An Optimization Model for Energy Saving Opportunities in Cashew Processing Industry

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Abstract
A study was conducted to investigate the energy conservation potential in cashew processing industries in Udupi. The objective was to conserve energy, reduce fuel cost and realize energy bill savings. The industries are categorized in to single owned, family owned, small scaled, medium scaled and large scaled industries. Five large scale industries are selected for carrying out study. One among them is chosen to prepare a generalized mathematical model to minimize operating cost subject to prevailing constraints. Optimization of mathematical model provides a savings in thermal energy to an extent of 14.28% and electricity to an extent of 52.9%. The conventional production cashew processing industries have energy conservation potential in the order of 30–48%.

Keywords
Cashew Nut, Energy Conservation, Electricity & Fuel saving, Optimization

I. Introduction

Cashew (Anacardium Occidentale L.) is an important tropical crop in India with 1.18 million metric tonne processed through 3650 process industries spread into many states of the country. These process industries use electricity, biomass and sunlight for their process heat requirements. India the world's largest producer, processor and exporter of cashew-kernels with an area of 8.54 lakh hectares under cashew plantation. The annual production is 6.2 lakh tonnes of raw cashew nut with an average productivity of 820 kg/hectare. India is world's second largest producer and exporter of cashew next only to Vietnam. It is the second largest consumer of cashew and also the biggest processor with highest acreage under the crop [1]. The current production in the country accounts for 18.68% of the global production. It is employing over 0.5 million people of which 95% are women [2]. Most Cashew industries use steaming with energy supplement by wood and electricity. The efforts to reduce demands include use of high efficiency equipments, improved technologies, conserving energy by proper load agement and substitution to existing fuels to reduce production costs. The main possibilities are efficient usage of fuel and electricity by optimizing the operations [3]. These changes, even though introduced with some constraints but can be well managed to ensure quality and productivity.

There is a wide disparity in energy consumption to produce the same quantity of similar products in cashew processing. This wide variation in energy intensity of these mills due to variety of the fuel, installed capacity, production and percent utilization of the capacity reveals the scope of energy conservation to be in the order of 30-48% [5]. These operations need to be studied for efficient end use efficiency. These operations need to be studied for efficient end use efficiency [6]. The main purpose of the energy use assessment is to judge energy use pattern, energy loss sources and excess energy use points.

Cashew nut shells found in a number of tropical countries are biomass wastes and as such they constitute a great potential of renewable source for energy production. Cashew nut shells are one type of the most abundant biomass tropical wastes, which can be used for energy generation. However, there is lack of data for thermal conversion process of cashew nut shells such as pyrolysis individual gas products, yields and reaction kinetics [7]. In Biomass energy technologies, pyrolysis is of key importance as this thermal degradation of solid fuels is present in both combustion and gasification. It has a key influence over the quality of char that is either gasified or burned. Biomass thermo chemical technologies are strongly influenced by the reactivity of char produced in pyrolysis phase [8]. The design of any technology conversion system for pyrolysis of materials needs to be fully characterized.

A limited number of studies have been reported in the literature on energy with cashew processing industries. For the last three decades, renewable energy has been the main focus in energy search of cleaner energy alternatives to support a suitable development and cleaner environment. Cashew nut industries provide options for using renewable energy sources for cleaner environment and energy conservation. The present works aims at preparing a mathematical model and optimizing the operations to show reduction in energy and operating costs. Optimization of process conditions is critical in development of an efficient and economic process. Optimization reduces usage of process heat energy and electricity above the maximum demand there by becoming cost effective tool to solution of industry related problems [9]. The mathematical model is prepared by collecting the data from a typical large scale cashew processing plant.

II. Proposed Mathematical Model

Udupi district has a total of 217 cashew nut processing industries. Out of this 42 are considered large scale industries with an output of 164,000 plus kg of cashew per day. This mathematical model is prepared for a large scale industry in which a detailed case study is carried out by the author.

The mathematical model for optimization of process heat and electric energy used in the industry is illustrated in terms of the decision variables, constraints, non-negativity constraints and the objective function. The details of these optimization parameters are indicated in present section

A. Decision Variables

Model has five decision variables based on the steam utilized by the Cooker & Borma and the electricity used by the Peeler, Vibrator & Filler machines as follows.

For Wood

X_{11} – kg of steam utilized by the Cooker

X_{12} - kg of steam utilized by the Borma

For Electricity

X_{21}- kW of electricity consumed by Peeler/hr

X_{22}- kW of electricity consumed by Vibrator/hr

X_{23}- kW of electricity consumed by Filler/hr

B. Constraints

1 Utility Constraints: This is required to maintain the appropriate

production of the steam in the Boiler for boiling raw cashew nuts in Cooker & drying shelled cashew nuts in Borma and to use electricity to run process equipments. The following equations (1) and (2) form utility constraints for using steam and electricity respectively. Their coefficients are calculated based on the data collected during the case study i.e., quantity of equipments and number of working hours from Table 1.

$aX_{11} + bX_{12} \geq c$ (1)

$dX_{21} + eX_{22} + fX_{23} \geq g$ (2)

2. Production Constraints

This is required to have a specified minimum output of the steam to have the specified final production. Here specified final production indicates the daily production of the industry where case study is carried out. Equations (3) and (4) form production constraints for minimum output of steam for Cooker and Borma respectively. The coefficients of the variables are based on the data collected during case study.

$aX_{11} \geq h$ (3)

$bX_{12} \geq i$ (4)

3. Non Negativity Constraints

All the decision variables are considered as non negative in order to show continual operation within the time zone considered for each machine, i.e., they are either equal to zero or greater than zero. Equation (5) forms a non negative constraint.

$X_{11}, X_{12}, X_{21}, X_{22}, X_{23} \geq 0$ (5)

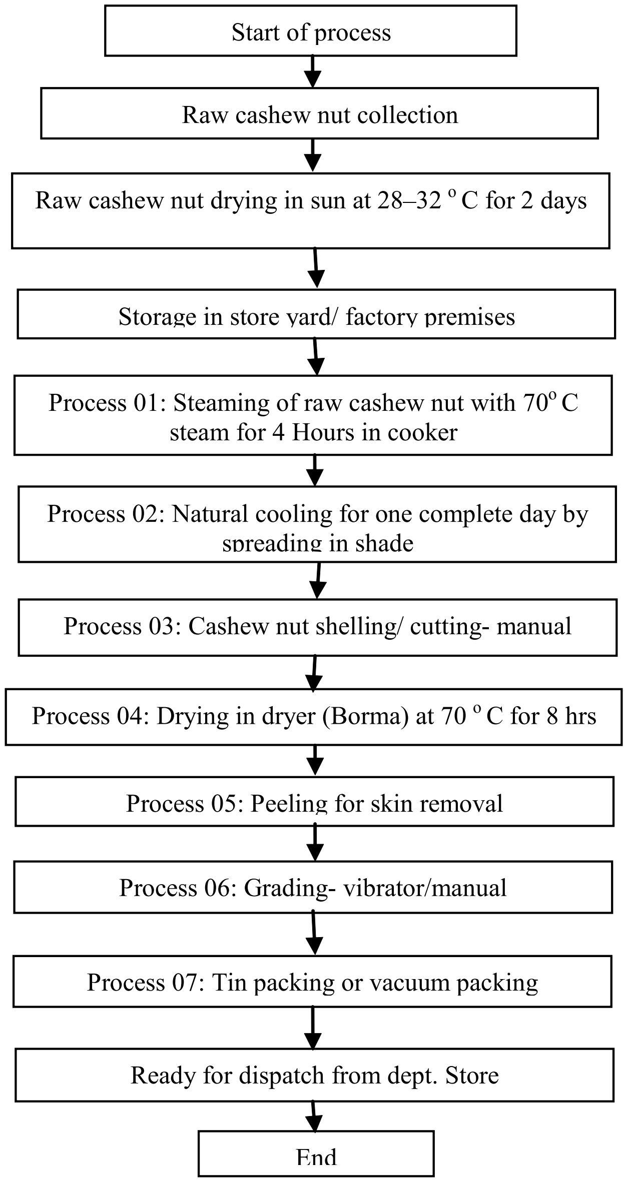
4. Objective Function

The objective function here is to minimize the fuel consumption to the boiler and electricity consumption to the consuming machines. If Z_1 is the cost of the production of steam per hour and Z_2 is the cost of utilization of 1 kW power per hour, then equation (6) below indicates the modeled objective function.

$\text{Min } Z = (X_{11} + X_{12}) Z_1 + (X_{21} + X_{22} + X_{23}) Z_2$ (6)

Where, Z is the total cost of fuel and electricity consumed per hour by the whole process. Here only three major electricity consuming machines are considered (Peeler, Vibrator and Filler). Others like lighting etc are not considered as their energy consumption is small.

Fig. 1- Process Chart for Cashew nut



III. Case Study

The raw cashew is moved to factories for processing after being thoroughly cleaned to free from all foreign matter before processing. Following are the four different processes adapted by the cashew processing industries by which the roasting is done to remove the hard outer shell.

A. Sun Drying

The raw cashew nuts are dried in sun for two days at temperature ranging from 28 to 32°C.

B. Drum Roasting

The nuts are heated at high temperature of nearly 100 – 120°C in a rotating drum and then shelled.

C. Oil Bath Roasting

Nuts get roasted in a bath and then shelled. Cashew shell liquid and also the cashew nut shell liquid (CNSL) is extracted as byproduct.

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D. Steaming

The modern cashew nut processing plants use steaming method for drying raw cashew nuts. It is another improved method adopted in present cashew processing. The nuts are steamed in cooker to make the shell soft and then cut open to get the kernel. The cooker is device where raw cashew nuts are stored and steam is passed for roasting.

Fig. 1 shows the cashew nut process chart of a typical industry. Initial preparations like collections of cashews from different sources, drying in sun for two days and storing in the store yard is seasonal and continuous activity. The processes 01 and 04 are thermal processes that use steam produced by the boiler for their operation. The process 02 is natural cooling of steamed cashews in shade. The process 03 is labor intensive manual process of removing the hard outer shell of cashew nut softened by steaming, by using mallets. The processes 05, 06 and 07 use electrical energy for their operation.

To illustrate the proposed model, a case study has been conducted on a typical cashew nut industry in Udupi, Karnataka, India. The fuel used for boiler is the wood logs that are locally available. The fuel consumption is about 300 kg/day for boiler operation of nine hours every day to produce an average of 5 kg/cm^2 steam. The removed nut shell of the cashew nut is also added to the boiler for burning which is not considered for calculations.

The steam supply for roasting/boiling a total of 4800 plus kg raw cashew nuts is 1.47 Bar for duration of 4 hours approximately and to two numbers Borma of (900+1500) kg each capacity is 2.94 Bar for duration of 8 hours for natural wholes i.e., shelled cashew nuts, every day. Boiler will run with minimum pressure till for an hour before the Borma stops operating. The other energy used is electrical energy for peeler, vibrator and filling machines. The connected load of the plant is 55 kW and contract demand is 70 kVA. Average daily electricity consumption is 480 kWh with specific energy consumption of 121.62 kWh/t. The power factor used is 0.83.

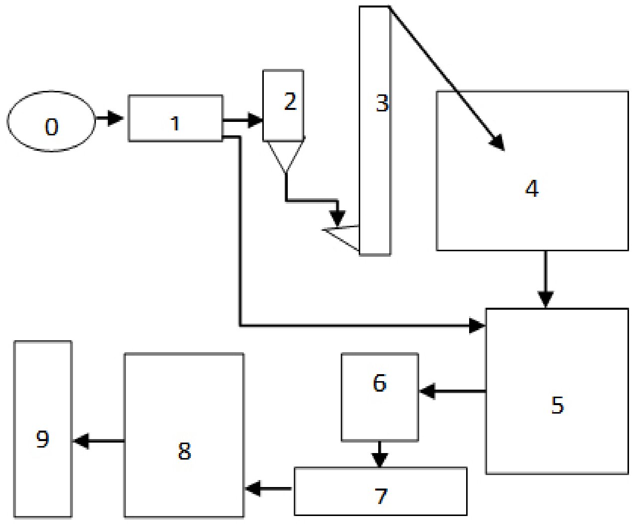
The plant has two production units A and B with a production (Borma) capacity of (1800+1500) 4800 kg of cashew nut with general shift only in a day. Filling process is carried out only in unit B. It is a large scale industry of its kind with a net output of 4500 kg approx. (65 bags x 75 kg). The normal working hours being morning 8 AM to 5.30 PM, works six day/ week basis. The heat is produced by burning wood and nut shell for generating steam or for producing hot air heat exchanger (occasional/seasonal) for drying of shelled cashew nut in Borma or in hot chamber.

The present machineries are working at lesser efficiency producing less production. Introduction of high efficiency machineries increase productivities and conserve energy. Irregular usage of production equipments and keeping on during unproductive hours also consumes energy.

A typical layout of a cashew nut plant is shown in the fig 2.

Well 0 supplies water to Boiler 1 for steam production and also for its top up time to time. The nuts are steamed in cooker 2 to make the outer hard shell soft and then cut open to get the kernel. The cooker is device where raw cashew nuts are stored and steam is passed for roasting. The roasted cashews are carried from the cooker by the bucket elevator 3. Bucket elevator is equipment that transports hot roasted cashew nuts. This can be bypassed by pouring the roasted cashew nuts directly to the yard 4 for cooling by gravity using dampers.

Fig. 2- Layout of a Typical Cashew Nut Plant



0-Well
1-Boiler
2-Cooker
3-Bucket Elevator
4-Nut Shell Removing
5-Borma
6-Peeling Machine
7- Vibrators
8- Grading Area
9- Packing

These are spread in the open yard for nut shell removing. The roasted /steamed raw nuts are opened by cutting manually using mallets and the nut shell is then removed to get kernels. The kernels are then kept in trays in a unit called Borma 5 which consists of chambers for drying. Drying is done by passing the steam produced by the boiler 1 for 8 hours. The dried kernels are sent to the peeling machines 6 where thin brown layer called testa is peeled off from kernel. The peeled kernels, in the edible form are then separated by size, shape and color in grading machine that consists of vibrators 7 for wholes and pieces. This is again either a manual or mechanized process depending on the type of the industry. The peeled kernels are spread in the separate yard (not shown) for manual separation in some industries. The wholes are then packed in tin or cartoons by packing or filler machine 9 for exports. Based on size, the pieces are packed in pouches or plastic bags for sale in local market and in tins for export.

Fig. 3 explains operating status of the equipments during the day. It gives the data of steam consumption by Cooker and Borma along with its operating and idle conditions. Cooker is operated for only four hours during a day while Borma is in operating condition for six hours a day.

The average steam consumed by cooker for steaming of raw cashew is 1.5 kg while for Borma it is nearly 3.5 kg.

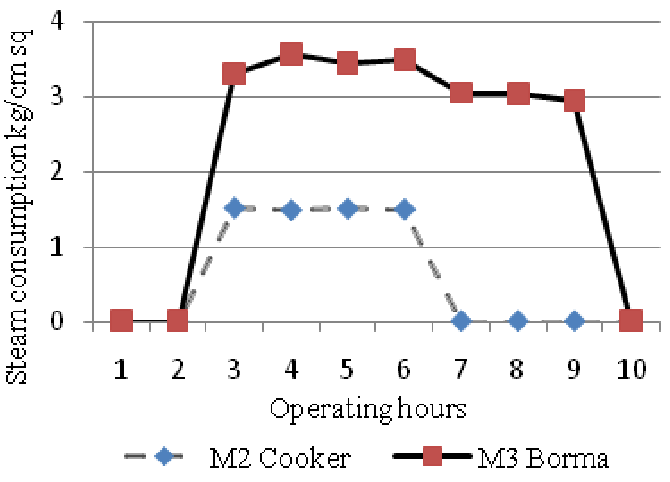


Fig.3-Equipment usage & operating status during the day

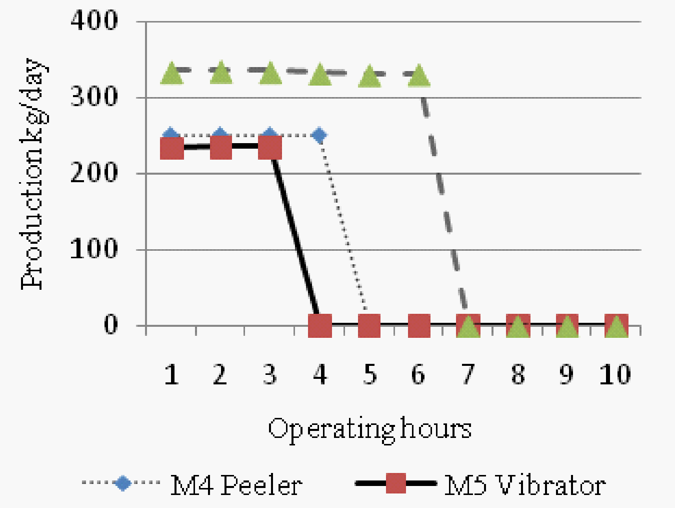


Fig.4-Equipment usage and operating status during the day

Fig. 4 explains operating status of the equipments during the day. It gives the data of electricity consumption by Peeler, Vibrator and Filler along with its operating and idle conditions. Peeler, Vibrator and Filling machines are in operating condition for four, three and six hours respectively showing 250, 235 and 350 kg per day of production.

The other data collected from the industry is mentioned in the Table 1 below. It gives the details of equipments used in cashew processing industry visited with their capacity, production rate working hours per day and the probable working time of the day.

The coefficients in equations (1), (2), (3) and (4) are calculated using Table 1. The value 'c' is average steam generated in the boiler. The value 'g' is calculated from the average daily energy consumption by three electricity consuming machines. The value 'h' is the average steam consumed by the cooker. The value 'i' is the average steam consumed by the Borma. Thus, the equations (1) and (2) with coefficients and values become

$16X_{11} + 14X_{12} \geq 4.3$ (7)

$36X_{21} + 3X_{22} + 6X_{23} \geq 480$ (8) and

The equations (3) and (4) with coefficients and values become

$16X_{11} \geq 1.5$ (9)

$14X_{12} \geq 2.8$ (10)

The equations (5), (6), (7), (8), (9) and (10) are subjected to optimization process using software.

IV. TORA – Optimization Software

The optimization of the above equations is done using optimization software 'TORA'. It is the Temporary-Ordered Routing Algorithm i.e. a mathematical set of instructions or programs. It is a mathematical (an Operations Research) software used by several industries worldwide for accurate solutions. It is menu-driven and Windows-based which makes it very user friendly. It can produce animated graphical linear programming solution. L-U decomposition is used in matrix inversion to guarantee computational accuracy. The TORA algorithm developed is based on formulating the mathematical model on Linear programming problem for the given objective function subjected to the specified five decision variables defining the four constraint equations.

Table 1: Equipments With Their Capacities and Production Rate of Cashew Nut Industry

M/c. No.	Equipment	Qt y	Capacity	Production Rate (approx)	Working hours per day	Probable time of Working.	
						Start	Stop
M1	Boiler	2	250-300 kg/hr	1500 kg/day	9	7 .30 AM	4.30 PM
M2	Cooker	4	300 kg	1200 kg/day	4	8.30 AM	12.30 PM
M3	Borma	2	(900+1500) kg.	3300 kg/day	7	9.30 AM	5.00 PM
M4	Peeling m/c	6	200-250 kg/ day	1500 kg/day	6	9.00 AM	3.00 PM
M5	Vibrator	1	200-250 kg/hr	700 kg/day	3	4.00 PM	7.00 PM
M6	Filling m/c	1	300-350 kg/h	2000 kg/day	6	12.00 PM	6.00 PM

The constraint equations along with the objective function are used to obtain the basic feasible solution. This initial basic feasible solution is iteratively solved to obtain the optimized values for the different system variables. The given optimization problem for obtaining economically feasible solution for the system variables was executed in TORA tool assuming a Linear Programming Problem and based on that the optimal solution was obtained for the process variables.

V. Results and Discussions

Using TORA software initially feasible solution was obtained for conventional energy consumption i.e., wood for burning in boiler for producing steam, and electricity for operating other machines. The investigation of the results indicates that there exists potential for energy saving by means of adopting the optimization tools. The operation of the system at optimal values of system variables is going to result in substantial savings in the fuel consumption as well as the electricity consumption. Optimization provides savings in thermal energy to an extent of 0.29 kg/hr and electrical energy to an extent of 13.33 kW/hr.

The Capacity, production rate and time of working utilized for the calculation purpose are as indicated in Table 1 that summarizes the operating schedule of six important process equipments used in processing of cashew nut namely boiler, cooker, Borma, Peeling Machine, Vibrator and Filling Machine. These machines are working at less efficiency. Higher efficient machines with energy efficiency increase the productivity as well as conserve the energy. The real time values as indicated in fig. 3 & 4 clearly reveal that in the time duration of 10 hours for processing the boiler is operational on a continuous basis while the other equipments have partial operating duration as indicated by '1' for the operating state and '0' for non-operating state of the machine. The percentage utilization of these six machines is respectively 90%, 40%, 40%, 60% 30% and 60% that are operating in a sequential manner. This clearly indicates that power utilization in the process can be optimized by following a strategy that ensures that the machines are in switched mode only during the time of their utilization. The continuous operation of the facilities throughout the 10 hours of operation can be easily generated through the energy calculations developed. This means by proper housekeeping energy conservation can be achieved. There is a vast scope for introducing renewable energy sources.

VI. Conclusion

The conclusions drawn from the study are based on the computational results and can be implemented on the actual shop floor for verifying the actual economic gain that can be attained through implementation of the energy interventions into processing of the cashew nut. The important observations of the study can be summarized as follows,

1. The immediate economic gain due to implementation of energy interventions is to the order of 10 to 20% through good housekeeping practices.
2. The economic gains can be enhanced through the second stage of interventions that include the implementation of technological interventions in terms of modifications in the processing technology by devising energy efficient devices and practices that would result in gain of the tune of 30-48%
3. The energy management practices are cost effective tools for conservation of energy components in the production activity and can have a positive impact on the overall organization structure.
4. Optimization of energy utility and production in the industry will provide the total cost of fuel and electricity consumed per hour by the whole process as Rs. 135000 per month.
5. There is vast scope for introducing renewable energy sources.

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