“PLANT DESIGN FOR THE PRODUCTION OF 1800 TONNES OF TOMATO PASTE PER DAY FROM FRESH TOMATOES”

*GROUP THREE - 2014 PLANT DESIGN (III) (CHE 522)*

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**EXECUTIVE SUMMARY**

This work is on the design of a processing plant for the conversion of raw tomatoes into tomato paste. The design specifies a production of 1800tonnes/day of tomato paste. The design project required assessment of necessary background for the project, relevance to local need, and motivation for the design. The process route as well as material and energy balance for the process was completed. Diagrams for the process such as the process flow diagram (PFD) and the piping and instrumentation diagram (P&ID) are drawn. Equipment selection, design, specification, sizing, and mechanical design of different unit operations involved in the process are developed. Estimations of capital investment and operating cost are made for the design. Plant location and layout of the project are considered. Finally, a safety analysis in the form of a hazard and operability study (HAZOP) was conducted on the designed plant. The result revealed there is justification for the plant as it would meet local needs. The process route for the plant was found to be feasible. The process route involved in the production of tomato paste involves washing, sorting, crushing, preheating, pulping, refining, homogenizing, evaporation, sterilization, and finishing. The equipment for the plant is available in the market. From material balance, it was obtained that the production of 1,800tonnes/day of tomato paste will require 8,256.9tonnes/day of raw tomatoes. A total capital investment of $21,656,977 (N4,331,395,400) is needed. Annual total production cost of the plant is $520,184,700 and the total annual income of the plant is $540,000,000. Annual net profit of $ 14,861,475 (N2,972,295,000) was realized. A one year six months pay back period and a rate of return of 68.6% were obtained. It is concluded that the plant has technical feasibility and economic viability. It was recommended that funds be made available for setting up of this plant. Also, more investment in raw tomato production should be made by farmers. Design of a three-in-one tomato processing plant (tomato paste, tomato powder, and lycopene) should be carried out. And reuse of heat generated within the process should be considered. The government should subsidize the production cost of cultivating raw tomatoes and the processing cost of tomato paste.

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**CHAPTER ONE**

**INTRODUCTION**

**1.1 Background**

Tomato paste is a thick paste made from ripened tomatoes with skin and seeds removed. Paste has a Brix of 25 – 36. (FAO, 2009)

Tomato (Lycopersicum esculentum) is a commercially important vegetable throughout the world both for the fresh fruit market and the processed food industries (Atherton and Rudich, 1986). Apart from its characteristic flavor and aroma, it is also a good source of vitamin C and significant sources of vitamin A and B (Robinson, 1976). It has about 20-25mg ascorbic acid per 100g (Dike and Atchey, 1986). The mineral content of tomato is high and varies from 0.3 to 0.6% (Gould, 1983). Tomatoes may be consumed fresh or processed to canned whole peeled tomatoes. It may also be processed to produce juice, concentrated tomato juice, puree or paste. In

tomato processing operations, tomatoes are first crushed and filtered to remove the seeds, skin and mucilage. The process results in the production of two products, tomato juice and waste. The waste mainly consisting of skin and seeds is called tomato pulp or pomace. The main processing steps in the production of a tomato paste include washing, sorting, trimming, breaking, juice extraction, concentration, pasteurization, filling and cooking. After washing and sorting, tomatoes are chopped and subjected to cold break or hot break. During juice extraction, the heated tomato pulp is passed through two extractors. The type of extractors (paddle or screw) and screen size of extractors affect the quality of the final product in particular its texture and consistency (Hayes et al., 1998). Tomato paste is strained tomatoes concentrated by evaporation with or without the addition of basil leaf, and contains not less than 24% salt free tomato solids (Luh and Kean., 1998). The characteristics quality factor of tomato paste depends on the quality of starting raw materials (variety and ripening stages) processing conditions (time, temperature and pressure), storage time and conditions (Farahnaky and Hill., 2007). Tomato paste contains both water soluble materials and insoluble components. The consistency of a tomato paste is mainly controlled by the amount of pectin, total soluble solids, and size distributions of insoluble constitute (Luh and Kean, 1998). The main quality parameters of tomato pastes perceived by the consumers are color, consistency and flavor, in addition there are compositional standards (Farahnaky and Hill, 2007).

**1.2 Design Task and Project Scope**

The objective of this project was to design a plant that processes fresh tomato feed into tomato paste. The design specifies a production of 1,800tonnes of tomatoes paste/day. The design project required assessment of necessary background for the project, relevance to local need, and motivation for the design. The process route as well as material and energy balance for the process was to be completed. Diagrams for the process such as the process flow diagram (PFD) and the piping and instrumentation diagram (P&ID) have also been drawn up. Equipment selection, design, specification, sizing, and mechanical design of different unit operations involved in the process were expected. Estimations of capital investment and operating cost were made for the design. Plant location and layout of the project were considered. Finally, a safety analysis in the form of a hazard and operability study (HAZOP) was conducted on the designed plant.

**1.3 List of Assumptions**

The following assumptions have been made in the completion of the design:

* A basis of 100kg/h feed flowrate was taken for the material balance which was later reverted to the original basis.
* Steady-state operating conditions were assumed for the equipment.
* Tomato is made up of 7%TS (Total Solids) and 93% Water (Maroulis and Saravacos, 2003)
* The final product (tomato paste) will be made up of 30% TS - FAO (2009) specified between 25 – 36% TS.
* The plant will operate continuously for 300 days annually while the remaining period will be used for clean up and general maintenance.
* Selling price of raw tomatoes is $105 per ton and that of tomato paste is $1,000 per ton.
* That there will be continous demand of the tomato paste all year round.
* Tonnes here in this work is taken to be metric tonnes except stated otherwise.
* 1 US dollars is equivalent to 200 Nigerian Naira (XE, 2015)

**1.4 Relevance to Local Needs**

In Nigeria, tomatoes are grown in large and commercial scales in the North but consumed equally across the length and breadth of the entire country. Tomatoes are either used fresh or processed into paste, puree, ketchup and powder. Unfortunately, they are not only seasonal but highly perishable and deteriorate few days after harvest, which dampens the farmer’s spirit to farming as he is forced to sell off produce at a loss, to avert imminent total wastage. For these reasons, processing of tomatoes into various products prove very vital. Canning of tomato paste has helped to curb this huge wastage, but the capital intensive nature of the industry had resulted into only a small percentage of the produce being absorbed by this industry. (Abdulmalik et.al, 2014)

Processing of tomato into paste and concomitant products is very important since these products can be kept for several months without spoilage; which will check glut and under-pricing, excessive price fluctuation and wastages. Essentially, this venture will not only be advantageous to the farmers, processors and balance of payment of the country, it will also help create the much needed jobs which have often proof elusive in many quarters. With the total investment estimate of a small scale processing centre being N7,540,000 with an estimate return of N 12,150,000 for a 6 (six) month’s production year, It shows that there is high return on investment in this enterprise and is worth giving a try. There is absolutely no doubt that private driven tomato processing in Kano and its environs will be a money spinner for investors because potential rewards are high as pointed out. (Adegbola, 2012)

Nigeria is a major consumer of tomato paste of which only between 20-30 percent is produced domestically; however, 25-50 percent of the input for this domestic paste is imported from China (CBN, 2011). This leaves the market for domestically produced tomato paste underserved. The country has a huge market for tomato paste; the size of the Nigerian market for tomato paste is about 200,000 tonnes per annum and this goes up if the West African market is included i.e. the size of the market rises to around 400,000 tonnes per annum. Consumers will buy more if the price is relatively low but may be willing to pay a higher price if product is of good quality. It is advisable for producers of tomato paste to control sale of the product when tomato is in season but rather intensify production. Potential markets for tomato paste includes:

* Hotels
* Restaurants
* Caterers
* Supermarkets
* School (Boarding houses)
* Market Wholesalers

It should be noted that marketing of the product should not be limited to one state or region as the demand for the product is nationwide. (Adegbola, 2012)

This project if executed will go a long way in creating employment to the teaming population of unemployed graduates. Will contribute immensely to the gross domestic product (GDP) of the country. CP Africa (2013) reported that government spends more than $360 million annually to import more than 300,000 metric tonnes of tomato paste from companies such as china’s Baoding Sanyuan Food Packing Company. This project will curb such wanton waste and the money re-injected to vitalize the nation’s economy. The product has the potential to be exported to other countries.

**CHAPTER TWO**

**SELECTION OF PROCESS ROUTE**

**2.1 Process Alternatives**

Necessary steps to undertake in production of processed tomato as described by Adegbola (2012) are outlined below:

**Selection of raw materials for processing:** Fresh, matured and uncontaminated tomatoes are used for processing. Especially without infected bruises, and must be of high quality (good species). All raw food and materials should be handled with care in order to avoid bruises and damages. Foods should be kept off the ground and protected from insects. Raw materials should be kept cool by storing them away from sunlight. Bruised but not infected tomatoes can also be processed but putting in mind that bruises encourage infestation

**Weighing:** Correct weighing of raw materials and ingredients is critical in processing. This step together with adequate mixing of ingredients has the most important effect on both quality of the product and uniformity of the batches of products.

**Sorting:** Crop is sorted by maturity and colour. Sorting should be done as early as possible by picking to remove any mouldy or rotten tomatoes.

**Cleaning:** Washing in clean portable water.

**Blanching:** known as pre-heat treatment before processing. In case of tomatoes for example, the tomatoes are put in boiled water for 5 minutes and thoroughly covered and removed from the water after the said time and cooled immediately by pouring cold water. This process helps to de- skin, de seed and to remove offensive odour.

**Pasteurization:** This is also known as post-heat treatment. Processed foods can be pasteurized in their bottles using hot water. It is important to note that the product and the water shall maintain the same temperature at all times, otherwise the bottles will burst. The filled bottles with their lids closed are placed in a larger pan of water with water heated to boiling point. This could be done for at least 45 minutes for tomato paste. The time of pasteurization varies from one product to another; Pasteurization is used to preserve acidic foods such as bottled fruit juice for several months. It preserves foods by destroying enzymes and microorganisms, but the mild heating causes few changes to the eating quality or, and nutritional value of food.

**Preservatives (chemical):**They prevent the growth of micro organisms and help preserve food. There are many types of chemical preservatives that are used in food processing. For example, sodium benzoate, sodium metabisulphite, sulphur dioxide, sodium chloride (common salt), citric acid etc. Sulphur dioxide is more effective against moulds or bacteria than yeasts and has the additional advantage of slowing down browning or darkening of some of some products. As a general rule, if a product is to be opened (i.e. if pasteurized) and used up at once, a chemical preservative should not be necessary. If a product is opened, part used and resealed, the use of a preservative can be considered.

Fenco (2014) gave a detailed description of the processing steps in production of tomato paste as outline in this subsection:

Fresh tomatoes arriving at the plant in trucks are unloaded into a collection channel (also known as flume), a stainless steel or cement duct into which a quantity of water 3 to 5 times higher than the amount of unloaded tomato is continuously pumped. For example, a 10 tons/hour rate requires at least 30m3/hour of water.

This water flow carries the tomatoes into the roller elevator, which then conveys them to the sorting station. The delivery trucks park-up alongside the flume and, while the trailers containing the tomatoes are being tilted towards it, an operator, using a special tube, pipes a vast quantity of water inside the truck, so that the tomatoes can flow out from the special 50 x 50cm opening. In this way the tomatoes and the water will be gradually feed into the flume without getting damaged.   
  
The tomatoes then arrive at the sorting station, after having been rinsed under a clean water spraying system (preferably drinking water). Here, the staff removes the green, damaged and excessively small tomatoes which are placed on a reject conveyor (or an auger) and then collected in a large box or directly inside a truck to be taken away. The tomatoes suitable for processing are transported to the chopping station (this may be a hammer mill or a special mono-pump provided with pre-feeding screw) where they are chopped. The pulp is pre-heated to 65-75°C for cold break processing or to 85-95°C for hot break processing. The main control panel on the evaporator regulates the pre-heating temperature.

The heated tomato pulp (fiber, juice, skin and seeds) is then conveyed via a special pump to an extraction unit composed of two operating stations: a pulper and a refiner, equipped with two sieves having different sized meshes. The first sieve processes solid pieces up to 1 mm, while the refiner processes solid pieces up to 0.6 mm, depending on the type of sieve fitted on the machine (the manufacturer can supply sieves with different sized holes if necessary). Two products therefore come out of the extraction unit: refined juice for concentration and waste. The average extractor yield varies according to different factors: the pulp’s temperature (a higher temperature will mean an increased juice yield), the variety of tomatoes treated, the type of sieve fitted, the rotation speed and the shape of the rotor on each dejuicing body unit. On average, however, the yield is about 95%. For example, if the extractor is fed with 100 kg of hot pulp, it will produce 95 kg of juice and 5 kg of waste. In addition, there is also a hypothetical product waste of about 1-3% from the grading stations. Therefore, 100 kg of tomatoes unloaded from the trucks will produce about 93-94 kg of juice to be concentrated. At this point the refined juice is collected in a large tank which constantly feeds the evaporator. This tank is equipped with maximum and minimum level indicators-adjusters which control the pump supplying juice to the evaporator.   
  
The juice in this storage tank is fed to the evaporator which automatically regulates juice intake and finished concentrate output; the operator only has to set the Brix value on the evaporator’s control panel; during normal working conditions, the evaporator does not require any further regulations. The juice inside the evaporator passes through different stages (also called effects) where its concentration level will gradually increase until the required density is obtained in the final stage or “finisher”. Here the tomato paste is automatically extracted via a pump controlled by\_an\_electronic\_refractometer.   
  
The entire concentration process (evaporation) takes place under vacuum conditions and at low temperatures, significantly below 100°C. Product circulation inside the various concentric tubular exchangers is carried out by special stainless steel pumps which are designed to ensure that the product is conveyed inside the exchanger tubes at a speed of over 1.2 m/sec to avoid “flash evaporation” thus avoiding to get burnt. This means it is possible to process for extensive periods without having to shut down the machine (record has it that FENCO evaporator installed at H.J.Heinz in Australia, using HB products, operated non-stop for 32 days without cleaning).   
  
Evaporator output is measured in liters of evaporated water per hour while concentrating tomato juice with an initial 5°Brix concentration and producing tomato paste double concentrate at 30° Brix. All the tomato juice evaporators are designed according to these parameters. The evaporative capacity of tomato juice concentrators is greatly influenced by the viscosity level. If the tomato paste has a low Bostwick value, then the concentrator’s output level will also be low; on the other hand, a higher Bostwick value means an increased output level. It is therefore fundamental to know if the productivity data supplied by a manufacturer refers to HB or CB finishedproducts.   
  
The concentrate is sent from the evaporator directly inside the aseptic system tank. From here it is pumped at high pressure inside the aseptic sterilizer-cooler and then to the aseptic filler, where it is filled into pre-sterilized aseptic bags housed in metal drums. The sterilization temperature and the holding time vary according to the product’s pH value. Generally speaking, a product with a pH value equal to or less than 4.2 could have a sterilization temperature of 115°C measured at the end of the holding section, and a holding time of at least 60-90 seconds. On the other hand, if the pH value is greater than 4.2, it is advisable to acidify the product in order to bring it to about 4.1, improving taste and final product quality, thanks also to the reduced sterilizing temperatures/time. The sterilized tomato paste is cooled down to about 35-38°C before being piped into pre-sterilized aluminum bags housed in special metal or plastic bins via a special aseptic filler. The packaged concentrate can be kept up to 24 months depending on its pH value and ambient conditions. When storing for over 12 months, it is however advisable to conserve it in refrigerated cells, more to reduce oxidization, which could cause darkening than to protect the product’s aseptic quality.

**2.2 Block Diagram for the Selected Process Route**

Having reviewed the different process alternatives for the production of tomato paste from fresh tomato, the selected process routes is described below. The selected route was arrived at by comparing alternative process routes. The justification for the selected route is that it possesses the capacity of further processing wastes obtained from the juice extractor to recover more juice. Also unlike existing routes which are most likely suited for small scale processing, the selected route handles large volume of tomato paste product.

*Fresh*

*Tomato*

*Tomato*

*Paste*

*Fresh*

*Water*

1

2

3

4

5

6

11

10

9

8

7

12

Figure 2.1 Block Diagram for Production of Tomato Paste from Raw Tomatoes

**LEGEND:**

1. Washing
2. Sorting
3. Crushing
4. Preheating (Hot Breaking)
5. Pulping
6. Refining
7. Homogenizing
8. Evaporation
9. Sterilization
10. Aseptic tank
11. Finishing
12. Product Storage

**2.3 Process Description of the Selected Process Route**

From figure 2.1, the process for the processing of tomatoes into tomato paste follows the following stages:

WASHING

The tomato is washed with clean water using about 3times by weight of tomatoes. Water is introduced as spray. The reception area comprises of unloading system which includes recirculation pump, staff platform, sludge and dirt discharge, and an air water bubbling system. (SSP, 2014).

SORTING

Automatic fruit sorting use either image processing, computer vision or machine learning. For tomatoes, factors considered are size and colour. This system involves the following process: Firstly, fruits are collected in a chamber. From the chamber they move through escalators safely where the weight of the fruits are estimated. It moves toward another chamber where the image of fruit is captured by more than one camera in different angles. For detecting fruit growth (raw or ripped), smell of the fruit is detected by sensors of wireless various algorithms network. Image is then processed where different algorithms are applied for finding expected feature like size, depth, 3D model, texture and colour. Based on the decision drawn after the process above, the fruit is classified into different categories like big, small, medium sized, ripe/unripe or defectives. Finally automatic packing system packs the fruit according to the categories provided. (Naik and Patel, 2003).

CRUSHING

Tomatoes are carried to a crushing unit, where they are processed into small pieces, resulting in a mixture composed of liquid and solid parts. Crushing system uses a mill containing a rotor that spins and crushes the tomatoes at high speeds. The resulting paste is pumpable and ready for thermal treatment. (SSP, 2014)

PREHEATING

In the preheating unit, the crushed tomatoes undergoes enzymatic inactivation. Hot break is recommended for high viscosity product. It inactivates completely the pectin enzymatic activity, increasing the consistency and viscosity of the mixture. Hot break temperature is between 85-95oC (Fenco, 2014).

PULPING

The crushed tomato is fed into an electrically driven mechanical pulper. This separates the juice from seeds and skins. The tomatoes are rubbed against a perforated drum by two brushes which are fixed to the central shaft driven directly by the motor. The juice passes through the perforated drum into the outer stationary drum and collected through an outlet. The remaining seeds and skins are pushed out through an outlet connected to the inner perforated drum. (Practical Action, 2015)

REFINING

At the refiner section, further juice is recovered from the seed and peels.

HOMOGENIZING

High pressure homogenization is an entirely mechanical process, the tomatoes products are forced through the homogenizing valve producing changes in the particle structures:

* Single cells production.
* Disaggregation of agglomerates.
* Reduction of oil globules size.
* Cutting effect on fibers, seed and others.

These mechanisms relate to the changes in the structure of an aqueous tomato dispersion caused by the application of mechanical energy.

The tomato pulp contributes many relatively special particles, which are insoluble in water and which must be reduced in size and uniformly dispersed throughout the product. If this is done, a product with an excessively rough texture will result. Further, since the carotene pigment is contained in these particles of pulp, failure to properly disperse them will result in a product with poor uniformity and depth of colour. (GEA, 2015)

EVAPORATION

This involves the removal of water from the juice and serves two main purposes:

* Improve microbiological stability with reduction of water activity, which is the predominant factor in most organic degradation processes;
* Reduce transportation, packaging, distribution and storage costs by minimizing volume and weight.

STERILIZATION

The sterilizer has 4 layers tubular structures, the inner two layers and the outside layer will go through with the hot water and the middle layer will be running with the product. The product will be heated by the hot water to the setting temperature and then hold the product under this temperature for few times to completely sterilize the product and then cool down the product by the cooling water or chilled water. The sterilizer consist of product tank, pump, heat exchange, holding tubes and control system.

ASEPTIC TANK

In aseptic process technology, product safety takes top priority. Food processors use sterile tanks as storage or buffer tanks. Aseptic storage prevents contamination of the product and helps to ensure a long shelf life and stability. Sterile tanks can perform a buffer function in the process upstream of the filling line (GEA, 2015)

PACKING, LABELING AND STORAGE

The product is the packaged, labeled all stored for sales.

**CHAPTER THREE**

**MATERIAL AND ENERGY BALANCES**

Raw tomatoes contain 7%TS (Total Solids) and 93% water. The tomato solids contain mainly of soluble carbohydrates, which are usually measured with a refractometer as ºBrix (% Sucrose), and converted to %TS with special tables (Maroulis and Saravacos, 2003). FAO (2009) opined that the preferred raw material for tomato paste processing is 5 – 6.5 °Brix.

Although, the ºBrix value refers to %Sucrose in aqueous solution, for preliminary calculations it can be assumed to be equivalent to %Total Solid (%TS), by weight. (Saravacos and Kostaropoulos, 2003)

**3.1 Material Balances**

Continuous operation is assumed (no accumulation)

Basis: 100kg/h of tomato feed

WASHER

w1

100kg/h

93% H2O x1 y1

7% TS x2

w2

The tomato feed is washed with 3 times by weight of water entering at stream w1 (Fenco, 2014)

Input = Output

x1 + w1 = w2 + y1

Where w1 = Input washing water

w2 = Output waste water

x1 = Input tomato into washer

y1 = Output tomato from the water

100 + 300 = 300 + y1

y1 = 100kg = x2

SORTER

x2 y2

x3

Culls

Assumption is that 5% of tomato is sorted as culls. (Saravacos and Kostaropoulos, 2003)

100 = y2 + (0.05) 100

y2 = 100 – 5

y2 = 95kg = x3

Material in = material out for both crusher and preheater

PULPER

x3 y3

z3

Where x3 = Crushed tomatoes

y3 = tomato juice

z3 = pomace = x4

Assuming 6.5% of the crushed tomato is pomace. (FAO, 2009)

95 = (0.065 x 95) + y3

y3 = 95 – 6.175

y3 = 88.82kg = z5

REFINER

X4 y4

z4

Where x3 = Pomace

y3 = Recovered juice

z3 = Ultimate solid waste

Tomato pomace and skins are high-moisture products (often more than 80% moisture) (Feedipedia, 2015)

x4 = 6.14kg

y4 = Amount of moisture in pomace x efficiency of the refiner

y4 = 0.8 x 6.175 x 0.95

y4 = 4.693kg = x5

HOMOGENIZER

x5

X5 y5

y5 = x5 + z5

y5 = 88.82 + 4.69

y5 = 93.51kg = x6

EVAPORATOR

z6  100% H2O

0%TS

93.5kg

x6 y6

93% H2O 70% H2O

7%TS 30%TS

y6 = tomato paste

z6 = water evaporated

Performing component balance

93.5 (0.93) = z6 + y6 (0.70) … (1)

93.5 (0.07) = 0 + y6 (0.30)… (2)

y6 = 93.5 x 0.07 = 21.8kg

0.3

This shows the plant requires a processing ratio of 4.6kg of raw tomatoes to give 1 kg of tomato paste. This gives a better processing ratio of 5 to 7kg of raw tomatoes to 1kg of tomato paste reported by FAO, 2009.

z6 = 93.5 – 21.8

z6 = 71.68kg

To determine the amount of tomato feed;

100kg tomato feed = 21.8kg tomato paste

Xkg tomato feed = 1800 x 1000kg tomato paste

100 = x

21.8 1800 x 1000

X = 100 x 1800 x 1000

21.8

X = 8,256,880.7kg/day (Raw tomato feed)

= 8,256.9 tons/day (Tomato feed)

Amount of tomato juice into the evaporator;

93.5kg tomato juice = 21.8kg tomato paste

X tomato juice = 1800 x 1000kg tomato paste

X tomato juice = 93.5 x 1800 x 1000

21.8

= 7,720,183.5kg tomato juice per day

= 321,674.3kg/hr

Mass flow rate of crushed tomatoes into preheater:

95kg = 21.8kg tomato paste

Xkg = 1800 x 1000kg tomato paste

X = 95 x 1800 x 1000

21.8

X = 3,727,800,000kg/day

Mass flow rate of tomato paste into sterilizer = 1,800,000kg/day

**3.2 Energy Balance**

The material flows obtained from material balances are utilized in energy balance calculations. For preliminary calculations of equipment sizing and process economics the heat balances are most important, and they can be estimated on the process block diagram. Calculation of heat balances around each processing unit requires thermo-physical data, particularly specific heats, enthalpies, and densities of the process streams. (Saravacos and Kostaropoulos, 2003).

In this work, energy balance is carried out on pre-heater, sterilizer and evaporator.

PREHEATER

Pre-heater in hot breaking raises the temperature of crushed tomatoes to about 920C. (Fenco, 2014)

Heat Duty = mass rate of substance x specific heat capacity of the substance x (Temperature out- temperature in)

Steam flowrate = Heat Duty

[specific Heat capacity of water x (Temp. in – Temp. out)

Specific heat capacity of tomatoes = 3.98kJ/kg0C (Engineering Toolbox, 2015).

Assumng input into the preheater is at ambient temperature of 300C and output at 920C.

Mass flowrate into the preheater is 3,727,800,000kg/day.

Heat Duty = 3,727,800,000x3.98x(92-30)

=9.20x10kJ

Assuming steam enters as saturated at 1100C and leaves at 1000C

Steam flowrate = 9.20x1011

4.2x10

= 2.19x1010Kg/day

STERILIZER

Assuming that it is required to raise the temperature of tomato paste to 850C and then cooled to 400C.

Heat Duty = 1,800,000x 3.98 (85-35)

= 358,200,000 kJ

Steam flowrate = 358,200,000

4.2 x 10

= 8,528,571.4Kg

For cooling

Assuming cooling water enters at 200C and leaves at 400C

Heat Duty = 1,800,000x 3.98 (85 -40)

= 322,380,000kJ

Cooling water flowrate = 322,380,000

4.2 x 20

= 3,837,857Kg

EVAPORATOR

Mass flowrate to evaporator = 7,721,000.00

Heat Duty of evaporation = 7,721,000 x 3.98 (110-45)

Q = 1,997,422,700J/day = 83,225,945.83J/hr

**CHAPTER FOUR**

**EQUIPMENT SELECTION AND DESIGN/SPECIFICATION/SIZING**

HOMOGENIZER

Type: High Pressure Homogenizer

Material of Construction: Stainless steel - SS316

The size of Homogenizer is determined by the volumetric flowrate.

Mass flowrate into Homogenizer = 7,721,009Kg/day

Volumetric flowrate = Mass flowrate

Density of tomatoes

Density of tomatoes = 1400Kg/m3 (www.answer.com)

Volumetric flowrate = 7,721,009

1400

= 5,515m3/day

= 5,515,000L/day

= 5,515,000

24

= 229,791.7L/hr

EVAPORATOR

Type: Triple Effect Evaporator

Material of Construction: SS316

The size of evaporator is determined by the area of heat transfer

Mass flowrate to evaporator = 7,721,000.00

Heat Duty of evaporation = 7,721,000 x 3.98 (110-45)

Q = 1,997,422,700J/day = 83,225,945.83J/hr

But Q = UxAxDelatT

Where U is the overall heat transfer coefficient

Assuming U = 6000J/(m2s0C)

Assuming temperature difference DeltaT = 650C

A = Q

UxDeltaT

= 83,225,945.83

6000 x 65

= 5,121.6m2

Table of Equipment Specification and Size

|  |  |  |  |
| --- | --- | --- | --- |
| **EQUIPMENT** | **RATED**  **THROUGHPUT** | **TYPE** | **MATERIAL OF CONSTRUCTION** |
| Homogenizer | 229,791.7L/h | High pressure | SS316 |
| Pulper + Refiner | 233,453.5L/h | Turbo operated | SS316 |
| Evaporator | 5,121.6m2/h | Triple Effect | SS316 |
| Storage Tank | 5,357L/h | Vertical-on-leg | SS316 |
| Washer | 344,036.70kg/hr | Spray type | CS |
| Sterilizer | 5,357L/h | Heat Sterilizer | SS316 |
| Crusher | 326,834kg/hr | Roll Crusher | CS |
| Preheater | 100m2/hr | Heat Exchange | CS |
| Sorter | 344,036kg/hr | Automatic | CS |

**MECHANICAL DESIGN**

Temperature and pressure are the two important factors that affect the mechanical design of evaporator systems. Many other factors like startup, shutdown, upset, dryout, external loading from supports, pulsating pressure, wind loading, earthquake load etc. also significantly affect the evaporator operation.

**Operating temperature and pressure:** The operating temperature is the temperature that is maintained for the specified operation of the metal vessel suitably selected during design. The operating pressure is the pressure at the top of a pressure vessel. However if it’s a tall vessel static hydraulic head even during mal-operation needs to be consider.

**Design temperature and pressure:** It is important to determine both minimum and maximum anticipated operating temperature and pressure in order to obtain the design temperature and pressure. The design pressure generally is the sum of the maximum allowable pressure and the static head of the fluid in the pressure vessel. The combination of temperature and pressure affect the mechanical design of the equipment. Much of design considerations are also related pressure design too.

**Maximum allowable working pressure:** The maximum allowable working pressure is the maximum pressure to which the equipment can be safely operated. Generally, it should not be less than the maximum anticipated operating pressure divided by a factor of 0.90

**Thermal expansion:** Differential thermal expansion between various parts of equipment has a significant effect on the mechanical design. There may be a significant difference of expansion between the shell and the tube side because of temperature difference of two fluids. Thermal expansion may also determine the way in which tubes are fixed to the tube sheet. Usually a suitable expansion joint is centrally placed between two segments of the shell when the differential expansion may be large.

**CHAPTER FIVE**

**PLANT LOCATION AND PLANT LAYOUT**

The location of plant can have a crucial effect on the profitability of project, and the scope for future expansion. Many factors must be considered when selecting a suitable site.

Katsina Ala Local Government Area is selected for siting of this plant. Katsina Ala is in Benue State of Nigeria. Benue is a state in the mid-belt region of Nigeria with a population of about 4,253,641 in 2006 census.. There are other ethnic groups including Igede, Etulo and Abakwa. Benue is a rich agricultural region, some of the crops grown there are potatoes, cassava, soyabean, etc. Benue state lies within lower river Benue trough. Its geographical coordinates are longtitude 70,471 and 10001 east. Latitude 60251 and 8081 North and shares boundaries with five other state namely: Nasarawa state to the North; Taraba state to the east; Cross River state to the south; Enugu state to the South-west and kogi state to the west. The state also shares a common boundary with the republic of Cameroon on South-east. (en.wikipedia.org).

The principal factors used consider Benue State a suitable location for the plant is as enumerated by Sinnott, 2005.

* **Marketing Area**

The states that bound Benue state form a good market for the sales of the tomato paste. Also Benue state sharing boundary with Republic of Cameroon makes it s good choice with respect to international marketing**.**

* **Raw Materials**

Benue state is one of the states that cultivate tomato in large quantity. Other states include Sokoto, Gombe, Tobe, Kano, Kaduna etc. (www.forafera.com ). The abundance of the raw material makes it suitable for siting the plant.

* **Transport**

The transport of materials and products to and from the plant is an overriding consideration in site selection. Benue state has good roads and waterways (River Benue as well as Katsina Ala River).

* **Availability of Labour**

Benue people are industrous. They have both skilled and unskilled manpower that will be useful in construction as well as operation of this plant.

* **Utilities (Services)**

Utilities will be readily available for the plant in form of cooling water from rivers, electricity and petroleum products.

* **Environment Impact, and Effect Disposal**

The waste produced from the plant will be adequately evaluated and managed. Benue state has good ecological characteristics that will provide effective sink to the treated waste produced by the plant.

* **Local Community Considerations**

The local communities in Benue state have the ability to provide adequate facilities for plant personnel: schools, banks, housing, recreational and cultural facilities.

* **Land**

Sufficient suitable land is available for the proposed plant and for future expansion. The lands are flat, well drained and have suitable load-bearing characteristics.

* **Climate**

The climatic condition in Benue state is adequate. The have a stable geological formation.

* **Political and Strategic Considerations**

There is political stability in Benue state. Benue state government supports agriculture and industrialization and will be willing to offer capital grants, tax concessions, and other inducements to direct this project.

**PLANT LAYOUT**

The economic construction and efficient operation of a process unit depends on how well the plant and equipment specified on the process flow-sheet is laid out. The principal factors considered in setting out the layout of this plant are:

1. Economic considerations: construction and operating cost.
2. The process requirements.
3. Convenience of operation.
4. Convenience of maintenance.
5. Safety
6. Future Expansion.
7. Modular construction

(Sinnott, 2005)

**CHAPTER SIX**

**ECONOMIC ANALYSIS**

The first stage in evaluating the profitability of a proposed new product is to compare the total cost of the product (for example, per tonne produced) with the current market price. It is also necessary to estimate future demand for the product, and to determine the trend in the selling price over several previous years. It is necessary to estimate the number of years that the product can be sold at a satisfactory profit, this is more useful than estimating the possible operating life of a plant! Backhurst and Harker in Ray and Johnston, 1989) make the following observation: ‘...it is suggested that a large chemical organisation will not invest in a new process unless it is possible to sell the product for less than half the current market price’.

**6.1 Cost Estimation**

The cost of major equipment was obtained using SuperPro Software Version 8.5. This was gotten by specifying the rated output for each equipment.

Historical cost method formular was used to scale up cost of equipment to capacity.

C2 = C1 (S2/S1)n

Where C2 = capital cost of the equipment with S2

C1 = Capital cost of the equipment with capacity S1

n = 0.6

The equipment cost is summarized on the table below:

|  |  |
| --- | --- |
| **Equipment** | **Purchasing Cost (dollars)** |
| Homogenizer | 510,580.00 |
| Pulper + refiner | 48,050.00 |
| Evaporator | 987,816.00 |
| Storage Tank | 28,000.00 |
| Washer | 30,000.00 |
| Sterilizer | 1,364,602.00 |
| Crusher | 881,988.00 |
| Preheater | 129,000.00 |
| Sorter | 531,200.00 |
| **Total** | **4,511,236.00** |

The fixed capital investment was calculated using Lang Method. Since tomato processing is a solid-fluid processing Lang Factor of 3.63 was used and a contingency factor of 15%.

Fixed capital investment = ($4,511,236) (3.63) (1.15)

= $18,832,154

Total capital investment = Fixed Capital Investment + working capital

Working capital = 10 – 20% of fixed capital investment

Total capital investment = 18,832,154 + [0.15 x 18,832,154)

= $21,656,977 (N4,331,395,400)

A total capital investment of $21,656,977 for a 1,800tonnes of tomato paste per day (540,000tonnes of tomato paste annually) gave is a good estimate. Bloomberg (2015) estimated a total capital investment of $25 million for a proposed 400,000tonnes of tomato paste annually to be sited in Nigeria.

Gross Earning = Total income – Total production cost

Total production cost = manufacturing cost + general expenses

But Manufacturing cost = Direct production cost + fixed charges + plant overhead costs

Total Production Cost: a quick way of determining Total Production Cost is to note that the Cost of Raw Material between 10 – 50% of Total Production Cost (Peters and Timmerhaus, 1991) Cateli, 2012 used 60 %.

**6.2 Profitability Analysis**

**Processing Margin:** A market survey carried out gave the following values for the cost raw tomatoes as well as tomato paste: raw tomatoes was $ 82.8 while tomato paste was $ 1,226.5 in 2009, $ 91.4 for raw tomatoes and $ 839.2 for tomato paste in 2012 (Catelli, 2012) Bloomberg, 2015 gave $ 350 for raw tomatoes and $ 1,500 for tomato paste. Adegbola, 2012 gave $ 90.7 for raw tomatoes and $ 2,205 for tomato paste.

From the foregoing, a processing margin of $ 105 for raw tomatoes and $ 1,000 for tomato paste is assumed for this work

From material balance, 8,256.9tons/day of raw tomato feed is required for plant. Using 300 days annual operating capacity;

Cost of raw materials = 105x8,256.9x300 = $260,092,350

Therefore, Total Production Cost = $260,092,350/0.5 = $520,184,700 (as raw tomatoes constitute 50% of the total production cost, so the total production cost is simply double the cost of raw materials)

Selling Price of Tomato Paste is $1,000 per ton

Total Income = Selling Price x annual production rate = 1,000x1,800x300 = $540,000,000

Gross earning = 540,000,000 – 520,184,700 = $ 19,815,300

Using tax of 25%

Net profit = $ 19,815,300x (1 – 0.25) = $ 14,861,475 (N2,972,295,000)

Pay Back Period (PBP) = Total investment / Net profit = $21,656,977/$ 14,861,475 = 1 year 4 months.

Rate of Return (ROR) = [Net profit/total capital investment] x 100% =

($ 14,861,475/$21,656,977) x 100 = 68.6%

**CHAPTER SEVEN**

**SAFETY**

Safety is critical in every industrial operation. Tomato processing being an example that requires engineered safety into the operation. Hazard (anything that could cause harm) can be encountered in tomato processing as a result of moving parts of equipment used to carry out various tasks, energy involved (in form of steam), noise, heat, vibration, fire, biological hazards (micro-organisms).

**7.1 HAZOP**

The methodology employed to guarantee safety in operation of this plant is HAZOP (Hazard and Operability Studies).

The technique Hazard and operability studies has been used and developed over approximately four decades for ‘identifying potential hazards and operability problems’ caused by ‘deviations from the design intent’ of both new and existing process plants. (Lihou, 2009).

The primary keyword, which reflect both the process design intent and operational aspects of the plant used are flow, pressure, temperature, level, separate, mix, reduce.

The secondary keywords, used in conjunction with primary keyboard are No, Less, More, Reverse, Also, other. (www.litroutech.com Accessed, 24/9/2009).

In this study, the approach employed is to route the plant equipment by equipment, line by line and the result recorded under: Deviation, Cause, Consequence, Action, Hazard. Key Equipment is spelt out for the HAZOP study.

**WASHER**

**Design intent:** To wash fresh fruits.

**Deviation:** Flow/No; Flow/Less

**Cause:** Blockage of water pipeline, supply valve or pump.

**Consequence:** The unwashed tomatoes would move to the next process unit resulting in an offspec product quality.

**Hazards:** Harm to consumers.

**Safegaurd:** Regular maintenance.

**Action:** Repair or replace bad equipment.

**CRUSHER**

**Design Intent:** To carry out size reduction of fresh tomatoes.

**Deviation:** Reduce/No; Reduce/Less

**Cause:** No or Low rotor speed due to poor power supply worn out blade.

**Consequence:** Tomato lumps will be sent forward.

**Hazards:** the poorly crushed tomatoes would damage pumps upstream of the process line.

**Safeguard:** Regular maintenance.

**Action:** Repair and Replacement.

**PREHEATER**

**Design Intent:** To raise temperature of the crushed tomatoes to 920C.

**Deviation:** Temperature/No; Temperature/Low; Temperature/High.

**Cause:** No steam supply or steam partially supplied. Steam flow rate could be excessively high.

**Consequence:** If no or low temperature, poor enzyme inactivationwould occur. If high temperature, the cost of the operation would escalate.

**Hazard:** Poor enzyme inactivation result in biological activities which would cause spoilage.

**Safeguard:** Install low and High Alarm.

**Action:** Confirm that steam line is supplying adequately**.**

**PULPER**

**Design Intent:** To separate the juice from seeds and skin.

**Deviation:** Separate/Also.

**Cause:** Worned mechanical parts of the pulper.

**Consequence:** The juice would contain imparities.

**Hazard:** High load on the homogenizer.

**Safeguard:** Regular Maintenance.

**Action:** Repair and replace.

**EVAPORATOR**

**Design Intent:** To lower the moisture content in tomato juice.

**Deviation:** Temperature/low; Temperature/High.

**Cause:** Same as preheater.

**Consequence:** Offspec product.

**Hazard:** Spoilage

**Safeguard:** Controllers should be installed at the evaporator..

**Action:** Repair and Replace.

**7.2 SHE POLICY**

For the operation of the plant, the following safety policy shall be observed by management and plant operation.

**Safety Policy**

It shall be the policy of the staff and management of this processing plant to ensure that operations are carried out in manners that would not pose threat to both the workers and everyone impacted by the operations. Accident prevention shall be the soul of the operation. Safety shall be first and always.

**Health Policy**

It shall be the policy of staff and management of this plant to ensure that occupational health and hygiene shall receive utmost importance. That care shall be taken to ensure that no health is impaired or aggravated in the course of the operation of this plant. Regular medical examination shall be conduct for early diagnosis.

**Environment Policy**

It shall be the policy of staff and management of this plant to be committed to safeguard both built and natural environment. Sustainable development shall form the main stay of the operation. Waste management and pollution control shall be given utmost concern. Environmental ethics shall be inculcated.

**7.3 SAFTEY PRACTICE**

Before any task is carried out in this plant, the following shall be in

place:

1. Job safety Analysis shall be conducted.
2. Tools box meeting
3. Adequate personal protective equipment shall be worn
4. Good house keeping shall be in place
5. All incidents shall be reported and investigated to prevent future reoccurrence.

**CHAPTER EIGHT**

**CONCLUSION ANS RECOMMENDATION**

**8.1 CONCLUSION**

The need to establish a tomato paste plant in Nigeria cannot be overemphasized. The plant promises to eliminate glut experienced by tomato producers in periods of increased supply. It also possesses the prospect of boosting the gross domestic products of the country. The design of the plant being carried out indicates that it is technically feasible to construct the plant because the equipment is available, the process route is feasible, and the process conditions attainable. It was also shown from HAZOP studies that the safety and operability concerns of the plant can be taken care of by proper engineering control, environmental control and personal protection. The economic analysis shows that the plant is highly profitable. With a high rate of return and short pay back period.

**8.2 RECOMMENDATION**

From the results obtained in this plant design exercise, it is recommended that investment should be made to set up this plant. More investment should be put into cultivation of raw tomato which will help to reduce the price of tomato raw material. Tomato plant should not be constructed for only tomato paste but a three in one plant (Tomato Paste, Tomato Powder, and Lycopene) should be designed and constructed – this will encourage the utilization of waste which will increase the annual income for the plant that make it possible for the plant to double its profit margin. A technology should be developed for the plant which will re-inject heat produced in the process to serve utility purposes thereby lowering the total production cost of the plant.

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