International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.11 No.07, pp 269-285, 2018

A Review of Advances in Bioethanol Production Processes from Oil Palm Empty Fruit Bunch

Solano R[1]*, Rodríguez M[2], Ballesteros K[3], Jiménez A[4]

[1]Multifunctional Nanomaterials Research Group.School of Engineering. Universidad de Cartagena. Street 30 # 48-152. Cartagena, Colombia.
[2]Design of Processes and Use of Biomass Research Group.School of Engineering.Universidad de Cartagena. Street 30 # 48-152. Cartagena, Colombia.
[3]Particles and Processes Modeling Research Group.School of Engineering.Universidad de Cartagena. Street 30 # 48-152. Cartagena, Colombia.
[4]Research Laboratory on Catalysis and New Materials.School of Exact and Natural Sciences.Universidad de Cartagena. Avenue 50 # 29-11. Cartagena, Colombia.

Abstract : Many studies are carried out in different countries to find alternatives of hydrocarbon-based fuels,1 which include hydro, wind, biofuels, solar, and geothermal energy. One of the major biofuels isbioethanol, a clear, colorless liquid, biodegradable, and lowin toxicity, and can be considered as a high-octane fuel oroctane enhancer in domestic petrols. The pre-treatment process for oil palm empty fruit bunches (OPEFB) or empty fruit bunches (EFB)for produce bioethanol require convert the complex lignocellulose structures into enzymatically digestible forms and easy handling for use. The pre-treatment can to be divided into physical, chemical, biological and physico-chemical tre-treatment. Various studies on the subject are presented below either a single treatment or combination of several. Nevertheless, the most important problem with bioethanol downstream processing is the dewatering step due to azeotropic formation during distillation of ethanol-water mixtures. Currently, different methods like direct contact membrane distillation (MDBR), extractive batch distillation, pervaporation, adsorption, molecular sieve and pressure Swing Adsorption (PSA) are used for bioethanol dehydration with regard to the absolute ethanol production. Also, mass and energy integration processes are also reviewed.
Keywords : bioethanol, pretreatment, process integration, purification.

1. Pretreatment of biomass oil palm empty fruit bunches (OPEFB)

In 2014, Aisyah, Uemuraa and Yusup in Perak, developed a pre-treatment physicochemical where the OPEFB was dried, grinded and passed through a mesh. Later the OPEFB was heated to180 ºC and then was cooled to 40 °C and after they added 1.2 g of CaO and NaOH into the EFB and water mixture. Obtaining thus the solid yield of the reaction increased significantly for hydrothermal pretreatment with NaOH addition (90.08

DOI= http://dx.doi.org/10.20902/IJCTR.2018.110732

%) when compared to the hydrothermal pretreatment of EFB (75.51 %) and with addition of CaO (73.91 %)[1]. In 2013, in Republic of Korea Kim and Kim soaked the OPEFB in H_2SO_4 solution, after in water and dried to 105 ºC. Then fiber was soaked in NaOH solution and dried at 121 C and 5 psi, then to be soaked in water for remove NaOH on the surface of the biomass repeated times and was dried. The delignification yield after sequential acid/alkali treatment of EPFB fiber was approximately 70%[2]. Table 1 consolidates conditioning methods and pretreatment of biomass.

Table 1.Methods and pretreatment of biomass

Method	**Conditions**	**Performance lignin removed (%)**	**Reference**
Pre-treatment physicochemical With NaOH	Drying, grinding and shaking after alkaline hydrotreatment First heated to 180 ºC. Cooled 40 ºC. Mass of biomass 30g. Volume of water 300 mL. Reaction time 10 min. 1.2 g of NaOH.	NaOH addition (90.08 %)	[1]
Sequential acid/alkali treatment with H_2SO_4 and NaOH	Heated at 105-121ºC and 15 psi for 24 hrs. 4% (v/v) H_2SO_4 solution and 10 N NaOH solutions.	The delignification yield was 70%.	[2]
Phosphoric acid pretreatment and combined with fungi.	fungus Pleurotusfloridanus to 31 ºC and neutral PH, 8 ml phosphoric acid (85.7%), Washed with 40 mL acetone and centrifuged at 1900g	Phosphoric acid pretreatment 89.4% and combined with lignin yield of 62.8%.	[3]
Chemical pretreated with aqueous ammonia	60 C, 12 h, and 21% (w/w) aqueous ammonia	41.1% lignin removal	[4]
Acid pretreatment with sulfuric acid	1% (w/v) sulfuric acid, to 190 C and dried at 45 C for more than 3 days	decreasing 90% the lignite content in sample	[5]
Alkaline hydrotreatment with NaOH	95 g NaOH (8% p/v), for heated at 100 º C for 10, 20 and 60 min, dried at 10000 rpm	conversions of lignin solids of 96%	[6]
Physical and hydrotreatment simultaneously with NaOH and CaOH with H_2O_2	Dry at 105 C for 24 hrs. to 5 gr sample, concentrations 100 mMNaOH and CaOH with H_2O_2 and dried 100 ºC	Almost 100% of lignin.	[7]
Phisycal and Chemical treatment with NAOH and irradiation	Dried and milled NaOH 10%, 150 ºC, ratio 5:1 NAOH and EFB and irradiation 8 (energy variation of 100 kGy up to 500 kGy)	92,2% total lignin removed	[8]
Pretreatment dilute acid (H_2SO_4)	Optimal condition 161.5 C, 9.44 min and 1.51% acid loading	Content of lignin removed of sample to 43% lignin yield	[9]
Steam explosion (SE) pretreatment	300 gr of OPEFB was dried at 65 ºC for 72 h. saturated with steam to 195 ºC for 6 min.	Lignin analyses showed a reduction of 68.12%	[10]
Physical and alkaline treatment combined with NaOH	Dried at 65 ◦C for 48 h, milled, sieved through a mesh 42 (0.350 mm) NaOH of 0,5 to 5,5% in solution at 121 ºC and 80 min	Presence of lignin decayed in a 70%.	[11]
Chemical pre-treatment with NaOH and mechanical pre-treatment	3% NaOH, 110 C for 45 min. milled to average 1mm and washed with water	85% lignin removal	[12]

Physical and chemical pretreatment	Washed, defibrated and ground. AFEX at 135 °C, 45 min retention time.	Particle size was reduced	[13]
Chemical pretreatment with NaOH	NaOH 127.64 ◦C, 22.08 min, and 2.89 mol L^{-1}	74,33% lignin removal	[14]
Physical and acid pretreatment	Dried and milled. The sulfuric acid at 100 ◦C to 150 ◦C, time ranged from 30 to 90 min, and acid loading 0 to 1.3% weight acid/weight liquid.	63% total lignin removed	[15]
Chemical pretreatment with Ethanol/benzene, $NaClO_2$, KOH and deionized water	The EFB of 0,5 -1cm. Ethanol/benzene (1:2 v/v) mixed solvent. $NaClO_2$ solution at (pH 4–5) at 70 C for 1 h. 6 wt% KOH solution at 20 ºC for 24 h. deionized water until the pH 7	Average thickness of nanofibers was within the range 1–3.5 nm	[16]
Biological pretreatment	Six days at 30º C cultivated. *P. ostreatus* CECT 20311 fungi	The lignin degradation to 50% with P. ostreatus, a higher value than the 41% reached with *P. chrysosporium*	[17]
Chemical pretreatment (Ozone treated) with NaOH	For ozonetreated:100 mL of NaOH (5 wt.%) for 1 h. washed with distilled water. dried in the oven at 105 °C for 50 min	lignin degradation of 84.7 wt.%	[18]
Bisulfite pretreatment	Pretreated samples were washed and Five oxygen-catalyzed at 0.6 MPa and 30 min at 120 ºC	Lignin removed 75%	[19]
Phisycal and Bisulfite pretreatment	Milled to particle sizes ranging from 0.30 to 0.45 mm. Pretreated samples were washed and Five oxygen-catalyzed at 0.6 MPa and 30 min at 120 °C	Lignin removed 79,6%	[20]
Bisulfite pretreatment	The bisulfite pretreatment at (180 C, 30 min, 8% $NaHSO_3$, 1% H_2SO_4). Reacted with a solution of sodium bisulfite at 180 C for 30 min, at 8% and 10% $NaHSO_3$	Lignin removed 79,1%	[21]
Phisycal pretreatment (Ball milling (BM))	6–24 h, constant speed of 230 rpm	Lignin removed 81,32%	[22]
Phisycal, chemical and hydrothermal treatment, combined.	Crushed particle size 5 mm. 1% NaOH (w/w). team treated at 230 C for 15 min in pressure vessel	Lignin decrease until 80 %	[23]
High-pressure steam pre-treatment (HPST)	Press-shredded at 250 ºC and 9.4 MPa. HPST conditions of 170/0.82, 190/1.32, 210/2.03, and 230 ºC/3.00 MPa for 2, 4, 8, and 10 min. oven-dried at 105 ºC for 24 h	Lignin reduction of 83%.	[24]

Chemical pretreatment (organosolv pretreatment)	Aqueous ethanol 1:10 (10 g in 100 mL). Concentration (35, 55, and 75% vol), at reaction temperature (80, 100, and 120 °C) and reaction time (30, 60, and 90 min). ($KMnO_4$) 0.1 N, Sulfuric acid (H_2SO_4) 4.0 N and Potassium iodide (KI) for 10 minutes	Decrease lignin concentration of 75%	[25]
Alkaline pretreatment with NaOH and steam.	Wash EFB with NaOH 2%, 4 h at 30 ºC, with solid to liquid ratio of 1:10. Heating at 121 C and 117 kPa during 6 min	Lignin removed 92.3 %.	[26]
Chemical pretreatment with sulfuric acid	Air-dried and pretreated at 170 C with 0.8 wt% sulfuric acid and a solid/liquid ratio of 1:6. stirring speed 100 rpm and 15 min	lignin content decreased	[27]
Ultrasonic pre-treatment with H_2SO_4	500 ml of 2% H_2SO_4 with 50 g of OPEFB. Ultrasonicated at a power of 2 kW, 20 kHz for 15, 60 and 45 min, and amplitude of study was 15%, 60% and 90%	Lignin removed 81,9 %.	[28]
Alkaline pre-treatments	Washed, air-dried and refined to size of about 2-4 cm. applied pre-treatments at liquid/solid ratio 12:1 for 60 min, Sodium Hydroxide (NaOH) 2% w/v, 120 ºC. The fibers were washed and spin-dried	Lignin removed 91,3 %. ’	[29]
Sequential pretreatment (Phisycal, dilute acid and alkali pretreatment)	Washed and dried at 90 C for 24 h. Dilute sulfuric acid at concentration of 0,1-8,0% (v/v) at 121 C, 15 psi for 1 h, 10 N NaOH solution at ambient temperature for 4 h, then, was heated at 121 C, 15 psi for 15 min	Removed 70% lignin.	[30]

2. Purification process in bioethanol production

Jeon et al. [31] evaluated the production of anhydrous ethanol using oil palm empty fruit bunch in a pilot plant by distillation and dehydration process. The initial conditions were 92-93 °C and 16-20 %wt. After the ethanol was refluxed to the top portion of the rectification column. Operation conditions were a 1/10 reflux ratio, 77-78 °C top portion temperature, and 100.5 °C bottom portion temperature. Consequently, 93.7 wt% ethanol was produced by the authors.Subsequently, the pressure swing adsorption (PSA, dehydration) process was applied in this study.The dehydration process was operated at a feed/purge ratio of 7/3 for the stable production of anhydrous ethanol. Consequently, 99.6 %wt ethanol was produced. Coelho et al. [32] studied the bioethanol dehydration using natural clinoptilolite. The results showed that by working at optimum condition, feed with 96% (v/v) initial ethanol concentration could be purified up to 99.9% (v/v). In addition, the optimum operational conditions to reach 99.9% for final ethanol concentration were found equal to 10.7 °C, 4.9 bar and 8 mL/min for liquid temperature, pressure and flow rate, respectively. Table 2 shows the advances for the purification of bioethanol.

Table 2. Advances for bioethanol purification: Review.

Method	Initial experimental conditions	Result of purification process	Reference
Distillation and dehydration (pressure swing adsorption).	Distillation: 92-93 °C and 16-20 %wt. Dehydration: feed/purge ratio of 7/3.	99.6 %wt	Jeon et al. [31].
Dehydration (natural clinoptilolite).	96% (v/v)10.7 °C, 4.9 bar and 8 mL/min.	99.9% (v/v)	Coelho et al. [32].
Direct contact membrane distillation (MDBR).	24 h of the fermentation using whey enriched with sucrose (100 g dm^{-3}).	53.74 g dm^{-3}	Tomaszewska and Białończyk [33].
Direct Contact Membrane Distillation (DCMD).	490 cm^2, effective membrane. for 860 h.	Ethanol flux 1-4 (kg EtOH)/m^2 per day	Barancewicz and Gryta [34].
Direct contact membrane distillation (DCMD).	PP, 0.2 µm. ΔT between 13 and 20 ◦C. 3 h using clean 10 wt.% ethanol feed.	Ethanol flux in permeate of 1.2 L m^{-2} h^{-1}	Lewandowicz et al. [35].
Membrane (capillary) distillation.	Porosity of 70% and the effective area of 0.0183 m^2. Feed temperature of 310 K.	2.5-4 g dm^{-3} h^{-1}	Tomaszewska and Białończyk [36].
Membrane distillation (MD-DHN-BP system).	Ethanol feed (65 % wt.) and 45 °C	87 % wt.	Woldemariam et al. [37].
Membrane distillation (SGMD).	PTFE, 169 cm^2 active area, 0.22 µm pore size and porosity of 70%. flow rate (600 mL min^{-1}), feed concentrations (7 %wt), flow rate of the sweeping air (4.63 NL min^{-1}), temperature of the feed solution (55 °C) and temperature of the sweeping air (25 ±1°C).	Ethanol flux of 1.8 L m^{-2} h^{-1} in the permeated.	Mahdi et al. [38].
Vacuum membrane distillation (VHG + VMD).	300 g/L glucose loading.	127.4 g/L (16.1% v/v) ethanol and permeate flux of 63.7 g/L-h.	Zhang et al. [39].
Vacuum membrane distillation (VMD).	PVDF membranes (0.18 µm and 85%, porosity). It was observed that feed velocity and temperature had a significant effect on VMD. 0.6 m/s -1.1 m/s (feed velocity) and temperature from 50 °C to 70 °C	4.6 L m^{-2} h^{-1} to 9.5 L m^{-2} h^{-1}, distillation flux.	Zhang et al. [40].
Extractive batch distillation (semi-continuous).	Dividing wall distillation column using glycerol as entrainer. ethanol-water mixture of composition 92% wt.The glycerol was supplied at 60 °C.	99% wt.	García et al. [41].

Extractive batch distillation.	Glycerol charge (2.0:1.0). Mixture of ethanol-water (94% wt.) and ambient pressure (604 mmHg).	98% wt.	Navarrete et al. [42].
Extractive batch distillation.	Ethanol and water (85% in mass of ethanol). The batch distillation column operated at atmospheric pressure (604 mmHg).	0.96 mol fraction of ethanol.	Pacheco-Basulto et al. [43].
Pervaporative dehydration.	PVA membranes (membrane area of 2 m^2).Permeate side pressure (<10 mbar), Product flow pressure (2.5 bar), Feed flow rate (20 L h^{-1}), Temperature of the feed (98 °C) and Feed ethanol (85% wt.).	99.7 % wt.	Niemistö et al. [44].
Fermentation-pervaporation.	Polydimethylsiloxane (PDMS) membrane. The continuous process evaluated by the authors had a duration of 210 h.	446.3 g/L of ethanol, with ethanol separation factor ranging from 8 to 12 and ethanol flux between 202.2-299.7 g/m^2 h.	Fu et al. [46].
Pervaporative dehydration.	Polydimethylsiloxane/polyetherimide (PDMS/PEI) composite. The permeate pressure maintained below 5 mm Hg. Feed temperature: 20 °C to 60 °C and ethanol initialconcentrations of 1-10% was studied.	Total flux of 231–252 g/m^2 h.	Lee et al. [47].
Pervaporation.	vinyltriethoxysilane (VTES)-g-silicalite-1/PDMS/PAN thin-film composite membrane (72.34 cm^2). Temperature of 35 ℃, feed flow rate was kept at 2.0 L/min, downstream pressure was maintained at 210 Pa and the feed concentrations of 1.6-8.8 %wt.	22.1-61.4 %wt. Separation factor of 7-14.	Yi and Wan [48].
Fermentation coupled with pervaporation.	Three runs of fermentation-pervaporation experiment was carried out lasting for 192 h, 264 h and 360 h. Fermentation broth temperature of 35° C and feed concentration between 10-61 g L^{-1}.	The total flux of the polydimethylsiloxane (PDMS) membrane: 350 g m^2 h^{-1}-600 g m^2 h^{-1}.	Fan et al. [49].
Pervaporation.	PDMS membranes. 3 %wt. ethanol in the feed mixture, The feed flow rate and temperature were 20 L h^{-1} to 80 L h^{-1} and 22 °C, respectively, with a permeate pressure of less than 5 mmHg.	The mass flux of permeate, enrichment factor and permeate concentration achieved by authors were 5.85 g m^{-2} h^{-1}, 8.8, 18.18 %wt, respectively.	Bello et al. [50].
Pervaporative dehydration.	PVA and methylated silicium membrane. Feed concentration of 94% wt, permeate pressure of 300 Pa and 60°C.	Ethanol flux: 0.27 and 1.65 kg m^{-2} s^{-1} for PVA and methylated silicium, respectively.	Moussa et al. [51].
Pervaporative dehydration.	Chitosan-Alginate/PES membranes. Feed concentration: 95.5 %wt.	99.6 %wt.	Asih et al. [52].

Pervaporation.	polyamide thin-film composite membranes (10.24 cm^2, effective area) with modified polyacrylonitrile. Feed conditions: 90 wt% aqueous ethanol solution at 25 °C	99.5 wt%	Huang et al. [53].
Vapor phase dehydration (dehydration column).	Dehydration of ethanol was conducted on dehydration column with a length of 30 cm and a diameter of 2 inches.	Above 99% wt.	Krido et al. [54].
Pervaporation dehydration.	Ultrathin zeolite X membranes (3.14 cm^2). 90/10 %wt. ethanol/water mixture by pervaporation at 40-65 °C, permeate side pressure between 0.7-1.2 kPa and flow rate of 0.7 dm^3 min^{-1}.	Total flux of 3.37 ± 0.08 kg m^{-2} h^{-1} and a separation factor of 296 ± 4.	Zhou et al. [55].
Adsorption.	1 ml of the azeotrope ethanol water mixture was added to 0.3 g of zeolite Na-A in 1.5 mL vial with a contact time of 1 h.	The maximum water adsorption capacity was 100 mg of water for 1 g of adsorbent used.	Abdullah et al. [56].
Purification via dehydration.	Natural clinoptilolite phase dehydration using natural zeolite (clinoptilolite). Feed with 96% (v/v) initial ethanol concentration. 10.7 °C, 4.9 bar and 8 mL/min for liquid temperature, pressure and flow rate, respectively.	99.9% (v/v).	Karimi et al. [57].
Regenerable molecular sieve.	Ethanol initial concentrations between 90-95 wt%. and 100 min of adsorption.	93.62-97.71 wt%	Chen et al. [58].
Distillation and either adsorption or pervaporation.	Distillation: fermented liquid containing ethanol 6-12% (v/v). During distillation process (5.5 h), cooler water was always flowed into cooler to keep the temperature at 79 °C. Adsorption: zeolite 3A and the bioethanol resulted from distillation unit with the concentration of 90-95%. Pervaporatión: the bioethanol was pumped to the membrane module. The pressure in permeate side was adjusted at 6 mbar. After the operating condition was achieved, the process was operated for 2 hours.	Higher than 99%.	Kusmiyati and Susanto [59].
Adsorption.	Feeds containing 80-95 %wt ethanol at 90-110 °C and 136-243 kPa	99 %wt	Ranjbar et al. [60]
Pressure Swing Adsorption (PSA).	87.0 %wt ethanol.	99.5 wt%	Jeong et al. [61].

3. Process integration in bioethanol production

Sharifah Soplah Syed Abdullah, Yoshihito Shirai, Ahmad Amiruddin Mohd Ali, Mahfuzah Mustapha and Mohd Ali Hassan, evaluated the production of bioethanol from petiole sugars of the oil palm within an integrated palm biomass biorefinery, obtaining that for 33.9 million liters/year of bioethanol production, the specific cost of production Of bioethanol is estimated at $ 0.52 / l, and bioethanol produced from sugarcane ranges between $ 0.31-0.34 / l and that from other lignocellulosic wastes between $ 0.49-0, 60/l [1]. Jegannathan Kenthorai Raman and Edgard Gnansounou evaluated ethanol production using Aspen Plus and Aspen Process Economic Analyzer through a techno-economic analysis based on four lignocellulosic residues, sugarcane bagasse, coffee cut-stems, rice husks and empty fruit bunches in Colombia. They found that the empty fruit bunches show the highest ethanol yield (313.83 L/t) and the rice husk (250.56 L/t). On the other hand, the economic analysis showed that the cost of production of ethanol with empty fruit bunches was the lowest with (0.49 US $/L) and without (0.58 US $/L) of cogeneration scheme [2]. Table 3 shows the advances in mass and energy integration processes.

Table 3.Advances in mass and energy integration processes for bioethanol production

Approach	Conditions	Important conclusions	References
The bioethanol production from oil palm frond (OPF) petiole sugars within an integrated palm biomass biorefinery was carried out	The integrated biorefinery will be located at one of the 4 mills.	The specific production cost of bioethanol is estimated at $ 0.52/l bioethanol.	[61]
The ethanol production was evaluated using Aspen Plus and Aspen Process Economic Analyzer carrying out the simulation and the economic evaluation, respectively.	The ethanol production cost was assessed for the standalone ethanol plant and the ethanol plant coupled with a cogeneration system	Ethanol production cost using Empty fruit bunches was the lowest with (0.49 US$/L) and without (0.58 US$/L) cogeneration scheme.	[62]
A hierarchical four-level approach to determine economic potential that includes input/output structure, process flow structure, heat integration (HI), and economic feasibility.	-A bioethanol plant with a production of 30.2 t/d.	The heating energy was reduced considerably by heat integration. The value of bioethanol was estimated at $0.8–$1.3/kg.	[63]
A hierarchical four level economic potential approach for: bioethanol and jet fuel by bioconversion, combined heat and power via gasification, the heat integration (HI), and the economic feasibility.	Three energy conversions from 400 t/d wet to empty fruit bunches.	The biooil hydrocarbon plant is most economical due to the highest economic potential.	[64]
Integration of flows, materials and energy of oil extracted from fresh fruit bunches as raw material for the production of biodiesel and bioethanol	Ethanol production in situ	A reduction in unit energy costs down to 3.4%, whereas the material and energy integration leaded to 39.8% decrease of those costs.	[65]
To used computational fluid dynamics and an integrated system.	-Mass fractions of 0%, 10%, 25% and 50% to hydrothermally treatment.	Low energy consumption during coal drying and hydrothermally treatment of	[66]

	- To evaluated coal drying, hydrothermally treatment of Empty fruit bunches, cofiring, and power generation	Empty fruit bunches can be achieved.	
An improved process integration technology that includes: drying, gasification and combined cycle processes for the use of Empty fruit bunches	Used a fluidized bed dryer with superheated steam as the main evaporator.	The integrated drying can further reduce the energy consumption in drying up to about 30% compared to a standalone drying process employing exergy recovery.	[67]
To investigate the economic convenience of supercritical water gasification technology applied to a potential industrial case study with Aspen plus 7.2	The feedstock is 35 Mg/h of empty fruit bunches.	The results show a great benefit of the purposed solutions and their environmental sustainability.	[68]
Innovative design of production of crude palm oil and palm oil based on process integration technology	Considered a conventional boiler based cogeneration system and an internal combustion engine based cogeneration system.	The significant energy surplus in both processes	[69]
The unit operations are simulated using commercial software, Aspen Plus V7.1, which is a standard process simulation tool and has been widely adopted to simulate biomass CHP (Combined Heat and Power) systems.	In the first stage of pretreatment process, the sago biomass is fed to a pretreatment reactor and mixed with diluted sulphuric acid (18 mg acid/dry g of biomass) that catalysis the hydrolysis reaction at a temperature of 158 °C. High pressure (13 bar) steam is used in this stage to maintain the temperature.	By using combined biomass in the integrated SBB with onsite enzyme production and making use of existing man power its economic performance can be improved (6.6 years of payback period).	[70]
The diluted acid was selected for pretreatment stage of sugarcane bagasse and three bioethanol production topologies were simulated through ASPEN PLUS™	Saccharification/fermentation: 101.325 kPa, 321 K, Cellulase enzyme 20 FPU/g cellulose/101.325 KPa, 303 K *S. Cervisiase.* Purification: molecular sieves	Designs of heat exchange network for thermal integration of the process were used to reduce the consumption of natural resources, reduce operating cost, and enhance environmental performance.	[71]
The biorefinery used in this work is the process for first and second generation (1G/2G) ethanol and bioelectricity production	Hydrothermal pretreatment consists in contact of lignocellulosic	Presented results indicate that energy integration provided considerable reduction in energy consumption and consequently in operating costs of the plant for all evaluated scenarios.	[72]
The application of a linear programming (LP) cooperative game model to allocate benefits that accrue from interplant integration	A case study of the literature and the results are compared to those determined through alternative techniques of cooperative play with two	The model allowsto determine the optimum configuration and the distribution of benefits in a single step.	[73]

in an Eco industrial park	industrial case studies on the integration of interplants in the palm based biomass processing complex and sago-based biorefinery (SBB).		
Extractive dividing-wall column and pressure swing adsorption processes for bioethanol recovery/purification are simulated in Aspen HYSYS v8.2	-The realistic feed stream of 10 wt% ethanol, 89.9 wt% water and 0.1 wt% carbon dioxide. -Pressure swing adsorption process involves distillation for removing most of water, before dehydration by pressure swing adsorption	Pressure swing adsorption process has 33% lower cost of manufacture per unit product than extractive dividing-wall column process.	[74]
To simulations of an autonomous distillery were carried out, along with utilities demand optimization using Pinch Analysis concepts with the use of the commercial software UniSim Design.	-Pressure 80 bar -Temperature 510°C -The next system: a traditional Rankine Cycle and a Biomass Integrated Gasification Combined Cycle	The use of thermal integration techniques allows a reduction of the steam process and consequently produces more bagasse surplus or increases the excess electricity	[75]
The second-generation ethanol modelled through a process simulation developed in the software Aspen Plus environment and performed an analysis of the conversion technologies in terms of yield, efficiency, feedstock and level of process integration.	Efficient hexose and pentose fermentation -Enzyme strain development and solid co-product valorization for process heat and power generation. A production capacity of about 40,000 t ethanol/y for the plant. and total energy input of 108 MW, 36 MW.	The net process energy efficiency is calculated in the range from 35% to 37%	[76]
A computational tool developed within an equation-oriented process simulator that couples the simulation of first and second-generation bioethanol production with a global optimization algorithm	Sugarcane bagasse is already used mainly for supplying electric and thermal energy to the process itself	The production of second generation ethanol increases thermal demands in at least 25%. The electric power surplus is diminished in at least 31%	[77]
Aspen Plus was used to investigate the energy requirement of a configuration of double-effect forward-integrated columns and response surface methodology was applied to optimize the process and analyze some operating parameters	An extra stripping section to reduce the risk of fouling in the process. Multicomponent mixture in the process.	Utility costs were 30.9% in the former design and 32.4% in the latter	[78]
A bioethanol integration based on mass pinch analysis for the analysis and design of product exchange networks formed in	The combination of analytical-graphical and cost-benefit analysis for facilitate the whole bioethanol based biorefinery. A biorefinery producing	Integrated bioethanol exchange networks are effective in preventing significant loss of revenue in the processes involved	[79]

biorefinery pathways featuring a set of processing units producing or utilizing bioethanol.	bioethanol from wheat with arabinoxylan (AX) co-production using bioethanol for AX precipitation.		
An analysis for the separation process in bioethanol production incorporating mass and energy integration where, energy integration used SYNHEAT optimization model and for the mass integration process a direct recycle strategy	Optimized azeotropic separation processes in conjunction with process integration. Utility cost savings, energy requirement savings, and increased area of the sequences with mass and energy integration for a best bioethanol separation process	-The conventional sequence had savings of 16.75 % in utility costs and 96 % of mass integration of solvent, and to the optional sequence OSS-EI-III had savings of 5.48 % in utility costs due to energy integration and mass integration of 97 % solvent	[80]
A hybrid thermal integration scheme is proposed for a pressure-swing distillation column by combining an internally heat integrated distillation column with vapor recompression column	The pressure-swing distillation is a conventional standalone. The two performance indexes for the estimated, namely energy consumption and total annual cost.	The hybrid integrated thermal internal distillation column configuration showing a promising performance from the standpoint of energy (82.88%), utility cost (64.05%) and savings (22.16%)	[81]
To evaluate the reduction of process steam demand and water usage obtained through heat integration and an exergy analysis to quantify the reduction in irreversibility generation owing to heat integration procedure using the software Aspen Plus and pinch method.	Two cases of study: Case I: all sugarcane juice is destined to produce ethanol. Case II: 50% sugar production and 50% ethanol production.	The heat integration was reduced in terms of the steam consumption in 35%. The reduction in water consumption was 24% and 13% compared to conventional cases without heat integration.	[82]

Acknowledgments

The authors recognized to the University of Cartagena for providing the bibliographic databases for the development of this review article.

References

1. M. S. Siti Aisyah, Y. Uemura, and S. Yusup, "The Effect of Alkaline Addition in Hydrothermal Pretreatment of Empty Fruit Bunches on Enzymatic Hydrolysis Efficiencies," *Procedia Chem.*, vol. 9, pp. 151–157, 2014.
2. S. Kim and C. H. Kim, "Bioethanol production using the sequential acid/alkali-pretreated empty palm fruit bunch fiber," *Renew. Energy*, vol. 54, pp. 150–155, 2013.
3. M. M. Ishola, Isroi, and M. J. Taherzadeh, "Effect of fungal and phosphoric acid pretreatment on ethanol production from oil palm empty fruit bunches (OPEFB)," *Bioresour. Technol.*, vol. 165, no. C, pp. 9–12, 2014.
4. Y. H. Jung, I. J. Kim, J. I. Han, I. G. Choi, and K. H. Kim, "Aqueous ammonia pretreatment of oil palm empty fruit bunches for ethanol production," *Bioresour. Technol.*, vol. 102, no. 20, pp. 9806–9809, 2011.
5. Y. H. Jung, I. J. Kim, H. K. Kim, and K. H. Kim, "Dilute acid pretreatment of lignocellulose for whole slurry ethanol fermentation," *Bioresour. Technol.*, vol. 132, pp. 109–114, 2013.
6. D. Carrillo-Nieves, L. Zumalacárregui-de-Cárdenas, R. Franco-Rico, and I. Sarvari-Horvath, "Kinetic of biogas production from oil palm empty fruit bunches," *Dyna*, vol. 81, no. 187, pp. 96–101, 2014.
7. M. Misson, R. Haron, M. F. A. Kamaroddin, and N. A. S. Amin, "Pretreatment of empty palm fruit bunch for production of chemicals via catalytic pyrolysis," *Bioresour. Technol.*, vol. 100, no. 11, pp. 2867–2873, 2009.
8. A. Kristiani, N. Effendi, Y. Aristiawan, F. Aulia, and Y. Sudiyani, "Effect of Combining Chemical and Irradiation Pretreatment Process to Characteristic of Oil Palm's Empty Fruit Bunches as Raw Material for Second Generation Bioethanol," *Energy Procedia*, vol. 68, pp. 195–204, 2015.
9. S. Chiesa and E. Gnansounou, "Use of empty fruit bunches from the oil palm for bioethanol production: A thorough comparison between dilute acid and dilute alkali pretreatment," *Bioresour. Technol.*, vol. 159, pp. 355–364, 2014.
10. J. D. C. Medina, A. Woiciechowski, A. Z. Filho, P. S. Nigam, L. P. Ramos, and C. R. Soccol, "Steam explosion pretreatment of oil palm empty fruit bunches (EFB) using autocatalytic hydrolysis: A biorefinery approach," *Bioresour. Technol.*, vol. 199, pp. 173–180, 2016.
11. J. D. Coral Medina *et al.*, "Biological activities and thermal behavior of lignin from oil palm empty fruit bunches as potential source of chemicals of added value," *Ind. Crops Prod.*, vol. 94, pp. 630–637, 2016.
12. A. A. Kamoldeen, C. K. Lee, W. N. Wan Abdullah, and C. P. Leh, "Enhanced ethanol production from mild alkali-treated oil-palm empty fruit bunches via co-fermentation of glucose and xylose," *Renew. Energy*, vol. 107, pp. 113–123, 2017.
13. M. J. Lau, M. W. Lau, C. Gunawan, and B. E. Dale, "Ammonia fiber expansion (AFEX) pretreatment, enzymatic hydrolysis, and fermentation on empty palm fruit bunch fiber (EPFBF) for cellulosic ethanol production," *Appl. Biochem. Biotechnol.*, vol. 162, no. 7, pp. 1847–1857, 2010.
14. M. Han, Y. Kim, S. W. Kim, and G. W. Choi, "High efficiency bioethanol production from OPEFB using pilot pretreatment reactor," *J. Chem. Technol. Biotechnol.*, vol. 86, no. 12, pp. 1527–1534, 2011.
15. R. J. Bouza, Z. Gu, and J. H. Evans, "Screening conditions for acid pretreatment and enzymatic hydrolysis of empty fruit bunches," *Ind. Crops Prod.*, vol. 84, pp. 67–71, 2016.
16. F. Fahma, S. Iwamoto, N. Hori, T. Iwata, and A. Takemura, "Isolation, preparation, and characterization of nanofibers from oil palm empty-fruit-bunch (OPEFB)," *Cellulose*, vol. 17, no. 5, pp. 977–985, 2010.
17. Y. Piñeros-Castro and M. Velásquez-Lozano, "Biodegradation kinetics of oil palm empty fruit bunches by white rot fungi," *Int. Biodeterior. Biodegrad.*, vol. 91, pp. 24–28, 2014.
18. W. N. N. Wan Omar and N. A. S. Amin, "Multi response optimization of oil palm frond pretreatment by ozonolysis," *Ind. Crops Prod.*, vol. 85, pp. 389–402, 2016.
19. L. Tan *et al.*, "Pretreatment of empty fruit bunch from oil palm for fuel ethanol production and proposed biorefinery process," *Bioresour. Technol.*, vol. 135, pp. 275–282, 2013.
20. L. Tan *et al.*, "Bisulfite pretreatment changes the structure and properties of oil palm empty fruit bunch to improve enzymatic hydrolysis and bioethanol production," *Biotechnol. J.*, vol. 10, no. 6, pp. 915–925, 2015.

21. L. Tan *et al.*, "Fractionation of oil palm empty fruit bunch by bisulfite pretreatment for the production of bioethanol and high value products," *Bioresour. Technol.*, vol. 200, pp. 572–578, 2016.
22. S. X. Chin, C. H. Chia, S. Zakaria, Z. Fang, and S. Ahmad, "Ball milling pretreatment and diluted acid hydrolysis of oil palm empty fruit bunch (EFB) fibres for the production of levulinic acid," *J. Taiwan Inst. Chem. Eng.*, vol. 52, pp. 85–92, 2015.
23. S. O-Thong, K. Boe, and I. Angelidaki, "Thermophilic anaerobic co-digestion of oil palm empty fruit bunches with palm oil mill effluent for efficient biogas production," *Appl. Energy*, vol. 93, pp. 648–654, 2012.
24. A. S. Baharuddin *et al.*, "Selective component degradation of oil palm empty fruit bunches (OPEFB) using high-pressure steam," *Biomass and Bioenergy*, vol. 55, pp. 268–275, 2013.
25. Nurfahmi, H. C. Ong, B. M. Jan, C. W. Tong, H. Fauzi, and W. H. Chen, "Effects of organosolv pretreatment and acid hydrolysis on palm empty fruit bunch (PEFB) as bioethanol feedstock," *Biomass and Bioenergy*, vol. 95, pp. 78–83, 2016.
26. D. Piarpuzán, J. A. Quintero, and C. A. Cardona, "Empty fruit bunches from oil palm as a potential raw material for fuel ethanol production," *Biomass and Bioenergy*, vol. 35, no. 3, pp. 1130–1137, 2011.
27. F. B. Ahmad, Z. Zhang, W. O. S. Doherty, V. S. J. Te'o, and I. M. O'Hara, "Improved microbial oil production from oil palm empty fruit bunch by Mucor plumbeus," *Fuel*, vol. 194, pp. 180–187, 2017.
28. R. Yunus, S. F. Salleh, N. Abdullah, and D. R. A. Biak, "Effect of ultrasonic pre-treatment on low temperature acid hydrolysis of oil palm empty fruit bunch," *Bioresour. Technol.*, vol. 101, no. 24, pp. 9792–9796, 2010.
29. T. Y. Ying, L. K. Teong, W. N. W. Abdullah, and L. C. Peng, "The Effect of Various Pretreatment Methods on Oil Palm Empty Fruit Bunch (EFB) and Kenaf Core Fibers for Sugar Production," *Procedia Environ. Sci.*, vol. 20, pp. 328–335, 2014.
30. S. Kim, J. M. Park, J. W. Seo, and C. H. Kim, "Sequential acid-/alkali-pretreatment of empty palm fruit bunch fiber," *Bioresour. Technol.*, vol. 109, pp. 229–233, 2012.
31. H. Jeon *et al.*, "Production of anhydrous ethanol using oil palm empty fruit bunch in a pilot plant," *Biomass and Bioenergy*, vol. 67, pp. 99–107, 2014.
32. T. C. Coelho, O. Souza, N. Sellin, S. H. W. Medeiros, and C. Marangoni, "Analysis of the reflux ratio on the batch distillation of bioethanol obtained from lignocellulosic residue," *Procedia Eng.*, vol. 42, no. August, pp. 131–139, 2012.
33. M. Tomaszewska and L. Białończyk, "Ethanol production from whey in a bioreactor coupled with direct contact membrane distillation," *Catal. Today*, vol. 268, pp. 156–163, 2016.
34. M. Tomaszewska and L. Bia, "Production of ethanol from lactose in a bioreactor integrated with membrane distillation," pp. 1–6, 2013.
35. M. Barancewicz and M. Gryta, "Ethanol production in a bioreactor with an integrated membrane distillation module," *Chem. Pap.*, vol. 66, no. May 2011, pp. 85–91, 2012.
36. G. Lewandowicz, W. Białas, B. Marczewski, and D. Szymanowska, "Application of membrane distillation for ethanol recovery during fuel ethanol production," *J. Memb. Sci.*, 2011.
37. D. Woldemariam, A. Kullab, E. U. Khan, and A. Martin, "Recovery of ethanol from scrubber-water by district heat-driven membrane distillation: Industrial-scale technoeconomic study," *Renew. Energy*, pp. 1–11, 2017.
38. M. M. A. Shirazi, A. Kargari, and M. Tabatabaei, "Sweeping Gas Membrane Distillation (SGMD) as an Alternative for Integration of Bioethanol Processing: Study on a Commercial Membrane and Operating Parameters," *Chem. Eng. Commun.*, 2015.
39. Q. Zhang *et al.*, "Ethanol production by modified polyvinyl alcohol-immobilized Zymomonas mobilis and in situ membrane distillation under very high gravity condition," *Appl. Energy*, vol. 202, pp. 1–5, 2017.
40. L. Zhang, Y. Wang, L. H. Cheng, X. Xu, and H. Chen, "Concentration of lignocellulosic hydrolyzates by solar membrane distillation," *Bioresour. Technol.*, vol. 123, pp. 382–385, 2012.
41. U. M. García-Ventura, F. O. Barroso-Muñoz, S. Hernández, and A. J. Castro-Montoya, "Experimental study of the production of high purity ethanol using a semi-continuous extractive batch dividing wall distillation column," *Chem. Eng. Process. Process Intensif.*, vol. 108, pp. 74–77, 2016.

42. S. Navarrete-Contreras, M. Sánchez-Ibarra, F. O. Barroso-Muñoz, S. Hernández, and A. J. Castro-Montoya, "Use of glycerol as entrainer in the dehydration of bioethanol using extractive batch distillation: Simulation and experimental studies," *Chem. Eng. Process. Process Intensif.*, vol. 77, pp. 38–41, 2014.
43. J. ángel Pacheco-Basulto *et al.*, "Purification of bioethanol using extractive batch distillation: Simulation and experimental studies," *Chem. Eng. Process. Process Intensif.*, vol. 61, pp. 30–35, 2012.
44. J. Niemistö, A. Pasanen, K. Hirvelä, L. Myllykoski, E. Muurinen, and R. L. Keiski, "Pilot study of bioethanol dehydration with polyvinyl alcohol membranes," *J. Memb. Sci.*, vol. 447, pp. 119–127, 2013.
45. C. Fu *et al.*, "Ethanol fermentation integrated with PDMS composite membrane: An effective process," *Bioresour. Technol.*, vol. 200, pp. 648–657, 2016.
46. H. J. Lee, E. J. Cho, Y. G. Kim, I. S. Choi, and H. J. Bae, "Pervaporative separation of bioethanol using a polydimethylsiloxane/polyetherimide composite hollow-fiber membrane," *Bioresour. Technol.*, vol. 109, pp. 110–115, 2012.
47. S. Yi and Y. Wan, "Separation performance of novel vinyltriethoxysilane (VTES)-g-silicalite-1/PDMS/PAN thin-film composite membrane in the recovery of bioethanol from fermentation broths by pervaporation," *J. Memb. Sci.*, vol. 524, no. July 2016, pp. 132–140, 2017.
48. S. Fan, Z. Xiao, and M. Li, "Energy efficient of ethanol recovery in pervaporation membrane bioreactor with mechanical vapor compression eliminating the cold traps," *Bioresour. Technol.*, vol. 211, pp. 24–30, 2016.
49. R. H. Bello, O. Souza, N. Sellin, S. H. W. Medeiros, and C. Marangoni, "Effect of operating variables on the pervaporation of ethanol produced by lignocellulosic residue," *Procedia Eng.*, vol. 42, no. August, pp. 512–520, 2012.
50. M. Moussa, V. Athès, Y. Imbert, I. Souchon, O. Vitrac, and M. L. Lameloise, "Pervaporative dehydration of bioethanol using silica and PVA membranes: Analysis of permeation performances and effect of volatile organic impurities," *Procedia Eng.*, vol. 44, pp. 1173–1176, 2012.
51. M. A. Pratiwi, R. W. Sudrajat, S. Sutanti, and H. Susanto, "Preparation of Chitosan-Alginate/PES Pervaporation Membranes for Bioethanol Dehydration," *Adv. Mater. Res.*, vol. 1123, pp. 182–186, 2015.
52. Y. H. Huang *et al.*, "A study on the characteristics and pervaporation performance of polyamide thin-film composite membranes with modified polyacrylonitrile as substrate for bioethanol dehydration," *Polym. Int.*, vol. 63, no. 8, pp. 1478–1486, 2014.
53. S. K. Wahono, Hernawan, A. Kristiani, S. Tursiloadi, and H. Abimanyu, "Characterization and utilization of gunungkidul natural zeolite for bioethanol dehydration," *Energy Procedia*, vol. 47, pp. 263–267, 2014.
54. H. Zhou, D. Korelskiy, T. Leppäjärvi, M. Grahn, J. Tanskanen, and J. Hedlund, "Ultrathin zeolite X membranes for pervaporation dehydration of ethanol," *J. Memb. Sci.*, vol. 399–400, pp. 106–111, 2012.
55. A. H. Abdullah, N. N. Zulkefli, A. S. Abd Aziz, and R. Mat, "Synthesis of zeolite Na-A from local kaolin for bioethanol purification," *Indian J. Sci. Technol.*, vol. 9, no. 9, 2016.
56. S. Karimi, B. Ghobadian, M. R. Omidkhah, J. Towfighi, and M. Tavakkoli Yaraki, "Experimental investigation of bioethanol liquid phase dehydration using natural clinoptilolite," *J. Adv. Res.*, vol. 7, no. 3, pp. 435–444, 2016.
57. W. C. Chen *et al.*, "Optimizing the efficiency of anhydrous ethanol purification via regenerable molecular sieve," *Appl. Energy*, vol. 135, pp. 483–489, 2014.
58. Kusmiyati and H. Susanto, "Fuel Grade Bioethanol Production from Iles-iles (Amorphophaluscampanulatus) Tuber," *Procedia Environ. Sci.*, vol. 23, no. Ictcred 2014, pp. 199–206, 2015.
59. Z. Ranjbar, M. Tajallipour, C. H. Niu, and A. K. Dalai, "Water removal from ethanol vapor by adsorption on canola meal after protein extraction," *Ind. Eng. Chem. Res.*, vol. 52, no. 40, pp. 14429–14440, 2013.
60. J. seong Jeong, H. Jeon, K. mo Ko, B. Chung, and G. W. Choi, "Production of anhydrous ethanol using various PSA (Pressure Swing Adsorption) processes in pilot plant," *Renew. Energy*, vol. 42, pp. 41–45, 2012.
61. S. S. S. Abdullah, Y. Shirai, A. A. M. Ali, M. Mustapha, and M. A. Hassan, "Case study:

Preliminary assessment of integrated palm biomass biorefinery for bioethanol production utilizing non-food sugars from oil palm frond petiole," *Energy Convers. Manag.*, vol. 108, pp. 233–242, 2016.
62. J. A. Quintero, J. Moncada, and C. A. Cardona, "Techno-economic analysis of bioethanol production from lignocellulosic residues in Colombia: A process simulation approach," *Bioresour. Technol.*, vol. 139, pp. 300–307, 2013.
63. T. X. Do, Y. il Lim, S. Jang, and H. J. Chung, "Hierarchical economic potential approach for techno-economic evaluation of bioethanol production from palm empty fruit bunches," *Bioresour. Technol.*, vol. 189, pp. 224–235, 2015.
64. T. X. Do and Y. Il Lim, "Techno-economic comparison of three energy conversion pathways from empty fruit bunches," *Renew. Energy*, vol. 90, pp. 307–318, 2016.
65. L. F. Gutiérrez, Ó. J. Sánchez, and C. A. Cardona, "Process integration possibilities for biodiesel production from palm oil using ethanol obtained from lignocellulosic residues of oil palm industry," *Bioresour. Technol.*, vol. 100, no. 3, pp. 1227–1237, 2009.
66. A. Darmawan, D. Budianto, M. Aziz, and K. Tokimatsu, "Retrofitting existing coal power plants through cofiring with hydrothermally treated empty fruit bunch and a novel integrated system," *Appl. Energy*, 2017.
67. M. Aziz, P. Prawisudha, B. Prabowo, and B. A. Budiman, "Integration of energy-efficient empty fruit bunch drying with gasification/combined cycle systems," *Appl. Energy*, vol. 139, pp. 188–195, 2015.
68. S. Langè and L. A. Pellegrini, "Economic analysis of a combined production ofhydrogen-energy from empty fruit bunches," *Biomass and Bioenergy*, vol. 59, no. 0, pp. 520–531, 2013.
69. M. Aziz, T. O. Da, and T. K. Ashiwagi, "Design and Analysis of Energy-Efficient Integrated Crude Palm Oil and Palm Kernel Oil Processes," pp. 143–150, 2015.
70. Y. K. Wan, J. Sadhukhan, and D. K. S. Ng, "Techno-economic evaluations for feasibility of sago-based biorefinery, Part 2: Integrated bioethanol production and energy systems," *Chem. Eng. Res. Des.*, vol. 107, pp. 102–116, 2016.
71. K. Ojeda, E. Sánchez, M. El-Halwagi, and V. Kafarov, "Exergy analysis and process integration of bioethanol production from acid pre-treated biomass: Comparison of SHF, SSF and SSCF pathways," *Chem. Eng. J.*, vol. 176–177, pp. 195–201, 2011.
72. C. M. Oliveira, A. J. G. Cruz, and C. B. B. Costa, "Improving second generation bioethanol production in sugarcane biorefineries through energy integration," *Appl. Therm. Eng.*, vol. 109, pp. 819–827, 2016.
73. R. R. Tan, V. Andiappan, Y. K. Wan, R. T. L. Ng, and D. K. S. Ng, "An optimization-based cooperative game approach for systematic allocation of costs and benefits in interplant process integration," *Chem. Eng. Res. Des.*, vol. 106, pp. 43–58, 2016.
74. Y. Y. Loy, X. L. Lee, and G. P. Rangaiah, "Bioethanol recovery and purification using extractive dividing-wall column and pressure swing adsorption: An economic comparison after heat integration and optimization," *Sep. Purif. Technol.*, vol. 149, pp. 413–427, 2015.
75. M. O. S. Dias, M. Modesto, A. V. Ensinas, S. A. Nebra, R. M. Filho, and C. E. V Rossell, "Improving bioethanol production from sugarcane: Evaluation of distillation, thermal integration and cogeneration systems," *Energy*, vol. 36, no. 6, pp. 3691–3703, 2011.
76. G. F. Porzio, M. Prussi, D. Chiaramonti, and L. Pari, "Modelling lignocellulosic bioethanol from poplar: Estimation of the level of process integration, yield and potential for co-products," *J. Clean. Prod.*, vol. 34, pp. 66–75, 2012.
77. F. F. Furlan, C. B. B. Costa, G. de C. Fonseca, R. de P. Soares, A. R. Secchi, A. J. G. da Cruz, and R. de C. Giordano, "Assessing the production of first and second generation bioethanol from sugarcane through the integration of global optimization and process detailed modeling," *Comput. Chem. Eng.*, vol. 43, pp. 1–9, 2012.
78. L. C. B. A. Bessa, M. C. Ferreira, E. A. C. Batista, and A. J. A. Meirelles, "Performance and cost evaluation of a new double-effect integration of multicomponent bioethanol distillation," *Energy*, vol. 63, pp. 1–9, 2013.
79. E. Martinez-Hernandez, J. Sadhukhan, and G. M. Campbell, "Integration of bioethanol as an in-process material in biorefineries using mass pinch analysis," *Appl. Energy*, vol. 104, pp. 517–526, 2013.
80. M. V??zquez-Ojeda, J. G. Segovia-Hern??ndez, and J. M. Ponce-Ortega, "Incorporation of mass and

energy integration in the optimal bioethanol separation process," *Chem. Eng. Technol.*, vol. 36, no. 11, pp. 1865–1873, 2013.

81. B. Kiran and A. K. Jana, "A hybrid heat integration scheme for bioethanol separation through pressure-swing distillation route," *Sep. Purif. Technol.*, vol. 142, pp. 307–315, 2015.
82. E. A. Pina, R. Palacios-Bereche, M. F. Chavez-Rodriguez, A. V. Ensinas, M. Modesto, and S. A. Nebra, "Reduction of process steam demand and water-usage through heat integration in sugar and ethanol production from sugarcane – Evaluation of different plant configurations," *Energy*, 2015.

*****

Extra page Not to be printed.

For your Research References Requirements,

Always log on to =www.sphinxsai.com

International Journal of ChemTech Research

[www.sphinxsai.com]

International Journal of TechnoChem Research

[www.technochemsai.com]

*****