Design and Economic Evaluation of Tiger Nut Alcoholic Drink Manufacturing Plant

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Abstract

The boom in the demand for alcoholic beverages in Ghana has led to the manufacture and sale of these products from different feed stock, mainly parts of a plant or whole plant. However, the scientific, engineering and economic evaluation of the production of these alcoholic products is mostly overlooked. This work looks at the design and economic evaluation of a plant to manufacture 10,000ton/year tiger nut alcoholic beverage. Seven (7) main unit operations are involved in the production of tiger nut alcoholic drink, that is sorting, grinding, filtration, mixing, pasteurization, cooling and packaging. A total of 165kW of power is needed to efficiently run this plant. The profitability analysis carried out on the plant showed the following; a payback period of about four (4) months, a rate of return of over 100% with the total capital investment being the fixed and working capital for the first year. The cumulative cash flow depicted positive profit margin right from the first year where a value of $ 8,093,253 was recorded.

Keywords: ***alcoholic beverage; tiger nut, net plant value, profitability analysis, cummulative cash flow***

Introduction

Plant design is the selection and sequencing of units for desired physical and/or chemical transformation of materials (Sinnott and Towler, 2009). This involves the economic evaluation of the plant using economic indicators such as rate of return on investment, payback time, discounted cash flow etc. to ascertain the profitability and viability of the plant (Sinnott and Towler, 2012). Total fixed capital cost, total manufacturing cost and break-even points of the plant are used in determining the economic performance of the plant.

Cultivation of tiger nut started since the fourth millennium BC in Egypt, where it is used as food, medicine and perfumes (De-Vries, 1991) and for several centuries in Southern Europe. In recent times, it is often grown for its edible tubers (tiger nuts), especially in Spain for the production of a milky beverage called Horchata de chufa (Mosquera *et al*., 1996; Beneyto *et al*., 2000). That notwithstanding, it is considered a weed in many countries and so has not been put to much use (Sánchez-Zapata *et al*., 2012). Tiger nut (*Cyperus esculentus*) which is a tuber crop grown mainly for its use as food is cheap and readily available in Ghana. It is also used as medicine and fish bait, and it is taken either directly, by roasting or by using it to produce milk (Rita, 2009). Milk from tiger nut is a refreshing purely natural vegetable drink and or dessert, which is prepared with water, sugar and the tiger-nuts. It is a very nutritious, energy drink both for young and old (Rita, 2009). Tiger nuts possess such qualities such that having it in an alcoholic beverage preparation serves as energy drink rich in proteins providing some of the protein supplements of the body at an affordable price. The aphrodisiac benefits of tiger nut in these alcoholic beverages is also of much interest to consumers in Ghana. Howbeit, with all the attention given to tiger nut alcoholic beverage, no proper scientific and engineering documentation on the processing have been reported to the best of our knowledge. This work looks at the design and economic evaluation of tiger nut alcoholic drink manufacturing plant.

Seven (7) unit operations are involved in the manufacture of tiger nut alcoholic beverage. They are sorting, grinding, filtration, mixing, pasteurization, cooling and packaging. Appropriate type and size of equipment to be used at each stage of the production is determined by performing material and energy balances around each equipment and the whole plant. The plant is environmentally friendly as it has no known pollution related issues. Effluent and chaff from washer and filter respectively are taken to farms to fertilize the soil or can be discharged into sewer since there are no hazardous chemical present in it.

This plant design is to produce 10,000 ton/year tiger nut alcoholic beverage. The plant is to be sited at Aduamoa in the Kwahu South District of Ghana for the following reasons; availability of raw material and lower cost, quality of tiger nut, availability of labour amongst other factors.

Materials and Methods

Process Description

Fresh tiger nuts were purchased from local traders in Central market in Kumasi. Tiger nut of mass flow rate 210 kg/h is sorted and washed. It is grinded together with three parts of water in a hammer mill. The slurry is pumped at a rate of 0.84 m3/h to a filter press where it is filtered. The filtrate is pumped at a rate of 0.77 m3/h to a mixer where alcohol and additives are added. The chaff is collected and later disposed as animal feed. In the mixer, the ratios are 0.430, 0.395, 0.205 milk, alcohol and additives respectively. The resulting mixture (product) is pumped at 1.78 m3/h to a pasteurizer where it is pasteurized at 78oC for 15 seconds to kill the pathogenic microorganism *staphylococcus aureus*. It is then pumped to a cooler at the same rate and finally packaged. Figure 1 is the block flow diagram of the process.

Process flow and P & ID diagrams were designed using ChemCAD version 6.3.1.4168.

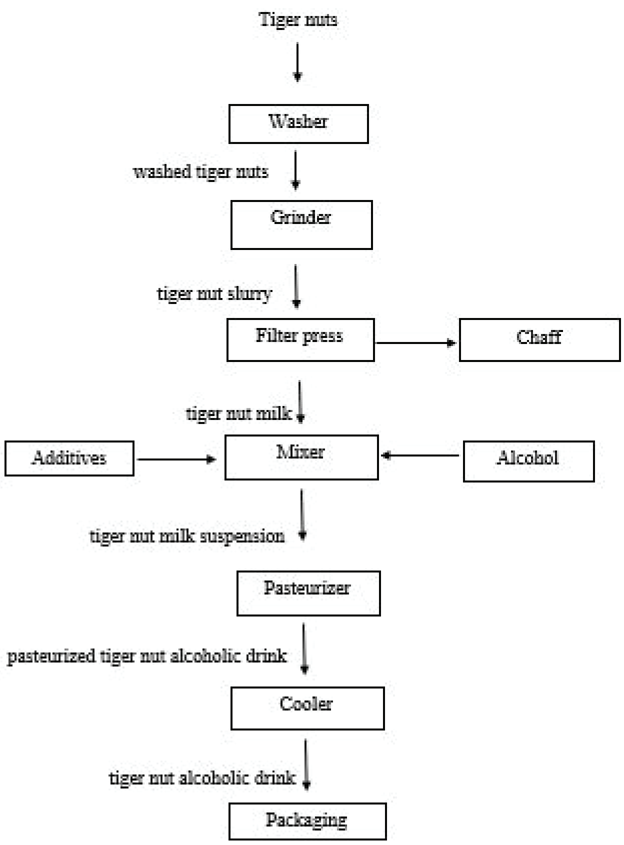

Figure 1. Block flow diagram for tiger nut alcoholic drink

Equipment selection, sizing and costing

Equipment were carefully selected for the plant. The major equipment considered are grinder (hammer mill), filter press, mixer, pasteurizer and cooler. The pasteurizer used is a double pipe pasteurizer and the cooler is a shell and tube heat exchanger. Material and energy balance were performed around major equipment to determine size and energy requirement. The detailed item estimate method (Timmerhaus, 1991) was used to evaluate the cost of the plant. The cost of equipment was obtained from quotations as given by Jincheng, China and used in calculations.

Plant cost evaluation

Rate of return on investment (ROR)

ROR was used as an economic indicator to assess the profitability of the plant. It is the expression of the yearly profit obtained from an investment to the total capital invested in a project either as a fraction or as a percentage (Sinnot, 2005). It is expressed mathematically as

$$ROR = \frac{Annual\ Cash\ Flow}{Total\ cost\ in\ the\ year} \times 100$$

Payback time

Mathematical and graphically methods were used to determine the payback time; the time required after the start of the plant to recoup the initial investment from the income. It was calculated as the reciprocal of the rate of return (Sinnot, 2005). Graphically, it is the point of interception between the cash flows curve and the time (in years, x-axis), which is also known as the break-even point.

Results and Discussions

Plant process and P & ID

The total installed capacity of the plant is 10,000ton/year. The major equipment on the plant are washer, hammer mill, filter press, mixer, pasteurizer and cooler. Approximately 210kg/hr of tiger nut is processed yielding about 1902kg/hr tiger nut alcohol drink (Fig. 1). At the washing step, 628kg/hr of water is used to wash off dirt and other unwanted foreign materials on the tiger nut. A hammer mill is use to grind tiger nut-water mixer into a slurry and pumped to a filter press for filtration where 52kg/hr chaff (waste) is removed from the mixture giving a milky product for further processing. 752kg/hr, 365kg/hr of alcohol and additives respectively are added to the tiger nut milk and mixed thoroughly. The product is pasteurized at 78oC and cooled in a shell and tube heat exchanger for packaging. Table 3 shows the energy consumption of the major equipment on the plant in terms of electric power. The total electric power used by the plant is 162kW, with the cooler consuming the highest, 82.5kW.

The piping and instrumentation diagram (Fig. 3) show the arrangement of pipelines on the plant and their inter connection with different equipment. Control loops are found around some critical equipment. Level controls are found on the slurry tank (E-3) and filter press (E-6) controlling the level of material going in and out. Temperature is controlled on the pasteurizer (E-11), maintaining a constant temperature for sterilization.

Equipment Sizing and specification

Table 2 and 3 show the summary of material and energy balance respectively around major equipment on the plant. The material balance calculations were used to determine the size of equipment and specifications.

Fiter press

The filter press used on the plant is the automatic plate shifting and cloth washing type with a membrane pore size of 20µ. The piston flowrate to membrane pump ratio (L/H) is 1.27 with a filteration cycle time of 5 minutes. The total capacity of the filter press is 12.2L and has a hydraulic volume of 8.24L (Table 4)

Pasteurizer

Table 5 shows the specifications of the pasteurizer. A heat load (Q) of 74.7kW is required with an overall heat transfer coefficient of 200 (W/m2.oC) and a thermal conductivity of 10 W/m2.oC. The transfer area (A) is 15.89m2 having an internal diameter (Di) and outer diameter (Do) 0.038m and 0.020m respectively. The pasteurizer is made of stainless steel and is a tubular type.

Mixer

Mixing of alcohol, tiger nut milk and additives takes place in a mixer, 2.7 m3 in volume. The height and diameter is 1.54m and 1.5m respectively. The mixer has 4 curved blades with impeller diameter 0.20m. The power of the mixer motor is 1.83kW(Table 6) .

Cooler

The shell and tube heat exchanger is used as the cooling device on the plant. Its heat tranfer area (A) is 9.3m2 having a total number of 88 tubes, each with an area of 0.122m2. The tube side heat transfer coefficient (hi) is 290.7 W/m2.oC and that of the shell side heat transfer coefficient is 1450.04 W/m2.oC. The overall heat transfer coefficient (U) is determined to be 174.8 W/m2.oC (Table 7).

Grinder

A grinder of the following specifications is used on the plant; power requirement (0.77kW), capacity (0.84m3), height (1m), diameter (1.034m), feed size (8mm) and product size (1mm) (Table 8)

Pumps

Pumps used on the plant are positive displacement pumps with 85% efficiency. Pump capacities range between 0.5 – 1.14m3/h and electric power consumption is from 0.3kW up to 0.65kW. All pumps are manufacture with stainless steel (Table 9).

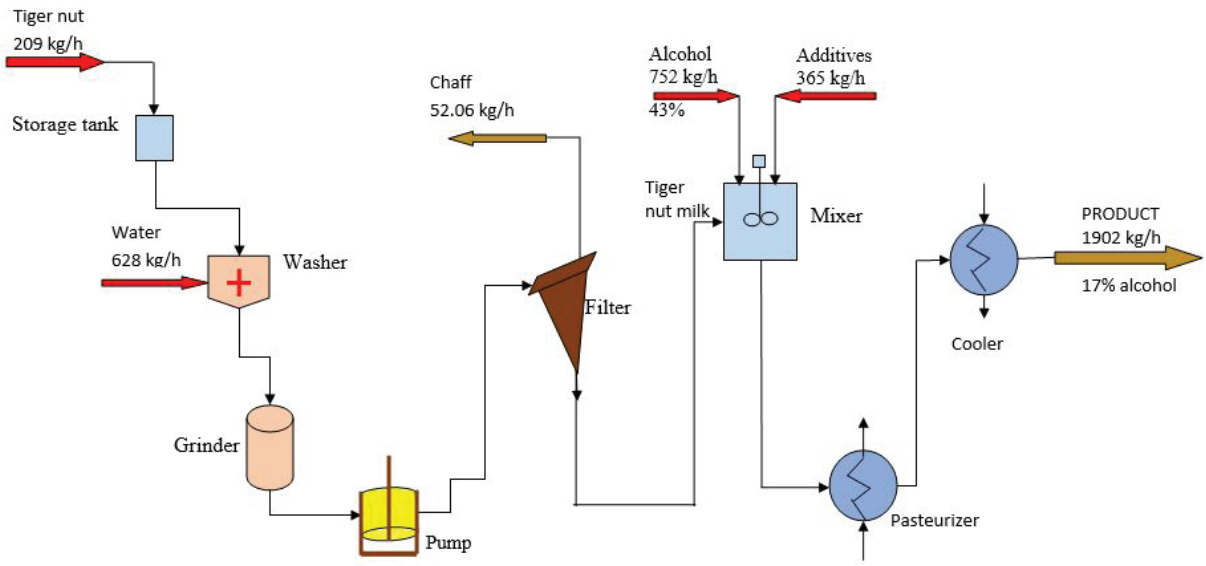

Figure 2: Process Flow Diagram for tiger nut alcoholic drink

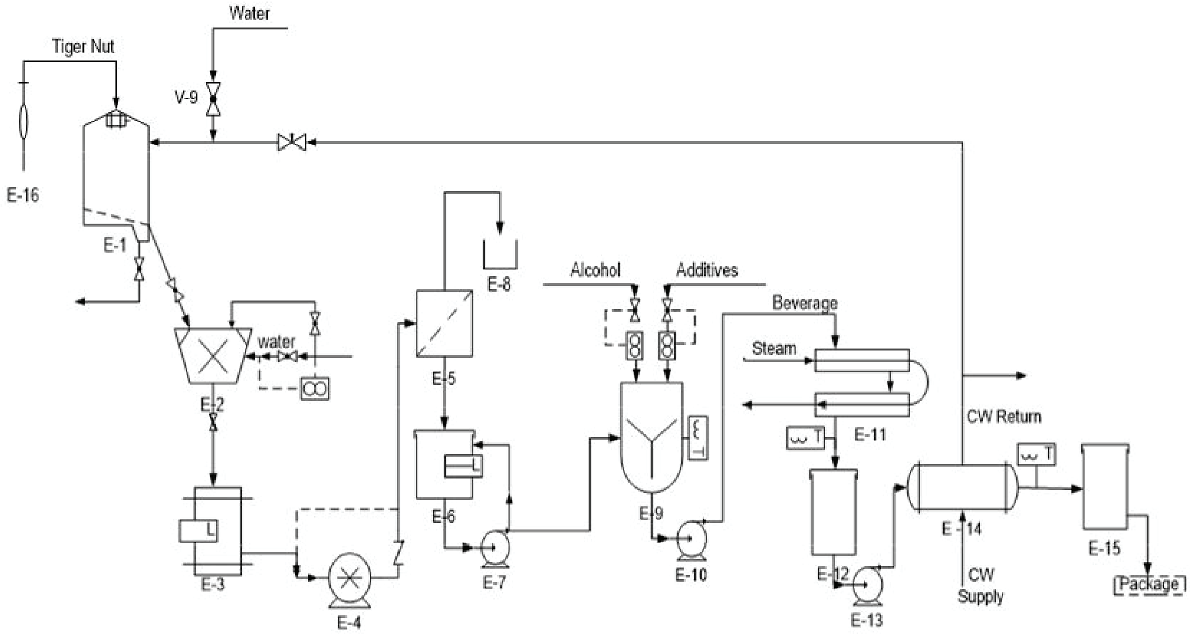

Figure 3: Piping and Instrumentation Diagram (P&ID) for tiger nut alcoholic drink plant

Table 1. Equipment list as shown in P & ID diagram

Displayed text	Description	Material of construction
E-1	Washer	Stainless steel
E-2	Grinder (Hammer mill)	Stainless steel
E-3	Slurry Tank	Stainless steel
E-4	Slurry Pump	Stainless steel
E-5	Filter Press	Stainless steel
E-6	Filtrate Tank	Stainless steel
E-7	Filtrate Pump	Stainless steel
E-8	Chaff Collector	Stainless steel
E-9	Mixer	Stainless steel
E-10	Beverage Pump to Pasteurizer	Stainless steel
E-11	Pasteurizer	Stainless steel
E-12	Pasteurization Holding Tank	Stainless steel
E-13	Pump to Cooler	Stainless steel
E-15	Storage Tank	Stainless steel
E-16	Hoist	Stainless steel

Table 2: Material Balance Summary (Basis: 1902 kg/h tiger nut alcoholic beverage)

EQUIPMENT		**MASS IN (kg/h)**	**MASS ACCUMMULATED (kg/h)**	**MASS OUT (kg/h)**
WASHER Tigernut		209.29	-	209.29
GRINDER	Tiger nut Water Total	209.29 627.88 837.17	-	837.17
FILTER PRESS	Filtrate Residue Total	837.17	-	785.11
				52.06
				837.17
MIXER	Alcohol Additives Milk Total	752.19 365.30 785.11 1902.6		1902.6
PASTEURIZER		1902.6	-	1902.6
COOLER		1902.6	-	1902.6

Table 3: Energy Balance Summary

EQUIPMENT	**POWER OUTPUT (kW)**	**EFFICENCY (%)**	**POWER INPUT (kW)**
Grinder	0.578	62.5	0.926
Pasteurizer			74.7
Mixer	1.82	80	2.28
Cooler			82.5
Slurry Pump (to filter)	0.234	85	0.275
Pump to mixer	0.219	85	0.257
Pump to Pasteurizer	0.528	85	0.621
Pump to cooler and filler	0.528	85	0.621
	TOTAL	**162.198**	

Table 4: Filter press specification

PARAMETR	SPECIFICATION
Volume of Filter (L)	12.2
Hydraulic volume (L)	8.24
Cycle duration (min)	5

Type	Automatic plate shifting Automatic cloth washing device
Membrane pore size (μ)	20
Initial flowrate of piston/membrane pump (L/h)	1.27

Table 5: Pasteurizer specification

PARAMETER	**SPECIFICATION**
Q (KW)	74.7
U ($W/m^2.^oC$)	200
A (m^2)	15.89
L (m)	134
l (m)	4.69
D_A (m)	0.070
D_i (m)	0.038
D_o (m)	0.020
ΔT (^oC)	23.5
K ($W/m^2\,^oC$)	10
X	0.002
Material	Stainless steel
Type	Tubular

Table 6: Mixer specification

Property	**Quantity**
Diameter (m)	1.5
Height (m)	1.54
Volume (m3)	2.7
Impeller Diameter (m)	0.20
Power required (kW)	1.82
Power of Motor (kW)	2.28
Blade Geometry	Curved
Number of blades	4

Table 7: Cooler specification

Design Parameters	**Value**
Heat transfer area, A	$9.3m^2$
Area of one tube, At	$0.122m^2$
Number of tube, Nt	78
Shell diameter, Ds	266mm
Tube cross-sectional area	$0.0001287m^2$
Cooling water linear velocity	0.15m/s

Tube side heat transfer coefficient, hi	290.7W/m^2 °C
Baffle spacing, Lb	0.068m
Tube pitch, Pt	20mm
Equivalent diameter, de	11.3608mm
Shell-side heat transfer coefficient, hs	1450.04 $m^{2\,o}C$
Overall heat transfer coefficient, U	174.8W/m^2 °C
Tube side pressure drop	1044.4Pa
Shell side pressure drop	4.438kPa

Table 8: Grinder specification

Design Parameters	**Value**
Power Requirement (kW)	0.770
Capacity (m^3)	0.84
Height (m)	1
Diameter (m)	1.034
Feed size, (mm)	8
Product size, (mm)	1

Table 9: Pump specification

List	**Type**	**Capacity (m^3/h)**	**Efficiency (%)**	**Power (kW)**	**Material of Construction**
Pump to Filter Press	Positive Displacement	0.53	85	0.3	Stainless Steel
Pump to Mixer	Positive Displacement	0.48	85	0.3	Stainless Steel
Pump to Pasteurizer	Positive Displacement	1.14	85	0.65	Stainless Steel
Pump through cooler to filler	Positive Displacement	1.14	85	0.65	Stainless Steel

Economic evaluation

Rate of return on investment (ROR)

With an initial capital of $ 449,339, working capital $ 79,295, plant life of 10 years and salvage value $ 14,000, the rate of return on investment for the plant is 153%. Sinnot and Towler (2012) report that, with a high ROR, a process plant is profitable. Having a ROR of more than 100% is an indication that the plant would be profitable and make the necessary economic gains.

Payback time

From figure 4, the payback time for the plant is about 4 months and the plant life is 10 years. The annual cash flow graph follows the standard cash flow for process plants as reported by Sinnot and Towler (2012), where there is an initial negative profit at begin of the plant life due to monies borrowed to purchase equipment and start up the plant. However, as the plant begins to manufacture products, revenue is generated from the sale of the products which gradually moves the graph from the negative regions into the positive gains. The cumulative cash flow depicted positive profit margin right from the first year where a value of $ 8,093,253 was recorded. That is after running 50% throughput the first year. 50% was selected since there was simulation and test running of the facility. After the first year, 80% throughput was made the reference with a progression rate of 3.5% over the years. Table 10 a, b and 11 gives a summary of the cost estimates used in determining the profitability of the plant.

Table 10a: Cost estimations of plant based on fixed capital investment

FIXED CAPITAL INVESTMENT	
Direct cost	
Description	Cost, $
Purchased Equipment	111,084
Purchased Equipment Installation	43,323
Instrumentation and Control	14,441
Piping	34,436
Electrical Equipment and Materials	11,108
Building Services	32,215
Yard Improvements	11,108
Service Facilities	61,096
Land	14,000
Total Direct Cost (TDC)	**332,811**
Indirect Cost	
Engineering and Supervision	33,325
Construction Expenses	33,281
Contractor's Fee	16,641
Contingencies	33,281
Total Indirect Cost (TIC)	**116,528**
Fixed Capital Investment (FCI)	**449,339**
Working Capital (WC)	**79,295**
TOTAL CAPITAL INVESTMENT (TCI)	**528,634**

Table 10b: Cost estimations of plant based on manufacturing cost

MANUFACTURING COST	
Direct Production Cost	
Description	Cost ($)
Raw material	2,785,880

Operating Labour	2,089,410
Supervision and clerical Labour (SCL)	313,412
Plant Maintenance and Repairs	40,440
Operating Supplies	6,066
Laboratory Charges	313,412
Utilities	2,089,410
Royalties	696,470
Total Direct Production Cost	8,334,500
Fixed Charges	
Depreciation	40440
Taxes	17,974
Insurance	4,494
Total Fixed Charges	62,908
Total Plant Overhead Cost	1,221,631
TOTAL MANUFACTURING COST	9,619,039
GENERAL EXPENSES	
Description	Cost ($)
Administrative Expenses	438,776
Distribution and Marketing Expenses	1392940
Research and Development	417882
TOTAL GENERAL EXPENSES	2,249,598
TOTAL PRODUCT COST	11,868,637

Table 11: Cash flow for tiger nut alcoholic drink plant for 10 years at different operational capacities

ITEM	YEAR					
	0	1 (50% capacity)	2 (80% capacity)	3 (82.4% capacity)	4 (85% capacity)	5 (87.6% capacity)
Total Capital Investment (I)	528,634	6,069,319				
Gross Annual Sales Forecast (A)	0	23,364,486	37,383,178	38,504,673	39,659,813	40,849,607
Total Product Cost (B)		5,799,318	12,106,010	12,348,130	12,595,093	12,846,994
Gross Profit (A-B-I)	-528,634	11,495,849	25,277,168	26,156,543	27,064,720	28,002,613
Depreciation (C)	0	0	40,440	80,880	121,320	161,760
Annual Taxable income (A-B-C)	0	11,495,849	25,236,728	26,075,663	26,943,400	27,840,853
Annual tax (D)	0	2,873,962	6,309,182	6,518,916	6,735,850	6,960,214
Annual Net Profit (A-B-C-D)	-528,634	8,621,887	18,927,546	19,556,747	20,207,550	20,718,879
Annual Cash flow (A-B-D)	-528,634	8,621,887	18,967,986	19,637,627	20,328,870	20,880,639
Cumulative Cash Flow	-528,634	8,093,253	27,061,239	46,698,866	67,027,736	87,908,375

ITEM	YEAR					
	6 (90.2%)	7 (93%)	8 (96%)	9 (96%)	10 (96%)	11 (96%)
Total Capital Investment						
Gross Annual Sales Forecast (A)	42,075,096	43,337,348	44,637,469	44,637,469	44,637,469	44,637,469
Total Product Cost (B)	13,103,935	13,366,014	13,633,333	13,906,000	14,184,120	14,467,802
Gross Profit (A-B)	28,971,161	29,971,334	31,004,136	30,731,469	30,453,349	30,169,667
Depreciation (C)	202,200	242,640	283,080	323,520	363,960	404,400
Annual Taxable income (A-B-C)	28,768,961	29,728,694	30,721,056	30,407,949	30,089,389	297,655,267
Annual tax (D)	7,192,240	7,432,174	7,680,264	7,601,987	7,522,348	7,441,317
Annual Net Profit (A-B-C-D)	21,576,721	22,296,520	22,757,712	22,805,962	22,567,041	22,323,950
Annual Cash flow (A-B-D)	21,778,921	22,539,160	23,040,792	23,129,482	22,931,001	22,728,350
Cumulative Cash Flow	109,687296	132,226,456	155,267,248	178,396,730	201,327,731	224,056,081

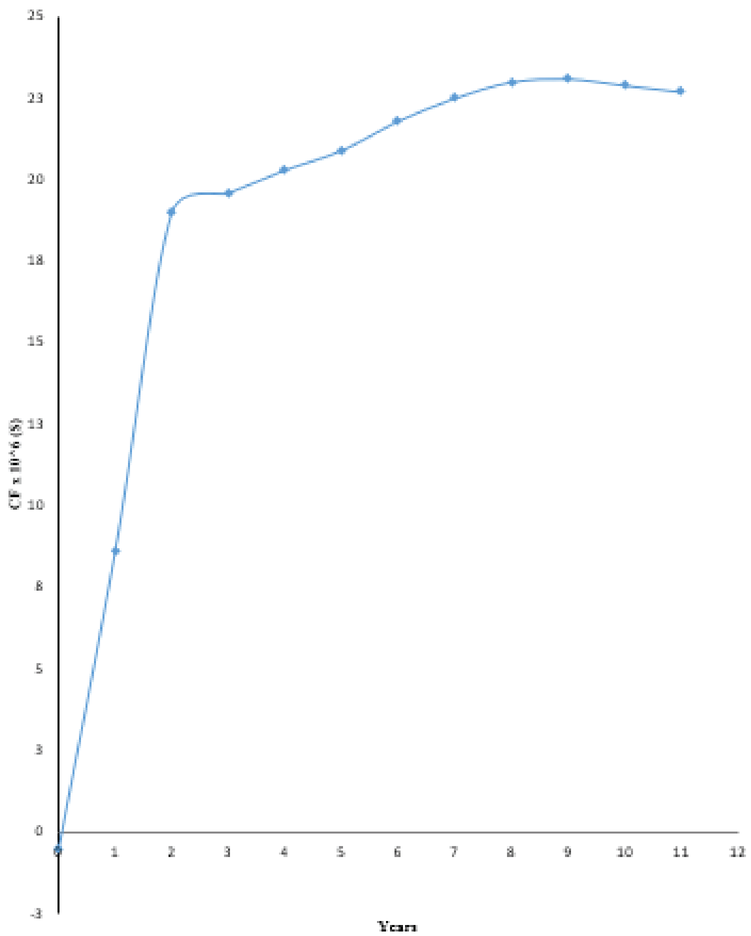

Figure 4: Annual cash flows graph for tiger nut alcoholic drink plant

Conclusion

With a payback time of about 4 months and a rate of return on investment of more than 100%, it is worth investing into a plant to produce tiger nut alcoholic beverage. Total power consumption for this plant is about 162kW, relatively low compared to other manufacturing processing plants. Furthermore, since the raw material for this plant is abundant in its growing areas, adding value to it through processing is much desired, considering the strong interest in consumers for tiger nut because of the aphrodisiac benefits. The plant is environmentally friendly, as it has no known pollution related issues.

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