GLOBAL ENGINEERS & TECHNOLOGISTS REVIEW
www.getview.org

HEXANE ECONOMIZATION IN PALM KERNEL OIL PLANT: A STUDY AFTER PROCESS DESIGN IMPROVEMENT

SIVARAO[1], KUMAR[2], N., WIDODO[3], W.S. and HAERYIP SIHOMBING[4]

[1, 2] Department of Manufacturing Process
[3] Department of Manufacturing Design
[4] Department of Manufacturing Management
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, MALAYSIA
[1]sivarao@utem.edu.my
[3]wswidodo@utem.edu.my
[4]iphaery@utem.edu.my

ABSTRACT

Hexane (C_6H_{14}) is used as a solvent to extract oil from palm kernel to produce crude palm kernel oil (CPKO) which is a common cooking ingredient. The main intention of this research work is to reduce hexane loss during the extraction process of oil from palm kernel. This research project was carried out in a leading vegetable factory in Malaysia. Although this plant managed to get high yield (average 48.5 %) compare with other similar conventional plants in Malaysia but the hexane loss is very high, 8.5 litre/Metric Ton (l/MT) in average. To reduce the hexane loss, few modification jobs were carried out; adding of new shell and tube condenser, sealing of leakages and developed a set of standard operating procedures. Preliminary investigation after the improvement steps found that, reduction of hexane loss showed a decrease of about 30 % from the average of 9.5 % litre/MT of palm kernel 6.5 litre/MT of palm kernel after the improvement. This amounted of hexane savings of 3 litre/MT of palm kernel which is equivalent to about RM 727,660 for 8 months after the process improvement taken into effect.

Keywords: *Palm Kernel, Hexane, Extraction, Condenser.*

1.0 INTRODUCTION

Solvent extraction as a process utilizes solvents to extract the residual oil from oil-bearing seeds, cakes and brans (Dacera *et al.,* 2003). Vegetable oil has been the main source of fat for human consumption. Most edible oils and fats are soluble in liquid hydrocarbons and hexane is the most commonly used hydrocarbon fraction for solvent extraction (Dacera *et al.,* 2003). The solvent used in this process is not expanded, but is used over and over again in the process of recycling and a large volume of the solvent always remains in various stages of the closed processing cycles.

Reducing production cost by reducing the hexane loss during the process is the key point of this study. The main aim of this research work is to reduce hexane losses during the oil extracting process from palm kernel and to study how effectively hexane and oil in the form of mischella can be separated in order to reduce the production cost while increasing the profit. Using Hexane to extract oil is called solvent extraction or solvent extraction plant. Solvent is a liquid, solid, or gas that dissolves another solid, liquid, or gaseous solute, resulting in a solution that is soluble in certain volume of solvent at a specified temperature.

In solvent extraction plant, hexane is commonly used as a solvent to extract the oil from the palm kernel. Hexane is a hydrocarbon with the chemical formula C_6H_{14}; that is, an alkane with six carbon atoms. According to a report by the Cornucopia Institute, hexane is used to extract oil from grains as well as protein from soy, to such an extent that in 2007, grain processors were responsible for more than two-thirds of hexane emissions in the United States (NVO Hexane Report, 2010). The report also pointed out that the hexane can persist in the final food product created; in a sample of processed soy, the oil contained 10 ppm, the meal 21 ppm and the grits 14 ppm hexane. Using hexane to extract oil is commonly used for oil-cake extraction (soya bean meal, groundnut meal, rice bran meal, cotton seed meal, sells seed, guar meal, copra meal), oilseeds (soya bean, sunflower seed, groundnut, cotton, sal, niger, mustard, castor), vegetable oils (palm olefins, soya bean oil, rap seed oil, sunflower seed oil), grains (wheat, corn, rice, sorghum, millets, barley) (Yuhazri *et al.,* 2012) and (House *et al.,* 1981).

In Malaysia there is a leading vegetable oil plant using hexane to extract oil from palm kernel. This is the only plant in Malaysia using hexane for direct extraction from palm kernel flakes. This plant is divided into two sections where the first section is preparation plant and the second section is a solvent extraction plant. In the preparation plant, the palm kernels will be hammered, crushed, flaked and conditioned by indirect steam and then, this flaked meal will be sent to the second section, solvent extraction plant where hexane will be pumped and flushed to these flakes to extract the oils. By using hexane about 48 % of crude palm kernel oils and 52 % of by-product, palm kernel meal can be produced.

By using this technology this plant is able to extract more crude palm kernel oils, yield an average 48 % compared with conventional press which would only be 44.5 % in average (Hai, 2002). Although this plant uses hexane for solvent extraction from palm kernel and gain higher yield compared with other conventional methods, but they are facing problem to recover hexane efficiently. Average hexane loss at the end of the day is about 9.5 of hexane per ton of palm kernel losses encountered. Basically this plant faces problem with high hexane losses during the process of extracting oils from palm kernels. Complete process flow of preparation and extraction sections are show in the form of flow chart in Figure 1.

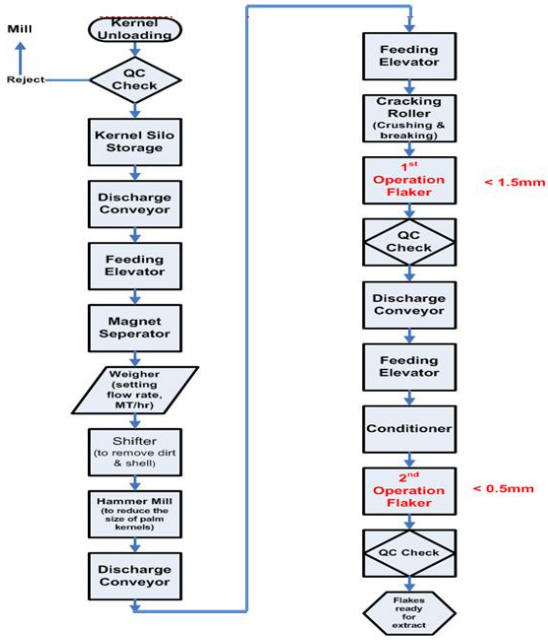


Figure 1: Preparation plant flow chart.

1.1 Preparation Plant

Preparation plant is the place where daily production is set by key in the required flow rate (MTs/hour) of palm kernels in the weigher machine. In this plant, after past the magnetic separator to separate metal pieces, palm kernels from silos will send to weigher to produce required flow rate per hour. After the weigher machine, the palm kernels will enter to hammer mill where the palm kernels will be hammered to reduce the size and for further reduction the kernels will past to the cracking roller machine where the kernels will be crushed and break further. To get high yield of crude palm kernel oils (CPKO), the kernels must be soft and small size. So to get that result, the broken kernels will send to 1st operation flaker where all these kernels will be flaked to below 1.5 mm thickness and then all these materials will send to conditioner where these flakes will be heated up with jacketed steam to get temperature about 70 °C. After the conditioner these soft flakes will enter to 2nd operation flaker to get flakes thickness below 0.3 to 0.5 mm. Finally these flakes are ready to extract oil. All these process are online continuous process.

1.2 Extraction Plant

After the final process in preparation plant, the flakes will be transferred to the extractor with 2 compartments. In this extractor, the fresh hexane will be pumped into these flakes to extract the oil. This oil called miscella, means oil and hexane mixed together where miscella contains about 60 % of hexane. To separate oil and hexane, this miscella will go through another process in distillation plant. After the oils were extracted from the flakes, the by-product, palm kernels meals from the 2nd compartment will be produced. This by-product, palm kernel meals contains around 40 % of hexane. To separate meals and hexane, these by products will be sent to another plant, meal de-solventizing. Process flow of the extraction plant is shown in Figure 2.

Distillation is the process to separate the miscella into crude palm kernel oil and hexane. In this plant the mischella will be heated up in three different stages and temperature till capture all the hot hexane vapor and this hot vapor will be vacuumed to three different condensers to cool it and regain the hexane in liquid form and will be re-used. In this meal de-solventizing plant, the by-product will be heated up by going through a super heater and by using vacuum about –0.5bar, the hot hexane vapor will be sucked into condenser where, heat transfer will take place to convert the hexane into vapor to liquid form. This liquid hexane will be stored in working tank and will be recycled to the extractor.

Whatever hexane missed to collect in distillation and meal de-solventizing process, will be sent to absorption plant where, in this plant absorption oil will be used to trap whatever missing hexane. The hexane, which dilute with abruption oil, will send to absorption column and followed by heat exchanger to heat up the hexane to separate it from absorption oil and then will past to 2nd heat exchanger to bring back the hexane to liquid form and finally all the collected hexane will be transferred to the hexane working tank. After the hexane removed through the above process, the oil called crude palm kernel oil, CPKO and the by-product is palm kernel meal. By this extraction process around 48 % Crude palm kernel oils and 52 % of by-product, palm kernel meals is produced. The CPKO will be transferred to main storage tank to sell out or further process in the refinery plant. The palm kernel meal will send to palletizing plant to produce palm kernel pallets and palm kernels meal.

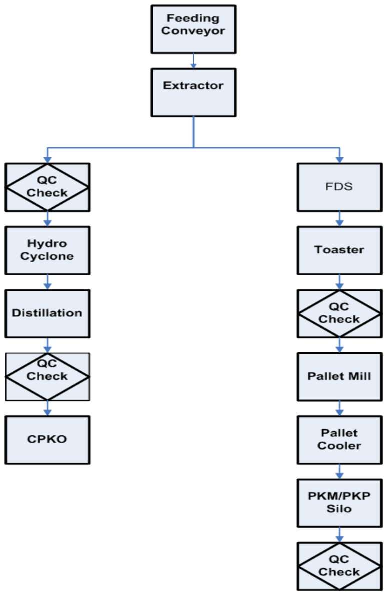


Figure 2: Extraction plant flow chart.

2.0 MATERIALS AND METHODS

2.1 Pre-assessment

Pre-assessment audit were carried out on high hexane loss followed an assessment to focus the major problems and implementation to reduce the hexane loss and finally monitoring and evaluation of the final result. The pre-assessment audit was conducted in May, 2011. Pre-assessment audit was conducted to focus area of high hexane loss based on fish bone diagram as shown in Figure 3. Input details were collected through current result, parameters, interviews, questionnaires and brain storming sections.

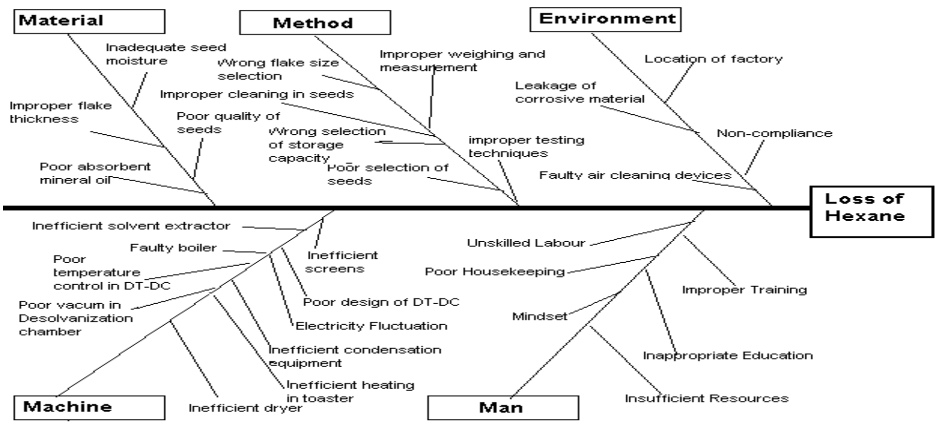


Figure 3: Fishbone analysis.

Based on the pre-assessment findings, the audit was focused on:

(i) Excess loss
Excess loss is the amount of additional loss through:

(a) oil from the final oil stripper.
(b) air from the meal dryer cooler.
(c) meal from meal dryer cooler.
(d) air from the mineral oil system.
(e) water from waste water evaporator.
(f) inconsistent operation.

The excess loss due to inconsistent operation occurs during the period starting when the input conditions change and ending when the input conditions change back to normal, or during the period starting when the input condition change and ending when steady state is achieved after the operating parameters have changed.

(ii) Fugitive loss
Fugitive loss is the amount of solvent loss from the process equipment through flanges, doors, packing glands, pump seals, valves stems, sight glasses, etc. This loss occurs when the pressure inside the vessel is higher than atmospheric pressure, causing solvent vapour inside the vessel to leak out through any orifice.

(iii) Purging loss
Purging loss is amount of solvent loss from process equipment resulting from freeing the process equipment of solvent vapour for inspection or maintenance. This loss occurs as a result of opening up the process equipment and as a result of using purge fans to pull air through the process equipment. During normal operation, purging loss does not exist. Purging loss only exists when the plant is shutdown. Thus, the solvent loss as a result of purging can not be quantified in terms of litters of solvent loss per ton of palm kernel processed on a direct basis, as with other categories of solvent loss.

2.2 Assessment

Based on findings in the fish bone diagram, the assessment audit was conducted in July 2011. The assessment was focused on excess loss, fugitive loss and purging loss. The purpose of the assessment was to collect detail information on high hexane loss due to excess loss, fugitive loss and purging loss.

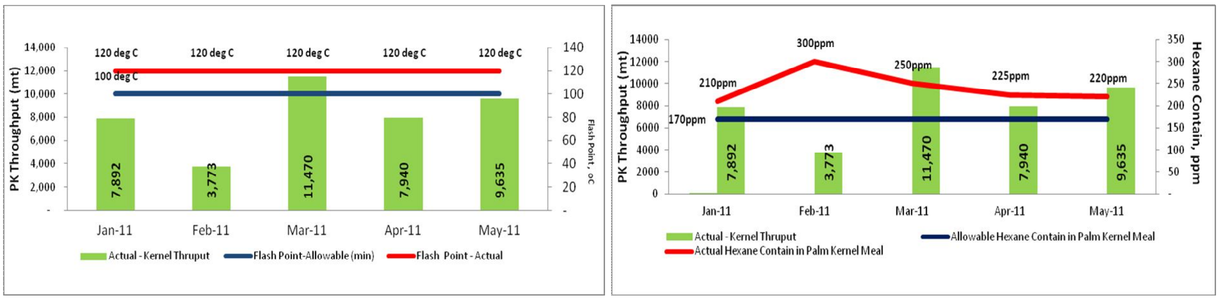
2.2.1 Assessment phase 1: excess loss

Excess loss is the only area able to do analyse the quantity of hexane contains in crude palm kernel oil, palm kernel meal, vent gases from absorption and water from waste water system. Hexane contains in crude palm kernel oil measured by flash point temperature meanwhile hexane contain in palm kernel meal and waste water measured by mg/kg or ppm and hexane contain in vent gases from absorption measured by kg/ or ppm. According to Solvent Extractors Association Handbook of India 9th revised edition 2009, the allowable range for for flash point is min 100 °C, hexane contain in palm kernel meal is 170 ppm, hexane contain in vent gases is 50 mg/ and hexane contain in waste water is 10 ppm. Detail audit of analyzing the hexane contains were carried on January till May 2011 and the average for these 5 months are as per in Table 1.

Table 1: Detail audit data.

	January 2011	February 2011	March 2011	April 2011	May 2011	Acceptable
Palm Kernel thru put (MT)	12,250	11,510	12,505	12,500	12,498	-
CPKO-Flash Point (°C)	120	120	120	120	120	Min 100
Hexane in Palm Kernel Meal (ppm)	210	300	250	225	220	170
Vent gases from absorption (mg/ltr)	600	500	550	580	570	50
Water (ppm)	8	6	10	8	8	10

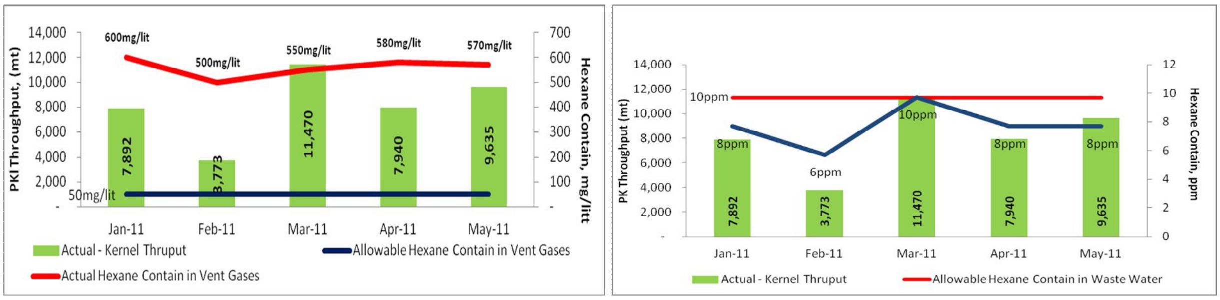
Base on data from Table 1, four independent plots were developed to have a clear picture of the improvement in better hexane recovery.



(a) **(b)**

Figure 4: (a) comparison of actual & allowable with PK thru put, **(b)** comparison of hexane contain in palm kernel meal with PK thru put.

From Figure 4(a), 4(b), 5(a) and 5(b), it was found that there is high hexane loss in vent air from absorption compare with other hexane losses in CPKO, palm kernel meal and waste water. Decision was made to focus on hexane loss in vent air and to draft an action plan and improvement. Detail studies and audits were carried out in distillation section as shown in Figure 6.



(a) **(b)**

Figure 5: Comparison of hexane contain in **(a)** vent air with PK thru put, **(b)** waste water with PK thru put.

The vent air blows through absorption section but the unrecovered hexane vapor comes mainly from distillation section, while small amount from extractor. To save 50 % steam of the distillation is achieved using hot De-solventizer vapors in a unique falling film economizer. This reduces the steam consumption and the load on the final condenser. This is followed by a steam heated rising film evaporators and stripping column operating under vacuum.

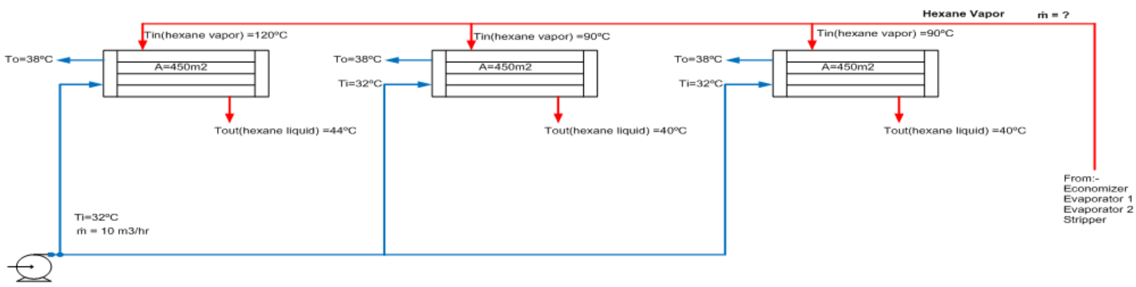


Figure 6: Distillation section before modification.

The vapors from falling film economizer, rising film evaporators 1 and 2 and from stripper column will be sucked into condensers to condense hexane vapor to liquid form. The hexane vapor that is not condensed in the last condenser is typically passed through a mineral oil absorption system. The hexane liquid will be transferred into special water separator to remove the waste water. After maximum recovery by condensation further hexane content in the exhaust air can be further reduced only by an absorption by intimate contact with chilled mineral oil in specially designed packed column. Thereafter the air is exhausted to the atmosphere with the maximum hexane content and the absorber oil is stripped with direct stream to remove the traces of hexane and send for re-circulation to cold absorber.

The special absorber unit is a packed column. The air aspirated with the feedstock into the plant has to be evacuated. This air is a carrier of hexane at its saturation vapor pressure. So the exhaust air is cooled first in chilled water vent condenser to a temperature around 20 °C for maximum recovery by condensation. To reduce the hexane content in vent air, there are two options considered: upgrade complete absorption section and add 1 more condenser to increase the condensation capacity. Since the cost is high to upgrade the complete absorption system, recommendation given to management to add 1 more condensers in the distillation plant. Table 2 shows the existing and the recommendation.

Table 2: Existing and proposed distillation installation.

Condenser	Area (m^2)	Water Flow Rate (m^3)	Water Temperature (°C)		Hexane Vapour Temperature (°C)	
			In	Out	In	Out
C1	450	200	32	38	120	44
C2	450	200	32	38	90	40
C3	450	200	32	38	90	40

*Recommendation: Add new condenser of 450m^2

2.2.2 Assessment phase 2: fugitive loss

Decisions taken to carry out pressure test all equipment and piping with pressurized water to ensure that the system is free of leaks prior to start operation.

2.2.3 Assessment phase 3: purging loss

Purging loss only exist once the plant is starting back after the shutdown. Case study was carried for the year 2010 of high hexane losses during the plant start back after more than 1 day shutdown as shown in Figure 7. The actions that can be taken to minimize the purging loss are:

(i) Improve equipment reliability through design improvement and trough preventive maintenance processes. This will reduce the frequency for which maintenance and inspection are required, thus reducing the frequency of vapor freeing and its related purging solvent loss.

(ii) Allow the normal vapor recovery system to run as long as possible prior opening up the process equipment. This will recover the majority of the solvent prior to vapor freeing, thus reducing purging loss.

(iii) Discharge the purge fan through a condenser to recover as much as the solvent vapor as possible, thus reducing purging solvent loss.

Decision was taken to carry out action plant no 2 due to able to carry out the action immediately without any major cost.

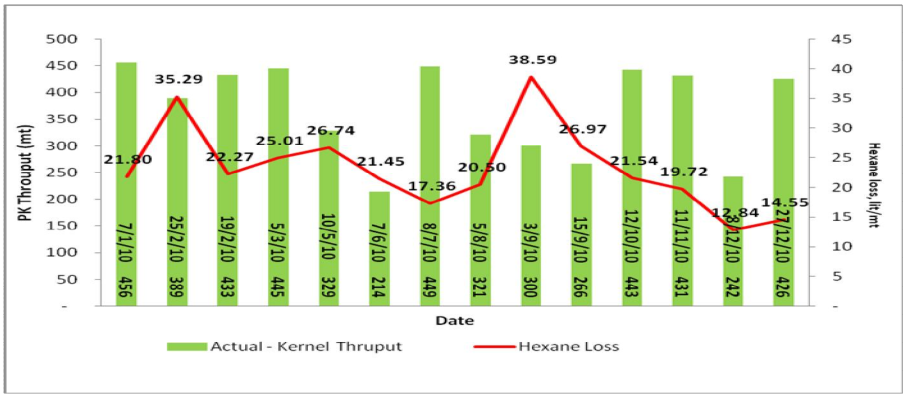


Figure 7: Hexane loss after plant starting back from shut down.

2.3 Implementation

Once the action plans were selected for excess, fugitive and purging loss, decision taken to implement the action plans in stages, 1st excess loss followed by fugitive loss and finally purging loss.

2.3.1 Excess loss

On 23 December 2011, added 1 more condenser, 450 m^2 to increase the cooling capacity from 1350m^2 to 1800m^2 (refer to Figure 8). This mainly to condense the vapor from economizers, evaporators and stripper and reduce the excess load in absorption section.

2.3.2 Fugitive Loss

On 02 June 2012, the complete solvent extraction plant was shutdown for annual maintenance works. The action taken to pressure tests all the equipment including economizers, evaporators, stripper, vapors lines and vessels. The pressure test carried out by using water and found the water leaking from economizer top manhole, evaporators transfer line flange, several piping flange and 1 elbow cracked. Gaskets were changed to all the leaking area and replaced new elbow.

2.3.3 Purging Loss

A shutdown procedures was planned and a case study was carried out from June to August 2012, decision taken that vacuum pump, steam and cooling tower need to be operated continuously for 3 hours before the plant completely shut down. This due to allow the normal vapor recovery system and recover the majority hexane vapor to be condensed.

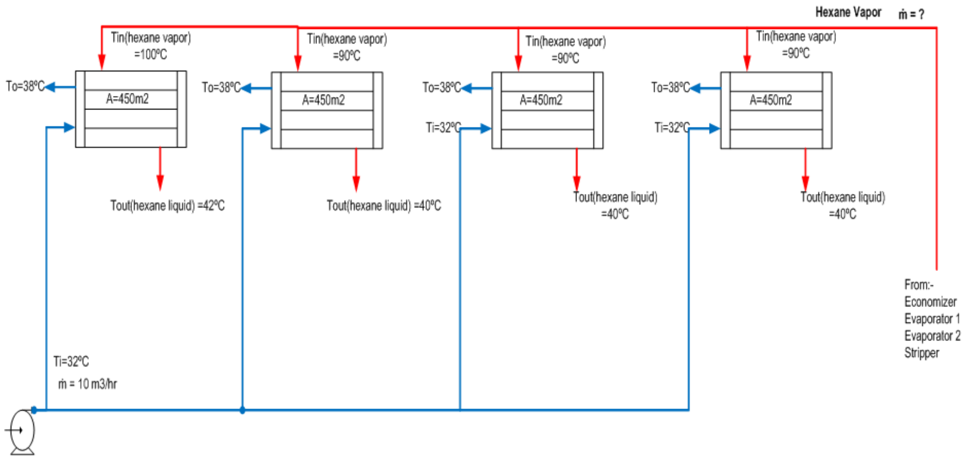


Figure 8: Distillation section after modification.

3.0 Results and Discussion

The results after the improvement were recorded in three different stages. The findings and discussion are focused on hexane loss in excess loss, purging loss and fugitive loss.

3.1 Excess Loss

After installed new condenser to increase the cooling capacity from 1350 m^2 to 1800 m^2, results are monitored for hexane content in ventilated air from January 2012 to May 2012. Based on the results, a graph was plotted as per Figure 9(a). This graph shows hexane contains in vent reduced from average 560 mg/litre taken in January-May 2011 to average 132 mg/litre. Detail analysis of hexane loss also carried in the same period. Figure 9(b) is the results and found after the installed new condenser, the hexane loss reduced from average 9.5 litre/MT to 7.5 litre/MT.

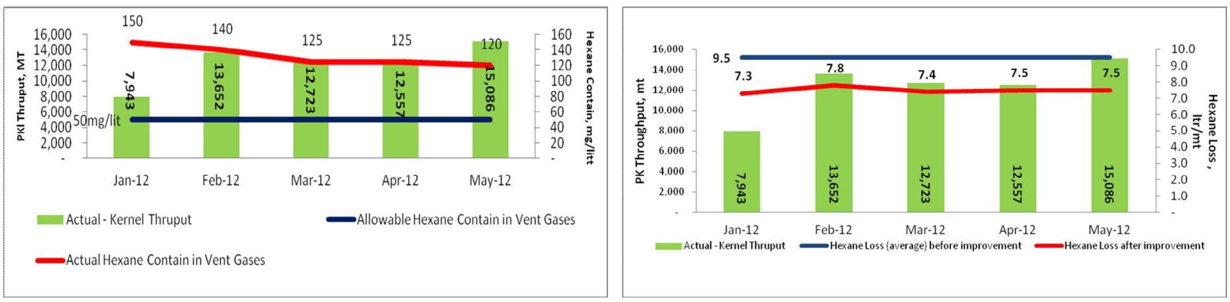


Figure 9: (a) Monitoring hexane in vent air, **(b)** hexane excess loss before and after modification.

3.2 Fugitive Loss

After rectified all the leakages especially from economizer, evaporators' flanges and elbows and fittings, detail analysis was carried for 3 months. A graph was plotted base on the results. Figure 10(a) clearly shows the improvement and saving about 1 litre/MT after stop the leakages.

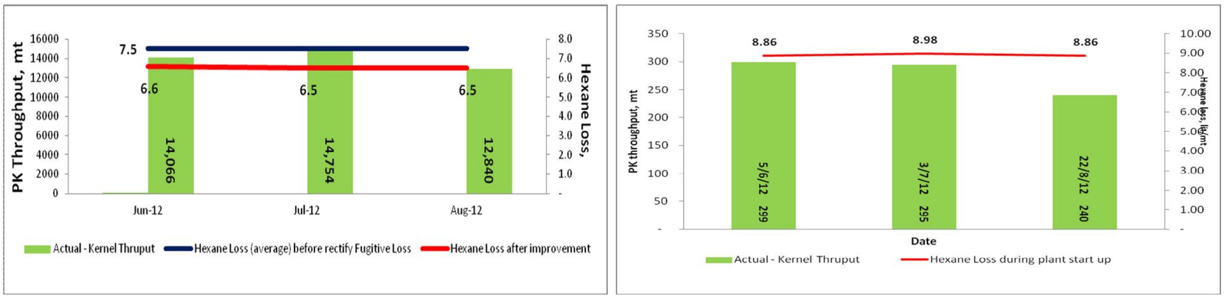


Figure 10: Hexane before and after modification, **(a)** fugitive loss, **(b)** Purging loss.

3.3 Purging Loss

Although the hexane loss due to purging cannot be quantified in terms of litre of solvent loss per ton of palm kernel processed on a direct basis but it's very important to keep the hexane loss as low as possible during the plant start up after shutdown. Following the specific shutdown and start-up procedures complying detailed checklists, the results have been improved as shown in Figure 10(b).

4.0 CONCLUSION

Hexane loss has always been the significant reason incurring cost for operating of an extraction plant. Perhaps, in the past, there were times when additional solvent usage was accepted as part of having lower residual oils in the meal and mill feed or even lower energy costs in steam production, but discarded by recent food and safety regulations. However excessive expenditure for additional solvent recovery or pollution control equipment would not be necessary if a plant is properly operated and maintained. Table 3 clearly shows the total saving of RM 727, 660 from January 2012 to August 2012 after the improvements we implemented.

Table 3: Total saving of hexane

	January 2012	February 2012	March 2012	April 2012	May 2012	June 2012	July 2012	August 2012
PK throughput (mt)	7,943	13,652	12,723	12,557	15,086	14,066	14,754	12,840
Hexane Loss (/mt)	7.3	7.8	7.4	7.5	7.5	6.6	6.5	6.5
Hexane Price (RM/s)	2.89	2.82	2.82	2.43	3.17	3.22	3.05	2.94
Average Hexane loss in year 2011	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Saving (RM)	50,494	65,536	75,450	61,020	95,704	131,261	134,871	113,324

ACKNOWLEDGMENTS

Authors would like to thank Faculty of Manufacturing Engineering and Universiti Teknikal Malaysia Melaka for supporting this research Special thanks to Ministry of Higher Education (MOHE) for awarding research grants (GLuar/2012/FKP(1)/G00010) and (PRGS/2012/TK01/FKP/02/1/T0003) which very much helped in completing the study without much hurdles.

REFERENCES

[1] Dacera, D., Jenvanitpanjakul, P., Nitisoravut, S. and Babel, S. (2003): Hexan Reduction in a Thai Rice Bran Oil factory: A Cleaner Technology Approach. *Thammasat Int. Journal of Science and Technology,* Vol.8, No.4, pp.6-16.

[2] NVO Hexane Report (2010): Soy Protein and Chemical Solvents in Nutrition Bars and Meat Alternatives, Cornucopia Institute.

[3] Hai, T.C. (2002): The Palm Oil Industry in Malaysia: From Seed to Frying Pan, Plantation Agriculture - WWF Malaysia.

[4] House, R.J.R., Harcombe, A.O. and Guinness R.G. (1981): Hexane Losses in Solvent Extracted Soya Meal: Measurement by Gas Chromatography and Brief Evaluation. *Journal of the American Oil Chemist' Society,* pp.626-629.

[5] Yuhazri, M.Y., Haeryip Sihambing, Umar Nirmal, Saijod Lau and Phongsakorn Prak Tom. (2012): Solid Fuel from Empty Fruit Bunch Fiber and Waste Papers part1: Heat Released from Combustion Test. *Global Engineers and Technologists Review.* Vol.2, No.1, pp.7-13.