Production of Bio-Ethanol from Iraq Date Crop

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Abstract: This research studied the possibility of producing bio-ethanol from Iraqi date crop. The juice of the Zahdi species of Iraqi dates is chosen for this purpose since it is available in large quantities in Iraq and has good sugar contents. The production procedure consists of fermentation, distillation and dehydration processes. A special rig is designed and assembled for the production. The fermentation process involved the use of three different types of yeast (the bread yeast, cheese Yeast and whey) to choose the best type that requires shorter fermentation time. It is found that the fermentation times for these yeasts are 25, 40 and 34 hrs respectively. The fermentation process is followed by the distillation process, which was performed in three stages. Finally, the dehydration process which is the most important and difficult process because it takes a long time to produce the required concentration of ethanol. This process involved the use of two different types of drying materials (ethylene glycol and calcium oxide). Experimental results show the importance of using dates as a source of bio ethanol in Iraq. It is found that 1 ton of Zahdi yields 300 L of bio-ethanol. It is also found that the cost of 1 L bio-ethanol is about 1022 ID which is about 85 cents. This cost can be reduced in case of mass production. This price is comparable with ethanol prices worldwide.

This work proved that date crop in Iraq is an important source of renewable energy comparable to crude oil.

Keywords: Bio fuel, Ethanol, Fermentation, Distillation, Dehydration.

Introduction

The world is on the verge of an energy crisis because of the limited sources of energy as fossil fuels are unable to meet the continuously increasing demand for energy. This associated with fluctuating prices of fossil fuels, the world's awareness of environmental pollution, forced the world to search for alternative sources of energy which are non-polluting and renewable. The most promising alternatives to petroleum fuels are bio fuels mainly (ethanol and methanol and bio diesel). Bio diesel is produced from many sources such as corn oil, soya beans, algal oil..etc [1]. Currently bio-ethanol is produced and used as a fuel on large scale in many countries such USA, Brazil, China and India. Emphasis was placed on the role of bio fuels in reducing carbon dioxide emissions as it is assumed that the use of ethanol by 85% in the operation of vehicles will lead to lower green house gases emissions.

Despite the advantages of ethanol as a clean fuel compared to oil, it represents less than 1% of the global market for fuel for automobiles. Scientists aim to expand the use of clean fuels in automobiles as it considered the second largest source after industry for the deployment of carbon dioxide on the surface of the earth.

Ethanol is the most widely used as a renewable fuel. The turbulences in the oil market during the last four decades and the global desire to reduce net CO_2 emission has made ethanol a desirable fuel [2]. Sugars and grains are the dominant feedstock for ethanol production, but lignocellulosic biomass is considered as the key feedstock in the future [3]. Further, despite its high octane number, ethanol contains only 70% of the energy content of gasoline. The challenge, therefore, is to produce advanced bio-fuels that have high energy content and are compatible with storage and transportation infrastructures designed for petroleum based products, which are also economically feasible to produce on an industrial scale. Potential advanced bio-fuels that could supplement or replace gasoline include short-chain alcohols and alkanes [4].

Ethanol is presently the only renewable source of liquid transportation fuels and offer many potential environmental and economic benefits. The production of the raw biomass material and its subsequent conversion to fuels creates local jobs, provides regional economic development, and can increase farm and forestry incomes. Ethanol also offer many environmental benefits including reduction of carbon dioxide emissions associated with global climate change and improved waste utilization. The chemical composition of many bio-fuels also leads to improve engine performance and reduces unwanted pollutants such as carbon monoxide and unburned hydrocarbons. Billions of litres of ethanol are used annually for transportation fuels [5]. A computer-based air-fuel model of spark-ignition (SI) internal combustion engines was developed by [6]. They analyzed the performance of a SI engine fuelled with ethanol and ethanol-gasoline mixture. Performance parameters of the engine were evaluated at different engine speeds, compression ratios and equivalence ratios. It indicated that the thermal efficiency with ethanol and E80 exceeds that with gasoline with the difference slightly increasing with the speed. The performance with E80 lies between those of gasoline and ethanol. A similar pattern is exhibited by the variation of the mean effective pressure with engine speed while the optimum values of the thermal efficiency and IMEP occur at about 6000 rpm.

Alcohol can be prepared from bio-sources such as sugar cane, beat root, dates….etc. Three processes are used, namely, fermentation, distillation and dehydration.

The fermentation process is normally operated as a batch, but the process may also be continuous or partially continuous. In a conventional batch process, the yeast culture often close to 10% of the fermenter volume is added to the cooled mash and allowed to ferment to completion, usually in less than 2 days. The volume of stillage which results after distillation is inversely proportional to the concentration of ethanol at the end of the fermentation. Also, ensuring that fermentation has reached completion and that residual sugars in the beer are minimized can lower the Chemical Oxygen Demand (COD) of the resulting stillage [7]. After fermentation, the liquid portion of the slurry has 8-12% ethanol by weight. Because ethanol boils at a lower temperature than water does, the ethanol can be separated by a process called "distillation." Conventional distillation/rectification systems can produce ethanol at 92-95% purity. The residual water is then removed using molecular sieves that selectively adsorb the water from an ethanol/water vapour mixture, resulting in nearly pure ethanol (>99%). The residual water and corn solids that remain after the distillation process are called "stillage." This whole stillage is then centrifuged to separate the liquid (thin stillage) from the solid fragments of the kernel [8]. Finally, the dehydration process is separation of ethanol from water by distillation is limited to a purity of around 96% due to the azeotropic properties of ethanol/water mixtures. Traditionally, azeotropic distillation was employed to produce higher purity ethanol by adding a third component, such as benzene, cyclohexane or ether, to ``break" the azeotrope and produce dry ethanol. Except in the high purity reagent-grade ethanol market, azeotropic drying has been supplanted by molecular sieve drying technology, which is not only more energy enceinte but also avoids the occupational hazards associated with the azeotropic chemical admixtures. In this case, two molecular sieve beds are placed in parallel with one drying while the other is regenerating. During the regeneration phase a ``side stream" of ethanol/water (often around 50%) is produced, which must be redistilled before it can be returned to the drying process. The ``bottoms" from side stream distillation is often blended into the stillage, adding to the stillage volume (The Alcohol Textbook, 3rd ed, 1999) [9].

The use ethanol as a fuel has the following advantages:

1. Partial substitute for fossil fuels in cars.

2. Directing the agriculture sector towards the energy sector.

3. Providing additional economic and national income to the region.

4. Creating a cleaner environment as it helps in reducing carbon dioxide and carbon monoxide and unburned hydrocarbons.

Experimental Work

The lowest concentration of sugar in any raw material should be 8% in order to be qualified for the production of bio-ethanol. Therefore the date crop is well qualified for the production of high-purity ethanol since its sugar concentration of is very high (the eaten part), between 68-73 % (by weight) [10].

The quantity and quality of juice produced depend on species of date. As very well known there is variety of species of Iraqi dates, it was found that the Zahdi species yield's the maximum quantity of juice since it has high sugar contents. In 2006 the production of Zahdi species crop is 654 240 ton which shows steady increase of production [11].

The process of bio-ethanol production from dates is divided into four stages:-

1) The production of juice stage.

2) Fermentation stage.

3) Distillation stage.

4) Dehydration stage.

Preparation of date's juice

The juice is the thick liquid extracted from dates with a yellowish, red or dark red to black. Two techniques are available for production, the cold and the hot techniques. In cold technique the yellowish red (gold) colour is obtained, while in the hot technique the dark colour is obtained [11]. As mentioned above the juice is bought from local markets.

Fermentation stage

This process converts sugar into ethanol and carbon dioxide using some special yeast according to the following reaction:

$$C_6H_{12}O_6 \xrightarrow{\boxed{\text{Yeast}}} 2C_2H_5OH + 2CO_2 \qquad (1)$$

The fermenter is shown in fig 1. It is fabricated in the laboratories of Mechanical Engineering Department.

Three types of yeast are used in the present works which are:-

1- The bread yeast.

2- The cheese yeast.

3- Whey.

The materials and quantities used in the fermentation process for each type of yeast are shown in table (1).

Fig. (1)the Fermenter

1. Iron tank, 2. Special pump for chemicals, 3. Cooling system, 4. Pressure gauge, Thermometer and Vent valve,

5. Volume flow meter, 6. Plastic connecting pipe.

Table (1) Materials and quantity used in the fermentation process

Type of yeast	Material	Quantity
bread yeast	Juice	5 L
	distilled water	15 L
	Yeast	100 g
cheese Yeast	Juice	5 L
	distilled water	15 L
	Yeast	100 g
Whey	Juice	5 L
	distilled water	15 L
	Yeast	500 g

The fermentation procedure is as follows,

The tank is filled with 15 L of warm distilled water (35 ^oC) and 5 L of juice. The circulation pump is run for 4-5 hrs with the tank open to mix the ingredients. The yeast is dissolved in 0.5 L of warm distilled water (35 ^oC) and mixed with ingredients. The tank is then tightly closed.

The circulation process continues to stimulate the yeast and speed up the fermentation process. At the start of the fermentation process the temperature of the mixture rises and therefore cooling is needed to keep the temperature constant in the specified range.

Cooling or heating process is needed depending on the weather in order to keep the temperature of ingredients constant at 30-35 ^oC. If the work is done in hot climate cooling is needed while heating is needed when work is done during cold climate.

When the fermentation process is complete the output is known as "low wine" which contains 12% alcohol by volume.

The distillation process

This process is designed to raise the ethanol concentration from 12% to at least 91% at the end of distillation. The columns utilize the differences in the boiling points of ethanol and water to boil off and separate the ethanol. There are a large number of chemical compounds in the molasses. But the disparity in degrees of boiling these substances plays a crucial role in the separation of ethanol. The process is carried out in three stages to get required alcohol concentration. The distillation apparatus is shown in fig 2 . It is fabricated in the laboratories of Mechanical Engineering Department.

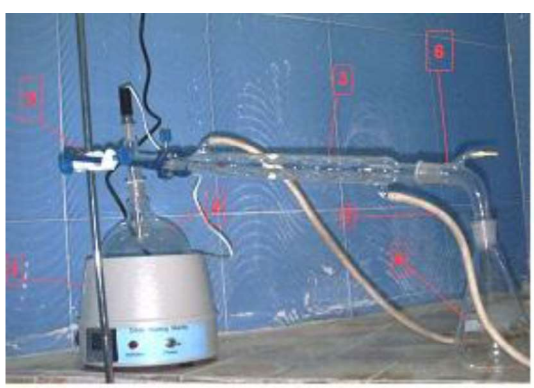

Fig.(2) The Distillation Apparatus

1. Digital heating mantle, 2. Flask capacity one litre, 3. Condenser, 4. Collector flask,

5 condenser Stand 6.Connections to connect different parts of the column,

7. Cooling water supply

The dehydration process

Anhydrous ethanol production has become one of the most important issues for many countries in the world due to the great efforts directed to use bio-fuels. The quality of produced ethanol is determined by the operating conditions. The technology used and its benefits is related to the quality and costs of ethanol.

This process is designed to get the ethanol concentration to (99.6%).

The dehydration process is carried out using two types of drying agents which are ethylene glycol and calcium oxide. The procedure is as follows:

The drying agent is mixed with the output of the distillation process for 10 min. The amount of drying agents' equal 80% of the amount of ethanol 91%. The mixture is then heated until evaporation in a dehydration column at a temperature lower than the evaporation temperature of the last stage of distillation process. The residues of the dehydration process is heated to 157 ^{o}C to reduce its water content then cold to 80 ^{o}C and recycled with the fresh charge of the dehydration column.

Results and Discussion

The fermentation process

Due to time limitations the date juice is bought from local markets. The fermentation process is carried out using three types of yeast:-

1- The bread yeast.
2- Cheese yeast.
3- Whey.

Fig 3 shows the time required to complete the fermentation process for the three types of yeast. It is shown that the bread yeast required the shortest time which is about 25 hr compared to 40 and 34 hr for cheese yeast and whey respectively. The fermentation time must shortened to reduce production cost.

As the fermentation time is reduced the power consumption is reduced and the amount of raw material that can be fermented during a specified period of time is increased.

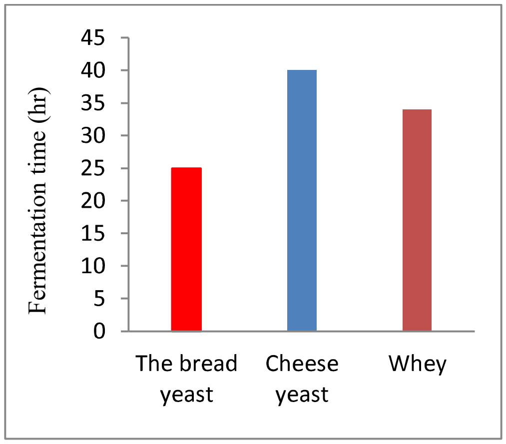

Fig. (3) Fermentation time for each type of yeast

The distillation process

Fig 4 shows the relationship between evaporation temperatures, alcohol concentration in the distillate. During this stage one liter of fermented juice is put in flask and heated to a preset evaporation temperature by a digital heating mantle. Different temperatures are tried to obtain the best temperature in terms of concentration and time. This temperature is found to be 107 °C. It is clear that as the evaporation temperature increases the alcohol concentration decreases due to the evaporation of large amount of water and distillation time deceases also. It is found that the evaporation temperature of 107 °C gives a good reduction in time about 18% with small change in alcohol concentration in the distillate. At the end of this stage the alcohol concentration is 44% and distillation time 2.15 hr.

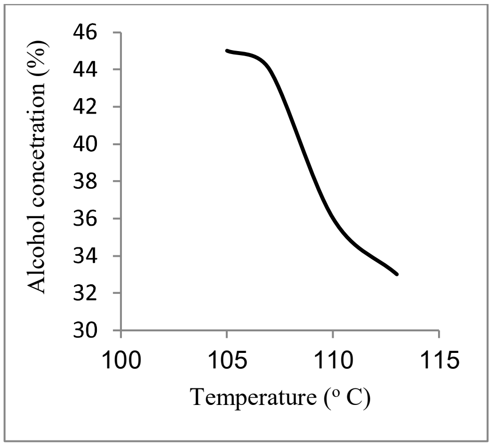

Fig.(4) Effect of evaporation temperature on alcohol concentration in the distillate for the first distillation stage

Figure (5) shows the relationship between evaporation temperatures, alcohol concentration in the distillate. The output of the first stage (44% ethanol concentration) is heated and evaporated again in the column at temperature higher than final stage. Also different evaporate temperatures are tried to obtain the best temperature in term of concentration and time. This temperature is found to be 92 °C. As in the first stage is noticed that increase the evaporation temperature reduces the alcohol concentration and distillation time. However it is clear form results that the temperature of 92 °C gives small reduction in concentration and a large reduction in distillation time about 21.5%. Therefore this temperature is recommended for this stage which gives 81% alcohol concentration and 5.30 hr distillation time.

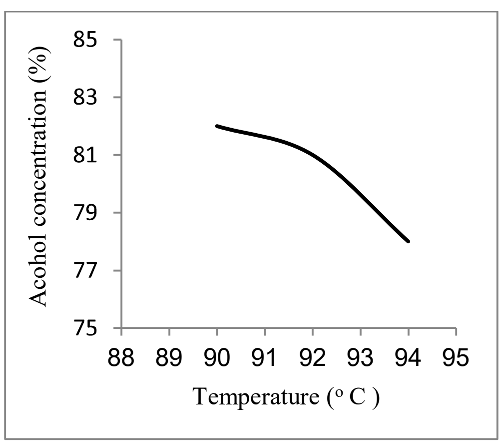

Fig.(5) Effect of evaporation temperature on alcohol concentration in the distillate for the second distillation stage

Figure (6) shows the relationship between evaporation temperatures, alcohol concentration in the distillate. The output of the second stage (81% ethanol concentration) is heated and evaporated again in the column at temperature lower than second stage. Also different evaporate temperatures are tried to obtain the best temperature in terms of concentration and time. This temperature is found to be 85°C. Also the same procedure is repeated. The output of this stage is a condensate with 91% ethanol concentration at 20 ° C. Each liter of second stage output gives 900 ml .

The overall output of three stages is 100 ml of condensate with 91% ethanol concentration at 20 ° C for each one liter of fermented juice. As in the first and second stages is noticed that increase the evaporation temperature reduces the alcohol concentration and distillation time. The results show that the 85 °C gives small reduction in concentration and a large reduction in distillation time about 8.5%. Any further increase in temperature gives large reduction in concentration and small reduction in time which is not preferred. Therefore the 92 °C is recommended for this stage which gives 91% alcohol concentration and 8.15 hr distillation time.

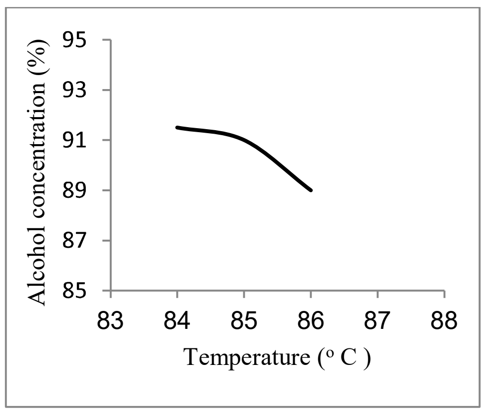

Fig.(6) Effect of evaporation temperature on alcohol concentration in the distillate for the third distillation stage

Figure (7) shows the alcohol concentration obtained in the present work is comparable with the work of ref [12].

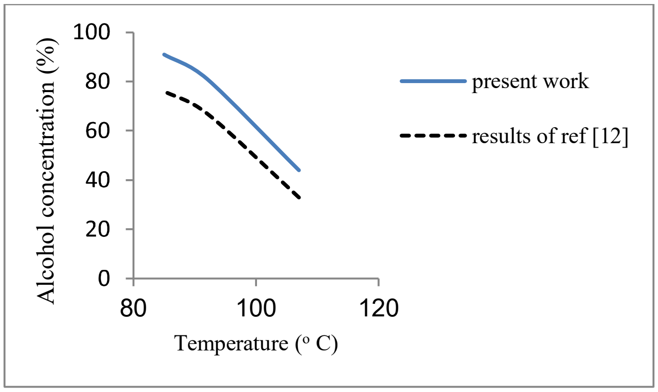

Fig.(7) A comparison between alcohol concentration obtained in this work and results of ref [12]

The dehydration process

Two types of drying agents are used in the dehydration process which are ethylene glycol and Calcium Oxide (CaO).The output of the dehydration process should be at least 99.6% alcohol concentration. The process is carried out at different temperature. It is found that the 80^{o}C gives 99.6% alcohol concentration with a dehydration time 16 hrs. Fig 8 shows the results of this experiment using ethylene glycol as drying agent while Fig 9 shows the results with CaO as a drying agent. It is found that each liter of ethanol (91%) yields 900 ml of ethanol (99.6%) at the end of dehydration process. It is noticed that the yielded alcohol concentration at same temperature (80 °C) is slightly less for CaO but with shorter time (about 9%).

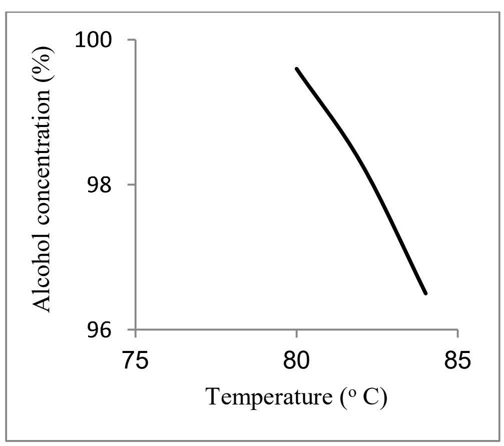

Fig.(8) Effect of evaporation temperature on alcohol concentration in dehydration process with ethylene glycol

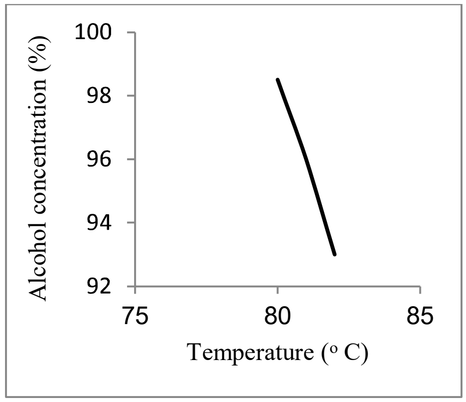

Fig.(9) Effect of evaporation temperature on alcohol concentrationin dehydration process with CaO

Cost of production

The total cost to produce one liter of ethanol can be calculated by summing the cost of raw material, the cost of power consumed and the cost of cooling water in addition to any other costs.

Energy cost

Energy is one of the major parts cost to produce ethanol. Figure (10) shows that the minimum energy is consumed in the fermentation process when using the bread yeast 0.275 kWh/L of ethanol. Fig 11 shows the minimum energy consumption for each stage of distillation process. The figure shows that the minimum energy consumed in the distillation process is 0.844 kWh/L of ethanol. Figure (12) shows that the minimum energy is consumed in the dehydration process with CaO 0.67 kWh/L of ethanol.

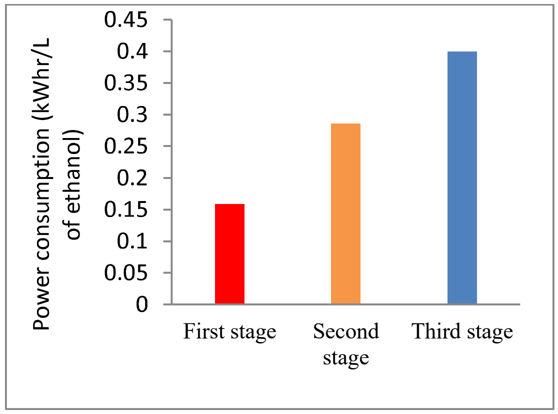

Fig.(10) Power consumption in distillation Process

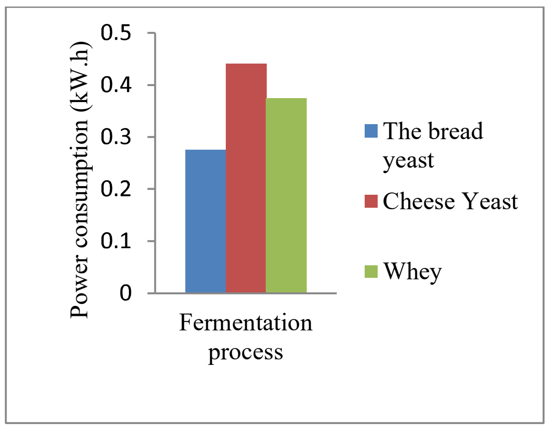

Fig.(11) Power consumption in Fermentation process

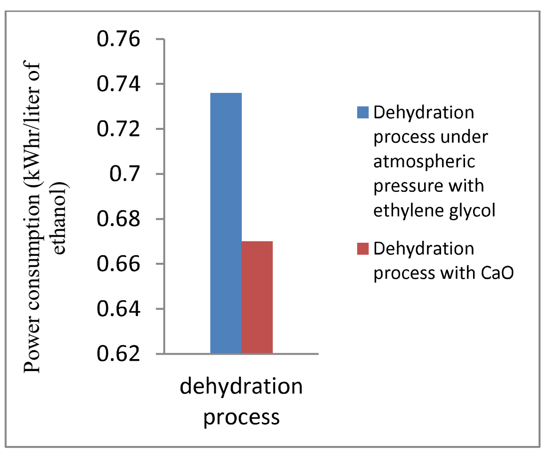

Fig.(12) Power consumption in dehydration process with ethylene glycol and CaO

Cooling water cost

The minimum amount of cooling water is consumed in the fermentation process when using the bread yeast which is 1.44 m^3/L of ethanol. The minimum amount of cooling water in the distillation process is (0.024 m^3/L of ethanol). Finally, the minimum amount of water cooling in the dehydration with (CaO) which is 0.022 m^3/L of ethanol.

Table 2 shows the results of total cost to produce one liter of ethanol. The results show that the total cost to produce one liter of ethanol is 1022 ID which is about 85 cents. This price is approximately similar to the ethanol price worldwide. It is found that 1 ton of Zahdi yields 300 L of ethanol. Cost calculated in present work is higher than the real cost in the case of mass production, where more than 70% of energy requirements can be supplied and the recycling of steam supplied from a separate boiler. The water requirements are relatively moderate. The water used in the fermentation should have the properties of drinking water, while water for cooling does not require any water quality treatment.

Table (2) Total cost to produce one liter of ethanol

The raw material	Quantity /L of ethanol	Unit Price (ID/unit)	Total (ID / L of ethanol)
Juice	2.5 L	300	750
Yeast	50 g	5	250
Drinking water	0.0075 m^3	25	0.1875
Cooling water	1.48605 m^3	2.5(1)	3.715
Energy	1.844 kWh	10(2)	18.44
Total			1022

(1)Reference is Ministry of Municipalities and Public Works(http://www.mmpw.gov.iq).

(2)Reference is Iraqi Ministry of Electricity (http://www.moelc.gov.iq/ar/index.php).

Properties of produced bio ethanol

The produced bio-ethanol is tested at the laboratories of Petroleum Research and Development Center of the Ministry of Oil in IRAQ, to obtain its physical properties. The equipment used are:

1) Gas Chromatograph (GC) to measure the concentration of ethanol.
2) Digital density meter to measure density and specific gravity of ethanol.
3) Calorimeter to measure the gross heat of ethanol.

Table 3 shows the measured properties of the bio-ethanol produced in present work compared with the properties given in Refs [13,14]. The comparison shows good agreement.

Table (3) properties of produced bio-ethanol

Properties	Bio-ethanol in this work	Bio-ethanol	Gasoline	Unit
Concentration	99.6	99		v/v %
Density 15.6 ^oC	0.7956	0.7939	0.7197	g/cc
Sp.Gr 15.6 ^oC	0.7965	0.7948	0.72	
Gross heat	7081.31	7100	11300	cal/g

Conclusions

From the results of the present work, the following conclusions can be written-:

1-The novelty of this work is that it proved that Iraq date crop is a major source of renewable bio energy, in addition to crude oi since it is produced in huge quantities. This adds extra revenue for this country.

2-High sugar content in the dates makes the dates one of the important sources in the production of ethanol.

3- Use of bread yeast in the fermentation process gives minimum time for the process compared to the other yeast types.

4- Dehydration process using ethylene glycol is better from other processes because this process consumes less energy.

5- Ethylene glycol is better than Calcium Oxide (CaO) since it gives good results in terms of high concentration of ethanol and less energy consumption in dehydration process.

6-Cost of one liter of ethanol is 1022 ID which is about 85 cents.

References

1. Grace Pokoo-Aikins, Ahmed Nadim, Mahmoud M. El-Halwagi and Vladimir Mahalec "Design and analysis of biodiesel production from algae grown through carbon sequestration. Clean Techn Environ Policy (2010) 12:239–254

2. Taherzadeh, M. J. and Karimi, K. "Acid-based hydrolysis processes for ethanol from lignocellulosic materials: A review," BioRes.2, 472-499, (2007).

3. Sun, Y. and Cheng, J. "Hydrolysis of lignocellulosic materials for ethanol production: A review," Bio resource Technol. 83: 1-11, (2002).

4. Sung Kuk Lee, Howard Chou, Timothy S Ham, Taek Soon Lee and Jay D Keasling "Metabolic engineering of microorganisms for bio-fuels production" From bugs to synthetic biology to fuels. Curr. Opin.Biotechnol 19: 556–563, (2008).

5. Fischer, C. R., Klein-Marcuschamer, D., Stephanopoulos, G. "Selection and optimization of microbial hosts for biofuels production" Metab. Eng 10: 295–304, (2008).

6. El-Awad M. M., et al "A Computer-Based Air-Fuel Model for Analyzing the Performance of Spark-Ignition Internal Combustion Engines", International Conference on Mechanical, Automobile and Robotics Engineering (ICMAR'2012) Penang, Malaysia, (2012).

7. Shama G. "Developments in bioreactors for fuel ethanol production". Process Bio chem; 23 (5):138-145, (1988).

8. Alexander E. Farrell, Richard J. Plevin, Brian T. Turner, Andrew D. Jones, Michael O'Hare, Daniel M. Kammen "Ethanol Can Contribute to Energy and Environmental Goals," Science 311(5760), 2006

9. Swain R L B, The Alcohol Textbook, 3rd ed. Nottingham, UK: Nottingham University Press, p. 289-293, (1999)

10. Hussain S. H. "Effect of heat treatment on locally produced date syrup properties". Al-Forat Journal for Agricultural Sciences, Vol 4, No 4, (2012).

11. Adnan Kahtan Ebraheem "Production and Analysis of Bio-ethanol from Dates Syrup". M.Sc. Thesis, University of Babylon (2013), Iraq.

12. Lide, D. R. CRC Handbook of Chemistry and Physics, CRC press. ISBN 0849304814, 44th ed. p. 2582-2584, (2000)

13. Lange's Handbook of Chemistry, 10th ed. p. 1522-1528, (1967)

14. Bell Fuels: Lead-Free Gasoline Material Safety Data Sheet. http://www.sefsc.noaa.gov/HTMLdocs/Gasoline.htm, Retrieved 6 July (2008).