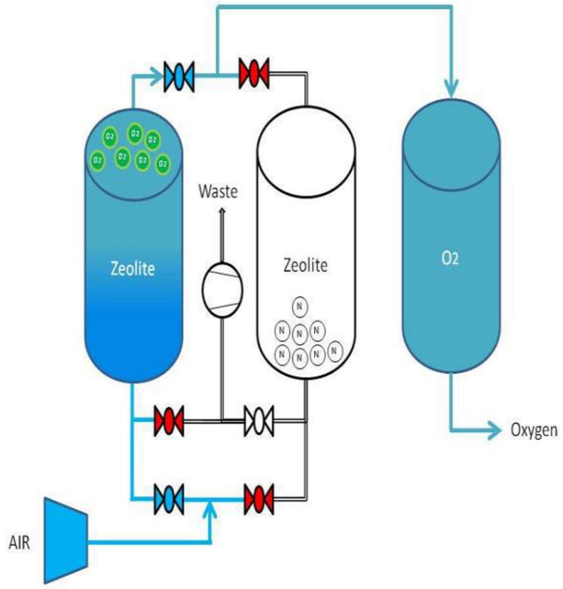

Fig.3: Vacuum Pressure Swing Adsorption (VPSA) (Beh & Webley 2003)

III. METHODOLOGY

A systematic design approach to concept evaluation developed by French (1999) was used which is a method of evolution based on use-value analysis.

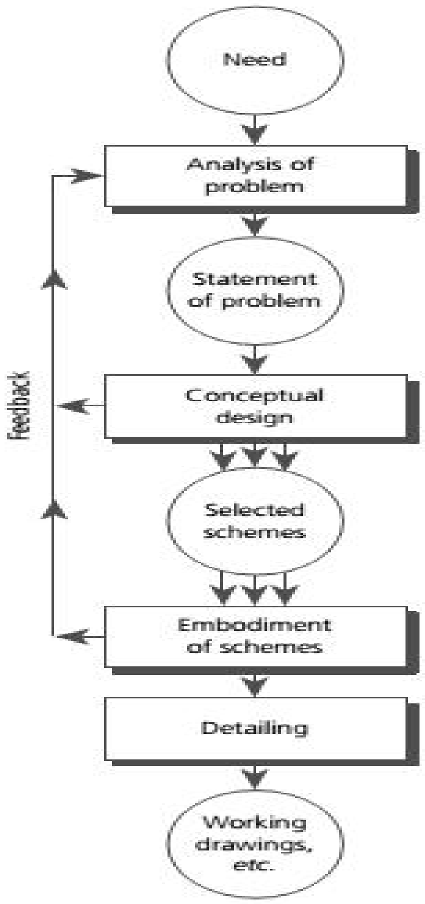

Fig.4: French model of design (1999)

Interpretation of model

Need

The initial task in the systematic approach to design is to identify the primary need, defined as the true need or the real design problem. This was described in the problem statement as the need for a storage facility that can delay ripening of climacteric fruits leading to a reduction in postharvest losses and improved quality, safety and marketability of fresh fruit

Analysis of the problem

Oxygen concentration, carbon dioxide concentration, humidity and temperature are all parameters that accelerate the deterioration of climacteric fruits if not controlled. The inability to control these parameters during fruits storage contribute to the decaying of the fruits which results in postharvest loses of climacteric fruits leading to financial loses.

Conceptual design

For the problem to be solved, the various designs should consider the following:

Function structures

A swing term air filtering machine should be designed and will be used to separate or absorb oxygen from the compressed atmospheric air (about 78% N_2, 21% O_2, and 0.03% CO_2) using Erythorbic acid inside the absorption tanks. The remaining gas composition will constitute more of N_2 (78%) andCO_2 (0.03%) which will be driven into the storage facility. Gaseous nitrogen is used in controlled and modified atmosphere fruits and vegetables storage and packaging to maintain the quality of fresh products by retarding oxygen dependent ripening and decay processes.

Mathematical Model

To develop a mathematical model for the N_2 swing term air filtering machine system the following main assumptions according to Coulson (2001), were taken into consideration:

- Gas behaves as an ideal gas.
- Absorbing properties throughout the cylinders would remain constant.
- The bed is clean at the initial state and there is no gas flow in it.
- Erythorbic acid is 100% efficiency.
- Air is considered a mixture of gases (about 78% N_2, 21% O_2, and 0.03% CO_2).

<u>The equation of state for an ideal gas is:</u>

$$\mathbf{pV = nRT} \qquad \text{equation (i)}$$

Where **p** is gas pressure inside the absorption cylinders, **V** is volume of cylinders , **n** is the number of moles of gas pumped into the cylinders, **R** = universal gas constant = 8.3145 J/mol K, **T** is the absolute temperature. The first law of thermodynamics, the conservation of energy i.e.

energy is neither created nor destroyed, may be written in differential form as

dq = du + p dV equation (ii)

Where **dq** is a thermal energy input to the gas, **du** is a change in the internal energy of the gas, and**p dV** is the work done by the gas in expanding through the change in volume **dV**.

Constant Volume Process:

If **V** = constant, then **dV** = 0, and from **(ii)dq** = **du**; i.e., all the thermal input to the gas goes into internal energy of the gas. We should expect a temperature rise. If the gas has a specific heat at constant volume of C_V (J/mol K), then we may set **dq** = **n**C_V **dT**. It follows, in this case, that

du = nC_V **dT** equation (iii)

Constant Pressure Process:

If **p** = constant, then **dp** = 0, and, from **1**, **p dV** = **nR dT**; i.e., the work done by the gas in expanding through the differential volume **dV** is directly proportional to the temperature change **dT**. If the gas has a specific heat at constant pressure of **Cp**, then **dq= n**C_p **dT**, and, from (**ii**) **(with iii),**

$$nC_p\,dT = nC_V\,dT + nR\,dT$$

Simplifying gives an important constitutive relationship between C_V,C_p, and **R**, namely:

$$C_p = C_V + R$$

Constant Temperature Process:

If **T** = constant, then **dT = 0**, and, from **1**, **d(pV) = 0**, i.e., pressure and volume are inversely proportional. Further, from **2**, **dq = p dV**; i.e., there is no change in internal energy (from**iii, du = 0**), and all the thermal input to the gas goes into the work of expansion. ***Factors affecting absorption properties of Erythorbic acid***

Pressure is directly proportional to the rate of absorption. The greater the concentration the more the absorption power as the reaction will occur at a fast rate. Reaction to occur in a closed system so as to allow for a maximum build up pressure.

Design features

- Thermocouple
- Compressor
- Fan
- Pressure valves
- Opening valves
- Foam rubber
- Absorption cylinders containing Erythorbic acid
- 12 volts battery
- Position for sachets with adsorbers
- Coolant inlet funnel

Functionality of each design feature

The storage facility in the form of a metal box should have an air tight environment; the door should be air tight so as to prevent the entrance and exit of gases. The thermocouple will detect the temperature inside the storage. The fan will should run automatically when the door is opened, so as to drive away any possible gases that might have gained entrance into the box. The fan should also maintain the optimum temperatures inside the storage and control the internal humidity. The foam rubber between the double walls will help to maintain the optimum temperature inside the box when water is allowed to flow on the foam rubber through the coolant inlet funnel. Ethylene absorbers (activated carbon impregnated with potassium permanganate) will absorb the produced ethylene gas by the fruits. Silica gel will adsorb the produced moisture which can be a media for microbial flora.

Design generation

Alternative designs which conform to the requirements are generated and their structuralsetups are clearly shown on fig.6, 7 and 8. Each solution is described and analysed in detail. Strengths and weaknesses of each design are discussed with the intention of selecting the best design solution for the design problem and from the alternatives; the most cost effective design will be further fabricated into a real functional controlled atmospheric storage facility.

Chosen design

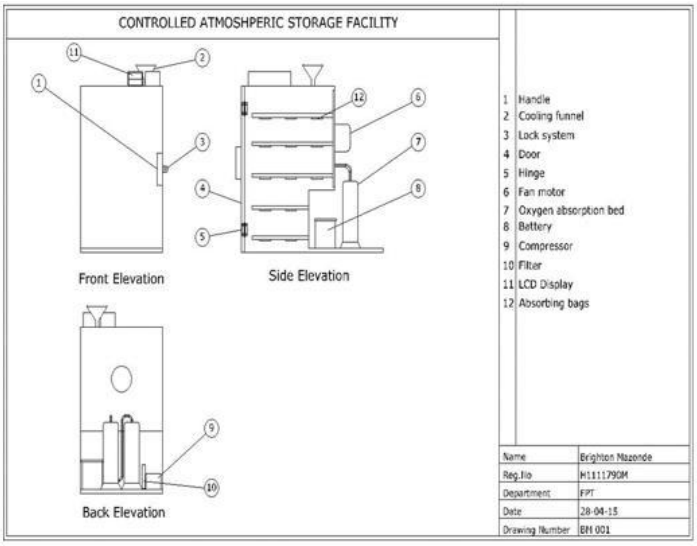

Fig.5: Diagram of the chosen solution 3 in 2-D.

Operating principle of chosen solution

The compressor supplies atmospheric air into the first absorption tank containing Erythorbic acid, when the first cylinder is filled up with air,the pressure in the tank forces air into the second tank containing Erythorbic acid as well. The gateway valve on top of the last tank (unseen on the diagrams) will be closed when the compressor is pumping air so that maximum pressure rises inside the two tanks and increase the rate of absorption. For 120 seconds the gateway valve will be closed and after that holding period the gases are flushed into the storage facility (mainly N_2).

The storage facility willin the form of a metal box has an air tight environment; the door is air tight so as to prevent the entrance and exit of gases. The thermocouple on top of the storage containerdetects the temperature inside the storage and decode the measurement onto the LCD display. The fan run automatically when the door is opened, so as to drive away any possible gases that might have gained entrance into the storage container. The fan maintains the optimum temperatures inside the storage and control the internal humidity. In between the walls of the storage container, there is a foam rubber which maintain the optimum temperature inside the box when water is allowed to flow on the foam rubber through the coolant inlet funnel. Ethylene absorbers/adsorbers (activated carbon impregnated with potassium permanganate) adsorbs the produced ethylene gas by the fruits. All adsorbers or absorbers will be placed in sachets/bags and their position is shown on the diagram.

Cost analysis of chosen solution

Table.2:Bill of materials

Item	Quantity	Cost(US$)
Compressor	1	20
Thermocouple	1	80
PVC tube	1m	2
Fan	1	10
Galvanized hollow steel	0.5m	10
Galvanized sheets	1m×1m×5	50
Gateway valves	1	4
12V car battery	1	30
Foam rubber	1m×1m×7	6
Electrical cables	1m	3
Silicon adhesive	3tubes	12
Steel flat bars	2m×4	20
Mesh wire	600mm×600mm×4	20
Erythorbic acid	500g	100
Activated carbon	500g	10
$Ca(OH)_2$	500g	15
$KMnO_4$	500g	10
Teabags	50	4
Miscellaneous		30
Total		**430**

A total amount of almost $430 was used for the fabrication of the CAS prototype. For the said functionality of the machine, the amount cannot be referred to as high considering the benefits it offers to fresh fruits producers.

Cost benefit analysis

In its simple form, cost-benefit analysis is carried out using only financial costs and financial benefits of the CAS machine design. Costs are either one-off, or may be ongoing. Benefits are most often received over time. As its name suggests, to use the technique simply add up the value of the benefits of offered CAS, and subtract the costs associated with it.

The target market for a start will be the 80 farmers from Honde Valley.

Costs:

Production costs-(80 units of CAS × 2 phases in a year)
(80 × 430 × 2) = 68800
Labour costs - (4 workers needed each paid 250/month)
(4 × 250 ×12) = 12000
Overhead costs
Insurance – (100 per month) = 1200
Rent - (200 per month) = 2400
Others - (200 per month) = 2400
Total costs per year 86800

Benefits:

Elimination of 40% postharvest losses per each phase
(40% × approximately 800 tonnes produced per phase ×2 phases)
(40% × 235000 ×2)
188000 per year
Payback time = (total cost ÷ total benefit)
= (86800 ÷188000)
= (0.46) × 12months
= 6 months

The payback period is the time required for the amount invested in CAS machine design to be repaid by the net cash outflow generated by the asset. It is a simple way to evaluate the risk associated with a proposed project.Therefore the payback period is approximately 6 months and this indicate that the machine is worth investing in.

Cost per unit = (total costs ÷ total units)
(86800 ÷ 160) = 550

Calculations

- Volume of each absorbing tank (t_1) = 1.66litres
- Total volume is $t_1 + t_2$ =1.66 × 2 =3.32 litres

Assuming there is 78% N_2 in atmospheric air

- Volume of N_2 in $t_1 + t_2$ is given as:(78/100)(3.32) = 2.5896 litres
- Therefore each tank will contain **1.2948 litres** of N_2

Specific gravity of N_2 = 0.9669 kg

1 litre of N_2 = 0.9669 kg

2.5896 litres of N2 =? Kg

2.5896 × 0.9669 = 2.5kg

2.58966 litres of N_2 has a mass of 2.5kg

Number of moles of N_2 = (mass ÷ Mr)

(2500 ÷ 28) = 89.3 moles

Concentration = (number of moles ÷ volume)

(89.3 ÷ 2.5896) = 34.5 Molar

The two tanks will supply a concentration of **34.5 Molar** of N_2 inside the CAS.

Overview of detailed design in 3d view

Fig.6: Front and back view

Determination of CAS functionality

Gas permeable filter bags were used to package the adsorbents. In each bag, 5g of adsorbent material comprising 3g of activated carbon and 2g $KMnO_4$ was used. The bags were then placed inside the CAS to adsorb the produced ethylene by bananas. In addition, 2g packs of silica were placed in the CAS to adsorb the released moisture.

To ascertain effectiveness of the CAS, internal and external quality attributes of bananas i.e. SSC, total acidity, acid/sugar ratio and colour changes were evaluated to follow the ripening process. For the control, banana fruits were stored in a card box at room temperature whilst the other fruits were stored in CAS. Samples of fruit were drawn out from the stored batches on Day 0, 5, 10, 15, 20, 25 and 30.

The samples were separately measured for their colour changes first on the days listed above. One banana from each sample was peeled and blended separately in a blender with 10ml of distilled water added. A drop of the solution was drooped onto the viscometer to measure its SSC. The SSC measurements were done on day 0, 5, 10, 15, 20 and 30 for each sample. For % acidity peeled banana with 10ml distilled water were blended in a blender. 10ml from the solution were drawn and discharged into a beaker with 50ml distilled water. Three drops of phenolphthalein were added to the solution in a beaker using a dropper. 0.1 M NaOH was then titrated into the solution, this was done for each sample on every 5^{th} day interval.

Soluble solids content SSC%

The %SSC was determined using a refractomer (HRN-16, KROSS) according to AOAC (2005).

Total acidity (%)

This was determined by titrating banana solution against 0.1 N Sodium Hydroxide (Standard) using phenolphthalein as indicator. Results were expressed as percentage of Malic acid in flesh pulp weight according to AOAC (2005).

Colour changes

Banana samples were drawn from the stored batches and compared against a standard Banana Colour Guide adopted from Dole Fresh Fruit Company (2004).

IV. RESULTS & DISCUSSION

The suitable conditions for maximum absorption of oxygen from compressed air using C6H8O6 in a closed system had to be experimented so as to come up with apposite operational conditions, and the table below shows the results obtained.

Table.5: Effect of concentration, pressure and holding time of C6H8O6 reacting with compressed air

Concentration of $C_6H_80_6$ inside the 2 cylinders	**Pressure inside cylinders**	**Holding reaction time inside tanks**	**Behaviour of gas(es) produced when exposed to:**		
Molarity	**Bars**	**Seconds**	**Blue litmus paper**	**Red litmus paper**	**Glowing match stick**
0.1M	200	60	Neutral	Neutral	rekindles

0.1M	200	120	Neutral	Neutral	rekindles
0.5M	200	60	Neutral	Neutral	Rekindles
0.5M	200	120	Neutral	Neutral	Extinguishes
0.5M	200	180	Neutral	Neutral	Extinguishes
0.5M	200	240	Neutral	Neutral	Extinguishes

Effect of concentration, pressure and holding time of $C_6H_8O_6$ reacting with compressed air - The effect of concentration, pressure inside tanks and holding time for $C_6H_8O_6$ to react inside absorbing tanks as shown on table 5 played a pivotal role on the absorption of oxygen from the compressed atmospheric air. At a concentration of 0.1 M $C_6H_8O_6$, with 200bars of pressure inside the tanks under a holding time of 60 seconds, the gases produced were neutral on both red and blue litmus paper. According to Webley (2003), N_2 and O_2 are both neutral on litmus paper. This proved that the gas produced was a mixture of N_2 and O_2. Also the fact that the gases produced rekindled a glowing match stick proved that one of the gases was oxygen which is the unwanted gas because O_2 speeds up the production of ethylene in climacteric fruits during respiration. According to Beh (2003), if a glowing splint is exposed to oxygen gas it rekindles or relights. Changes in holding time, but not in concentration (0.1 M) did not show any change on the behaviour of produced gases as shown on table 5.

Changes on the behaviour of gases produced began to show up when the concentration of $C_6H_8O_6$ and holding time was increased to 0.5 M and 120 seconds respectively. Although the gases had no effect on litmus paper, they had an effect on the glowing match stick as it extinguished when it was exposed to the gases. This indicated that there was a very small oxygen concentration being released from the tanks or absorption of oxygen was well achievable in the tanks. As once demonstrated by Beh (2003), that in the presence of a glowing splint, N_2 gas will put out a lit splint. This showed that the gas being produced at 0.5 M concentration after a holding time of 120 seconds had no oxygen in it and according to the reaction of C6H806 with compressed air in a closed system the probable gas to escape is more of N_2 (78%) and a smaller composition of CO_2 (0.01%), oxygen is absorbed in the system. This gas (N_2) is very important because as stated by Kader, (2007) it is used in controlled and modified atmosphere fruits and vegetables storage and packaging to maintain the quality of fresh products by retarding oxygen-dependent ripening and decay processes.

Further increase on the holding time (180 to 240 seconds) at the same concentration (0.5M) did not show any change in effect on the behaviour of gas when exposed to litmus and glowing match stick. This is because $C_6H_8O_6$ had reached its optimum conditions which are pressure, holding time and concentration for it to further react and show some changes on the behaviour of the produced gas.

Concentration (0.5 M), pressure (200bars) and a holding time of 120 seconds are the critical parameters that lead to maximum absorption of oxygen by $C_6H_60_8$. According to Coulson (2001), for the effective absorption of gases using an air swing term filtering machine, the desired gas (in this case N_2) should obey the ideal gas law (p V= n RT), of which pressure, number of moles or concentration have shown to affect the absorption process.

The table below shows a summary of results obtained from day 0 to day 29 in both CAS and ATS. The colour of bananas in both CAS and ATS were also compared to the Standard Banana Colour Guide Chart (Appendix) on a 5th day interval as well. The average temperature in each storage was recorded as well and that in ATS was theoretically determined. All calculation on SSC, % Acidity and S/A ratio are shown on appendix

Table.6: External and internal quality attributes of bananas over a period of 29 days

PARAMETER	TIME													
	Day 0		Day 5		Day 10		Day 15		Day 20		Day 25		Day 29	
	ATS	CAS	ATS	CAS	ATS	CAS	ATS	CAS	ATS	CAS	ATS	CAS	ATS	CAS
Colour	G	G	G=Y	G	mYG	LG	YB	G=Y		mYG		YG		YB
%SSC	4	4	6	4	12	5.5	18	7		13		18		22
% acidity	0.23	0.23	0.19	0.23	0.15	0.21	0.13	0.20		0.19		0.18		0.18
S/A ratio	17:1	17:1	32:1	17:1	80:1	29:1	138:1	35:1		68:1		100:1		122:1
Temperature storage (°C)	ATS	16-17	ATS	15-16	ATS	16-17	ATS	17-18		16-17		15-16		16-17

Key:

- G-green, LG-light green, YG-yellow with green tips, G = Y-50% green & 50% yellow, mYG-more yellow than green, YB-yellow flecked with brown
- ATS – ambient temperature storage, CAS – controlled atmosphere storage
- %SSC - percentage soluble solid content or oBrix
- % Acidity - percentage acidity
- S/A ratio - sugar acid ratio

Graphical presentations of external and internal quality attributes of bananas over a period of 29 days

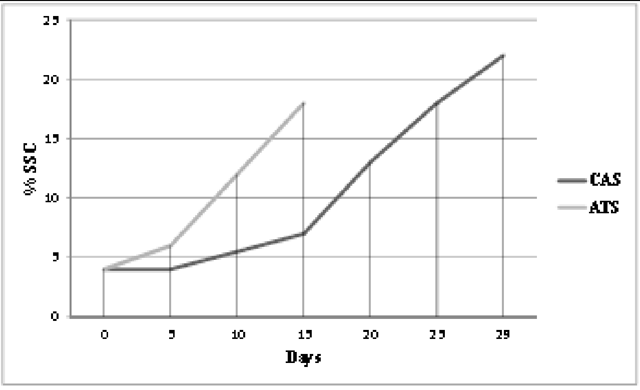

Fig.9: Soluble solid content of bananas during storage in CAS and ATS

Soluble solid content of bananas during storage in CAS and ATS -The graph shows that there was an increase in soluble solid content (SSC) of bananas stored in CAS and ATS during their ripening process. This is because during ripening, the starch of the banana is hydrolysed into sugar and so the SSC is increased. According to Marriott (1981), increase of SSC is an important trait of hydrolysis of starch into soluble sugars such as glucose, sucrose and fructose. Also starch reserves in fruit are an important factor in contributing to sugar contents in some ripe fruits .Upon ripening, there is a decrease in starch content present in unripe fruits from 20% to 23% to 1% to 2% in fully ripe fruits, with a concomitant increase in soluble sugars from less than 1% to 20% .

For the bananas that were stored in ATS, the increase in SSC was very rapid as from day 5 up to day 15.This was caused by a number of factors, to start with; temperature. Ambient temperatures range from 24 to 26 oC .These temperatures speed up metabolic processes found in bananas e.g. one of the metabolic processes is the conversion of starch into sugar [19].According to Anhwange(2009) ripening changes in fruit under ambient conditions are rapid, rendering fruits to a highly perishable state during transit and marketing.

Storage of bananas under these temperatures will automatically speed up their ripening process leading to a rapid increase in their SSC. Another factor leading to a rapid increase of SSC in ATS is the presence of oxygen inside the storage. According to Bunce (1994)[8] oxygen is responsible for aerobic respiration in bananas and starch is converted into glucose during respiration and this is why in ATS the rate of SSC increased daily. Thus, a decline in starch content is accompanied by an increase in soluble sugar content in the banana fruits.

An increase in activity of the enzyme amylase has been implicated in the degradation of starch to sugars and subsequent fruit-ripening in banana. Ripening is associated with change in composition i.e. conversion of starch to sugar [23].

Also the release of ethylene by the fruit itself in ATS accelerated the ripening and senescence processes, making the banana react very strongly to it (autocatalytic ripening). According to Berk (2009) ethylene is a phytohormone that controls or influences many aspects of plant growth and development including the conversion of starch to sugars. This why there was a rapid increase in from day 0 to day 15 in SSC, this also caused the bananas in ATS to have a short shelf life as compared to those in CAS.

For the bananas that were stored in CAS the increase in %SSC was not very rapid as compared to those in ATS especially at day 0 to day 5. The environment inside CAS enabled all this delay in increasing SSC percentage. A number of environmental parameters inside CAS affected this delay which are low temperatures (15 to 17 ^{0}C), presence of N2 or very low O2 concentrations, presence of ethylene absorbers.

The temperature range inside CAS was very low as compared to ATS, the water cooling system and the fan all played a pivotal role in maintaining the temperature ranges (15 to 17oC). Temperature is the most influential environmental factor because low temperatures (14-17 oC) suppresses most metabolic processes e.g. conversion of starch into soluble solids [23].

According to David (2004) [12] increasing temperature increases the rate of respiration, which is why the % SSC in ATS increased rapidly from the day 0. Also temperatures in CAS made the bananas to have a longer ripening life as compared to ATS as most of the metabolic processes were suppressed e.g. respiration.

The supply of gaseous nitrogen by flushing twice a day (throughout ripening process) in CAS helped maintain the quality of fresh bananas by retarding oxygen-dependent ripening processes. The conversion of starch into sugars occurred slowly in CAS as nitrogen inhibited the oxygen –dependent metabolic processes like respiration. Also nitrogen helped to prolong the ripening process of bananas in CAS by almost 14 days as respiration which leads to depletion of sugars, aging or senescence was inhibited. Yahia (1998) highlighted that the moment fruits and vegetables are harvested; an aging process kicks in until the complete decay of the products. Furthermore, chemical degradation of fruits caused by oxidation can be eliminated or stopped by flushing nitrogen on fruits.

The presence of ethylene absorbers (Activated carbon mixed $KMnO_4$) also helped to reduce the rate at which ripening occurred in CAS as they adsorb ethylene which is responsible for the ripening process of bananas. As stated by Kerry (2006) the ripening-related metabolic process accelerates the production of new ethylene-binding sites and ethylene released as a gas into the surrounding atmosphere. The released ethylene speed up the ripening and senescence processes, making the climacteric fruit react very strongly to it by a process known as autocatalytic ripening (Kerry 2006). The presence of silica gel in CAS facilitated in prevention of a media for microbial growth as it adsorbed moisture released by the bananas. The airtight environment inside CAS prevented the entrance of oxygen and exit of nitrogen as the door of CAS was very airtight, oxygen facilitates respiration, and respiration leads to depletion of sugars.

The percentage of soluble solid content of bananas stored in CAS was high enough (22%) than in ATS (18%) because in the post-harvest phase, respiration is supported by carbohydrate reserves of the produce; this leads to a net loss in its dry weight or negative growth. The more rapid the respiration rate was in ATS, the faster the bananas consumed their carbohydrate reserves, the greater was the heat produced and the shorter was the post-harvest life of the bananas in ATS.

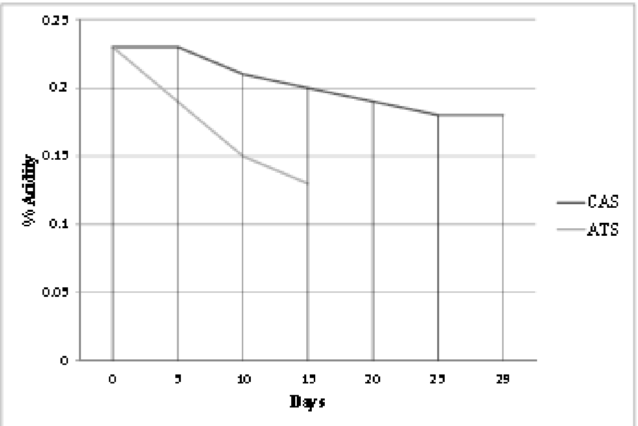

Fig.10: Acidity of bananas during storage in CAS and ATS

Acidity of bananas during storage in CAS and ATS - According to earlier reports indicated the presence of malic, citric, oxalic, and tartaric acids in the banana fruit, with malic acid being the principal acid [26]. The decrease in acidity during storage of bananas in both CAS and ATS may be attributed to the utilisation of organic acids in various biodegradable reactions. According to Dekock (2001) [15] there is little quantitative information available on the organic acids in bananas or on the changes which occur during ripening.

There was a very close relationship between colour and acidity of bananas. The greener the bananas were, the higher the acidity they were. The prevailing ethylene in ATS might have caused the rapid decrease in acidity of bananas, as ripening occurred. In ATS there was a rapid decrease in percentage acidity as shown on fig.12 from 0.23% on day 0 to 0.13% on day 15 and this was caused by the effect of temperature which speeded up the respiration process leading to the conversion of starch into sugars at a fast rate compared to CAS. The increase in sugars may lead to the decrease in acids this is well observed when eating a fully ripened banana, it taste sweeter than an un-fully ripened one. Ideally the sugars overcome the bitter taste from the acids found in bananas.

In CAS from day 0 to day 5 as shown on fig.12 there was a high constant acidity in bananas of 0.23% because there was no change in the colour of bananas, this shows that ripening process was still constant. The environmental conditions inside CAS delayed this ripening process. The conversion of starch into glucose by enzymes was inactivated from day 0 to 5.From day 5 to day 25, there was a slow decrease in % acidity as the ripening process was occurring slowly, the conversion of starch into sugars was occurring at a very slow rate, thus the decrease in % acidity was also very slow. Again there was another relationship observed that the higher the SSC the lower the % acidity. From day 25 to day 29 there was a constant value of percentage acidity this was maybe caused by the ending of the ripening process. Also the effect of the predominant yellow colour on the peel of bananas on day 25 and day 29 evidenced that the acidity level was the same.

At the end of the ripening process of ATS bananas, the % acidity was lower (0.13) than that of ATS (0.18%) this supports the benefits manipulated from CAS as stated by Thompson (1988) that there is smaller loss of acidity, sugars and that the nutritional and sensory quality is higher in CAS. Thus respiration rate which is determine by temperature of storage of fruit is an indicator of overall metabolic activity level, progression of ripening and potential storage life of the fruit i.e. a low respiration rate means that the energy reserves will take longer to be consumed and the fruit can be stored for longer [23] .

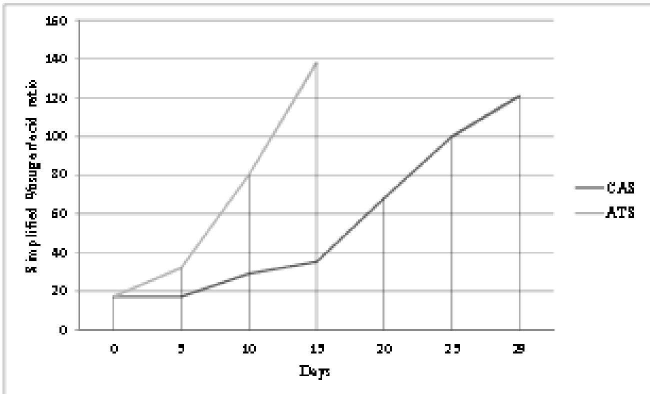

Fig.11: Sugar/acid ratio of bananas during storage in CAS and ATS

Sugar/acid ratio of bananas during storage in CAS and ATS-It is clear from figure 11that sugar/acid ratio of Williams's banana fruits increased gradually and significantly with increasing shelf life period reached the maximum values at end of ripening process period. During ripening of bananas the total soluble solids increase [23].

However sugar forms the main compound of soluble solids, since the amount of sugar in fruits usually increases as the fruit matures and ripens [11].

Usually organic acids decline during ripening as they are respired or converted to sugar (Will, 1989). Organic acids are important in giving a desired a desired sugar to acids balance which results in pleasing fruit taste during ripening.

The differences in the simplified ratio shows that ATS had the largest peak of 138 because the %SSC of ATS at day 15 was lower (18%) than that of CAS (22%) on day 29 the causes were explained on the changes in soluble solid content of bananas during storage in CAS and ATS above. Also the percentage acidity of bananas in ATS on day 15 was lower (0.13) than that of CAS (0.18) on day 29, the causes of it was also explained on changes in acidity of bananas during storage in CAS and ATS explained above.

The table below shows the results of changes in weight of filter bags containing adsorbers from day 0 to day 29 in CAS

Table.7: Initial and final weight of filter bags

DAY	INITIAL		FINAL	
	AC + $KMnO_4$	**Silica gel**	**AC + $KMnO_4$**	**Silica gel**
0 to 10	5g	2g	5.5g	2.3g
10 to 20	5g	2g	5.7g	2.3g
20 to 29	5g	2g	5.8g	2.2g

Effectiveness of the adsorbents on peel colour from day 0 to day 29 in CAS - The adsorbers contributed to the effectiveness of the CAS this was noted from the prolonged ripening process as compared to ATS. The used up adsorbers were replaced with new adsorbers for only three times in the whole ripening process. The changes in mass of adsorbers proved their functionality and adsorption power to their respective target gases. For instance the moisture released by bananas during slowed respiration was adsorbed by silica gel so as to prevent creating a medium for microbial growth in the primary package. The gain in mass of the filter bag containing silica gel from day 0 to day 10 (from 2g to 2.3g) was as a result of the adsorbed moisture. According to Kader (2002) the amount of silica gel to add in the sachet should be low to prevent death of fruit from complete loss of moisture, this is why only 2 grams of silica gel was used.

Activated carbon combined with KMnO4showed great adsorption characteristics for ethylene and hence can possibly delay ripening as this occurred in CAS.According to Adam (2011) [1] the increasing ethylene concentration triggers the increase in respiration rate (metabolic activity) and attendant biochemical and physiological transformations that occur during ripening.

According to Hassler (2003)[18] in the physical adsorption process, molecules are held by the carbon's surface by weak forces known as Van Der Waals Forces resulting from intermolecular attraction.

This is true because from day 0 to day 10, there was a slight colour change of bananas, they only changed from green to light green for 10 days without changing adsorbers. On day 10 adsorbers were changed, onwards up to day 20, ripening was delayed very well as it took 10 days for bananas to change from light green to more yellow than green. Green colour was maintained throughout the 10 days although its intensity reduced towards the 20th day giving rise to a more yellow than green colour of bananas. On day 20 adsorbers were changed, onwards up to day 29, ripening was delayed again as it took 9 days for bananas to change colour from more yellow than green to yellow flecked with brown which marked the end of the ripening process. To a greater extend the changes in mass of filter bag shows how much weight of ethylene was adsorbed and also other impurities. According to Austin (1999) [4] when gas impurities are brought into contact with adsorbent, it attracts and holds the impurities on its internal surfaces and external surfaces. Ethylene adsorbers facilitated in prolonging the ripening process of bananas in CAS as they prevented the autocatalytic reaction which leads to ripening and colour changes. In terms of peel colour development, it has also been observed that the breakdown of chlorophyll (responsible for the green colour) is also temperature dependent [1]. It can be seen that the parameters in controlled atmospheric environments i.e. temperature, gases, humidity, adsorbers do work hand in hand, in other words each parameter affects the other. The dark yellow colour at the advance stages of ripening are due to the completion of ripening processes [56].

A standard Banana Colour Guide Chart was used to compare these colour changes. The amalgamation of the two adsorbing organic substances proved to have a higher adsorbing capacity due to increased number of gas trapping sites. The change in colour of filter bag containing KMnO4 to brown showed the decline in adsorption power and a change would be needed. According to Kader (2002) [21] when $KMnO_4$ reacts by oxidizing ethylene to ethylene glycol, a visible colour change occurs, fresh $KMnO_4$ medium is purple in colour but, after reacting with ethylene, it turns brown. The colour change occurs first on the pellet's surface and eventually penetrates the core, indicating the reactive capacity is nearing exhaustion.

Inside the ATS, the temperature made chlorophyll degradation occur at a fast rate that is why within 5 days from day 0, the bananas had changed their colour from green to 50% green and 50% yellow. Temperature affected the whole ripening process by speeding up the metabolic processes including respiration and chlorophyll degradation [1]. Also the presence of oxygen facilitated in speeding up ripening process, all oxygen dependent reaction were enhanced including respiration as well [17]. This is why the ripening process of bananas in ATS ended up within 10 days only as compared to those bananas that were in CAS which took 29 days to complete the ripening process, making a difference of 14 days in the ripening process.

V. CONCLUSION & RECOMMENDATIONS

Conclusion

From the above discussed results, it can be seen that the CAS machine design had an appropriate environment to delay the ripening process of bananas. It played an integrated role in many of the biochemical changes occurring during ripening of such as SSC, acidity and colour of bananas. An additional of 14 days in the normal ripening process of bananas means a lot to a banana farmer or vendor because each day in the normal ripening process can lead to an increase in the 40% of postharvest losses.

Recommendations

To fully commercialize the design machine a direct power supply is required as an alternative source of energy to run the machine e.g. solar energy because the machine might be used in remote areas where electrical energy is not available. Also the fact that the machine is designed for the Food Industry, appropriate materials are needed during fabrication. For example, stainless steel shelves are better compared galvanized steel because stainless is not corrosive and does not react with the fruits even when moisture is released during respiration.

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