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Techno-Economic Analysis of Integrated Enzyme Assisted Aqueous Extraction of Soybean Oil

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Abstract.

Aqueous oil extraction is a process which replace organic solvent, hexane is most used in solvent extraction, with water. Comparing to typical solvent extraction and expelling processes, the aqueous extraction has higher oil yield (over 80%) than expelling process and that is exempt the issues resulted from chemical loading and remaining. The enzyme was used to improve the breakdown of cell and release free oil. The enzyme assisted aqueous extraction process (EAEP) includes dehulling, flaking, extraction and demulsification processes. SuperPro Designer was used to conduct the techno-economic analysis (TEA) of the extraction process. The total capital investment, operation cost and profits were evaluated. For EAEP extraction, that uses insolubility of water and oil, hence that could extract oil and protein simultaneously which decreases the operation cost especially on oil purification process and increases the profits from main product, soybean oil, and coproduct mainly protein in skim. Additionally, the free chemical loading and enzyme recycling also decrease material costs. Though the facility costs might increase due to extraction and demulsification processing unit, the value-added coproduct and high free oil yield are potential to have economic feasibility in pilot scale production.

Keywords. enzyme assisted aqueous extraction (EAEP), techno-economic analysis (TEA), soybean oil, skim, economic feasibility

Introduction

In industry, the process of oil extraction from oilseeds typically applies organic solvent extraction process such as hexane due to its cost-effectiveness and high yield over 95% (Li et al., 2006, Sekhon et al.,2015). However, that leads to some environmental and operational safety issues. Hence, the well-handled plant is required for the process and that results in high cost in investment. Otherwise, there is still the possibility that solvent could still remain in product which causes food safety and public health problems.

For reducing these substantial environmental and public health issues, aqueous extraction process (AEP) was investigated, which is a solvent-free extraction process uses water as extraction medium and can be used in various oilseeds (Rosenthal et al., 1996, Jung et al.,2009). The APE process is based on the insolubility of oil in the extraction medium rather than its dissolution as in hexane extraction process, which causes the low free oil yield (Johnson & Lucas, 1983, (Wu et al., 2009). The presence of protein forms the emulsion in cream fraction which is the hurdle for recovering free oil, and that is the reason that the promising oil extraction rate is only 60% in the early AEP investigation (Jung et al., 2009). Mass transferring is another critical factor for AEP, the raptured cell wall by extruding or flaking could increase oil extraction to around 71%. However, that is still quite lower than hexane extraction (Wu et al., 2009, Jung & Mahfuz, 2009).

Enzyme-assisted aqueous extraction process (EAEP) is applied mainly in demulsification to increase the final yield as much as 90% by denaturing proteins and destabilzing the cream to release oil (Chabrand & Glatz, 2009, Lamsal et al., 2006). There are several kinds of enzymes have been used depending on different oilseeds and extraction conditions (Yusoff et al., 2015). Moreover, the EAEP could extraction desired products (oil) and co-product (fiber, protein) simultaneously, and there is no need to do post-processing for recovering oil such as degumming process in hexane extraction. For overcoming two major obstacles of solvent-free extraction process, the four stages of EAEP applied in soybean oil extraction was developed by de Moura et al., (2011). That includes (1) mechanical pretreatment (dehulling and soybean flakes by extruding), (2) enzyme assisted aqueous extraction, (3) separation of cream and co-products and (4) demulsification of cream fraction to release free oil. Otherwise, the skim, containing enzyme, was recycled and reused in the extraction process to reduce the cost and increase the yields of oil and value-added coproducts.

According to prior studies based on oil conversion, those models can be regarded as a proper reference for Soybean is the main oil crop in the world, and it takes around 90% of U.S. oilseed production especially Illinois and Iowa (ERS, 2014). According to advantages of EAEP, including environmental friendly process, no additional post processes for oil recovering and simultaneous extraction of co-products, the process has the potential to reduce environmental impacts lower capital investment compared to typical hexane extraction (Lucas et al., 1982). The technology of EAEP was investigated and mentioned as above; however, the techno-economic analysis of EAEP was seldom and not well determined before. Based on the two stages integrated EAEP of soybean oil extraction, the material costs, operation costs, total capital investment are included in this TEA study. Additionally, the feasibility of upscale EAEP is also evaluated in this study according to the assessment of economic factors. As this TEA model for EAEP is built up, that could provide the useful information for soybean biorefinery industry applied in food or even bioenergy production.

Materials and Methods

EAEP Process

The EAEP process mainly includes dehulling, flaking, extrusion, water extraction, emulsification and centrifugation. In this study, the two stages of water extraction was used to improve the oil yield, and the liquid phase from the second stage water extraction was integrated back to the first stage of extraction to reduce the water consumption (Fig. 1).

During the process, the soybean hulls can be separated by aspiration due to its light density property, and sold as animal feeds. Before extraction process, flaking is the essential step to break the cell wall of soybeans and to make substrate porous to improve the accesses for water and enzyme to contact with oil body (Domíguez et al., 1994). Additionally, the further extrusion was used to enhance the action of enzyme on cell components as well, and the extrusion increased the surface area and the susceptibility of protein to enzyme and reduce the stability of the difficult-to-break oil rich emulsion (Lamsal et al., 2006). In extraction process, the insolubility of water and oil was used, and the ratio of solid to liquid is 1:6 (de Moura et al., 2011). After the extraction, the oil in water emulsion was formed, and the demulsification was enhaced by using protease to degrade olesion, which is the lipophilic protein surrounding lipid globules, to facilitate oil release (Rosenthal et al., 1996). The skim from the first extraction and the final insoluble were regarded as coproducts, which can be used in corn based ethanol production.

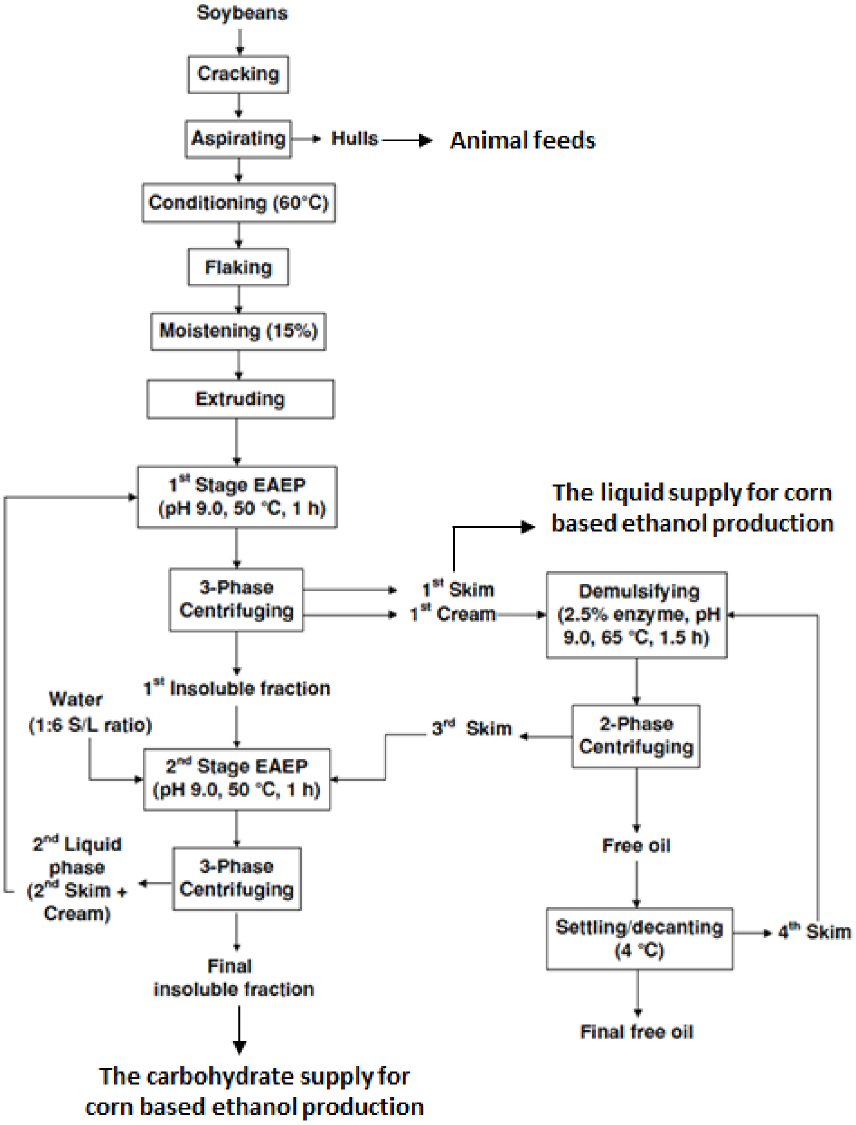

Fig. 1 Diagram of 2 stage EAEP for soybean oil production based on de Moura et al., 2011

Computer Modeling

SuperPro Designer v9.0 (Intelligen, Inc., Scotch Plains, NJ) was applied to conduct the EAEP for soybean oil production. That allows the processing characteristic, equipment and economic parameters to be defined along with conditions, capacity and characteristic for each stream (Ngo et al., 2014, Wood et al., 2014).

Based on the de Moure's research (2011), the 75 kg/hour of soybean input (pilot scale) was used as the base scale with 113.1 thousands kg of soybean oil annual production for scaling up to medium scale (17 million kg annual soybean oil production) and commercial scale (51 million kg annual soybean oil production), and the model is shown in Fig. 2. The model was built for 15 years of service time, 30 months of construction period, 4 months of startup period, 35% income tax and 10 years of depreciation period with 5% salvage value of directed cost (Haas et al., 2006).

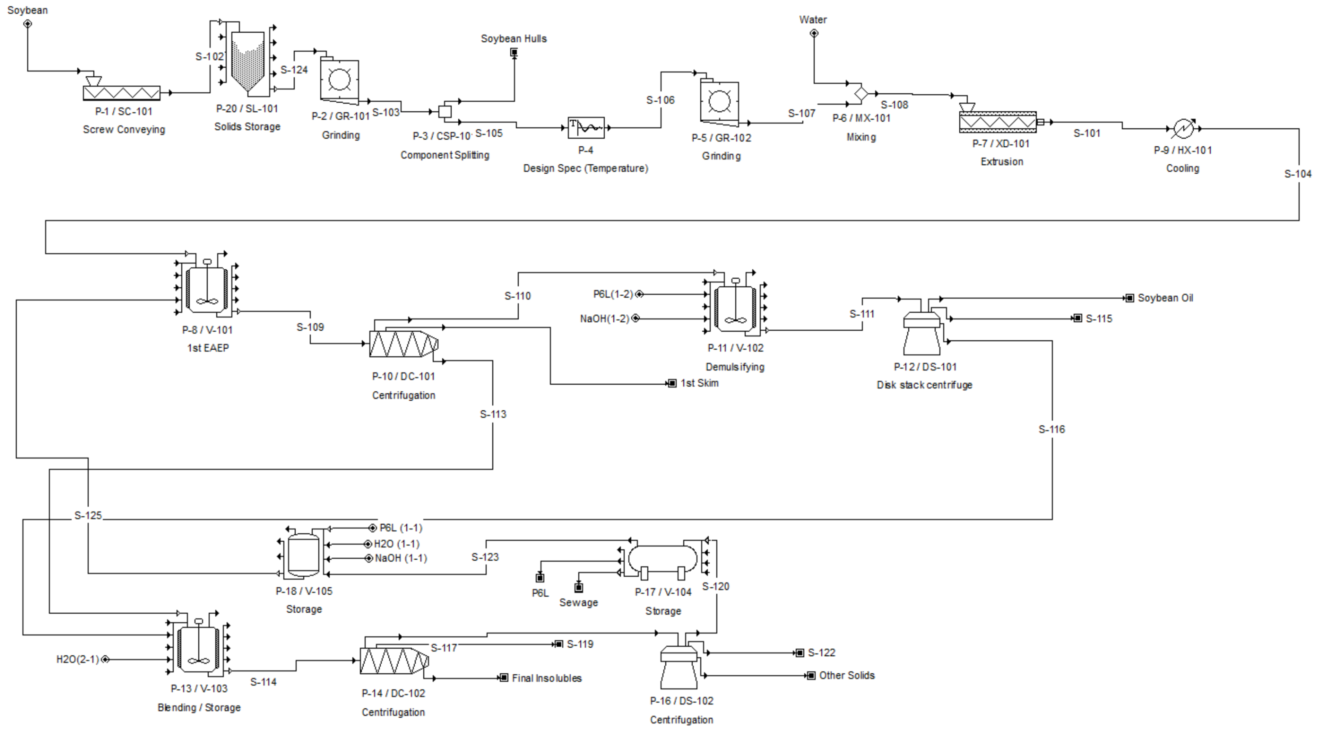

Fig. 2 TEA model of EAEP for soybean oil extraction

Assumptions

Fixed Costs

The fixed cost, which indicates the facility installed for producing stream includes total plant direct cost (TPDC), total plant indirect cost (TPIC), contractor's and contingency fee (CFC), startup cost and working capital which depends on the machine's purchase cost (PC). The purchasing cost of each machine was collected from the inventory record of the Center for Crops Utilization Research pilot Iowa State University (Table 1) and SuperPro designer v9.0 data base, and the 2015 price was calculated by inflation factor following the Eq. 1. Where C_c is the inflation adjusted price of equipment in current year; The C_p is the known cost of equipment in previous year; I_c and I_p are the inflation index factor for current year and previous year individually. Otherwise, the machine PC estimation for capacities scaling up was calculated by Eq. 2 following the power relationship, where PC_p is the machine PC for the predicted capacity, and PC_c is the machine PC of known capacity; n is the power used in estimation which is generally known as the six-tenths rule (n=0.6) (Peters et al., 2011). However, the power (n) varies based on different types of machine, and the estimations of each operating machine are listed in Table 2. Additionally, the machine PC is the basis for estimating the DFC of total producing stream. The TPDC, TPIC and CFC were estimated by multiplying the total machine purchasing price with different multipliers, which were the statistic number from chemical and enzymatic processes (Heinzle et al., 2006) (Table 3).

$$C_c = C_p \times \left(\frac{I_c}{I_p}\right) \qquad Eq. 1$$

$$PC_p = PC_c \times (\frac{q_p}{q_c})^n \qquad Eq. 2$$

Table 1 Purchase prices of main pilot scale machines used in EAEP process

Machine	Purchasing year	Price ($)	2015 Price
Kice, Aspirator	1993	7,748.77	13,000
Cracking roller mill	2000	7,515	10,000
Flaking mill	2000	4,294	5,900
Drive feeder	2002	13,618.97	17,000
Leistritz, Extruder	2001	143,763.33	180,000
3-phase Discanter	2015	128,000	128,000
850 L Tank	1998	18,555.12	26,000

Table 2 Estimation of each machine's price for scaling up based on pilot scale

		Soybean Oil Annual Production (Kg)		
	Power (n)	0.113 Millions	17 Millions	51 Millions
Screw Conveyor*	0.6	1,000	9,000	12,000
Silo/Bin*	0.6	5,000	5,000	5,000
Grinder	N/A	10,000	10,000	10,000
Flake miller	N/A	6,000	6,000	6,000
Aspirator	N/A	13,000	13,000	13,000
Extruder (drive feeder+ extruder)	0.6	197,000	242,000	308,000
Blending Tank I	0.49	26,000	268,000	443,000
Blending Tank II+		13,000	87,000	148,000
Blending Tank III+		16,000	181,000	292,000
3-phase Dicanter I	0.49	128,000	284,000	284,000
3-phase Dicanter II+		83,000	284,000	284,000
Disc-stack centrifuge I*	0.6	120,000	120,000	120,000
Disc-stack centrifuge II*+		104,000	550,000	550,000
Storage Tank*	0.54	26,000	160,000	296,000
Receiving Tank*	0.54	55,000	288,000	348,000
Unlisted equipment*	0.6	201,000	627,000	777,000

*: Data collected from SuperPro v9.0 data base; +: Estimated by power relationship (Eq.2) based on pilot scale; and powers (n) were collected the research of Peters et al., (2011).

Table 3 Fixed cost assumptions for EAEP of soybean oil production

Costs	Categories	Multiplier*
Total Plant Direct Cost	Total Purchase cost (PC)	
(TPDC)	Installation	0.47×TPC
	Process piping	0.68×TPC
	Instrumentation	0.26×TPC
	Insulation	0.08×TPC
	Electrical	0.11×TPC
	Buildings	0.18×TPC
	Yard improvement	0.10×TPC
	Auxiliary facilities	0.55×TPC
	TPDC	2.43×TPC
Total Plant Indirect Cost	Engineering	0.30×TPDC
(TPIC)	Construction	0.35×TPDC
Total Plant Cost (TPC)	TPDC+TPIC	
Contractor's Fee & Contingency	Contractor's fee	0.06×TPC
(CFC)	Contingency	0.08×DFC
Direct Fixed Cost (DFC)	TPC+CFC	
	Working capital	0.15×DFC
	Startup cost	0.05×DFC

Multiplier*: Assumption based on chemical and enzymatic processed (Heinzle et al., 2007)

Operating Costs

In this model, operating costs include raw material cost, labor cost, facility maintenance cost and utilities. Soybean and water are the main resources for EAEP oil extraction, and sodium hydroxide and protex 6L are used in extraction and demulsification processes. Electricity was used as the energy resource; steam and cooling water were used as heat transfer agents in the process. Additionally, the labor costs were also considered in the modeling. The unit cost input of materials, utilities and labor are listed in Table 4.

Table 4 Operating costs inputs (All inputs are 2015 prices)

		Cost	Unit	Citation
Materials	Soybean	0.351	$/kg	USDA ERS (2016)
	Water	0.00079	$/L	City of Ames (2016)
	Sodium hydroxide	20	S/kg	Sigma-Aldrich (2016)
	Protex 6L	19.42	$/kg	ChiralVision (2016)
Utility	Electricity	50.5	cents/kwh	US EIA (2016)
	Steam	12	$/MT	SuperPro data base (2016)
	Cooling water	0.05	$/MT	SuperPro data base (2016)
Labor	Agricultural machine operator	14.9	$/hr	Bureau of labor statistics (2016)
	Extraction worker	22.49	$/hr	Bureau of labor statistics (2016)

For labor costs, the soybean handling processes including cracking, aspiration, tempering, flaking and extrusion were operated by agricultural machine operators; the water extraction, demulsification and oil separation including centrifuging and discanting were operated by extraction workers. The labor requirements for each process equipment were between 0.1-1 (workers/unit/shift) which were as well listed in Table 5, and a shift is 8 hours typically. However, the relationship between labor requirements and the capacity of production is also not linear, and a 0.2-0.25 power of the capacity ratio is typically applied in plant scale-up (Peters, et al., 2011). In this study, a 0.25 power was used for the optimal estimation. Additionally, the laboratory quality control and assurance cost were also considered which were set as 15% of total labor cost (TLC) (Heinzle et al., 2007).

Table 5 Labor requirements for each operating unit (workers/unit/shift)

	Soybean Oil Annual Production (Kg)		
Operating units	0.113 Millions	17 Millions	51 Millions
Conveyor	0.2	0.3	0.3
Silo	1	1	1
Cracking	1	1	1
Aspirating	0.3	0.3	0.3
Flaking	1	1	1
Extrusion	1	3.48	4.57
1st stage extraction	1	3.29	4.26
1st Centrifuging	0.2	0.66	0.85
Demusification	1	2.66	3.34
1st Discanting	0.2	0.36	0.44
2nd stage extraction	1	3.50	4.47
2nd Centrifuging	0.2	0.69	0.84
2nd Discanting	0.2	0.47	0.62
Storage (sewage)	1	3.56	4.16
Storage (skim recycle)	1	3.98	4.39

These labor requirement indexes were set based on different machine (Ulrich, 1984 ,Peters, et al., 2011)

Besides materials, utilities and labor costs, the machine maintenance, insurance and local tax were also included. However, these costs all depended on DFC, and they were estimated as 7%, 1% and 2% of DFC individually for chemical and enzymatic processes (Heinzle et al., 2007).

Revenues

Soybean oil is the main product of the whole process, soybean hulls separated during aspiration is one of the coproduct of the EAEP. Additionally, the skim, generated from centrifugation after the water extraction, could be the material for the integrated cellulose ethanol production as water supply; the final insoluble fraction whose main component is soy fiber can be used as the fiber resources for cellulose ethanol production. Otherwise, the protex 6L was recycled to reduce material cost, and that could also be regarded as a saving credit. Therefore, the skim, final insoluble fraction were considered as the potential coproducts which was able to increase the revenues of whole process, and their selling prices are listed in Table 6.

Table 6 Selling prices of products of EAEP (All inputs are 2015 prices)

Products	Price	Unit	Citation
Soybean oil	0.7	$/kg	USDA ERS (2016)
Soybean hulls	0.21	$/kg	Feedstuffd (1980-2015)
Skim	0.0079	$/L	City of Ames (2016)
Insoluble fraction	0.6	$/kg	Alibaba (2016)
Protex 6L	19.42	$/kg	ChiralVision (2016)

Consequently, according to annual operating costs and annual revenues, the total profits were considered and the gross profit, gross margin percentage could be calculated based on Eq. 3 and Eq. 4. Also the net profit can be calculated including taxes and depreciation (Eq. 5), also investment (ROI) can be calculated based on net profit and total capital investment (Eq. 6).

$$Gross\ Profit = Total\ Revenue - (Total\ operating\ cost - credits) \qquad Eq.3$$

$$Gross\ Margin\ (\%) = \frac{Gross\ profit}{Revenue} \times 100\% \qquad Eq.4$$

$$Net\ Profit = Gross\ profit - Taxes + Depreciation \qquad Eq.5$$

$$Return\ on\ Investment\ (\%) = \frac{Net\ profit}{Total\ capital\ investment} \times 100\% \qquad Eq.6$$

Results and Discussions

Total Capital Investment

Total capital investment can be divided into direct fixed capital (DFC), working capital (WC) and start-up capital (SC). The purchased machine cost (PC) is the basis for total capital investment estimation, and that consists of main machines and unlisted machines, which includes motors, pumps and other auxiliary components. Otherwise, the PS is also the basis for total capital estimation.

Table 7 shows the total capital investment of three scales of EAEP used in soybean production. The total plan direct cost (TPDC) includes installation, processing piping, instrumentation, insulation etc., and they were all estimated by machine purchase price (PC). These items also indicate the multipliers used for the cost estimation cover the instrumentation and control facilities including the labor and auxiliary cost for the establishment of whole production line. For indirect cost, that covers the planning, construction, organization etc. which indicates engineering and construction costs, and the estimations were based on TPDC. Besides direct and indirect costs, the contractor's and contingency fees are required to add to DFC which indicates the additional cost resulted from unexpected event during the project life time (Heinzle et al., 2007). Before the plant starts to come to production stream, the validation processes are essential for all facilities, and that covers process, operation and installation qualification which all goes to start-up cost; moreover, during the start-up period, the consumption of raw materials, energy and consumables are counted as working capital. Therefore, these detailed costs are all covered in the total capital investment.

Table 7 Total capital investment breakdown of three scales of EAEP

Costs	Categories	Soybean Oil Annual Production (Kg)		
		0.113 Millions	17 Millions	51 Millions
Total Plant Direct Cost (TPDC)	Purchase cost (PC)	1,092,000	3,223,000	3,989,000
	Installation	513,000	1,515,000	1,875,000
	Process piping	742,000	2,192,000	2,712,000
	Instrumentation	284,000	838,000	1,037,000
	Insulation	87,000	258,000	319,000
	Electrical	120,000	355,000	439,000
	Buildings	197,000	580,000	718,000
	Yard improvement	109,000	322,000	399,000
	Auxiliary facilities	601,000	1,773,000	2,194,000
	TPDC	3,745,000	11,056,000	13,681,000
Total Plant Indirect Cost (TPIC)	Engineering	1,124,000	3,317,000	4,104,000
	Construction	1,311,000	3,870,000	4,788,000
	TPIC	2,434,000	7,187,000	8,893,000
Total Plant Cost (TPC)	TPDC+TPIC	6,179,000	18,243,000	22,574,000
Contractor's fee and Contingency (CFC)	Contractor's fee	371,000	1,095,000	1,354,000
	Contingency	556,000	1,459,000	2,032,000
Direct Fixed Cost (DFC)	TPC+CFC	7,106,000	20,797,000	25,960,000
Working Capital (WC)		1,066,000	3,120,000	3,894,000
Startup Capital (SC)		355,000	1,040,000	1,298,000
Total Capital	TPC+CFC+WC+SC	8,528,000	24,957,000	31,153,000

According to the results of total capital investment for three scales, TPDC takes the majority of total investment around 45%; TPIC, CFC, WC and SC take around 29%, 11%, 13% and 4% of total capital investment individually. Comparing the total capital investment among these three scales, the capacities were 594,000 kg, 89,100,000kg and 267,300,000 kg of soybean handling with the total capital investment of $8,528,000, $24,957,000 and $31,153,000 respectively. Additionally, the total capital investment has a power of 0.213 relationship with the ratio of capacity scaling up (Fig. 3), and the equation for scaling can be expressed in Eq. 7 where CI_p and CI_i indicate capital investment of predicted capacity and initial capacity individually.

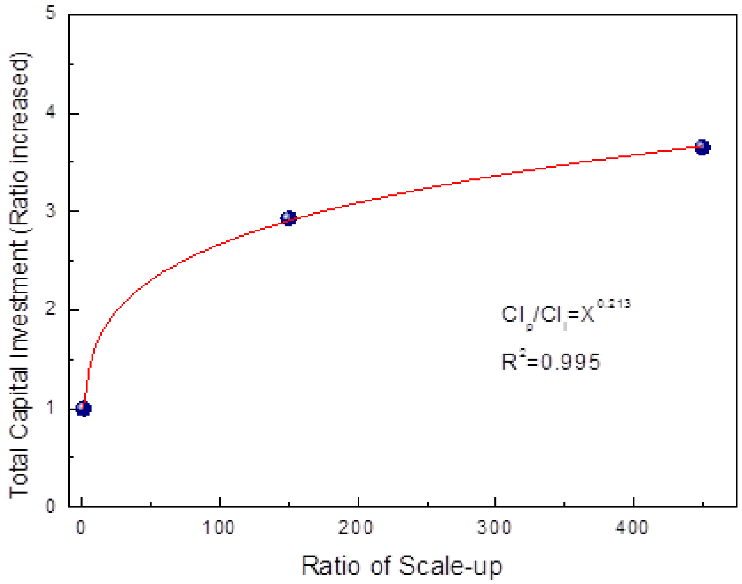

Fig. 3 The power relationship between total capital investment and ratio of scale-up

$$CI_p = CI_i \times \left(\frac{CI_p}{CI_i}\right)^{0.213} \qquad Eq.7$$

Operating Costs

Material, utility, labor related and facility related costs were considered in operating cost. However, the percentages of these costs had changed when the capacity was scaled up. Fig. 4 shows the breakdown of operating cost. In the small scale (0.113 millions), the facility cost took the most among all costs over 65 % which mainly came from facility maintenance fees. Labor and QA/QC costs were another critical resource of costs which almost achieved over 20% of total operating cost; the material was following after. By contrary, as the capacity was scaled up, the material cost had become the major component of operating cost over 80%, and others were below 10%. This results indicates the small capacity is much more facility and labor intense; in other words, the small scale has the least producing efficiency and same amount of labors could handle with more duty in the larger capacity. For material cost, as the capacity gets increased, the more materials are required to product more products. Therefore, the material cost become critical in larger capacity.

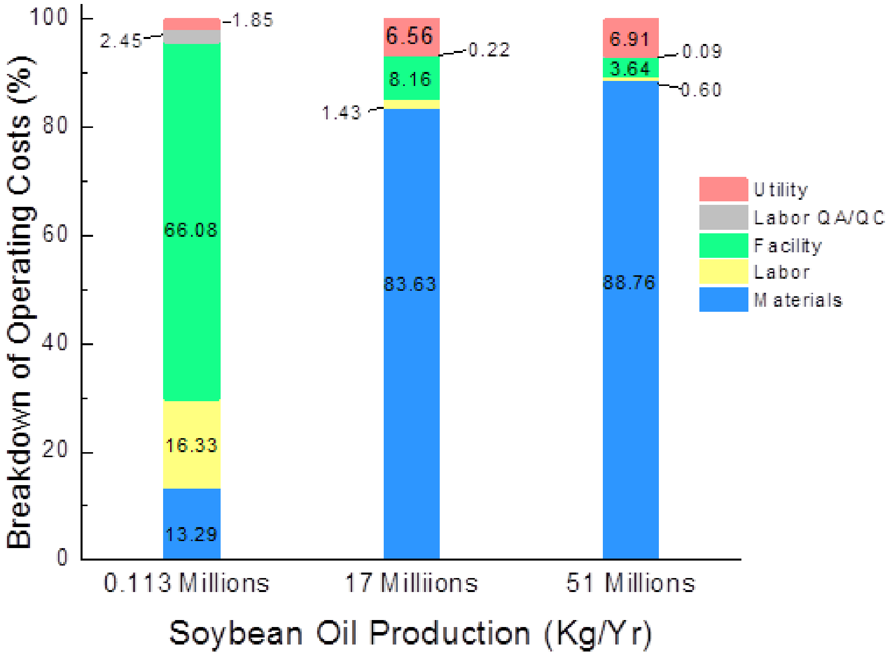

Fig. 4 Breakdown of operating cost

Material Costs

Soybean and water are the main materials in EAEP for soybean oil production, and Protex 6L is the enzyme used to assist oil release. Otherwise, sodium hydroxide was used in pH adjustment during extraction and demulsification processes. The percentage of material usages in whole production stream were 8.17%, 30.68%, 60.45% and 0.7% for sodium hydroxide (10N), Protex 6L, soybean and water respectively. However, due to the different purchased fee of each material, the Protex 6L, which has the highest purchased fee of 19.42.$/kg, took over 30% of total materials cost (Fig. 5).

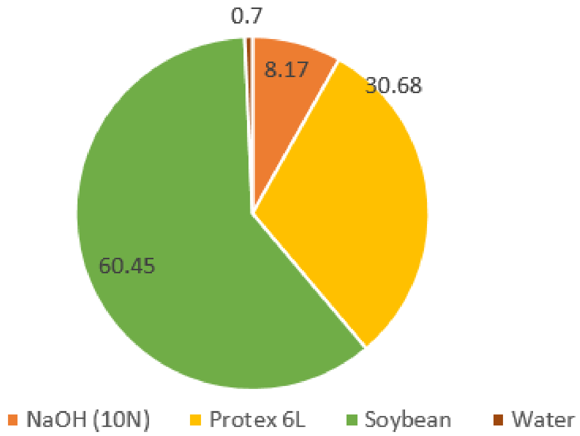

Fig. 5 Breakdown of materials costs (%)

Utility Costs

In utility cost, electricity is the main energy resource to function machines used in the production stream. Steam and cooling water were used as the heat transfer agents especially in evaporation and cooling processes.

Fig. 6 represents the breakdown of utility cost of three scales. From the results, the usage percentage of electricity got decreased as the capacity was scaled though the increment was not obvious. For steam usage, as the capacity increased, the more steam were required during the processing. However, these electricity consumption did not follow the linear relationship as the ratio of capacity scaling up, and there is a power of 0.89 relationship (Eq. 8) between electricity usage and ration of capacity scaling up (Fig. 7). And the U_p and U_i indicate the electricity usages for predicted and initial capacities respectively.

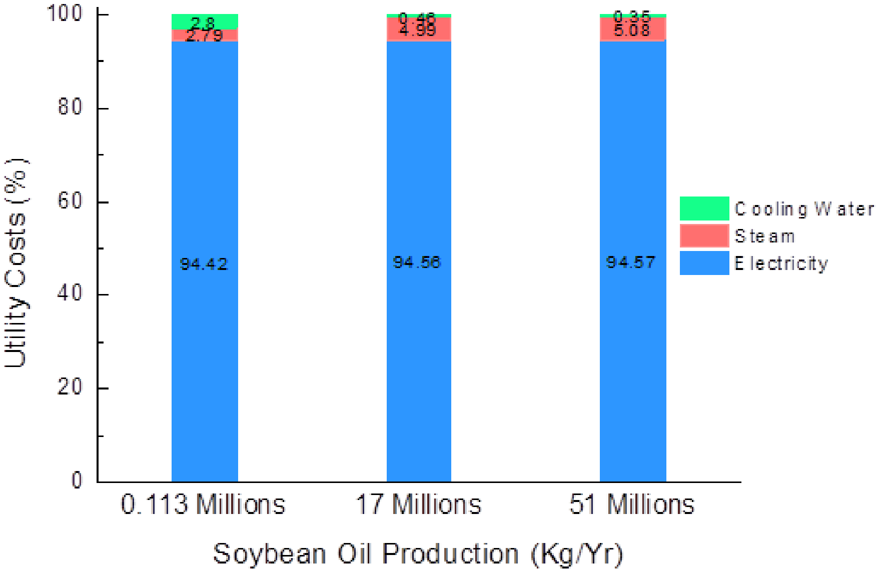

Fig. 6 Breakdown of utility cost

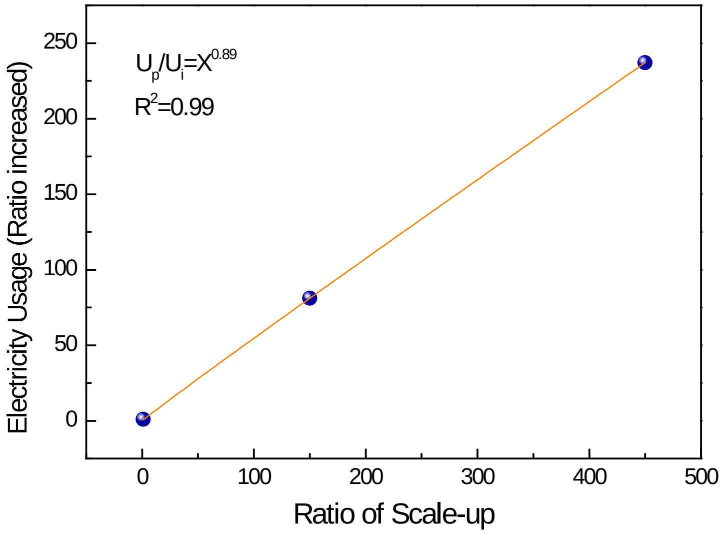

Fig. 7 The power relationship between electricity usage and capacity scaling up

$$U_p = U_i \times \left(\frac{U_p}{U_i}\right)^{0.89} \qquad Eq. 8$$

Labor Costs

In EAEP, that can be divided into two main processes, which were crops handling and extraction. For crops handling, it also can be regarded as the material preparation for the further extraction, and that included crop cleaning, drying, flaking, tempering and extrusion. For extraction, it included water extraction, demulsification and oil separation. Based on the assumption of the modeling, the agricultural machines workers were assigned to the crops handling process; and extraction worker were handling with extraction, demulsification and products separation.

Fig. 8 illustrates the percentage of labor cost in different scale productions. From the results, the agricultural machine workers take over 50% of total labor costs in the small scale production; the extraction workers are the majority of labor costs in larger scale production. This result indicates that as the capacity increased to larger scale, the more extraction workers were required, and it is corresponding to the larger amounts of oil/water emulsion which are handled in larger amounts of oil production. It also reflects the enzyme assisted extraction requires skilled extraction workers reasonably.

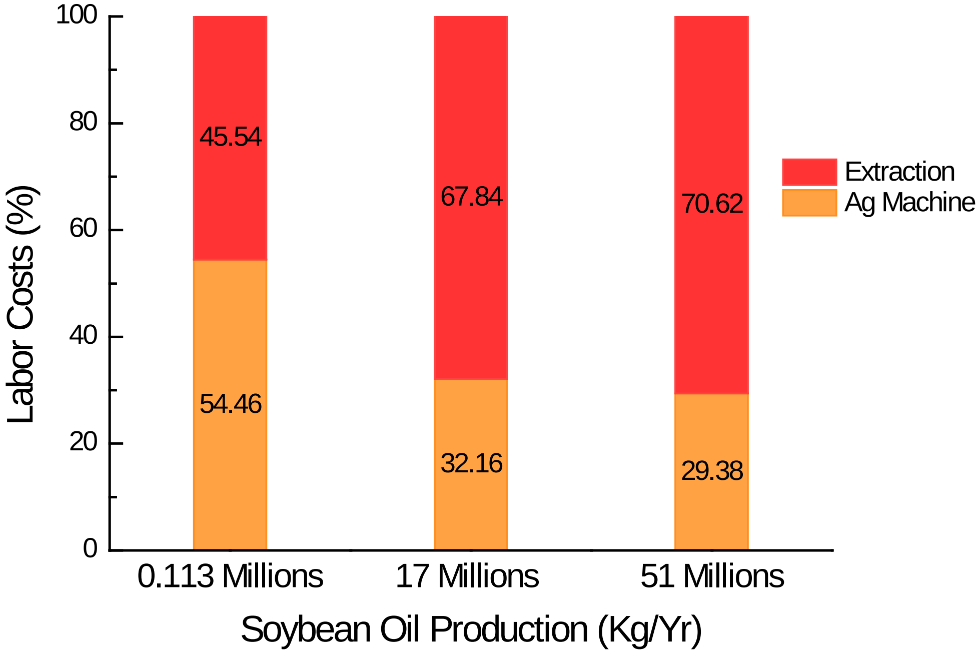

Fig. 8 Breakdown of labor cost

Labor QA/QC ,Facility Costs and Unit Production Cost

For labor QA/QC cost, it were estimated by the total labor cost (TLC) with 15%, and there were $65,000, $134,000 and $158,000 for 0.113, 17 and 51 millions kg of annual soybean oil productions. For Facility cost, it mainly came from machine maintenance fees, and they were $1,741,000 $5,635,000 and $8,437,000 for 0.113, 17 and 51 millions kg of annual soybean oil productions respectively.

Based on fixed, operating costs and the main product (soybean oil) annual production, the unit production costs of these three scales were calculated (Fig. 9). According to the results, the unit cost gets decreased with a power of -0.33 when more soybean oil are produced.

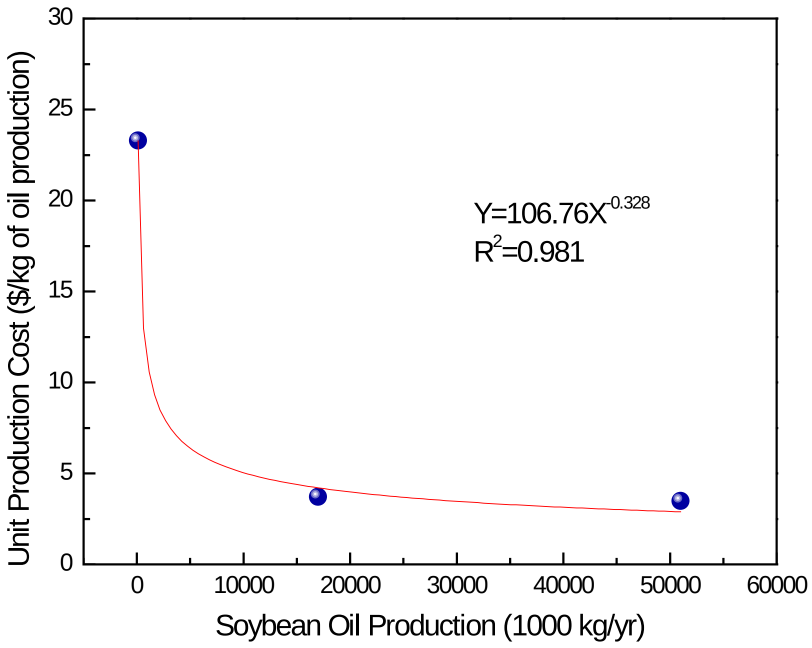

Fig. 9 The power relationship between unit production cost and soybean oil production

Revenues

Main Product and Co-products

Soybean oil is the main product of EAEP, and coproducts included soybean hulls, skim and insoluble fiber. For soybean hulls, it were generated from aspiration process, and it can be sold as animal feeds. For skim and insoluble fiber, based on the assumption of this model, the oil extraction is the part of integrated cellulose ethanol production process, and the skim can be used as water supply and the protein content could help the further cellulose fermentation (Sekhon, 2015); the insoluble fiber can also be reused in the ethanol production. Therefore, these two materials were considered as the coproducts of the EAEP. However, protex 6L were recycled during the process to reduce operating cost; therefore, protex 6L was regarded as credit of whole oil production which is also the saving for the total operating costs.

Table 8 shows the revenues from main product and each coproduct, the percentages in revenue of each product were presented as well. From the results, soybean oil takes around 24% of total revenues; the revenue from insoluble fiber takes over 70% due to it large amounts. Additionally, the coproducts for further integrated cellulose ethanol production take around 74%, skim and insoluble fiber. Therefore, it is obvious to see the oil production process especially using enzyme assisted process can not totally rely on the revenue from oil product. In other words, these co-products make themselves as the incentive for the oil extraction process.

However, the credits from enzyme recycled also reflects the high cost of enzymatic process again. If the enzyme was not recycles and reused, it would lead to high operating cost and it’s pretty difficult to earn the profits from the production line.

Table 8 The revenues of EAEP products (All prices are shown in 2015 value)

		Soybean Oil Annual Production (Kg)		
Revenues	% of total revenues	0.113 Millions	17 Millions	51 Millions
Soybean Hulls	2.46	8,134	1,220,040	3,660,120
Insoluble Fiber	72.83	240,628	36,093,918	1,082,81,086
Soybean Oil	23.84	78,774	11,816,047	35,448,142
Skim	0.87	2,881	432,209	1,296,624
P6L credits	N/A	110,741	16,380,382	47,603,081
Total		330,417	49,562,214	148,685,972

Profits

Profits can be divided into gross profit and net based on Eq.3 and Eq.5. The results are shown in Fig. 10.

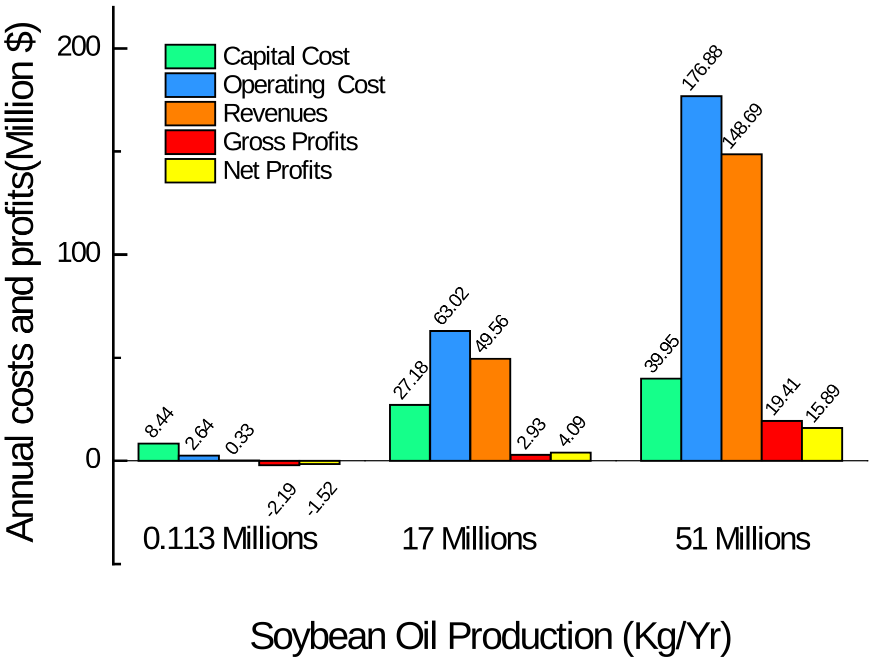

Fig. 10 Gross profit and net profit of EAEP

From the results, 0.113 millions annual oil production scales has negative gross profit, which indicate the production stream is unable to earn profits back to investment; however, the largest capacity is able to earn the profit with recycling all enzyme used in extraction and demulsification processes. Therefore, the small scale of the oil production using enzyme assisted method is quite economic unfeasible. As the scale is increased to commercial scale, the gross and net profit all have positive values, it indicates the production line is potentially profitable and economically feasible. Otherwise, according to these values, the breakeven point is located around 10 millions annual oil production.

Additionally, the gross margin and ROI can be calculated according to profit and capital investment and total revenues (Table 9). The gross margin indicates the ratio between the gross profit and revenue; the ROI represents how the plant earn the investment back. According to the ROI, the payback time can be estimated (Eq. 9), which indicates how many years are required to earn profit back. From the results, that also indicates the 0.113 millions annual oil production is still losing money on the investment; however, the medium scale and the largest scales have the positive ROI, the payback times are 5.9 and 1.9 years individually. These results indicate these two larger production scales have profitable potential due to the shorter payback time within 15 years of service time. And, the production line can start earn profits at the 6th and the 2nd year.

$$Payback\ Time\ = \frac{100}{ROI} \qquad Eq. 9$$

Table 9 Gross margin, ROI and payback time of EAEP

	Soybean Oil Annual Production (Kg)		
	0.113 Millions	17 Millions	51 Millions
Gross Margin (%)	-663.84	7.00	14.45
ROI (%)	-17.81	16.95	52.76
Payback Time (yr)	N/A	5.90	1.90

Conclusion

EAEP is an innovative process of oil extraction. However, the operating is still the main problem to make it into practical production stream. As only the main product, soybean oil, does mainly be relied on, it could merely provide about 24% of total revenues. For improving the economic feasibility of EAEP, it could be regarded as the pretreatment of integrated cellulose ethanol production. Thus, the skim and insoluble fiber can be sold as the materials for further ethanol production to improve the profit of oil extraction process. Otherwise, the application of protex 6L is a critical issue for EAEP because it contributes large proportion of operating costs. Therefore, the recycling is an essential process and it also can be seen as another saving credit of operating costs to make EAEP more feasible in commercial scale operation. From the results of study, the small scale is way too difficult to be applied in the industry; however, the EAEP is the process which has the potential in the commercial scale to combine with further cellulose ethanol production.

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