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RESEARCH ARTICLE

Optimization and production of bioethanol from cashew apple juice using *Saccharomyces cerevisiae* culture by solar energy

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ABSTRACT : Ethanol fuels unlike petroleum are renewable and can be produced from locally available cashew apple fruit juice (variety Vengurla-4) grown in the Konkan region of Maharashtra, India. The production and use of ethanol in the country has the potential to generate income in the rural areas by boosting the agricultural sector thus bringing social economic development and environmental benefits. The objective of this study was to show the ways ethanol production. Production of ethanol involves two processes fermentation and distillation. Raw fermented cashew apple juice after fermentation was used for ethanol production. Distillation process using concentrating solar cooker having the total distillation rate per day of the system was 2230 ml for first distillation with average distillation efficiency of the system as 33.41 per cent that increase the ethanol percentage up to 18.6 per cent from initial 12 per cent. After second distillation the value of ethanol concentration obtained was 35.5 per cent. Due to higher temperature, the water also evaporated along with ethanol. So it was not possible to get higher concentration of ethanol. Specific gravity and acid value of the 35.5 per cent ethanol were found to be 0.947 and 1.044 mg KOH/ g, respectively. These results indicate that cashew apple juice is a suitable substrate for yeast growth and the fermentation juice can be used for ethanol production.

KEY WORDS : Cashew apple juice, *Saccharomyces cerevisiae*, Fermentation, Distillation, Ethanol

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INTRODUCTION

Energy plays a crucial role in modern life. The main problem of the 21st century is the increasing demand of fossil fuels but the storage strata is limited. Now day's alternative fuel like ethanol has more demand in developed and developing countries for fulfillment of requirement for fuel. However, due to increasing petroleum shortage, production of ethanol from renewable resources has received considerable attention (Ames, 2001). Ethanol is a clean burning renewable source that can be produced from fermentation of glucose rich substrate (Yu and Zhang, 2004). In many part of the world demand for ethanol as an alternative fuel sources has steadily increased (Sheoran *et al.,*1996). Which helps the world to secure its future supply of energy by reducing its dependency on fossil fuels? Ethanol fuel is produced by fermenting and distilling biomass with high sugar content. Ethanol is a clear, colourless liquid with a characteristic agreeable odour. In dilute aqueous solution it has a somewhat sweet flavour, but in more concentrated solutions it has a burning taste. In India research and development efforts for using ethanol blended transport fuels started in 1980 (Linoj and Maithel, 2006). Nowadays, fermentation technology produces nearly 80 per cent ethanol as clean fuel and for which *Saccharomyces cerevisiae* is considered to be of most important yeast strain because of its biotechnological application in the field of fermentation technology (Sheoran and Jeffries, 1996). Ethanol produced by fermentation has been found to serve considerably as transportation fuel for cars, trucks and trains. In India, fuel

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ethanol could be blended in various proportions in petrol usually 5 to 10 per cent by volume. In Brazil, ethanol is added 24 per cent by volume in petrol.

India is currently the second largest fruit producer in the world after China (Costa *et al.*, 2009). Cashew is a traditional crop of Konkan region, mainly grown on hill slopes as rainfed perennial horticultural crop. Cashew (*Anacardium occidentale* L.) belongs to family Anacardiaceae. North Brazil is the origin of cashew. Cashew is produced in around 32 countries of the world, and the major cashew apple producing countries, based on the FAO, their production figures are, approximately, Vietnam, 8.4; Nigeria, 5; India, 4; Brazil, 1.6; and Indonesia, 1 million tons, respectively. In India cashew is grown mainly in Maharashtra, Goa, Karnataka and Keral along the west coast and Tamil Nadu, Andhra Pradesh, Orissa, West Bengal along the east cost (Hubballi, 2006).

The area under cashew in Konkan region of Maharashtra is about 1, 73,601 hectares with annual production of about 1.5 lakh metric tones (Haldankar *et al.*, 2007). The region is endeavored with the average solar energy availability of 450 –600 W/m^2 for 7 to 8 h in a day and 250 days in a year. Solar energy is the cheapest, inexhaustible and ample source of energy, which is a direct form of energy. Utilization of solar energy for thermal applications like distillation, cooking, heating and drying is well recognized in tropical and semi-tropical regions. Ethanol obtained using distillation process using concentrating solar cooker provides a solution for energy conservation in ethanol production.

EXPERIMENTAL PROCEDURE

Cashew apple fruit :

Cashew apple fruits of variety Vengurla-4 were used from available ones grown in the Konkan region of Maharashtra, India. The cashews were collected/harvested from cashew nut orchard of the Central Experiment Station, Wakawali (in the year 2009) of Konkan region, Maharashtra, India. Cashew apple appears as an alternative raw material for ethanol production, due to its vast availability and high concentration of reducing sugars (Pinheiro *et al.,* 2008).

Processing :

Cashew apple (*Anacardium occidentale* L.) fruits were picked at mature and ripe stages (Plate A). Cashew apple juice can be extracted by using basket press or mechanical juice extractor (Plate B and C). Cashew apple juice obtained from basket press had good quality as compared to mechanical juice extractor, therefore, juice obtained from basket press was used and the overlook of the extracted juice is shown in Plate D.

Plate A : Cashew apple fruits of variety Vengurla 4

Plate B : Basket press for extraction of cashew apple juice

Plate C: Mechanical juice extractor for extraction cashew apple juice

Plate D : Overlook of the extracted cashew apple juice

Physical properties of cashew apple :

Cashew apple variety Vengurla 4 was used for ethanol production from cashew apple juice. An average weight, length, diameter, volume of Vengurla 4 variety is reported in Table A. The cashew apple had an average length of 4.9 cm and diameter of 2.7 cm. The cashew apple was red in colour and it had an average volume 56.66 ml. The average juice recovery was 67.30 per cent.

Table A : Physical properties of cashew apple

Sr. No.	Physical property	Particulars
1.	Weight (g)	54.24
2.	Length (cm)	4.9
3.	Diameter (cm)	2.7
4.	Volume (ml)	56.66
5.	Colour	Red
6.	Juice recovery (%)	67.30

Chemical properties of cashew apple juice :

The data on chemical properties of cashew apple is reported in Table B. In cashew apple, TSS contained was 11.8 ^{0}Brix and the pH of apple was 4.4. The sugar and acidity was found to be 11.3 and 0.3 per cent, respectively. The chemical analysis of cashew apple revealed that the cashew apple is rich in sugars content. The acid sugar blend in the cashew apple was good and indicated that the apples could be successfully utilized for the production of alcohol.

Table B : Chemical properties of cashew apple

Sr. No.	Chemical property	Particulars
1.	Total soluble solid (^{0}Brix)	11.8
2.	pH	4.4
3.	Sugar (%)	11.3
4.	Acidity (%)	0.3

Microorganism :

A commercial strain of *Saccharomyces cerevisiae* was used for fermentation process (Pinheiro *et al*., 2008). For the fermentation the juice was supplemented with diammonium hydrogen phosphate (DAHP) as 1g/l and potassium metabisulphite (KMS) as 30 ppm. The juice was inoculated with pure culture of *Saccharomyces cerevisiae* var. ellipsoideus (NCIM-3315) as 0.30g/l.

Solar concentrating cooker :

Different types of concentrating cookers like flat absorber with flat reflectors, parabolic concentrator, compound parabolic concentrator, fresnel lens, cylindrical parabolic concentrator were used for various applications with lower temperatures to higher temperatures (Garge and Prakash, 2005). For this study the parabolic solar cooker (SK-14), which concentrated the incoming solar radiation at the focal point, was used as heat source for distillation of fermented cashew apple juice. The concentrating system followed the sun so that maximum sun rays were always focused on reflecting surface. A solar concentrating collector having aperture diameter of 1.4 m, depth 0.35 m and focal length of 0.30 m was used. The distillation of cashew apple juice was carried out on solar concentrating collector to get maximum concentration of ethanol.

EXPERIMENTAL FINDINGS AND ANALYSIS

The experimental findings of the present study have been discussed in the following sub heads :

Fermentation process for cashew apple juice :

The known volume of cashew apple juice was taken and the T.S.S. and pH content of cashew apple juice was adjusted to 24^0 Brix and 3.5, respectively by addition of sugar. The acidity was adjusted by addition of citric acid. The juice was supplemented with diammonium hydrogen phosphate (DAHP) as 1g/l and potassium metabisulphite (KMS) as 30 ppm. After adjusting T.S.S., pH and acidity, the measured volume of juice was taken in fermentation flask. The juice was inoculated with pure culture of *Saccharomyces cerevisiae* as 0.30g/l. The fermentation flask was incubated at 28 ± 2^0 C. The start of fermentation was indicated by evolution bubbles. The end of fermentation was indicated by cessation of foaming and bubbling. After fermentation assembly was dismantled.

First observation was taken after 24 h and then observations were continuously taken at alternate day till total soluble solid of juice was found to be constant. The fermentation was allowed to continue for 10 days at the end of which the total soluble solid was found to be 8.0^0 Brix. There was no further decrease in total soluble solid after 8 days of fermentation. Table 1 shows changes in TSS, pH and acidity in cashew apple juice during fermentation process.

Table 1 : Changes in total soluble solids TSS, pH and acidity in cashew apple juice during fermentation process

Sr. No.	Time (h)	TSS (^{0}Brix)	pH	Acidity
1.	0	24	3.50	0.6144
2.	24	18.4	3.47	0.7936
3.	72	12.2	3.53	0.9472
4.	120	8.8	3.63	0.6656
5.	168	8.6	3.65	0.704
6.	216	8.0	3.70	0.768
7.	264	8.0	3.68	0.793
8.	312	8.0	3.79	0.768
9.	360	8.0	3.66	0.704

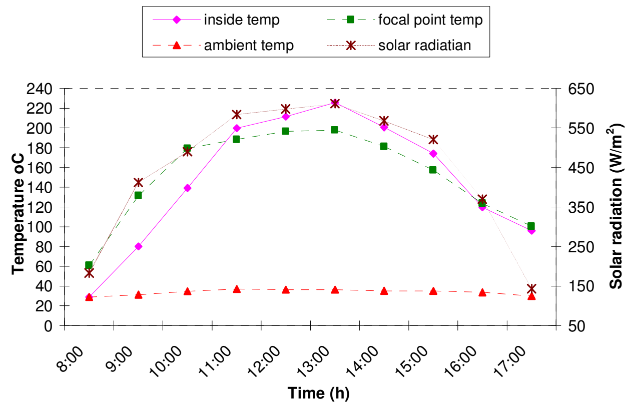

Fig. 1: Performance of parabolic solar concentrator for without juice in the container

Performance of solar concentrating collector for distillation of fermented cashew apple juice :

The parabolic solar cooker (SK-14), which concentrated the incoming solar radiation at the focal point, was used as heat source for distillation of fermented cashew apple juice. The angle of focus to attend the required temperature for distillation was fixed based on preliminary testing. The present study on distillation of cashew apple juice was carried out to get maximum concentration of ethanol which is shown in Plate 1.

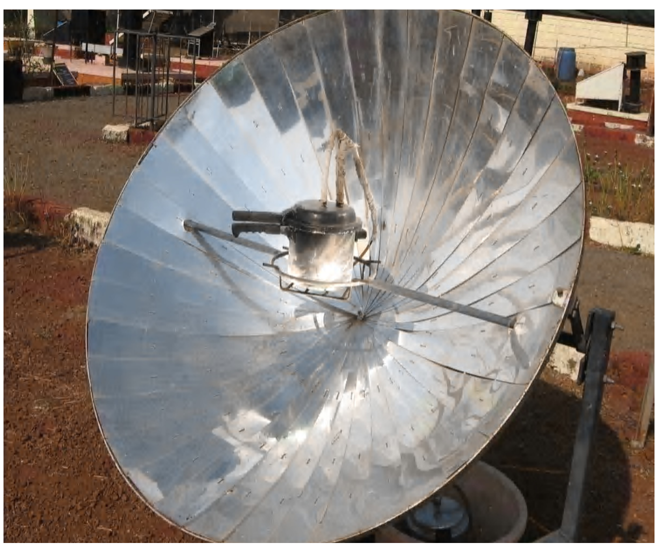

Plate 1 : Solar parabolic concentrator for distillation of ethanol

The performance of solar parabolic concentrator was firstly evaluated without load (*i.e.* without juice in the container). It was observed that the maximum temperature of the container has 225.7^{0}C reached at 13.00 h when solar radiation was 594 W/m^2 with 36.4^{0}C ambient temperature. Then there was a gradual decrease in the temperature along with time and solar intensity is presented in Fig. 1.

Solar parabolic concentrator with load was done for distillation of ethanol. When container was fully loaded with cashew apple juice with its designed capacity, the maximum temperature of inside container was 109.2^{0}C. The maximum solar insolation was 611 W/m^2 at 13.00 h. during the test Fig. 2 shows the temperature profile at full load test.

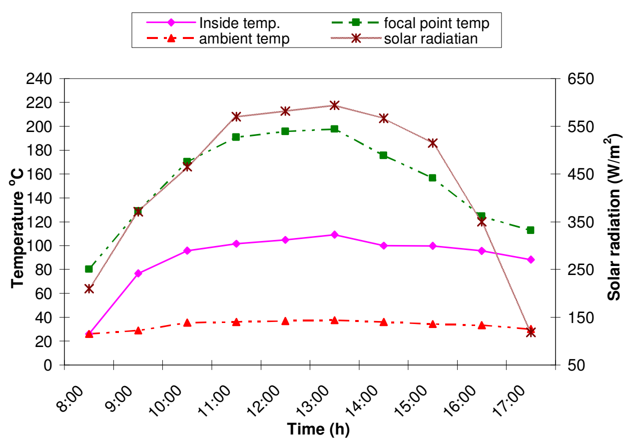

Fig. 2: Performance of parabolic solar concentrator for with juice in the container

Distillation efficiency of solar parabolic concentrator :

The solar parabolic concentrator was manually adjusted towards the sun as the sun inclination has changed. The condensation was provided to collect ethanol. The receiver was mounted on parabolic solar concentrator with its full load capacity *i.e.* 3.00 kg of fermented cashew apple juice for production of ethanol. During the test actual distillation was obtained between 9.00 to 16.00 h. The maximum distillation rate was obtained between 11.00 to 13.00 h. when a maximum solar intensity ranged from 450 to 600 W/m^2 was available and the distillation rate decreased after 13.00 h, as solar intensity decreased. The distillation efficiency of parabolic solar concentrator with time for different solar insolation is given in Table 2. Higher efficiency of the system was found to be 33.4 per cent at 13.00 h when solar intensity was 500 W/m^2 and ambient temperature 31.5 ^{0}C.

Table 2 : Performance of parabolic concentrator from water heating test. Water heating and cooling test

Time h	Water temperature ^{0}C initial	final	τ_o min	F'UL W/m2 K	F'UL /C	F' no.	Avg. F' no.	Thermal efficiency ηt
09.30 09.40	27.2	36.5	25	12.83	0.32	0.0946		
09.40 09.50	36.5	47.7	25	12.83	0.32	0.1242		
09.50 10.00	47.7	61.2	25	12.83	0.32	0.1267		
10.00 10.10	61.2	80.6	25	12.83	0.32	0.1274	0.1202	33.41
10.10 10.20	80.6	95	25	12.83	0.32	0.1281		

The relationship between cumulative distillation rate and solar radiations Vs time is shown in Fig. 3. The maximum distillation observed was 580 ml when solar radiation was 620 W/m^2 at 13.00 h and minimum distillation rate was measured at 16.00 h. The maximum range of total distillation rate was calculated during whole day *i.e.* from 8.00 to 17.00 h was 2230 ml from 3.00 kg of fermented cashew apple juice with ethanol concentration 18.6 per cent. Same trend was observed which is shown in Fig. 4 and 5 with minimum difference in solar radiation and ethanol distillation rate. Output of first distillation of 3 kg fermented cashew apple juice was used for second distillation for 8 to 17 hrs and output obtained was 1170 ml with ethanol concentration of 35.5 per cent.

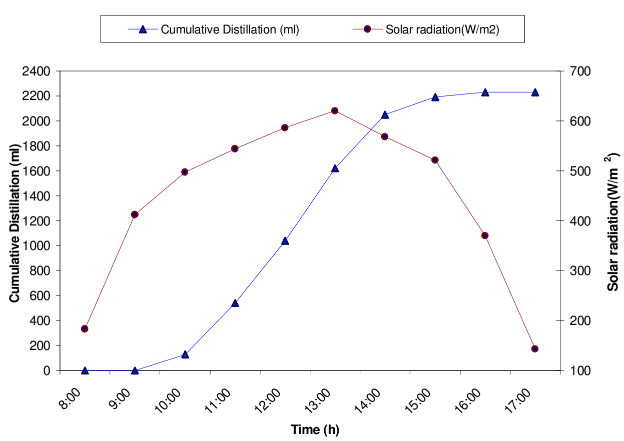

Fig. 3: Cumulative distillation rate and solar radiations vs. time

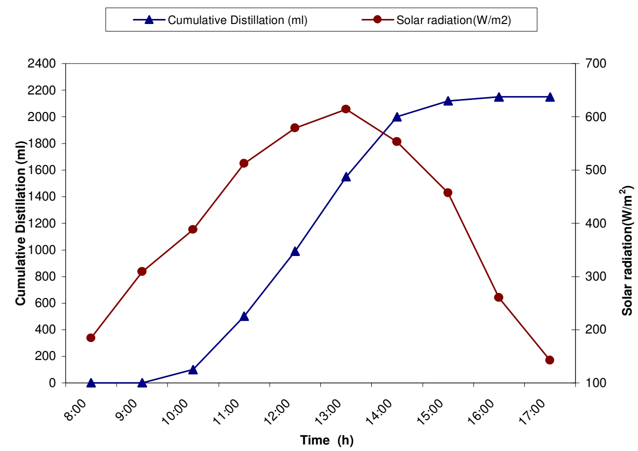

Fig. 4 : Cumulative distillation rate and solar radiations vs. time

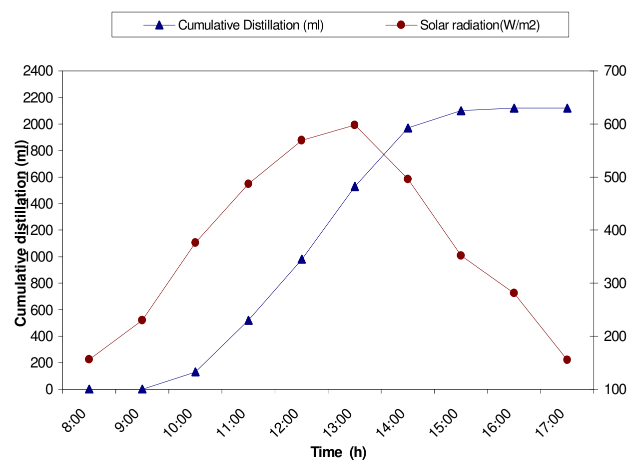

Fig. 5: Cumulative distillation rate and solar radiations vs. time

Water heating and cooling tests are recommended and both were performed with a load of water in the receiver container made from aluminum. The first test comprised of water heating using parabolic concentrator till the steady state temperature of water was reached under clear sky condition. Then the test of water cooling was done by shading the concentrator. The water heating and cooling curves is plotted between difference in temperature of water and ambient temperature vs. time *i.e.* (T_w-T_a) is given in Fig. 6 which shows the time required for boiling the water. For this test water required 55 min to reach the steady state temperature at 9.30 h when average solar insolation was 563 W/m^2. The analysis was done form both water heating and cooling curves. The water cooling curves provided overall heat loss coefficient (F'_{UL}) and optical efficiency factor (F'no) was computed by water heating test.

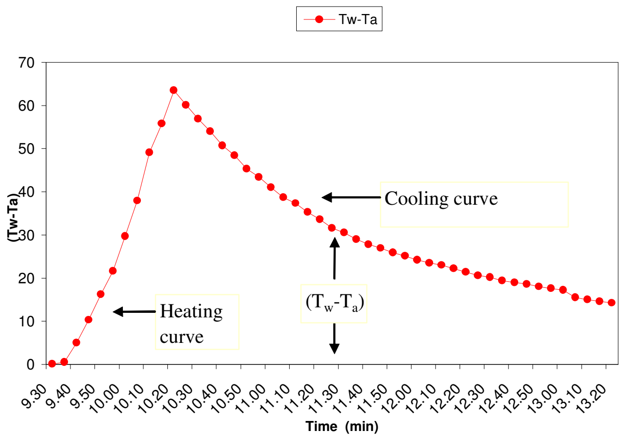

Fig. 6: Water heating and cooling curve test

Overall heat loss coefficient (F'UL) :

Cooling curve analysis :

The calculated value of [ln (T_w-T_a)] for each set of the data points that plotted with this value on Y-axis and time on X-axis was drawn (Fig. 7). Different points of the plot were fitted to a least square linear regression equation. The slope of the line equals to (-1 /τ_0), where τ_0 is defined as the time-constant for cooling.

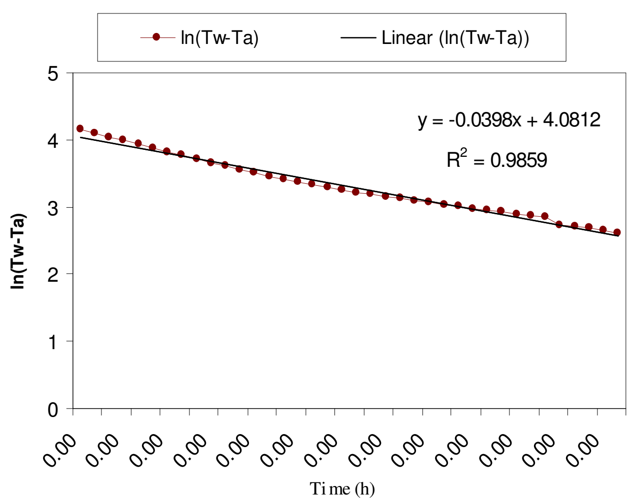

Fig. 7: Graph for cooling curve

Substituting known values of time-constant for cooling (τ_0) in equation 1, surface area of the container (A_{cont}), and total thermal capacity of the container in the equation 1, the value of the heat loss factor ($F'U_L$) of the cooker was evaluated.

$$F'U_L = \frac{(MC)'_W}{A_{cont}\,\tau_0} \qquad ......(1)$$

where,

A_{cont} = Total surface area of the container, m2

$(MC)'_w$ = Total heat capacity, which is equal to the sum of the heat capacity of container ($M_{cont}C_{cont}$) and the water (M_wC_w), J/K

C_{cont} = Specific heat of the material of container, J/kg K

C_w = Specific heat of water, J/kg K

M_{cont} = Mass of empty container with lid, kg

M_w = Mass of water kept in container during the test, kg

τ_o = Sensible cooling constant

By regression analysis of the test the value of the time constant (τ_o) is 25 min at the average ambient temperature of 31.5^{0}C. With the cylinder surface area of 0.0791 m^2 and values of the cooling time constant (τ_o), overall heat loss factor (F'_{UL}) was found to be 12.83 W/m^2. The overall heat loss factor (F'_{UL}) was found to be higher, because of increase in thermal resistance between the receiver cylinder and the surrounding.

Optical efficiency :

The optical efficiency factor gives the theoretical upper limit of the overall efficiency of solar paraboloid concentrator. This is related to the performance of reflecting surface, its reflectance. Water heating test was used for determination of optical efficiency factor (F'no). This obtained after analyzing the sensible heating curve as shown in Fig. 6.

$$F'_{\eta o} = \frac{\frac{(F'U_L)A_{cont}}{A_{aperture}}\left[\left(\frac{T_{wf} - T_a}{I_b}\right) - \left(\frac{T_{wi} - T_a}{I_b}\right) e^{\tau/\tau_o}\right]}{1 - e^{-\tau/\tau_o}} \qquad (2)$$

where,

T_{wi} = Temperature of water in the container at the beginning of the interval, C.

T_{wf} = Temperature of water in the container at the end of the interval, C.

τ = Duration of the interval (e.g. 10 minutes or 600 s), s.

I_b = Intensity of beam radiation incident on the aperture of the concentrator, averaged during the interval, W/m^2.

T_a = Ambient air temperature averaged during the interval, C.

A_{cont} = Total surface area of the container, m^2.

$A_{aperture}$ = Aperture area of the paraboloid concentrator cooker, m^2.

The value of the optical efficiency factor (F'no) was determined by using equation 2. The result of the test is given in Table 2. The optical efficiency factors (F'no) was found to be 0.1202 for average solar insolation of 500 W/m^2. The major factor, which affects this value, is reflectance of the reflector and absorptance of receiver cylinder.

Characteristic components of ethanol :

After distillation, the value of ethanol concentration was calculated by using standard ethanol curve shown in Fig. 8. Percentage of ethanol available in raw cashew apple juice was 12 per cent. After first distillation process, it was increased up to 18.6 per cent. The value of ethanol concentration solution obtained from second distillation was 35.5 per cent. Ethanol production of 35.5 per cent by volume is possible by using solar concentrating collector. Table 3 shows ethanol concentration during first distillation, second distillation and Plate 2 shows ethanol samples of first distillation and second distillation.

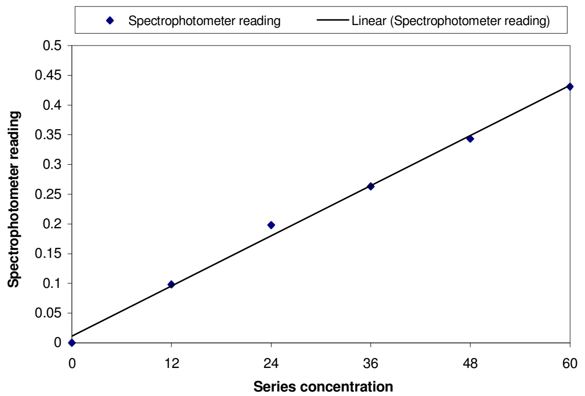

Fig. 8: Standard curve of ethanol

Table 3 : First distillation, second distillation and ethanol concentration

Sr.No.	Time(h)	1st Distillation(ml)	2nd Distillation(ml)
1.	8.00	0	0
2.	9.00	0	0
3.	10.00	130	50
4.	11.00	410	240
5.	12.00	500	310
6.	13.00	580	380
7.	14.00	430	170
8.	15.00	140	20
9.	16.00	40	0
10.	17.00	0	0
	Total	2230	1170
	Ethanol concentration	18.6 %	35.5 %

Plate 2 : Ethanol sampkes of first distillation and second distillation

After second distillation, the analysis of ethanol-water mixture was done. The characteristic components of ethanol *i.e.* the specific gravity and acid values were obtained 0.947 and 1.044 mg KOH/g, respectively. The efficiency of distillation unit for production of 35.5 per cent ethanol is about 33.4 per cent. The temperature of the fermented juice was much higher than boiling point of ethanol *i.e.* 78.5^{0}C. Due to higher temperature the water was evaporated along with ethanol. So it was not possible to get higher concentration of ethanol by using solar parabolic cooker. It was possible to get 95 per cent ethanol by further distillation in laboratory. For obtaining 100 per cent ethanol concentration, the benzene would be used as a dehydrating agent.

Conclusion :

This study could establish that cashew apple juice commercially for any industrial application for ethanol production from cashew apple juice was carried out on solar concentrating collector/cooker. Production of ethanol involves two processes *i.e.* fermentation and distillation. *Saccharomyces cerevisiae* was used as inoculation for better fermentation. The total distillation rate per day of the system was measured and it was obtained 2230 ml. The average distillation efficiency of the system for production of 35.5 per cent concentration ethanol is about 33.4 per cent.

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