# THE EFFECT OF MECHANICAL EXPRESSIONS ON RED ALGAE YIELD,

# *KAPPAPHYCUS ALVAREZII* L. DOTY

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## ABSTRACT

Commercial seaweed cultivation has been introduced to numerous parts of the world. Significant research is dedicated to its improvement of cultivation and processing. *Kappaphycus alvarezii*, a macroalgae, has spread throughout Southeast Asia and has been cultivated in many regions. The reliable cash income supports many coastal fishing communities. Separation of the solid-liquid fractions of fresh seaweed may provide additional value to seaweed farmers. Seaweed prices fluctuate due to variations in seaweed quality at the farm level. In addition, seaweed mostly grows better during the rainy season when there is a lack of sunlight to facilitate drying required for trade. If the seaweed can be immediately processed without drying and two products are obtained from liquid and solid separation, it will save space for drying and cost for adding new drying infrastructures. The liquid is used for agriculture fertilizer and the dry cake is used as an aquatic feed additive. Six factors were studied to improve liquid extraction with mechanical expression using a fractional factorial design with two levels. The high levels of factors are coded +1 and lower levels coded as -1. The lower level Comitrol™ blade space (1 mm blade space), low level initial temperature (22 $^{o}C_{)}$, low initial weight (20 gram) and high level final pressure (2800 Pa) gave the highest liquid recovery from *Kappaphycus alvarezii*. Speed of pressing and time held at final pressure had negligible effect on liquid recovery. The economic analyses showed that a 250Mg per year solid liquid processing facility is a profitable investment given a Minimum Attractive Rate of Return of 20%, because the Internal Rate of Return was shown to be 30.23%. An increase of 10% in variable costs over ten years decreases net cash flow (-$100.17); but an increased the selling price of 2.5% restored the IRR to 30.23%.

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# INTRODUCTION

## Background

Seaweed cultivation has been introduced to numerous parts of the world for both commercial purposes and research developments. Red algae *Kappaphycus alvarezii* was first introduced in Hawaii during the 1960s using a wild type from the Philippines (Parker, 1974). This species has since spread and consequently has been cultivated in the Philippines, Brazil, Indonesia, Malaysia, Fiji, Kiribati, and Tanzania. It became a source of livelihood in coastal fishing communities, generating a cash income for more than 1500 fishing families in Indonesia, l80,000 families in the Philippines and 400 families in the Republic of Kiribati (Hurtado et al. 2001); these values have increased since the market demand has grown quickly over time.

Red seaweed (*K. alvarezii*) is a short-term-harvested photosynthetic organism with an approximately 45 day cultivation cycle. According to Anantharaman & Thirumaran (2009), specific growth rates reach 5.7% per day during the summer season. The rapid growth maintains a continuous supply of fresh material that can be further processed for liquid extraction. Fragmentation is also another benefit of this species to facilitate propagation for mass-production where vegetative reproduction is the primary means of reproduction (Smith & Conklin, 2005).

Carrageenan extracted from this seaweed has a number of uses, including many applications as food additives such as a polysaccharide stabilizer (Spagnuoloa et al. 2005), cosmetics that effectively attenuate UV-causing cell damage and skin photo-aging (Ren et al. 2010), and drugs which can promote the body's immune system to inhibit tumor growth (Yuana et al. 2006). This carrageenan processing has been done for more than 30 years using different types of red algae, including *K. alvarezii*. Carrageeanan extraction uses massive amounts of water and chemical solution for soaking, cooking and extraction. The untreated waste from carrageenan processing dumped into the natural environment, for example into injection wells or drainage into the ocean, can cause serious environmental problems and impacts on natural ecosystems.

Low quality of seaweed material is a major concern for primary producers as it lowers the price received. One reason for lower quality is the post harvest handling including the drying process. Additional infrastructure is required for drying. A flat bamboo raft built above the ground is mostly used as the drying method. Particularly in the rainy season, additional plastic tarps are commonly used as a canopy to protect the seaweed from rewetting, preventing rotting and degradation (Neish, 2005). Unfortunately, seaweed grows better in the rainy season, thus requiring more cost inputs. In the rainy season the drying process also takes longer to reach the desired moisture content of about 37%. Therefore, an improved process is needed to ensure seaweed produced at the farmer level is saleable.

Research and development of *K. alvarezii* as a source of a liquid extract for crop fertilizers is still lagging compared to food and cosmetics processing. At the same time, where the population increases, more food needs to be produced. The increase of food demand will drive high use of fertilizer to raise food production (FAO, 2008). Thus, the liquid and solid recovery from liquid-solid separation will be a practical process alternative to supplement both the agricultural fertilizer and aquatic feed additive demands.

## Liquid Extract for Fertilizer

Liquid extracted from *K. alvarezii* contains plant regulator nutrients that increase crop yield: they increase grain quality in wheat (*Triticum aestivum* L), delay fruit senescence, and improve plant vitality and quality (Zodape et al. 2011). This seaweed also has growth regulators that can improve crop quantity. *K. alvarezii* extracts contain the plant growth regulator (PGRs) 3-acetic acid, giberellin $GA_{3,}$ kinetin, and zeatin. The liquid extracted from this seaweed has been used as a foliar spray for different crops such as wheat (*T. aestivum*), soybean (*Glicine max*), and tomato (*Lycopersicon esculentum* Mill) (Prasad et al. 2010).

Seaweed liquid extract contains macro and micro elements needed for growing crops. Based on Rathore's (2009) study that showed the chemical constituents of *K. alvarezii,* seaweed extract is relatively high: phosphorus (33.99 mg/L); calcium (460.11mg/L); magnesium (581.20 mg/L); copper (values about 100-160 ppm); iron (values 6-9 ppm), and; other nutrients with values ranging from 2.7 to 0.01 ppm (Eswaran et al. 2005). Salinity also effects crop growth performance; for example, Lettuce( *Latuca sativa)* was moderately sensitive to high salinity (Unlukara et al. 2008) and salinity also decreased tomato seedling growth performance (McCall & Brazaityte, 1997). Liquid extract also has been used for soil conditioners (McHugh, 2003).

Crops require primary, secondary and micronutrients to properly grow. Based on essential plant guideline, Tucker (1999) stated that Nitrogen (N), phosphorus (P) and potassium (K) are primary nutrients required in the largest amounts by crops; therefore, they are applied in higher amounts than other nutrients. Secondary nutrients are calcium (Ca), magnesium (Mg) and sulfur (S), which are required in smaller amounts than primary nutrients. The others are micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), Copper (Cu), Boron (B) and molybdenum (Mo) these are required in even smaller amounts than secondary and primary nutrients.

## Aquatic Feed Additives

Solid particles have macro and micronutrients that can be used for aquatic feed binders. An increased demand of fish protein will require more feed to grow fish. A report published by FAO (2009) showed that *K. alvarezii* was used as a feed additive in several fish species pellets. It also contains a natural antioxidant (Kumar et al. 2008) and is rich in nutrient profiles that are useful for animal digestion (Fayaz et al. 2005). Seaweed was also used to increase pellet water stability and minimize organic waste from the feed. For example, it was used to feed juvenile tiger shrimp, *Penaeus monodon,* and the result showed a high specific growth rate (SGR), a high survival rate and a high food conversion ratio (FCR) (Penaflorida & Golez, 1996). Even though seaweed cannot be used as a sole replacement diet for many fish, adding seaweed to aquatic feed can have an increase in yield, a high food-conversion ratio, and a high survival rate of shrimp (Hasan & Chakrabarti, 2009).

## Economic Value Projection

Seaweed production and values show an increasing trend over time. According to McHugh (2006), the Australian Center for International Agricultural Research (ACIAR) showed that red seaweed (*K. alvarezii*) production increased over time in the Indo-Pacific islands and India, with about 220,150 Mg of dried seaweed harvested in 2005. The Philippines alone produced 58,324 dry Mg in 1995, valued at US$44 million dollars

(Trono, 1999). This increase in the trend of producing red seaweed will require a better management practice to maintain both good quality product and a sustainable market.

The ratio of seaweed in the dried product for trade to freshly harvested seaweed is seven to ten kilograms fresh seaweed for one kilogram dried seaweed. Total dried seaweed production in Indonesia is about 155,000 Mg annually (Neish, 2005) for all *K. alvarezii*, *Spinosum* and *Gracilaria;* dried *K. alvarezii* alone is produced at about 100,000 Mg per year. Based on the ratio of dried to fresh seaweed produced, fresh seaweed is harvested at a rate of about 0.7 to 1.0 million Mg per year. The dry seaweed price trend at farm gate from 2005 to 2012 fluctuated and was the highest in July 2008—about $2 per kilogram—which is almost four times higher than it was in 2005. However, this high price was only temporary and decreased to about $1.20 per kilogram by the following year. In January 2012, the price was below $1 per kilogram and by July 2012 because of low demand and high production.

## Value Adding

Red seaweed is traded in raw form after it is sun-dried until approximately 37% moisture content wet basis. It is then further processed for carrageenan extraction which is widely applied in the food, cosmetic and medical industries. On the other hand, solid-liquid separation from fresh seaweed is relatively new in seaweed processing and is not yet a common practice. Solid-liquid process is an alternative to increase the value of seaweed products and facilitate handling where seaweed is locally grown.

Seaweed production is mostly governed by climatic conditions at the places where it grows, such as Indonesia, where there are only two seasons: dry and rainy.

Production is mostly higher during the rainy season (Anonym, n.d.). Seasonal patterns also influence the drying process. During the rainy season, the lack of sunlight naturally makes the seaweed take longer to dry. Therefore, extra costs will be required in order to purchase tarps to provide a shaded infrastructure for drying the seaweed; however, some seaweed farmers choose to place the seaweed on the ground where it becomes contaminated with sand, dirt and other unwanted materials (Neish, 2005). This practice results in a low quality product and can directly contribute to low price to the farmer as it requires extra work to clean the seaweed from sand and dirt.

Liquid-solid separation is a process of fresh seaweed grinding and pressing through particular treatments to get the liquid out from the seaweed materials while producing a secondary product, solid particles. Size reduction of the feedstock, possibly disrupting cell walls, has a significant effect on liquid extraction. Studies done by Adeeko & Ajibola (1990) on ground nut and Ajibola et al. (1990) on melon seed oil extraction, show that coarsely comminuted samples gave consistently lower yield than finely comminuted samples. Applied pressure also alters liquid amount. Pressure of 25MPa was applied for Conophor nut (*Tetracarpidium conophorum*) and resulted in a better oil expression (Fasina & Ajibola, 1989). However, it is not known what size reduction and applied pressure will result in an optimal liquid expression from *K alvarezii*. Other treatments that I thought will alter liquid expression are temperature, duration of holding after hitting final point of pressure, and initial weight of seaweed (thickness). These parameters are independent of each another.

## Objective

The objective of this study is to determine the optimal mechanical factors expected to be important in seaweed pressing and to analyze the economic value for the solid-liquid separation processing. I hypothesize that the liquid and solid recovery from liquid-solid separation will be a practical process to meet demands both for agricultural fertilizer and aquatic feed additives. This processing will add value for seaweed farmers, agriculture, and aquaculture where liquid product can be applied for agriculture fertilizer and a solid recovery that can be used for aquatic feed additives and other animal feeds.

## MATERIAL AND METHODS

### Alga Collecting

Fresh red seaweed (*Kappaphycus alvarezii*) was collected from Kaneohe Bay, Hawai‘i. This species is abundant in the bay and has become an invasive species. Specimens were collected from the shallow waters (around 1 to 1.5 meter depth) of He’eia State Park. *K. alvarezii* has mostly settled either on top of or near the coral reef and is growing in high densities about 300 meters from the shore. The fresh seaweed was brought into a laboratory, where it was placed in plastic bags out of sunlight. Collection was done in the morning and experiments conducted in the afternoon.

### Preparation and Comminuting

The seaweed was cleaned by hand to separate wild-weed, dirt and dead portions. Initial sample weights were 450 grams. Seaweed samples were crushed using a comminuator (Comitrol™ processing model produced by Urschel Laboratory Incorporated, Valparaiso, Indiana, USA). There were two different cutting sizes employed: Comitrol™ cutting head 10 mm (production code: 2-060510-14) and 1 mm (production code: 2-K-015015-D). As described in King’s patent (U.S. Patent No 08161856, 2012) Comitrol™ is a cutting head commonly used for comminuation of food products using a head with a plurality of cutter support segments connected to the mounting rings, a cutting blade attached to a front-edge portion of each cutter support segment, and opposed first and second pivot pins extending from the upper and lower portions of the cutter support segment and through the upper and lower mounting rings.

Each of the pivot pins are positioned at a location closely adjacent to a forward edge of the cutter support segment and substantially near a cutting edge of the cutting blade.

Each sample was comminuted separately. The first sample was comminuted using ten mm horizontal knife spacing. The machine was first cleaned while it was off in order to remove any unwanted materials from the cutter before the seaweed was processed. An aluminum tray was placed at the base of the machine below the outlet to catch the comminuted sample. The machine was then powered on and the first sample was poured slowly into the comminuator machine feeder using a funnel. The sample was then comminuted and a recovery sample was collected by the aluminum foil tray, which consisted of a mixed liquid and solid sample. The mixed recovery sample was then measured using a digital scale and recorded in grams. The machine was powered off and the cutting head (10 mm horizontal spacing) was replaced with a blade with a one mm horizontal spacing. The machine was cleaned from the previous seaweed materials. A new tray was then placed at the base of the outlet of the comminuator machine and prepared for a second phase. The machine was powered on and the seaweed sample was then poured into the machine feeder using a funnel. The comminuted seaweed recovery was collected in the aluminum foil tray. The mixed recovery sample was measured using a digital scale and recorded in grams. At this time both samples were ready for pressing. The machine was powered off and was cleaned using water.

## Pressing

The seaweed samples were pressed at different treatments defined by the following variables. The variables were holding time after reaching the final pressure (s), initial weight (g), crosshead speed (mm/min), final pressure (kPa), temperature ($^{o}C$) and

Comitrol™ blade spacing (mm). The responses were liquid expressed (g), press cake thickness (mm), press cake weight (g), and solid particle dried cake weight (g).

A cylindrical metal tube (5.7 centimeter inside diameter, 8.7 centimeter in height) was used to hold the sample during pressing. The tube had a volume of 221.9 $cm^3$ and cross sectional area of 25.5 $cm^2$. Each sample was pressed using the Instron Corp Testing Machine (model number 1102, serial number 277). The pressing sequence and parameter treatment follow the experimental design described below. Each sample was pressed separately.

Liquid was captured in a metal cylinder (5.7 centimeter in diameter, 3.1 centimeter in height, with a volume of 79.06 $cm^3$) placed beneath the screen. The particles/cake was screened with an aperture 109 µm stainless steel wire cloth. Finer particles pressed through the sieve net was screened using an aperture 81 µm nylon cloth net. The liquid extract was measured in grams using a digital scale. Temperature, holding time, and end pressure were recorded using a 21X micrologger produced by Campbell Scientific Inc, USA.

Cake thickness and crosshead speed were recorded from the Instron Testing machine. The gage length indicator of the Instron machine where a pointer moving over a cylindrical scale showed the cake thickness. Crosshead speed was controlled by the crosshead gearing. Changing the gear size changed the plunger speed (crosshead).

## Nutrient Analysis

Liquid and solid samples were analyzed in the Agricultural Diagnostic Service Center at the University of Hawaiʻi at Manoa. The nutrients of interest were boron (B), calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), phosphorus (P), zinc (Zn), nitrogen (N). Salinity and pH were also measured for the liquid sample. Dry matter, ash, crude protein and cellulose were tested for the solid particle only.

## Economic Analysis Plan

An economic analysis was conducted for seaweed solid-liquid separation. The model applied to this analysis is a modification of the schematic economic module used by Kam et al. (2001) and the seaweed processing module designed by Neish (2005). The economic model is potentially market driven contingent upon financial parameters and processing parameters. Processing parameters were fed into modules for fresh material supply, comminuting, pressing, and drying. These values were summarized and translated into cost incurred by each module. Dollar amounts were reported in profit and loss module and a cash flow model for financial analysis.

A production summary provided an overview of requirements and annual productivity. The production liquid and solid particles were determined from the amount of fresh material used (raw seaweed) and production capacity from seaweed farmers. Synopses of the distribution of production time, labor hours, energy and comminuator usage, and facility area were provided for each solid-liquid separation phase. The energy costs associated with the comminuator machine and pressing machine were allocated based on amount of usage per production target. For aggregate development costs, such as the purchase of a processing warehouse and property, installing new seaweed processing machine, fresh material purchase, drying equipments, and planning and design, costs were allocated to each phase according to time and area of facility used.

The solid-liquid separation net income was based on liquid and solid particle sales, financial parameters, and costs associated with production. Net income before taxes and costs of fresh materials and production processes were estimated based on parameters including a module modified from Kam at al. (2001):

Production

- Projected Liquid Production (Mg/yr)
- Projected Solid Production (Mg/yr)
- Rate of Seaweed Processing (Mg/hours)
- Production capacity (Mg/yr)

Financial Parameters

- Sale price per kilogram liquid ($/L)
- Sale price per kilogram solid particle ($/Kg)
- Loan: annual loan rate (%)
- Tax: general sales tax rate

Variable Expenses Rates:

- Purchase ($/ha)
- Electricity ($/year)
- Utilities expenses ($/ha$^2$)
- Facility maintenance ($/year)
- Contingency ($/year)
- Design and Planning (% of constructions, installing processing machine, drying facility, warehouse production and other site preparation)

A ten years Profit and Loss Statement reported the net income after tax from an outline of sales revenue (based on production and sale price per kilogram of liquid and particle) and expenses, according to:

Variable Costs

- Fresh seaweed (raw material)
- Supplies
- Drying facility
- Energy (including utilities)
- Labor (Salaries)
- Maintenance
- General Exercise Tax

Fixed Cost (Annualized)

- Depreciation on Equipment
- Depreciation on Development

Other Expenses

- Contingency
- Interest Expense
- Income Tax Expense

A ten-year Cash Flow Summary reflects the flow of cash according to:

Cash Flow from Operating Activities

- Cash Collected
- Less: Total Operating Expenses

- Non-Cash Expenses (i.e.  depreciation)

Cash Flows from Investing Activities

- Purchase of Fixed Assets
- Proceeds from Sales of Fixed Assets

Cash Flow from Financing Activities

- Addition to Long-Term Debt
- Reduction in Long-Term Debt

Liquid-Separation (comminuting) processing costs were determined based on the results of mechanical expression experiments on the solid-liquid separation.  The operation schedule refers to the amount of fresh material provided.  The drying facility was designed based on the amount of particle produced per cycle, particularly for width and rate of the drying facility.  One production cycle takes about three days including comminuting and drying.  The production amount is calculated from total fresh seaweed per year dividing by the expected number of annual harvests.  Drying was assumed to be done without direct sunlight, relying primarily on air circulation in order to maintain color quality.

**TABLE 1.  Schedule of operation solid-liquid separation from *Kappaphycus alvarezii* Doty**

| Cycle Summary | Duration | % of Cycle | Operations | Unit | Value |
|---|---|---|---|---|---|
| Comminute | Kg/min | 100% | Rate of processing | hours | 1,388.89 |
| Pressing | Kg/min | 100% | Rate of processing | hours | 333.00 |
| Drying | Days | 100% | Rate of operation | days | 365.00 |

The solid-liquid separation was designed for a small-medium scale of production. Seaweed material is purchased from local cultivation adjacent to the seaweed processing area.  Seaweed is harvested every 45 days of cultivation under the seawater surface.  Up to now, seaweed is traded as dry material with about 37% of moisture content.  The drying process takes at least three to six days and can be longer with lower sun intensity (such as in the rainy season).  In the rainy season, drying process will require additional plastic tarps for covering the seaweed and preventing it from becoming wet again.  The cost of the drying process increases while the seaweed price may remain constant.  If seaweed is rewet as a result of a rain shower, it can rot, and rotten seaweed is sold for a much lower price and at some point of poor seaweed quality, it is not saleable anymore. The solid-liquid separation will directly process fresh-harvested seaweed, therefore, the seaweed farmers do not need to build a drying facility, and it will save labor time for the drying process, and also will cut other costs associated with drying process.

In some areas, farmer groups have been established.  A farmer group usually consists of 15 individuals and it is predicted they can produce up to 800 Mg fresh seaweed per year and it was assumed that half of their seaweed production is sold after solid-liquid extraction.  This liquid-separation process is designed for a small scale of investment.  The investment can be shared among farmer group members in a cooperative institution.  The group can apply for a loan from a financial institution for additional capital if needed.  The Department of Small-Scale Entrepreneurship-Indonesia provides a soft credit loan for small businesses.  The net income from sales of the solid and liquid product will be a shared benefit to all members of the cooperative and will return to the cooperative for increasing capital and production.

Seaweed price was about \$0.80/kilogram dried seaweed in Indonesia (Anonym, n.d.) by January 2012.  One kilogram of dried-seaweed (37 % of moisture content) required from 8-10 kg fresh seaweed, for an implied value of $0.8-$1.0/kilogram fresh seaweed. Fresh seaweed processing could result in two products; liquid and dried seaweed cake with an estimated price for the two products (solid-liquid) higher than the price for the dried seaweed. Furthermore, the increased demand for agricultural and fishery products will require more fertilizers to increase crop production and aquatic feed additives to increase fishery production volume. Another potential market for solid particle is as an additive for pet-foods.

## Experimental Design and Analysis

Six experimental factors as expected to be important in the seaweed pressing were employed. Each of the factors used two levels coded as, or transformed (subtract mean and divide by the stepsize) to, -1 and +1 (Box et al. 2005). An initial highly saturated two level fractional factorial of 16 treatments gave an estimate of the gradient and experimental error independently for each of six experimental factors. Experimentation was stopped after the initial gradient estimation when physical limitations were encountered.

The experimental levels for each factor were as follows:

1. Holding time; low level is 0s and high level is 15s
2. Initial weight; low level is 20g and high level is 40g
3. Crosshead speed; low level is 64mm/minute and high level is 127mm/minute
4. Final pressure; low level is 1400kPa and high level is 2800kPa
5. Initial temperature; low level is 22$^{o}$C and high level is 28$^{o}$C, and
6. Comitrol™ blade space; low level is 1mm blade space and high level is 10mm blade space. The details for the two level order is summarized in Table 2 below

**TABLE 2. Two level of factorial design for solid-liquid separation procession on *Kappaphycus alvarezii* Doty.**

| | Holding time (s) | Initial weight (g) | Cross head speed (mm/minute) | Final pressure (kPa) | Initial temperature ($^{o}$C) | Comitrol™ blade space (mm) |
|---|---|---|---|---|---|---|
| Low level -1 | 0 | 20 | 64 | 1400 | 22 | 1 |
| High level 1 | 15 | 40 | 127 | 2800 | 28 | 10 |
| Step size | 7.5 | 10 | 32 | 700 | 3 | 4 |

The Yates order treatment matrix given 6 factors at a quarter fraction is a $2^{6-2}$ square matrix where the $i^{th}$ column consists of a repeating pattern of $2^{(i-1)}$ low levels of the factor ( -1) followed by $2^{(i-1)}$ high levels of the factor (+1).

There are three different responses collected for each run. The responses were press cake thickness (mm), liquid recovery (g), dried cake weight (g). Solid cakes from each experiment were collected in separate trays and weighed, and trays placed into a ambient air dryer for drying. The dryer was a standard 55gal drum using a fan (model 4C443A, Dayton Electric Mfg. Co, Chicago, Illinois) to blow air conditioned room air through a false perforated (50% opening) floor. Cake was dried until the cake weight did not change over the previous 24 hours. These final weights were recorded as the dried cake weights. The dried samples were brought to Agricultural Diagnostic Center Laboratory of University of Hawai‘i for dry matter determination.

In this project, we focused on finding the first order effects of the major variables on three responses to determine feasibility and provide empirical values for economic analysis. A response (**R**) is calculated based on the matrix equation below:

$\mathbf{R} = Average(\mathbf{R}) + \mathbf{X}\,\mathbf{B}$

**X** = coded (transformed) treatment matrix

**B** = coefficient vector also called factor effects

As an example: There were six different effects for liquid expression as follow:

Liquid recovery →
- Initial weight
- Crosshead speed
- Final pressure
- Initial temperature
- Comitrol™ blade space
- Holding time

An effect is calculated based on equation below:

$$bi = \frac{avrg\ R(X_1H) - Avrg\ R\ (X_1L)}{X_iH - X_iL} + \frac{Avrg\ R\ (X_2H) - Avrg\ R(X_2L)}{X_2H - X_2L} \ \ldots. \ + \frac{Avrg\ R(X_nH) - Avrg\ R(X_nL)}{X_iH - X_iL};$$

where *bi* is effect, *R* is response, *H* is high order and *L is* low order. Or as:

$$\mathbf{B} = (\mathbf{X}^{t}\ \mathbf{X})^{-1}\ \mathbf{X}^{t}\ \mathbf{R}$$

Gradient value and T-test were computed based on equation:

$\nabla$ F(**X**) = $\frac{\partial F}{\partial x_1} + \frac{\partial F}{\partial x_2} + \ldots . . \frac{\partial F}{\partial x_n} = \mathbf{B}$ **,** where $\nabla$ is gradient operator, *R* is response and *X* is factorial level. The unit gradient is normalized using following equation $\mathbf{B}_u = \frac{\mathbf{B}}{|\mathbf{B}|}$ **,** where $\mathbf{B}_u$ is unit gradient, is gradient vector and |**B**| is magnitude. The t-*statistic* was computed with equation t-*statistic* = $\frac{bi}{error}$. The error value was estimated by a high order interaction without any first order effects or two-way interaction effects aliased with it. Effects were evaluated with t-statistic (Box et al. 2005).

# RESULTS

## Pressing

Data was analyzed using an Excel™ spread sheet with fractional factorial design and t-statistic to determine statistical significance levels among the experimental factors. Six experimental factors were analyzed with three different responses as show in Table 3 below. They were liquid recovery, pressed cake thickness and dried cake weigh. The highest liquid recovery was obtained with the combination of low level Comitrol™ blade space (1mm), low level initial temperature (22$^{o}$C), and high level final pressure (2800kPa) with only these three factors having significant effect on liquid recovery (99.95%). High cross head speed and low level initial weight affected liquid recovery at a 99.75% and 99% confidence level, respectively. Holding time had a low effect on the liquid recovery as shown in Table 3 below.

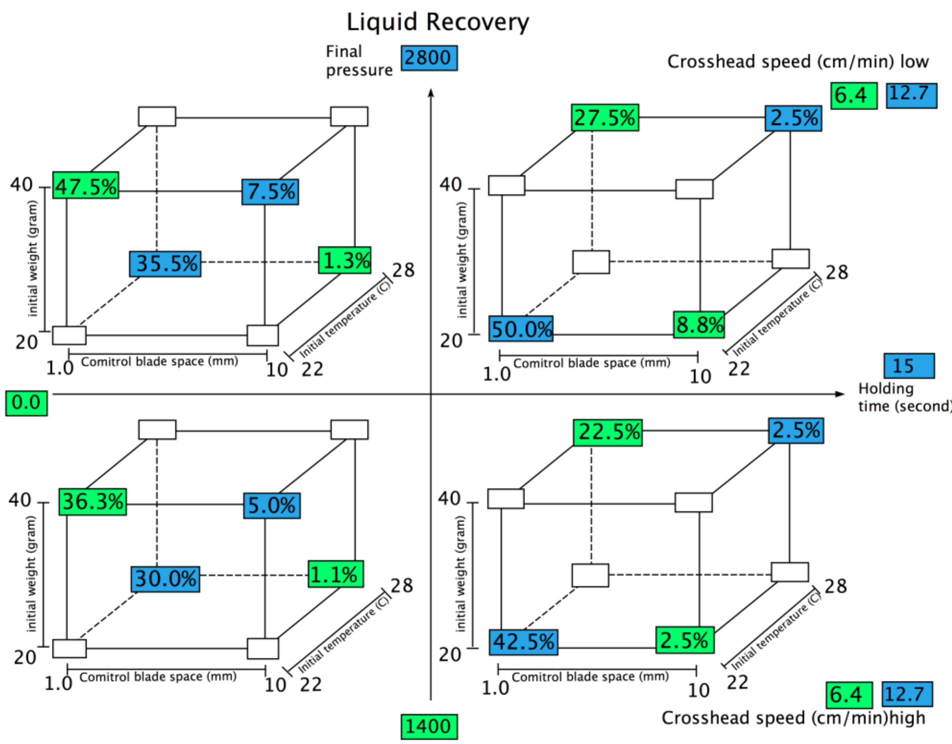
The pressed cake thickness yield varied among the experimental factors. High Comitrol™ blade space, low final pressure and high initial temperature had positive effects on the cake thickness at the 95.95%, 90%, 90% confidence level, respectively. High initial weight and low cross head speed each had a significant effect on the cake thickness (75%). Holding time had did not have a significant effect on pressed cake thickness (under 60%). High Comitrol™ blade space and high initial temperature were the only two factors that had significant effects on dried cake yield (95.00%). The other four experimental factors did not affect dried cake yield.

**TABLE 3. Probability points experimental results for process yields for six experimental factors of solid-liquid separation on red alga *Kappaphycus alvarezii* Doty.**

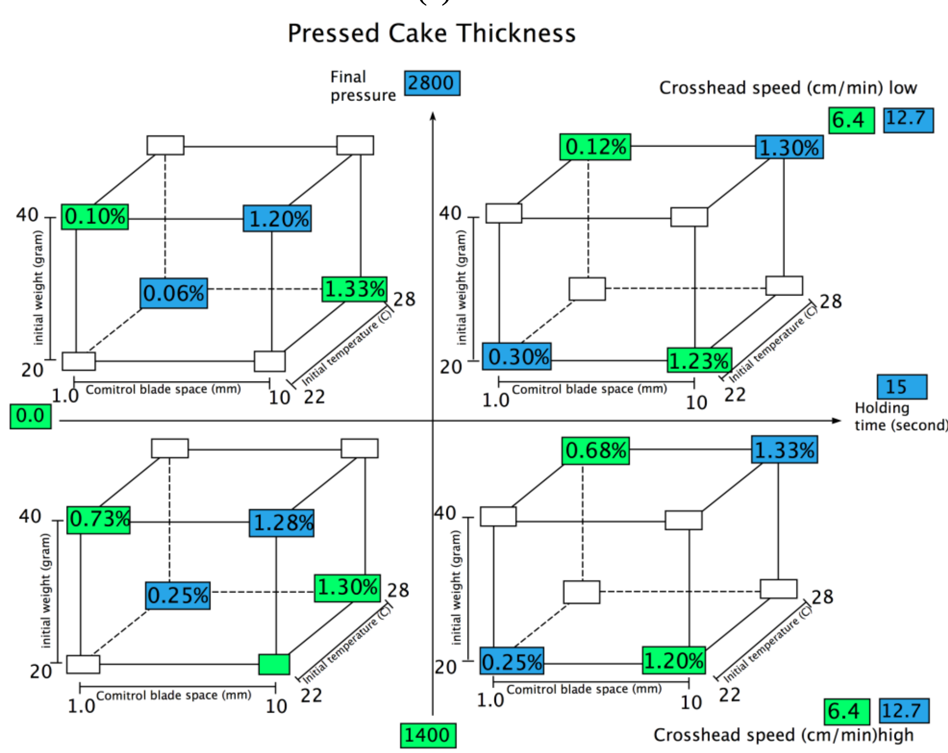
| Responses | Comitrol ™ blade space | Initial weight | Initial tempera ture | Final pressure | Holding time | Cross head speed | Error |
|---|---|---|---|---|---|---|---|
| Liquid recovery | -10.160 | -0.780 | -3.030 | 1.460 | 0.200 | 1.070 | 0.290 |
| Cake thickness | 0.302 | 0.029 | 0.002 | -0.056 | 0.004 | -0.026 | 0.009 |
| Dried cake | 0.440 | -0.240 | 0.440 | -0.050 | -0.050 | -0.050 | 0.240 |
| Confidence Level | | | | | | | |
| Liquid recovery | 99.95% | 99.00% | 99.95% | 99.95% | 75.00% | 99.75% | |
| Cake thickness | 99.95% | 75.00% | 90.00% | 90.00% | 60.00% | 75.00% | |
| Dried cake | 95.00% | 75.00% | 95.00% | < 60.0% | < 60.0% | < 60.0% | |

A negative effect indicates a negative change in a factor gives a response increase and a positive (no notation) indicates a positive change in a factor gives a response increase.

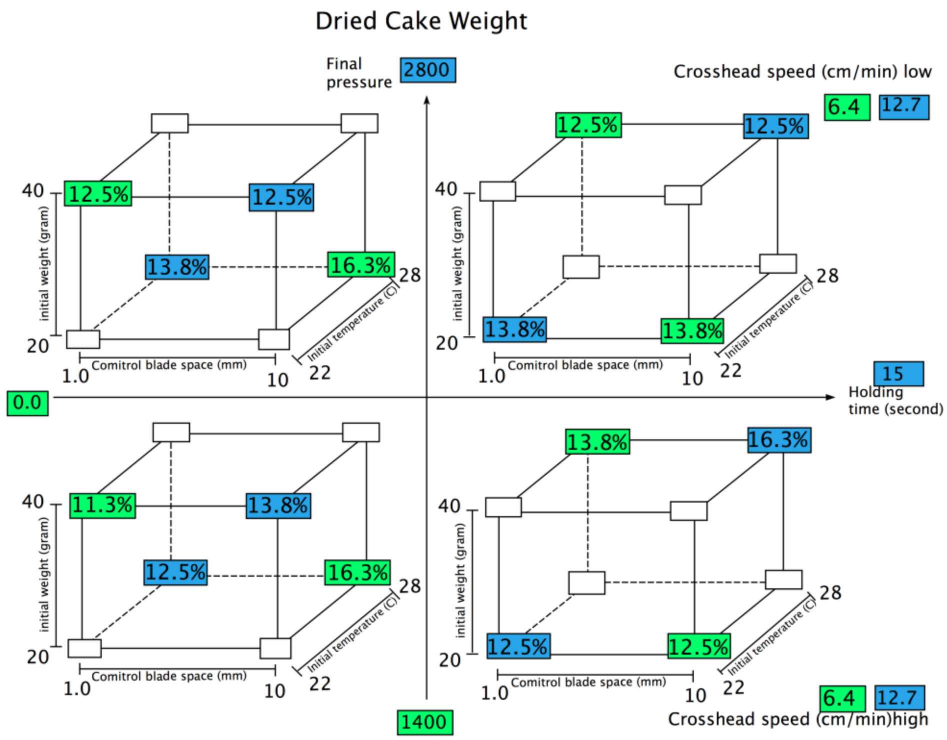
The two levels of the six experimental factors and results for the three responses were plotted as three dimensional cubes on the axii of the two less effective factors shown in Figures 1 (a), (b) and (c) below. For the liquid recovery, the highest result was 50% original mass as shown in Figure 1 (a) with the combination of low: Comitrol™ blade space, initial temperature, and initial weight resulted in increased yield, as did high final pressure and high holding time. As shown in Figure 1 (b), high Comitrol™ blade space and high initial temperature had a high effect on press cake thickness. Cross head speed, initial weight and holding time had a low affect on the cake thickness result. The dried cake weight as shown in Figure 1 (c) indicated that high level Comitrol™ blade space and high initial temperature affected an increase of the dried cake weight with the highest result was 16.3%. The other four experimental factors had negligible effect on dried cake weight.


Liquid Recovery
Final pressure
2800
1400
Crosshead speed (cm/min) low
Crosshead speed (cm/min)high
6.4
12.7
0.0
15
Holding time (second)
47.5%
7.5%
35.5%
1.3%
27.5%
2.5%
50.0%
8.8%
36.3%
5.0%
30.0%
1.1%
22.5%
2.5%
42.5%
2.5%
initial weight (gram)
Comitrol blade space (mm)
Initial temperature (C)

(a)


Pressed Cake Thickness
Final pressure
2800
1400
Crosshead speed (cm/min) low
Crosshead speed (cm/min)high
6.4
12.7
0.0
15
Holding time (second)
0.10%
1.20%
0.06%
1.33%
0.12%
1.30%
0.30%
1.23%
0.73%
1.28%
0.25%
1.30%
0.68%
1.33%
0.25%
1.20%
initial weight (gram)
Comitrol blade space (mm)
Initial temperature (C)

(b)




(c)

FIGURE 1. The three dimensional cubes for high and low level of factorial design for six experimental factors with each of three different response. 1 (a) is liquid recovery as per cent of intial mass, (b) is is pressed cake thickness (mm), and (c) dried cake weight (g). The values of each box at the corners are reponse values at that point in the factor space. The green boxed color is the low level and blue boxed color is high level for the crosshead speed.

## Nutrient Profile

Liquid recovery and dried cake were analyzed at the Agricultural Diagnostic Service Center at the University of Hawai‘i at Manoa. The detailed results are shown in Table 4. The liquid recovery had a high content of potassium (17,975ppm), sodium (5,34ppm) and nitrogen (524ppm). The electrical conductivity was very high (53mmhos/cm). The dried cake contains high levels of iron (380ppm) and Boron (139ppm). Zinc content is also relatively high (16ppm). It took an average of 2 days (48 hours) to reach a constant dry matter (79.69%).

**TABLE 4. Nutrient profiles of liquid and cake from solid-liquid separation on *Kappaphycus alvarezii* Doty.**

| Nutrients | Liquid | | Cake | |
|---|---|---|---|---|
| | (ppm) | (mmhos/cm) | (%) | (ppm) |
| Nitrogen (N) | 524.00 | | | |
| Phosphorus (P) | 28.24 | | | |
| Potassium (K) | 17,975.00 | | | |
| Ash (%) | | | 34.30 | |
| Crude Protein (CP) | | | 3.36 | |
| Calcium (Ca) | 136.10 | | 0.20 | |
| Magnesium (Mg) | | | 0.36 | |
| Sodium (Na) | 5,347.00 | | 2.48 | |
| Cellulose | | | 6.29 | |
| Dry matter (DM) | | | 79.69 | |
| Boron (B) | 2.41 | | | 139.00 |
| Copper (Cu) | 0.83 | | | 5.00 |
| Iron (Fe) | 8.84 | | | 380.00 |
| Manganese (Mn) | 0.36 | | | 7.00 |
| Zinc (Zn) | 0.85 | | | 16.00 |
| pH | | 6.20 | | |
| EC (Electric Conductivity) | | 53.00 | | |

## Economic Analysis

Site specific development assumptions are used to calculate the development cost for construction and site preparation of a 250m square (820.21 feet square) site. The cost of buying land per meter is $7.37 when the currency level is IDR 9,500 per $1.00. The land is considered purchased. The first 100m square is for drying facilities and the second 100 meter square is for a warehouse and a comminution and press machinery installation area. The warehouse is made from brick walls and wooden construction. The drying constructions are made of bamboo and wood in a rectangular shape. Transparent plastic film is used for roofing assembled with ventilation near the bottom floor. Although there is some degradation of seaweed color, solar heat should help with drying.

Nylon mesh of 40 micron opening is used for coating the drier floor and for holding the cake.

It is assumed that the drying facilities will be built by the owner with the help of two laborers. The labor wage is upper minimum standard wage or about the same for medium payment of local income in South Sulawesi, Indonesia (average income for civil servant). The commute machine is purchased on USD currency and the pressure machine price is subjected to necessity of the liquid-separation processing. Fresh seaweeds are purchased from the members of the seaweed farmer group. The farmer group consists of about 15 individuals with the estimated production of 40 Mg of fresh seaweed per year. The breakdown of the total area of the hypothetical facility is exhibited in Table 5 below and in appendix A. The cost associated with development is based on the facility area of the base model as summarized below.

**TABLE 5. Development cost summary in USD (250 Mg fresh seaweed per year).**

| Development | Unit | Life (years) | Number | Value | Total |
|---|---|---|---|---|---|
| Variable | | | | | |
| - Fresh seaweed | $/Kg | | 250,000.0 | 0.10 | 24,767.80 |
| - Labor | Total $ | | 3.00 | 250.00 | 9,000.00 |
| Total Variable Cost | | | | | 34,875.17 |
| Fixed | | | | | |
| - Area of construction | $/acre | | 0.5 | 7.37 | 368.42 |
| - Ware House Area | $/acre | | 1.0 | 7.37 | 736.84 |
| - Drying Area Construction | $/acre | | 1.0 | 7.37 | 736.84 |
| - Drying facilities | Total $ | 2 | 2.00 | 553.68 | 1,107.37 |
| Utility installation | | | | | |
| - Comminute machine | Total $ | 15 | 1.00 | 20,000.00 | 20,000.00 |
| - Pressure machine | Total $ | 15 | 1.00 | 3,789.47 | 3,789.47 |
| - Warehouse | Total $ | 10 | 1.00 | 1,413.68 | 1,413.68 |
| Total Fixed Cost | | | | | 27,045.26 |
| TOTAL | | | | | 61,920.43 |

The assumption of price for liquid per liter is 40¢ and dried cake is 50¢ per kilogram, and that 50% of the fresh seaweed weight is extracted as liquid and 13.8% is recovered as dried cake gain from solid-liquid separation process. The fresh material is 250 Mg per year. The total value for 250 Mg fresh seaweed after drying is about $26,174.47 with the assumption of 89¢ per kilogram of dried seaweed and the ratio is 8.5:1 (8.5 kilogram fresh seaweed to one kilogram dried seaweed). The breakdown is summarized in Table 6 below.

**TABLE 6. Assumption of liquid and dried-cake price of *Kappaphycus alvarezii* Doty from solid-liquid separation processing.**

| Financial Analyses (Assumption price) | Value | Unit | Yield | Unit |
|---|---|---|---|---|
| Fresh material | 250,000.00 | kg | | |
| Liquid recovery | 35.78 | % | 89,453.13 | |
| Dry cake | 12.50 | % | 31,250.00 | |
| Assumption liquid price per kilogram | 0.40 | $ | 35,781.25 | |
| Assumption dried cake price per kilogram | 0.50 | $ | 15,625.00 | |
| TOTAL | | | 51,406.25 | |
| Dried seaweed | 29,411.76 | kg | | |
| Price of dried seaweed | 0.89 | $/kg | 26,176.47 | |

Profit and Loss

The cost per kilogram of solid-liquid separation after tax for the 250 Mg fresh seaweed is 35¢ for the period of five years. It is assumed that there was no change in variable cost. The average price for both liquid and cake is 45¢ per kilogram. Production is assumed to reach full capacity (100%) by the first year as it is known seaweed grows well and is easily propagated. The loan from financial resources is assumed fully returned by the year ten. The other costs such as fresh seaweed price and unit variable costs are assumed constant for the ten years. Unit variable operating costs comprise approximately 56.32% of the total before-tax expenses. Interest expenses are based on a ten year loan for 80% of financing of capital investment at annual loan rate of 5.57% based on Indonesian government regulations on small-medium loan platform. The breakdown is summarized in Table 7 and the model for all ten years is shown in Appendix C.1.

Salvage value for each piece of equipment is estimated by market value for used equipment at the end of ten years of use. Comminuator machine and press machine are assumed fully operational for all ten years. Maintenance fee was assumed to be 5% of total annual fixed cost of the equipment. Market value for comminuator, pressure machine and warehouse after ten years is assumed $2,000.00, $500.00, and $141.00; respectively. The drying facility will have no salvage value after ten years. Drying facility is made of wood and bamboo and is rebuilt every other year and there is no economic value by the end of the ten years of investment. Construction areas will have an increased value since the land was considered purchased. The future land value will follow the inflation rate. However, I hope that this solid-liquid processing continues to work.

**TABLE 7. Income Statement for 250 Mg fresh seaweed (raw material) *Kappaphycus alvarezii* Doty from solid-liquid separation processing base model (USD) for five years.**

| Year | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Gross Receipts | | | | | |
| - Liquid | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 |
| - Dry Cake | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 |
| Total Gross Receipts | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 |
| Variable Operational Cost | | | | | |
| - Fresh seaweed | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 |
| - Electricity | 822.37 | 822.37 | 822.37 | 822.37 | 822.37 |
| - Maintenance | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 |
| Labor cost | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 |

| | | | | | |
|---|---|---|---|---|---|
| Total Variable Operational Cost | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 |
| Fixed Cost (Annualized) | | | | | |
| - Drying Area Construction | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 |
| - Area of Construction | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 |
| - Warehouse Area Construction | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 |
| - Drying facilities | 553.68 | 553.68 | 553.68 | 553.68 | 553.68 |
| - Comminute machine | 1,333.33 | 1,333.33 | 1,333.33 | 1,333.33 | 1,333.33 |
| - Pressure machine | 252.63 | 252.63 | 252.63 | 252.63 | 252.63 |
| - Warehouse | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 |
| Total Fixed Cost | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 |
| Contingency | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 |
| Total Operational Expenses | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 |
| Interest Expenses | 2,721.96 | 2,449.76 | 2,177.56 | 1,905.37 | 1,633.17 |
| Total Expenses | 42,500.68 | 42,228.48 | 41,956.29 | 41,684.09 | 41,411.90 |
| Net Income Tax | 212.50 | 212.50 | 212.50 | 212.50 | 212.50 |
| Net Income After Tax | 8,693.07 | 8,965.26 | 9,237.46 | 9,509.65 | 9,781.85 |
| Cost unit per kg after tax | 0.3539 | 0.3516 | 0.3494 | 0.3471 | 0.3448 |

<u>Cash Flow</u>

Production is assumed to reach full capacity from year one to ten. The model does not include prediction of inflation of fresh seaweed price and variable cost for ten years. Fixed equipment such as the comminuator and pressure has a 15 year life span. The drying facility is expected to last for two years. The warehouse is renovated every ten years. For a processing of 250 Mg fresh seaweed annually, it generated 89,453.13 kilogram liquid and 31,250 kilogram dried cake (120,703.13 kilogram in total). The break-even volume after tax is 99,804.54 kilogram (liquid and cake). The Minimum Attractive Rate of Return (MARR) was considered to be 20% which is equivalent to the

Bank of Indonesia interest rate. The Internal Rate of Return (IRR) for ten years is 30.23%. The External Rate of Return (ERR) is 25.69% and annual equivalent worth is $10,708.26. The IRR reflects the maximum return available to investors and for retained earnings. The annualized fixed cost was a straight-line depreciation for ten years.

**TABLE 8. Statement of cash flow for 250 Mg fresh seaweed (raw material) *Kappaphycus alvarezii* Doty from solid-liquid separation processing base model (USD).**

| Year | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Cash Flows form Operating Activities | | | | | | |
| Cash Collected | | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 |
| Total Expenses (Less) | | 42,500.68 | 42,228.48 | 41,956.29 | 41,684.09 | 41,411.90 |
| Non-Cash Expenses (add, i.e., Depreciation) | | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 |
| Net Cash* | | 11,297.84 | 11,570.04 | 11,842.23 | 12,114.43 | 12,386.62 |
| Cash Flows form Investing Activities | | | | | | |
| Purchase of Fixed Assets | 27,045.26 | | | | | |
| Proceeds** | | | | | | |
| Net Cash*** | 27,045.26 | | | | | |
| Cash Flows from | | | | | | |
| Addition to Long-Term Debt | 49,536.35 | | | | | |
| Reduction in Long-Term Debt (Less) | | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) |
| Net Cash**** | 49,536.35 | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) |
| Net Increase (Decrease) in Cash | 76,581.61 | 6,411.03 | 6,683.22 | 6,955.42 | 7,227.61 | 7,499.81 |
| Cash Starting Balance | 76,581.61 | 0 | 6,411.03 | 13,094.25 | 20,049.66 | 27,277.28 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Cash Ending Balance | | 6,411.03 | 13,094.25 | 20,049.66 | 27,277.28 | 34,777.09 |
| | | | | | | |
| MARR | 20.00% | | | | | |
| IRR (10 years) | 30.23% | | | | | |

* Provided by operating activities
** From sale of fixed assets
*** Used in investing activities
**** Provided by financing activities

## DISCUSSION

The present work was begun to investigate seaweed processing as a new market opportunity for seaweed farming, organic fertilizer and fish feed companies both locally and internationally. The fresh seaweed solid-liquid processing was a good approach in the seaweed industry that has not been done on an industrial scale. The development of solid-liquid separation tecnology is a practical and feasible model to accommodate high production of seaweed in Indonesia. The ecomomy analysis is a critical step to sensure future business investment. The model was analyzed for a small scale operation with the assumption that this model can be extended to coastal seaweed communities. The economic analysis was done to evaluate the benefit for an investor to take further action and put this opportunity into reality as a new bussiness.

Mechanical factors on liquid recovery has been investigated through experiment in the laboratory. This took place primarily for one semester which included sample collection, pressing and drying. The six experimental factors, holding time, initial weight, cross head speed, initial temperature and Comitrol™ blade space, were tested to identify the technological factors important in seaweed pressing. Factorial design with two levels was employed to search gradient lines in different values for each of the factors.This was done to answer the first objective of this paper. With two levels of factorial, the highest liquid recovery was achieved with 1mm blade spacing, initial temperature of 22$^{o}$C, final pressure of 2800kPa, and intial weight of 20g. Holding time and plunger speed were not effective in the process and do not need to be tightly controlled.

Particle size (fine and coarse cake) contributed to liquid recovery with the use of the physical method for liquid separation. The small blade space determined the size of the particle comminuted out of the machine. The use of one millimeter blade space for comminution resulted in largest liquid recovery after pressing. As the particle size decreased, a small increase in liquid recovery was achieved in agreement with Yang et al. (2010) and Wongkittipong et al. (2004). An experiment on ground nut and melon seed was done for oil extraction and the result showed that finely comminuted samples gave consistently higher yields (Adeeko & Ajibola,1990; Ajibola et al. 1990).

Room temperature affected the liquid recovery. The initial temperature (22 $^oC$) resulted in a high liquid recovery as shown in Table 3 above. This result was similar to a study that was conducted by Bargale et al. (1999) on soybean, where a temperature of 22 $^oC$ on soybean oil pressing using Instron Machine gave the highest oil recovery. Reducing processing room temperature one degree Celsius should increase liquid recovery according to the experimental results. However, this effort will increase the operational cost since additional air conditioning is needed to lower the room temperature.

Cake thickness level increased when 10mm Comitrol™ blade space was used. This larger space of Comitrol™ blade cut seaweed into larger particles. The coarse cakes will result in less liquid extracted. The coarse particle size would decrease liquid recovery from the press (Wakeman, 2007). However, the use of high level of Comitrol™ blade would have a contrary result with what this project was to try to solve. This project was to find process parameters to extract more liquid. In addition, less liquid extracted from seaweed pressing will affect the economic standing of the solid-liquid processing.

Of the experimental factors only Comitrol™ blade space and initial temperature affected the final dried cake weight. Moreover, it also suggests that optimizing the liquid recovery will decrease dried cake weight.

The experiment was concluded after an estimation of the first order effects. The highest result obtained with a Comitrol™ blade space of 1mm created particles that passed the screen aperture of 81µm. Although this was not quantified, the difficulty reducing seaweed to smaller particles, indicated no further reduction would be practical. On the other hand, the experimental result suggested that to maximize liquid recovery initial weight should be low. This will result in higher operational cost because it requires more time and space. Further experimentation in the direction of the gradient, i.e. increased pressure, lower initial weight and lower processing room temperature, may result in higher liquid expression. The economic analysis based on the current result is so lucrative no further experiments were conducted.

Nutrient profiles were tested in the laboratory for both liquid and cake. The results demonstrated the macro and micronutrient content which are important for plants as shown in Table 4. Potassium (K) is a macronutrient needed by a plant to grow. This element is essential for root growth and absorbed by plants in larger amounts than any other mineral element except nitrogen and in some cases calcium. Potassium will help the building of protein, photosynthesis, fruit quality and reduction of diseases (Barker & Pilbeam, 2006) and increase drought resistance, live roots and longevity of the plant (Egilla et al. 2000; Egilla et al. 2005).

Nitrogen is one of main three macronutrients needed for plant growth. Insufficiency of nitrogen will cause limited plant growth. Its presence in plants is also directly related to the level of nitrogen fertilization. Nitrogen concentration from solid-liquid pressing is a niche opportunity as a fertilizer additive to current fertilizers on the market today.

High salinity and sodium in water are constraints for plant growth. In many cases, the value of the water is decreased solely because of its high salt concentration. The general effect of salinity is to reduce the growth rate resulting in smaller leaves, shorter stature, and sometimes fewer leaves. Greenhouse tomato (*Lycopersicon esculentum L.*) fresh-yield decreased by 5.1% for each of dS $m^{-1}$ in excess of 2 dS $m^{-1}$ (Li, et al. 2000), and salinity also significantly reduced growth of tomato plants in terms of root volume and fresh weight (Lopez & Satti, 1996) and decreased root longevity (Shannon & Grieve, 1999) Therefore, the liquid from this processing should be diluted by at least 26.5 times before using as foliar spray.

Liquid from red seaweed (*K. alvarezii*) was tested as an additive fertilizer on wheat showing that grain was increased by 0.44% when the plants were sprayed with 1.0% of *K. alvarezii* extract and 2.5% was applied to okra (*Abelmoschus esculentus* L.) (Zodape et al. 2008, 2009). The seaweed extract was also applied for the germination process. String bean seed (*Vigna sinensis*) that was soaked with aqueous extract of seaweeds performed better when compared to the water soaked control (Sivasankari et al. 2006). The liquid also contained plant growth regulator (Prasad et al. 2010).

Using seaweed *K. alvarezii* as feed additives for marine fish and shrimp has shown a positive effect on shrimp cultivation. The cake mostly functioned as a binder for increasing the pelletability of the feed. There was an increased growth rate and survival rate of *Penaeus monodon* after adding *K. alvarezii* sap to the shrimp feed because of rich macronutrient content (Anil et al. 2011; Hasan & Chakrabarti, 2009), as fish feed binder (Penaflorida & Goleez, 1996). Amino acids are essential elements for fish and shrimp feed additives. Rajasulochana et al. (2010) stated lysine was the major amino acid constituent in the *K. alvarezii* and followed by asparagine, histamine, isoleucine, phenylalanine, tryptophan and eight other amino acids. However, in this work, I did not deeply look into protein profiles.

Adding value to fresh seaweed by solid-liquid processing is a benefit for seaweed farmers. The drying process is no longer needed. The cost of drying, such as building a drying facility and labor cost are eliminated. Drying seaweed takes about five days in the dry season and double the time during the rainy season, and the peak production is mostly during the rainy season. Seaweed farmers might allocate more of their time to take care of their seaweed on the ocean.

**TABLE 9. Comparative analysis for dried and fresh seaweed sale**

| | Seaweed Sale | |
|---|---|---|
| | Dried Seaweed | Fresh Seaweed |
| Gross receipt | 1,651.19 | 1,651.19 |
| Cost | | |
| Drying facility | 136.05 | 0.00 |
| Labor cost | 87.719 | 0.00 |
| Net Profit | 1,427.42 | 1,651.19 |

The IRR value showed that the solid-liquid processing is a viable investment. With the MARR (20%), the IRR is higher than MARR and ERR. IRR reflects the maximum return available to investors and for retained earnings or a rate of return used on capital budgeting to measure profitability of investment. MARR is an interest rate that the company should pay annually. The MARR is also a minimum rate of return on a company is willing to accept before starting a project, given its risk and the opportunity cost of forgoing other projects. The ERR directly takes into account the interest rate ($\varepsilon$) external to a project at which net cash flows generated over the project life can be reinvested and the MARR reflects the current rate of interest and additional rate for such factors as risk, uncertainty and contingency (Sullivan et al. 2009). With the IRR value of 30.23%, which is higher than MARR, the economic analysis suggests that this solid-liquid processing is a good investment. The positive value of PW ($44,894.08) is another indicator for a good business opportunity for fresh seaweed processing. The ERR showed that the net cash flow generated over the project life can be reinvested. With the discount rate of 20% for ten years, the annual equivalent worth was $10,708.26.

Sensitivity analysis was done to show the effect of fresh material supply on business opportunity for solid-liquid separation. Different fresh material volumes were modeled in order to determine the economic viability of solid-liquid separation. Financial analysis was performed for annual fresh seaweed of 50 Mg to 250 Mg fresh seaweed. My findings are exhibited in Table 10 below. The cost was normalized to local Indonesian rate and expressed in dollar. The unit variable cost constantly increases as the amount of fresh seaweed supplied goes down. The increase of unit production cost reduces the net income.

**TABLE 10. The effect of scaled production levels on operational expenses.**

| Expenses Summary | 50,000 (Kg fresh seaweed) | 100,000 (Kg fresh seaweed) | 150,000 (Kg fresh seaweed) | 200,000 (Kg fresh seaweed) | 250,000 (Kg fresh seaweed) |
|---|---|---|---|---|---|
| Gross Receipts from Production | | | | | |
| - Liquid | 7,156.25 | 14,312.50 | 21,468.75 | 28,625.00 | 35,781.25 |
| - Dry Cake | 3,125.00 | 6,250.00 | 9,375.00 | 12,500.00 | 15,625.00 |
| Total Gross Receipts | 10,281.25 | 20,562.50 | 30,843.75 | 41,125.00 | 51,406.25 |
| Variable Operational Cost | | | | | |
| - Fresh seaweed | 4,953.56 | 9,907.12 | 14,860.68 | 19,814.24 | 24,767.80 |
| - Electricity | 164.47 | 328.95 | 493.42 | 657.89 | 822.37 |
| - Maintenance | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 |
| Labor cost | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 |
| Total Variable Operational Cost | 15,307.51 | 20,425.54 | 25,543.58 | 30,661.61 | 35,779.64 |
| Fixed Cost (Annualized) | | | | | |
| - Drying Area Construction | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 |
| - Area of construction | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 |
| - Warehouse Area Construction | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 |
| - Drying facilities | 136.05 | 136.05 | 136.05 | 136.05 | 136.05 |
| - Comminute machine | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 |
| - Pressure machine | 328.95 | 328.95 | 328.95 | 328.95 | 328.95 |
| - Warehouse | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 |
| Total Fixed Cost | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 |
| Contingency | 247.68 | 495.36 | 743.03 | 990.71 | 1,238.39 |
| Total Operational Expenses | 18,315.88 | 23,681.59 | 29,047.30 | 34,413.01 | 39,778.72 |
| Interest Expenses | 1,839.03 | 2,059.76 | 2,280.49 | 2,501.22 | 2,721.96 |
| Total Expenses | 20,154.91 | 25,741.35 | 31,327.79 | 36,914.24 | 42,500.68 |
| Unit cost per Kg of fresh seaweed processing after tax | 0.8391 | 0.5358 | 0.4347 | 0.3842 | 0.3539 |

Economies of scale were examined using the cost unit of kilogram fresh seaweed processing of *K. alvarezii.* A consistent increase in the unit cost of production occurs when the total fresh seaweed material decreases as shown in Figure 2 below. The increased cost was due to low production (low income) where operational expenses and fixed costs were about similar to full production. Unit cost of production from 250 Mg fresh seaweed is 43.04¢ per kilogram. The solid-liquid processing should be at least 200Mg fresh seaweed per year to breakeven. In addition, total of expenses decrease in relation to the smaller fresh seaweed material level, a closer look at the cost allocation results in a bigger portion in the decrease of gross receipt than that of variable cost. Thus, cost of production continuously increases.

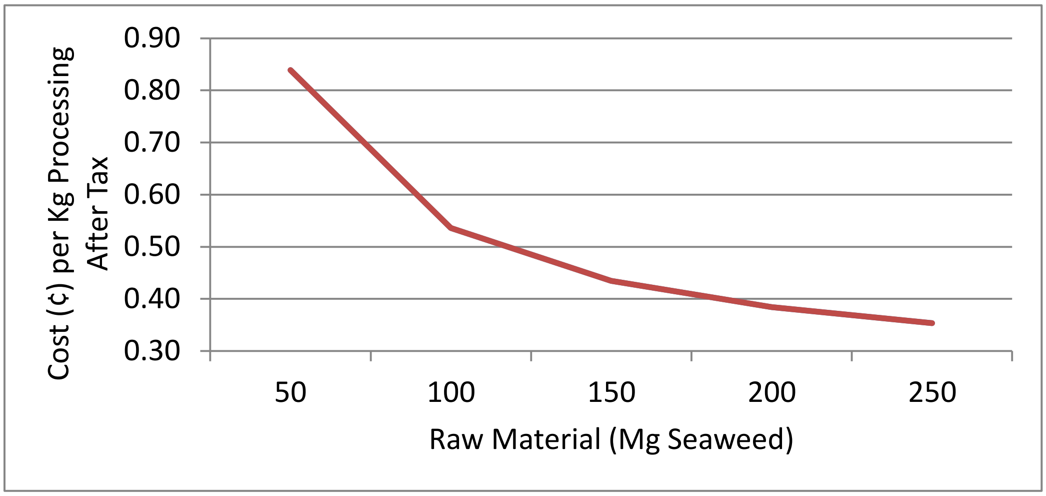



FIGURE 2. Size Economies of solid-liquid separation

Increasing the fresh seaweed material supply could potentially to increase the profit as shown in Figure 2. An upper production limit of 250 Mg of fresh material was based on the size of the comminuting machine. Upgrading of the machine would result in an increase of fresh seaweed that could be processed, and a consequent increase in profits. However, it will increase the variable cost and influence the profit gained. Seaweed growth also follows environmental conditions. During the rainy season, for example, seaweed grows more abundantly, while during the dry season, seaweed production is much slower. This seasonal variation in growth rate determines fresh material supply for solid-liquid processing.

Economic analysis of solid –liquid processing does not include the future price, inflation for variable costs over ten years. Variable costs such as electricity rate, construction materials, and fresh seaweed price and labor costs tend to increase over time. The increase of variable costs to about 5% will decrease 50.82% of net cash flow. If the variable costs continue increasing at 10% per annum over a decade and selling price is constant, the net cash flow is minus $100.17 per year, and the ERR and IRR fall below the MARR. The increase of 10% is based on historical inflation rate for a decade in Indonesia for agriculture equipment. The selling price of 50¢ per liter of liquid and 40¢ Kg of cake would no longer be profitable. Therefore, the company should identify other markets to increase the selling price at 2.5% to return to an IRR 30.23%.

# CONCLUSION

In summary, fractional factorial experimentation was used to evaluate six processing parameters independently. Liquid recovery of *K. alvarezii* was affected by the knife spacing of the Comitrol™ cutting head, final pressure and initial temperature. The highest liquid recovery of 50% was at the 1mm knife spacing, 2800kPa and 22°C. Pressed cake thickness was influenced by knife spacing of the Comitrol™ head, high level of plunger head-speed, high final pressure and low initial weight. The highest cake thickness of 1.33% was at the 10mm knife spacing of the Comitrol™ head and $28^0$C. The dried cake weight was influenced by the knife spacing of the Comitrol™ cutting head, initial temperature. The highest cake weight of 16.3% was at the 10mm knife spacing of the Comitrol™ cutting head and $28^0$C. The liquid will be raw material for crop fertilizer and dry particle (concentrate) is the proposed ingredient for aquatic animal feed. This solid-liquid separation is proposed as small-scale operation where it can be expanded to the village level where coastal seaweed farmers are growing seaweed. With the price assumption on the economic analysis model, the liquid-solid processing can be a viable and profitable alternative for seaweed farmers to offer their fresh seaweed. A solid-liquid processing facility should process a minimum of 200 Mg per year for economy of scale. An increase of over 10% per year in variable costs should be followed by an increase in the selling price by at least 2.5% for an internal rate of return 30.23%.

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# APPENDIX A

APPENDIX A-1. Schedule of Operation of Solid-Liquid Separation on *Kappaphycus alvarezii* Doty.

| Cycle Summary | Duration | % of Cycle | Operations | Unit | Value | Cycle Summary |
|---|---|---|---|---|---|---|
| Comminute | Kg/min | 100% | Rate of processing | H3`o urs | 1388.89 | Comminute |
| Pressing | Kg/min | 100% | Rate of processing | hours | 333.00 | Pressing |
| Drying | Days | 100% | Rate of operation | Days | 365 | Drying |
| Cycle Summary | Duration | % of Cycle | Operations | Unit | Value | Cycle Summary |

APPENDIX 0-2. Expense Rate Assumption (250 Mg fresh seaweed per year).

| Variable Expense Rates | Unit | Value | Amount | Total $ | Variable Expense Rates |
|---|---|---|---|---|---|
| Electricity Rate | $/kwh | 0.08 | 2,777.78 | 675.44 | Electricity Rate |
| Maintenance | % | 5.00 | 23,789.47 | 1,189.47 | Maintenance |
| Contingency (% of Operational Expenses) | % | 5.00 | 24,767.80 | 1,238.39 | Contingency (% of Operational Expenses) |
| Labor | 12 | 3.00 | 250.00 | 9,000.00 | Labor |

APPENDIX A-3. Financial Parameters.

| Financial Analysis | Unit | Value | Total |
|---|---|---|---|
| Assumption of Sale price per Kg liquid | $/Kg | 0.40 | 0.40 |
| Assumption of Sale price per Kg cake | $/Kg | 0.50 | 0.50 |
| Loan Rate, Annual | years | 10.00 | 10.00 |
| Loan interest | % | 5.57 | 0.056 |
| General Exercise Tax Rate | % | 0.50 | 0.01 |

## APPENDIX B

APPENDIX 0-1. Drying Facility.

| Drying (96 m2 x 2) | Size | Unit | Price | Total |
|---|---|---|---|---|
| - Wood beam | | | | |
| * Wood beam | 5x10 cm | 10 | 31.6 | 315.8 |
| * Wood beam | 4x6 cm | 28 | 5.3 | 147.4 |
| - Bamboo | 6 m | 96 | 2.1 | 202.1 |
| - White plastic tarp | 8x6 m | 8 | 26.3 | 210.5 |
| - Nails | 5; 3 cm | 7 | 2.6 | 18.4 |
| - Rubber tube | 5100 cm3 | 4 | 15.8 | 63.2 |
| - Stainless Steel Wire Cloth 40 micron | meter | 3 | 50.0 | 150.0 |
| TOTAL | | | | 1,107.4 |

APPENDIX B-2. Warehouse Construction.

| Warehouse (6x6 m2)) | Size | Unit | Price | Total |
|---|---|---|---|---|
| - Wood-pillar | 6x15 | 8 | 31.6 | 252.6 |
| - Wood-beam | 4x6 cm | 10 | 5.3 | 52.6 |
| - Roof | $/feet | 120 | 0.9 | 113.7 |
| - Wall construction | | | | |
| - Brick wall | $/piece | 2000 | 0.1 | 168.4 |
| - Cement | $/sack | 30 | 6.3 | 631.6 |
| - Labors | $/day | 18 | 10.5 | 189.5 |
| - Nails | $/Kg | 2 | 2.6 | 5.3 |
| TOTAL | | | | 1,413.7 |

## APPENDIX C

APPENDIX 0-1. Income Statement for 250 Mg fresh seaweed (raw material) *Kappaphycus alvarezii* Doty from solid-liquid separation processing base model (USD).

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Gross Receipts | | | | | | | | | | |
| - Liquid | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 | 35,781.25 |
| - Dry Cake | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 | 15,625.00 |
| Total Gross Receipts | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 |
| Variable Operational Cost | | | | | | | | | | |
| - Fresh seaweed | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 | 24,767.80 |
| - Electricity | 822.37 | 822.37 | 822.37 | 822.37 | 822.37 | 822.37 | 822.37 | 822.37 | 822.37 | 822.37 |
| - Maintenance | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 | 1,189.47 |
| Labor cost | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 | 9,000.00 |
| Total Variable Operational Cost | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 | 35,779.64 |
| Fixed Cost (Annualized) | | | | | | | | | | |
| - Drying Area Construction | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 |
| - Area of construction | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 | 73.68 |
| - Warehouse Area Construction | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 | 147.37 |
| - Drying facilities | 136.05 | 136.05 | 136.05 | 136.05 | 136.05 | 136.05 | 136.05 | 136.05 | 136.05 | 136.05 |
| - Comminute machine | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 | 1,800.00 |
| - Pressure machine | 328.95 | 328.95 | 328.95 | 328.95 | 328.95 | 328.95 | 328.95 | 328.95 | 328.95 | 328.95 |
| - Warehouse | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 | 127.27 |
| Total Fixed Cost | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 | 2,760.69 |
| Contingency | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 | 1,238.39 |
| Total Operational | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 | 39,778.72 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Expenses | | | | | | | | | | |
| Interest Expenses | 2,721.96 | 2,449.76 | 2,177.56 | 1,905.37 | 1,633.17 | 1,360.98 | 1,088.78 | 816.59 | 544.39 | 272.20 |
| Total Expenses | 42,500.68 | 42,228.48 | 41,956.29 | 41,684.09 | 41,411.90 | 41,139.70 | 40,867.51 | 40,595.31 | 40,323.11 | 40,050.92 |
| Net Income Tax | 212.50 | 212.50 | 212.50 | 212.50 | 212.50 | 212.50 | 212.50 | 212.50 | 212.50 | 212.50 |
| Net Income After Tax | 8,693.07 | 8,965.26 | 9,237.46 | 9,509.65 | 9,781.85 | 10,054.05 | 10,326.24 | 10,598.44 | 10,870.63 | 11,142.83 |
| | | | | | | | | | | |
| Cost unit per kg after tax | 0.3539 | 0.3516 | 0.3494 | 0.3471 | 0.3448 | 0.3426 | 0.3403 | 0.3381 | 0.3358 | 0.3336 |

APPENDIX 0-2. Statement of cash flow for 250 Mg fresh seaweed (raw material) *Kappaphycus alvarezii* Doty from solid-liquid separation processing base model (USD).

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cash Flows form | | | | | | | | | | | |
| Operating Activities | | | | | | | | | | | |
| Cash Collected | | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 | 51,406.25 |
| Total Expenses (Less) | | 42,500.68 | 42,228.48 | 41,956.29 | 41,684.09 | 41,411.90 | 41,139.70 | 40,867.51 | 40,595.31 | 40,323.11 | 40,050.92 |
| Non-Cash Expenses (add, i.e., Depreciation) | | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 | 2,392.27 |
| Net Cash* | | 11,297.84 | 11,570.04 | 11,842.23 | 12,114.43 | 12,386.62 | 12,658.82 | 12,931.01 | 13,203.21 | 13,475.40 | 13,747.60 |
| Cash Flows form | | | | | | | | | | | |
| Investing Activities | | | | | | | | | | | |
| Purchase of Fixed Assets | 27,317.37 | | | | | | | | | | |
| Proceeds** | | | | | | | | | | | |
| Net Cash*** | 27,317.37 | | | | | | | | | | |
| Cash Flows from | | | | | | | | | | | |
| Addition to | | | | | | | | | | | |
| Long-Term Debt | | | | | | | | | | | |
| Reduction in Long-Term Debt (Less) | 48,868.14 | | | | | | | | | | |
| Net Cash**** | | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) |
| Net Increase | 48,868.14 | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) | (4,886.81) |
| (Decrease) in Cash | 76,185.50 | 6,411.03 | 6,683.22 | 6,955.42 | 7,227.61 | 7,499.81 | 7,772.00 | 8,044.20 | 8,316.39 | 8,588.59 | 8,860.79 |
| Cash Starting Balance | 76,185.50 | 0 | 6,411.03 | 13,094.25 | 20,049.66 | 27,277.28 | 34,777.09 | 42,549.09 | 50,593.29 | 58,909.68 | 67,498.27 |
| Cash Ending Balance | | 6,411.03 | 13,094.25 | 20,049.66 | 27,277.28 | 34,777.09 | 42,549.09 | 50,593.29 | 58,909.68 | 67,498.27 | 76,359.06 |

| | |
|---|---|
| IRR (10 years) | 30.23% |

* Provided by operating activities

** From sale of fixed assets

*** Used in investing activities

**** Provided by financing activities