Editorial

This issue of the Palm Oil Engineering Bulletin has special significance to the Engineering and Processing Division. It has completed its 25th year of existence. Starting from a mere stapled loose sheets of papers by the late Ir J H Maycock, it has come a long way to what it is today without the luxury of a team of journalists and specialists to support it. Credit must be given to Maycock for his confidence that this will continue to survive. The time allocated to this Bulletin is just a few man-days a month and as a result the publication sometimes gets delayed by as much as even two months. But somehow we still managed to publish four issues per year without fail and we are sure that Maycock will be happy to hear this, wherever he is now.

I was contemplating on making this a special issue with useful articles that will be simple, useful and reasonably interesting to read. It may not have much appeal for non-technical people but if they try to read it, they will find it easy to understand.

Now let us see what we have in store for us as far as the industry is concerned. Palm oil price is predicted to decline following the current excessive crude palm oil (CPO) production rate. Hopefully the price may not remain there for too long as its price is tied to that of fossil fuel. We have already seen that with the advent of developments in biodiesel and other renewable energy. Fossil fuel and CPO prices cannot move in different directions. They are well linked.

The Australian government, supported by non-government organisa-
The industry still needs to shed its bad habits and assume a different approach to make our palm oil attractive with all the international compliance. Irrespective of the certification requirements or mechanism, the mills must ensure a very high standard of CPO production that no one can find fault with.

Currently, we do meet all the quality requirements but in terms of display to clients our industry need to transform significantly to match other similar industries. We have to take the lead in this, otherwise we will be forced to follow our neighbours to match them in competitiveness. When the price is high the mills must allocate a budget for uplifting the process machinery and surroundings.

CALL FOR ARTICLES

Personnel of the palm oil mills are invited to send in articles of relevance to the palm oil industry in Malaysia for publication in *Palm Oil Engineering Bulletin*. By sharing your expertise you will be helping the industry and the nation as a whole. The topics of interest are:

1. Plant modifications done in your mill that resulted in improvements in milling operation or maintenance.

2. Innovations done in your mill that produced improvements in the operation of the mill and that you are willing to share them with others.

3. Any special work done in your mill that directly resulted in improvements in OER and product quality.

Please submit your article to us and we shall be pleased to publish them in *Palm Oil Engineering Bulletin*. Feel proud to have your articles published in this Bulletin that is circulated throughout the industry and MPOB offices worldwide.
It gives me great pleasure to pen a few words in this 100th issue of the Palm Oil Engineering Bulletin to acknowledge my appreciation to the industry players for their good support given for the successful publication of this Engineering Bulletin for the last 25 years. The late Ir J H Maycock rightly deserves the credit for the creation of this Bulletin which made its maiden debut as a few stapled sheets of articles in March 1986. Now it has indeed grown and blossomed into a practical useful living publication catering for the needs of the millers in its basic role as vehicle to disseminate the latest technologies to them.

I would like to remind the industry that this Bulletin is not a research-based publication but a valuable guide on fundamental principles involved in milling activities which after some time the new generation of millers tend to forget. Most of the articles appearing in this publication are proven milling activities backed with years of research carried out in yester-years at Mongana Research Station, Palm Oil Research Division at Stork Amsterdam and others spanning nearly a century of dynamic activities.

Although there are incremental improvements in some of the unit operations, there is no revolutionary change in the milling process. New technology evolves everyday. The industry is urged to adopt and adapt the new technology to modernise the current milling processes. In this respect, MPOB is taking the leading role in research and develop new milling technology. It must be emphasised here that the new milling process should be energy efficient, clean and green, sustainable and has reduced carbon footprint to meet the challenges of the present world.

Datuk Dr Choo Yuen May
Elegy Written in an Oil Palm Estate  
(6 - 9 November 1999)  

N Ravi Menon*

Behold the sublime morning sun  
Edging stealthily from the hilly slopes  
Caressing and kissing the palms in turn  
Prompting them to wave at their source of hope.

The gentle breeze grazes the mighty fronds  
Within whose abode a thorny bunch resides  
An array of colourful fruits it fondly holds  
A cluster of golden balls guarded by thorny spikes,

Full many palms the hilly terrain bear  
Their roots firmly held by loving earth.  
The lush cover crop creep with loving care  
Like a green carpet spanning the land beneath.

Besides the estate office gathered the grumpy crowd  
An army routine born in colonial days of yore.  
The captain and his retinue standing proud  
Called the muster and poured the daily chore.

The crowd scattered to mount their auto coaches  
Holding bamboo poles, roared on muddy track  
Hearken! My friends, spare the infant bunches  
Lest the captain rebuke thee with a nasty bark.

With ease, like a toy, they lifted the bamboo pole  
A skill now natural with years in trade  
The unshaken hand poised the steady pole  
To bring bunches down scattering them far and wide.

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The trailing group, the scattered bunches filled
A trolley in green, laden full with fruit
on the track-less arbor, on uneven ground they pulled
Towards a grimy patch, besides the tractor route.

The blazing sun in celestial splendour,
Sprayed its rays on bunches, now a net gave abode
Draped in vivid colours and poised to surrender
They seemed to seek a hasty retreat to some divine shade

Over the lowly hills and vales, a tractor fluttered hissing
Anchored to an ash-coloured trailer with crimson trait
Close to the netted bunches it halted, arms swinging
And seized the bounty to feed the hungry mate.

To the slaughter house, the tractor made its stride
And threw the bounty unto the hostile hopper bars
In the far off estate grange, echoed the distant thud
As the bunches moaned on hitting the metal bars.

The golden fruitlets scattered far and wide
Over the hopper top and the concrete ramp
Ruthless wheels ground them and to a sticky paste they made
A carnage annihilating the finest fruits I hold in pomp.

Through His mercy we reap the blessed crop
His divine will make nature smile and give
The daily shine and timely shower of hope
To grant His best of creations a means to live
## 2011 MPOB Training Programme Schedule

<table>
<thead>
<tr>
<th>CODE NO.</th>
<th>COURSES</th>
<th>TITLE</th>
<th>DATE</th>
<th>VENUE</th>
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<tr>
<td>A</td>
<td>OIL PALM</td>
<td>Kursus Kemahiran Menggred Buah Sawit</td>
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<tr>
<td>1</td>
<td></td>
<td>Bil. 1: Wilayah Tengah</td>
<td>7 – 9 Jun</td>
<td>Hotel Le Paris, Port Dickson</td>
</tr>
<tr>
<td></td>
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<td>Bil. 2: Wilayah Utara</td>
<td>21 – 23 Jun</td>
<td>Hotel Sunway, Butterworth</td>
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<td>Bil. 3: Wilayah Selatan</td>
<td>19 – 21 Apr</td>
<td>Prime City Hotel, Klang</td>
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<td>Bil. 4: Wilayah Timur</td>
<td>10 – 12 Mei</td>
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<td>Bil. 5: Wilayah Sabah</td>
<td>26 – 28 Apr</td>
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<td>Bil. 6: Wilayah Sarawak</td>
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<td>Peperiksaan Bil. 16: Sabah</td>
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<td>Peperiksaan Bil. 17: Semenanjung</td>
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<tr>
<td>A1.2</td>
<td></td>
<td>Intensive Diploma in Oil Palm Management &amp; Technology (IDOPMT)</td>
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<td>Semester I</td>
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<td>Estate Attachment</td>
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<td>Semester II</td>
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<td>A1.3</td>
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<td>Kursus Operator Mekanisasi Ladang</td>
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<td>Tahap 1 dan 2</td>
<td>Sep – Feb</td>
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<td>Tahap 1 dan 2</td>
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<td>A1.4</td>
<td></td>
<td>Kursus Pengurusan dan Penyelenggaraan Tapak Semaian Sawit</td>
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<td>Bil. 1: Wilayah Sabah</td>
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<td>Bil. 2: Wilayah Timur</td>
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<td>PALM OIL</td>
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<td>Semester I</td>
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<td>Semester II</td>
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<td>Semester III</td>
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<td>Exam. Semester III</td>
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<td>A2.3</td>
<td>The 25th MPOB Oil Palm Products Surveying Course</td>
<td>27 Jun – 1 Jul</td>
<td>Hotel MS Garden, Kuantan, Pahang</td>
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<td>The 23rd MPOB Oil Palm Products Surveying Examination</td>
<td>18 – 20 Oct</td>
<td>Gurney Hotel, Pulau Pinang</td>
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<td>A2.4</td>
<td>Kursus Penyelia Kilang Minyak Sawit</td>
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<td>Kursus Pengendali Makmal Kilang Minyak Sawit</td>
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<td>MPOB HQ</td>
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<tr>
<td>A2.6</td>
<td>Kursus Drebar Enjin</td>
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<td>A2.7</td>
<td>Kursus Kemahiran dan Pengetahuan Asas Rawatan Tertiari Efluen Sawit</td>
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<td>A2.8</td>
<td>Cosmetic Course</td>
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### 2011 MPOB CONFERENCES/SEMINARS

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<th>B</th>
<th>CONFERENCES/SEMINARS</th>
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<tr>
<td>1.</td>
<td>International Conference on Oil Palm and the Environment</td>
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<td>MAEPS Serdang, Selangor</td>
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<td>3.</td>
<td>PIPOC</td>
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<td>4.</td>
<td>ISOPB - MPOB Seminar on Breeding for Sustainability in Palm Oil</td>
<td>18 Nov</td>
<td>KLCC, Kuala Lumpur</td>
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</table>

Note: *To be confirmed.

**For enquiry or further information, please contact:**

HRD & Conference Management Unit  
Tel. No. : 03-8769 4400 ext. 4865, 4867  
Fax No. : 03-8925 7549  
E-mail : rubaah@mpob.gov.my  
MPOB’s website : www.mpo.gov.my

All information are correct as at press time.
Spray Drying Palm Oil Mill Effluent

Fatah Yah Abdul Manaf*; Andrew Yap Kian Chung* and N Ravi Menon*

ABSTRACT

Malaysia produced 16.99 million tonnes of crude palm oil (CPO) in year 2010 and generated about 3.5 t of palm oil mill effluent (POME) for every tonne of CPO produced or about 0.6 t of POME for every tonne of fresh fruit bunched processed. The 1 m³ of POME could generate average 28 m³ of methane gas which is a negative sustainable factor in Life Cycle Analysis if these greenhouse gases are allowed to release into the atmosphere.

The Department of Environment proposed to further reduce the biological oxygen demand to 20 ppm under the Malaysian Environmental Quality Act 1974 and Environmental Quality (Prescribed Premises), and the Crude Palm Oil Regulations 1977 for tertiary POME treatment (POME). Meanwhile spray drying is one of the common processes applicable in industrial wastewater treatment plant. This involves use of a heat exchanger in sludge dryers to ensure that it is partly dried before sending it for further processing. The objective of this research work is to carry out preliminary technical feasibility study of spray drying POME generated from mills with clarifier tanks.

INTRODUCTION

Palm oil mills generate effluent when the fresh fruit bunches are processed to produce crude palm oil. This effluent has to be treated to reduce its biological oxygen demand (BOD) before being discharged into water course or used as a fertiliser for land application. There are many treatment methods for the palm oil mill effluent (POME) but the most common practise is the ponding method where the POME is digested by the microorganism until the BOD is reduced from the average 25,000 mg litre⁻¹ to 20 mg litre⁻¹ as proposed by the Department of Environment (DOE) recently. The common hydraulic retention times are one day in cooling ponds, four days in acidification ponds, 45 days in anaerobic ponds and finally 16 days in facultative ponds (Gurmit Singh et al., 1999).

Thus, the total hydraulic retention time needed is 66 days. This POME treatment method is cheap and requires minimal energy to operate but requires a large land area, produces unpleasant odour, methane and other greenhouse gases (Ma, 2000). The 1 m³ of POME could generate on average 28 m³ of methane gas which is a negative sustainable factor in Life Cycle Analysis, if these greenhouse gases are released into the atmosphere.

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In industrial wastewater treatment plant, spray drying is one of the common processes applicable, which involves the use of a heat exchanger in sludge dryers for the purpose of sludge drying. Figure 1 shows one of the typical spray drying wastewater treatment plants. The spray drying of POME could be an alternative treatment method thus eliminating the requirement of ponds resulting in the reduction of carbon footprints. In this, no unpleasant odour and methane gas would be produced.

The objective of this research work is to carry out preliminary technical feasibility study of spray drying POME generated by mills.

**PHYSICAL PROPERTIES OF POME**

The fresh POME collected from the de-oiling pond inlet is an acidic thick brownish colloidal slurry with pH at 4 - 5 containing about 95% water, 0.6% - 0.7% oil, and 4% - 5% total solids including 2% - 4% suspended solids that are mainly debris from palm fruit without unpleasant smell. The high concentration of organic matter constitute the high organic load in the form of chemical oxygen demand (COD), suspended solids (SS) and oil and grease (O&G). The amount of the nutrient retained in the residue is 45.63% lipid, 10.49% protein and 18.82% carbohydrate. The amino acids and fatty acids content of dried fresh POME residue are shown in Table 1 (Mahmud Ahmed, 2009).

Figure 1. Typical spray drying wastewater treatment plant.
Malaysia produced 16.99 million tonnes of crude palm oil (CPO) with average national oil extraction rate of 20.45% in year 2010 (MPOB, 2011). About 1.5 t of water is used to process 1 t of fresh fruit bunch which includes about 0.5 t of water used as boiler feed water. The volume of POME discharge depends on the milling operation. The national average is about 3.5 t of POME generated for every tonne of CPO produced or about 0.6 t of POME are generated for every tonne of fresh fruit bunched processed. Table 2 shows the characteristics of POME (Ma, 2000).

**Regulatory Standard for POME**

Palm oil mills release POME in tremendous volumes with its attendant polluting potential. Therefore POME requires proper management and handling strategies by the industries and government authorities. Malaysian experiences in effluent control in palm oil industry demonstrate that a set of well designed environment policies can be very effective in controlling industry pollution. All palm oil mills have to comply with the Environment Quality Act, 1974 in the management of palm oil mills. The effluent discharge standards applicable to CPO mills are presented in Table 3.

**SPRAY DRYING**

Spray drying is commonly used to dry aqueous or organic solutions, suspensions, dispersions or emulsions in chemical and food industries for food preservation or simply for weight and volume reduction. It consists of four process stages starting with atomisation of feed into a spray using centrifugal, pressure or kinetic energy. The selection of atomiser type depends upon the nature and amount of feed and the desired characteristics of the dried product. Higher dispersion energy generates smaller droplets. It is followed by spray drying using medium contact involving evaporation of moisture from an atomised feed by mixing the spray and the hot drying medium, typically air. The manner

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### Table 1. Amino Acids and Fatty Acids Contained in Dried Palm Oil Mill Effluent (POME) Residue

<table>
<thead>
<tr>
<th>Amino acids (g/100 g protein)</th>
<th>Fatty acids (g/100 g fatty acid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspartic acid 9.66 ± 0.19</td>
<td>Capric acid (10:0) 2.29 ± 0.03</td>
</tr>
<tr>
<td>Glutamic acid 10.88 ± 0.21</td>
<td>Lauric acid (20:0) 9.22 ± 0.03</td>
</tr>
<tr>
<td>Serine 6.86 ± 0.15</td>
<td>Myristic acid (14:0) 12.66 ± 0.11</td>
</tr>
<tr>
<td>Glycine 9.43 ± 0.17</td>
<td>Palmitic acid (16:0) 14.45 ± 0.12</td>
</tr>
<tr>
<td>Histidine 1.43 ± 0.04</td>
<td>Heptadecanoic (17:0) 1.39 ± 0.02</td>
</tr>
<tr>
<td>Arginine 4.15 ± 0.10</td>
<td>10 Heptadecanoic (17:1) 1.12 ± 0.02</td>
</tr>
<tr>
<td>Threonine 2.58 ± 0.05</td>
<td>Stearic acid (18:0) 11.41 ± 0.08</td>
</tr>
<tr>
<td>Alanine 7.70 ± 0.16</td>
<td>Oleic acid (18:1n-9) 8.54 ± 0.06</td>
</tr>
<tr>
<td>Proline 4.57 ± 0.10</td>
<td>Linoleic acid (18:2n-6) 9.53 ± 0.05</td>
</tr>
<tr>
<td>Tyrosine 3.26 ± 0.06</td>
<td>Linolenic acid (18:3n-3) 4.72 ± 0.04</td>
</tr>
<tr>
<td>PhenyIalanine 3.20 ± 0.07</td>
<td>Arachidic acid (20:0) 7.56 ± 0.03</td>
</tr>
<tr>
<td>Valine 3.56 ± 0.06</td>
<td>Eicosatrienoic (20:3n-6) 1.49 ± 0.02</td>
</tr>
<tr>
<td>Methionine 6.88 ± 0.15</td>
<td>Arachidonic acid (20:4n-6) 1.12 ± 0.03</td>
</tr>
<tr>
<td>Cystine 3.37 ± 0.06</td>
<td>Eicosapentaenoic (20:5n-3) 0.36 ± 0.02</td>
</tr>
<tr>
<td>Isoleucine 4.53 ± 0.11</td>
<td>Behenic acid (22:0) 2.62 ± 0.03</td>
</tr>
<tr>
<td>Leucine 6.86 ± 0.15</td>
<td></td>
</tr>
<tr>
<td>Lysine 5.66 ± 0.14</td>
<td></td>
</tr>
<tr>
<td>Tryptophan 1.26 ± 0.05</td>
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</tbody>
</table>
in which the spray contacts the drying medium influences droplet behaviour during drying thus exerting great influence on the properties of dried products. As soon as droplets of the spray come into contact with the drying medium, evaporation takes place from the saturated vapour film which is quickly established at the droplet surface. The temperature at the droplet surface approximates the wet bulb temperature of the drying air. Diffusion of moisture from within the droplet is sufficient to maintain saturated surface initially at a constant rate of evaporation. When the moisture content becomes too low to maintain saturated condition, a dried shell forms at the droplet surface and evaporation rate is dependent upon the moisture diffusion rate through the dried surface shell. The high specific surface area with the existing temperature and moisture gradients results in an efficient drying from an intense heat and mass transfer. The evaporation leads to a cooling of the droplet and thus to a small thermal load. Drying chamber design and air flow rate provide a droplet residence time in the chamber, so that the desired droplet moisture removal is completed and product removed from the dryer before product temperatures can rise to the outlet drying medium temperature. Hence, there is little likelihood of heat damage to the product but different products exhibit different evaporation characteristics such as expansion, collapse, fracture or disintegration and leading to porous, irregular shaped particles. Some products may still maintain a constant spherical shape but the particles become denser. Finally the dried product is separated from the drying medium using hydrocyclone, filter bag or electrostatic precipitator (Masters, 1991).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Amount (mg litre⁻¹)</th>
<th>Metal</th>
<th>Amount (mg litre⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and grease (O&amp;G)</td>
<td>4000</td>
<td>Phosphorus (P)</td>
<td>180.00</td>
</tr>
<tr>
<td>Biological oxygen demand (BOD)</td>
<td>25 000</td>
<td>Potassium (K)</td>
<td>2 270.00</td>
</tr>
<tr>
<td>(3 day @ 30°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>50 000</td>
<td>Magnesium (Mg)</td>
<td>615.00</td>
</tr>
<tr>
<td>Total solid (TS)</td>
<td>40 500</td>
<td>Calcium (Ca)</td>
<td>439.00</td>
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<tr>
<td>Suspended solid (SS)</td>
<td>18 000</td>
<td>Boron (B)</td>
<td>7.60</td>
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<tr>
<td>Total volatile solid</td>
<td>34 000</td>
<td>Iron (Fe)</td>
<td>46.50</td>
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<tr>
<td>Ammoniacal nitrogen</td>
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<td>Manganese (Mn)</td>
<td>2.00</td>
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<tr>
<td>Total nitrogen</td>
<td>750</td>
<td>Copper (Cu)</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zinc (Zn)</td>
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</tr>
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</table>

The drying medium is sucked or blown through a heater by the aspirator. Inlet temperature is the temperature of the heated drying medium measured prior to flowing into the drying chamber to vaporise the waterphase which does not have to be at a higher temperature than the boiling point of the solvent to evaporate the individual drops during the short residence time. The gradient between the wet surface and unsaturated gas leads to an evaporation at low temperatures. The final product is separated and has no further thermal load. The temperature of the medium with the solid particles before entering the cyclone is known as the outlet temperature. This temperature is uncontrollable as this depend on the heat and mass balance parameters in the drying cylinder such as inlet temperature, aspirator flow rate, peristaltic pump setting and concentration of the sprayed material. Due to the intense heat mass transfer and the loss of humidity, the particles can be regarded to have the same temperature as the gas.

The optimal choice for the temperature difference between the inlet and the outlet temperature is one of the most important points to consider when spray drying. Of course, other product specific factors, such as the melting point or decay temperature, must be taken into consideration. In spite of this, there is still some room for adjustment. The throughput of the device as well as the residual moisture content can be influenced within this temperature difference range (Büchi, 2002).

Spray dryer optimisation means greater capacity, greater energy efficiency and lower manpower input which are a complex and multifaceted task. Production efficiency could be maximised by maximising inlet temperature, outlet temperature and feed temperature. Furthermore production efficiency can also be increased by reducing downtime rather than by trying to operate each production hour close to the theoretical maximum. Environmental factor is also crucial for spray dryer efficiency. When the moisture in the ambient air is higher, less water can be evaporated in the spray drying process.

The capacity of spray drying is measured by the amount of water evaporated which is defined as the temperature difference between inlet and outlet in the drying air, ΔT. Larger the temperature difference, greater is the capacity of the spray dryer. The goal in spray dryer capacity optimisation is to maximise the temperature difference by raising the inlet temperature or lowering the outlet temperature.

The outlet temperature is a manifestation of the relative humidity in the outlet air. There are three sources of water in the outlet which are the humidity in the ambient air absorbed into the dryer, combustion products if a direct-fired gas burner is used as a source of heat and the water evaporated in the spray drying process. If the outlet temperature is too low, the product particles in the drying chamber will not become dry enough in the time allowed enabling sticky particles to cause blocking or plugging. If the outlet temperature is too high, excess capacity remains unutilised. Once the proper outlet temperature is established, it remains constant for a specific product in a particular dryer.

More energy is available for evaporating water at the higher inlet temperature but is limited for process reasons when the temperature difference has been optimised and the maximum outlet humidity has been reached. This means evaporating as much water as possible and operating just above the product’s sticky point. Build-up can occur in vessels that operate above a certain inlet temperature or below a certain outlet temperature. In addition, vessels can experience bridging. This is a manifestation of operating with a temperature difference greater than that which can produce a viable dry particle. Inlet temperature is limited to a point below which the undesired characteristics do not occur due to product denaturising, burns, deprived of desired
volatiles, or degradation in other ways at high inlet temperatures. Safety conditions such as product auto ignite should be aware to set reasonable limits for the inlet temperature. Theoretically, heating feed as close as possible to the inlet temperature is ideal so that all the energy available from the air heater can be used for water evaporation with no energy going toward heating the residual product. In most cases, it is impossible to heat the product greatly without causing product degradation. Thus, elevating the temperature as high as the product allows without degradation yields extra capacity from the spray dryer by acquiring heat from a source other than the main air heater. Higher concentrations of feed solids yield greater capacity.

Efficient operation leads to labour savings but dryer downtime results reducing the amount of available time for production. There are two major downtime which are planned routine service maintenance and dryer-related unplanned downtime. As part of regularly scheduled maintenance, spray dryer are cleaned in order to:

- remove build-up that can result in fire or explosion;
- eliminate build-up that is causing product quality issues;
- separate product groups or classes to prevent cross-contamination; and
- eliminate bacterial growth that can cause product quality issues.

The most common causes of unplanned spray dryer downtime are the plugging of cyclones, chamber outlets, conveying lines and similar equipment.

Many simple incremental operational improvements can be made to shorten turn around times. If start-up and shutdowns can be minimised or eliminated, the time between chamber washes can be extended. With fewer start-up and shutdowns, the use of fans and heaters between spray drying operations can be reduced, resulting in energy savings (Kent and McLeod, 2007).

HEAT AND MASS BALANCES

The bond moisture in a solid exerts an equilibrium vapour pressure lower than that of pure water at the same temperature whereas unbinds moisture in a hygroscopic material is that moisture in excess of the bound moisture. Only free moisture can be evaporated. As long as unbound moisture exists, drying proceeds at near constant rate. The close cycle principles is based upon recycling and reusing a gaseous medium, involve gas-tight dryer component fabrication and the drying chamber is operated at low pressure. Humidity have an important use in closed and semi-closed cycle spray drying calculation for determining the composition of solvent vapour in the medium leaving the scrubber condenser and recycling to the drying chamber.

According to Dalton’s Law, the amount of solvent vapour present in the medium is independent of the pressure, \( P_T \) but it does depend upon the temperature of the drying medium which is mixed. The absolute humidity, \( H_a \) is related to the partial pressure, \( P_L \) of the solvent vapour in the drying medium as shown below:

\[
H_a = \frac{w_L}{w_m} \left[ \frac{P_L}{P_T - P_L} \right]
\]  

where \( w_L \) is the molecular weight of the solvent and \( w_m \) is the molecular weight of the drying medium. Absolute humidity for air-water system at atmospheric pressure is read directly from psychometric charts as shown in Appendix 1.

The addition of heat to a wet droplet is insufficient to promote satisfactory drying as it is also dependant upon the humidity of the as it is surrounding drying air. The significance of partial pressure concerns the reverse driving force it provides resisting drying. The driving force for moisture evaporation from a saturated surface is the difference between the water vapour...
Pressure at the temperature of the surface and the partial pressure of the water vapour in the surrounding air. At the saturated surface, the partial pressure of water equals its vapour pressure and thus the rate of mass transfer from a saturated surface is:

\[
\frac{dW}{dt} = K_s A (H_w - H_a)
\]  

(2)

where \(K_s\) is mass transfer coefficient, \(H_w\) is the humidity at the saturated surface and \(A\) is area. For dynamic equilibrium the rate of heat transfer is equal to the product of the rate of mass transfer and latent heat of vaporisation, \(\lambda\).

\[
\frac{dQ}{dt} = h_s A (T_a - T_w) = \frac{dW}{dt} \lambda
\]  

(3)

thus

\[h_s (T_a - T_w) = K_s (H_w - H_a) \lambda\]

where \(h_s\) is heat transfer coefficient, \(T_a\) is the air temperature and \(T_w\) is the wet bulb temperature. Lewis number is given by the coefficient \(h_s\) and \(K_s\) by the humid heat, \(C_s\) which is the heat required to raise the temperature of a unit mass of wet air and its vapour 1°C at constant pressure. If condensation or vaporisations does not occur then:

\[C_s = 0.24 + 0.46 H_a\]

and

\[Q_s = m C_s \Delta T\]

(4)

where \(m\) is the droplet mass and \(Q_s\) is the air enthalpy.

The air transported product flow and temperature data for assessing drying performance are obtained from heat and mass balance data. It is common to base moisture balances on a unit weight of dry product.

Specification and design of spray dryers are based upon non-theoretical procedures but dependent upon pilot plant test data and existing industrial experience. The pilot plant test work to establish the optimum operating conditions for meeting the performance specification and the residence time to permit completion of drying and meeting of product specification are two important aspects to consider (Masters, 1991).

**METHODOLOGY AND RESULTS**

Fresh POME has been collected from the de-oiling pond inlet. Initial trial run using LabPlant SD-06 (OF301) laboratory spray dryer as shown in Figure 2, located in MPOB laboratory has produced good dried POME powder having 5% moisture content with air inlet temperature set at 220°C, pump speed 485 ml hr\(^{-1}\) (10), exhaust air velocity 4.3 m s\(^{-1}\) (50) and fast de-blocking.

The process has been scaled up by using APV Pasilac Anhydro AS MAL 150 laboratory spray dryer located in pilot laboratory of Chemical and Process Engineering Department, Faculty of Engineering and Architecture, Universiti Kebangsaan Malaysia, Bangi as shown in Figure 3 with the specifications shown (Table 4) has produced good dried POME powder with average moisture content of 5% with air inlet temperature set at 200°C.

The spray dried POME free flow powder from both spray dryers is shown in Figure 4. Small laboratory spray dryer produces coarser and darker powder compared to bigger pilot laboratory spray dryer.

The water evaporation rate of the APV laboratory spray dryer varies with the air temperatures applied to the drying process. Figure A3 in Appendix 1 shows the evaporation rate profile for air outlet temperature set at 90°C.

**Mass Flow Calculation**

The evaporation capacity of the plant, \(V\) at inlet air temperature 200°C and outlet temperature 90°C is approximately 3.5 kg H\(_2\)O hr\(^{-1}\) as shown in Figure A3 in Appendix 1.
### TECHNICAL INFORMATION

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation rate of water at inlet temperature of 250ºC using Standard Chamber</td>
<td>Approximately 1500 ml hr⁻¹</td>
</tr>
<tr>
<td>Air inlet temperature range</td>
<td>40ºC to 250ºC</td>
</tr>
<tr>
<td>Drying air throughput</td>
<td>Variable from 100 to 300 m³ hr⁻¹</td>
</tr>
<tr>
<td>Heater capacity</td>
<td>3 kW</td>
</tr>
<tr>
<td>Compressor</td>
<td>2.0 m³ hr⁻¹ @ 2.0 bar, 1.7 m³ hr⁻¹ @ 4.0 bar</td>
</tr>
<tr>
<td>Sample feed</td>
<td>Peristaltic pump with flow rate variable up to 32 ml min⁻¹ (2.0 litre hr⁻¹)</td>
</tr>
<tr>
<td>Jet de-blocking</td>
<td>Integral 2.3 bar compressed air supply with variable de-blocking plunger frequency</td>
</tr>
<tr>
<td>Spray system</td>
<td>2 fluid nozzle with standard 0.5 mm jet and options of larger diameters</td>
</tr>
<tr>
<td>Spray/hot air flow</td>
<td>Downward co-current</td>
</tr>
<tr>
<td>Power supply</td>
<td>220/240 V - 50/60 Hz - 13 amps</td>
</tr>
<tr>
<td>Dimensions</td>
<td>1110 x 825 x 600 mm (H x W x D)</td>
</tr>
<tr>
<td>Unit Weight</td>
<td>80 kg</td>
</tr>
</tbody>
</table>

*Figure 2. LabPlant SD-06 laboratory spray dryer.*

The laboratory results show that POME is having an average total solid content, Tₕ 5% by weight. Water content in the spray dried powder is 5% average by weight, thus Tₕ = 100 – 5 = 95. The mass flow rate, F is determined as:

\[
F = \frac{VT_p}{T_p - T_f} = \frac{3.5(95)}{95 - 5} = \frac{332.5}{90} = 3.6944 \text{ kg hr}^{-1} \quad (5)
\]

Thus, 3.6944 kg hr⁻¹ of dried POME with 5% moisture is produced from the APV laboratory co-current flow spray dryer incorporating a rotary atomiser. Atmospheric air at 25°C, RH 80% is heated indirectly in the electric air heater to 200°C before entering the dryer. Air is exhausted from the chamber at 90°C as mentioned before. Dried POME temperature is 80°C and the POME slurry is pumped to the atomiser at 25°C.

Surface area of the drying chamber is approximately 5 m² as shown in the equipment specification. Average POME slurry have a content of 95% as determined in the laboratory. Heat capacity of dry solid is approximately 1.6743 kJ/kg°C and the specific surface loss, U is about 8.3716 kJ m⁻² for insulated drying chamber.

Thus, \( w_i = \frac{95}{5} = 19 \text{ kg kg}^{-1} \) dry POME;

\( w_i = \frac{5}{95} = 0.0526 \text{ kg kg}^{-1} \) dry POME.
From the psychometric chart, $H_i = 0.0160$ kg kg\(^{-1}\) dry air. Air specific heat capacity is 1.006 kJ/kg°C and water vapour specific heat capacity is 1.84 kJ/kg°C. Latent heat of evaporation of water is 2501 kJ kg\(^{-1}\) and water specific heat capacity is 4.1858 kJ/kg°C.

Feed rate to dryer,

$$M_s = \frac{3.6944 \times 95}{100} \times \frac{100}{5} = 70.1936 \text{ kg hr}^{-1};$$

Feed air enthalpy,

$$Q' = 1.006(200) + 0.0160(2501 + 1.84(200)) = 247.0179 \text{ kJ kg}^{-1} \text{ air;}$$

Exhaust air enthalpy,

$$Q'' = 1.006(90) + H_e[2501 + 1.84(90)] = 90.54 + 2666.6H_e \text{ kJ kg}^{-1} \text{ air;}$$

Feed POME enthalpy,

$$Q'_f = 1.6743(25) + (19 \times 4.1858 \times 25) = 2030.1130 \text{ kJ kg}^{-1} \text{ POME;}$$

Dried POME enthalpy,

$$Q'_d = 1.6743(80) + (0.0526 \times 4.1858 \times 80) = 151.5684 \text{ kJ kg}^{-1} \text{ POME.}$$
<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
</table>
| Air Heater                 | Maximum air inlet temperature 300°C  
|                            | Temperature inlet 20°C  
|                            | Air quantity 125 m³/hr  
|                            | Power consumption at 300°C 12.6 kW  
|                            | Specific load 2 W/cm²  
|                            | Number of heater 3 pieces  
|                            | Heating effect per element 4200 W  |
| Centrifugal Atomiser       | Operational disc speed 25 000 rpm to 50 000 rpm  |
| Cartridge Filter           | Filter type Cartridge type LP 33P10S4N  
|                            | Filter media 100% PES  
|                            | Temperature Maximum 120°C  
|                            | Moisture absorption at 21°C, RH 65% 0.2% - 0.5%  
|                            | Weight 300 g/m²  
|                            | Thickness 0.57 mm  
|                            | Ultimate tensile strength 3.5 bar  |
| Installed Motors           | Fan motor 2.60 kW  
|                            | Atomiser motor 0.50 kW  
|                            | Feed pump motor 0.08 kW  
|                            | Power supply 3 phase 380 V, 50 Hz 17 kW  
|                            | Internal chamber diameter 1 m  |

Figure 4. Spray dried palm oil mill effluent (POME) powder.
Moisture balance.

Dry POME production rate = 3.6944 x 0.95 = 3.5097 kg hr⁻¹;

Moisture entering via feed = 3.5097 x 19 = 66.6839 kJ kg⁻¹;

Moisture leaving in POME = 3.5097 x 0.0526 = 0.1847 kJ kg⁻¹;

Moisture evaporated = 3.5097 x (19 - 0.0526) = 66.4992 kJ kg⁻¹.

\[ G_s(H_e - 0.015) = 66.4922 \] (6)

Enthalpy balance.

Dryer inlet: 247.0179\( G_s \) + (3.5097 x 2030.113)
= 247.0179\( G_s \) + 7125.0470

Dryer outlet: (3.5097 x 151.5684) + \( G_s \) (90.54 + 2666.6\( H_e \)) + [8.3716 x 5 x (90-25)]
= 247.0179\( G_s \) + 7125.0470 = 3252.7266 + 90.54 \( G_s \)
+ 2666.6\( H_e \)\( G_s \) (2666.6\( H_e \) - 156.4779)\( G_s \) = 3872.3204

From the equation (6) above,

\[ G_s = \frac{66.4992}{H_e - 0.0160} \]

3872.3204\( H_e \) - 61.8410 = 177326.7667\( H_e \) - 10405.6572
173454.463\( H_e \) = 10343.8162

Exhaust air humidity, \( H_e \) = 0.0596 kg kg⁻¹ dry air (12.545% RH - psychrometric chart)
Air flow rate, \( G_s \) = 1522.9687 kJ kg⁻¹.

Thus atmospheric air at 25°C and 80% (Figure A1 and Table A1) relative humidity is heated to 200°C and passed to spray dryer. The air is exhausted at 90°C (Figure A2) and 12.545% relative humidity.

From psychrometric chart, the wet bulb temperature at 200°C and 100% relative humidity is about 88°C. Adiabatic cooling from 200°C to 12.545% relative humidity is about 143°C.

Maximum thermal efficiency

\[ = \frac{200 - 88}{200 - 25} \times 100 = 64\% \]

Overall thermal efficiency

\[ = \frac{200 - 143}{200 - 25} \times 100 = 32.5714\% \]

Evaporative efficiency

\[ = \frac{200 - 143}{200 - 88} \times 100 = 50.8929\% \]

Degree of heat lost \[ = \frac{143 - 90}{200 - 90} \times 100 = 48.1818\% \]

PHYSICAL PROPERTIES OF PALM OIL MILL EFFLUENT (POME) AND POME POWDER

Fresh POME was collected from Rantau Palm Oil Mill in Negeri Sembilan. The samples were taken from de-oiling tank inlet before discharge into their treatment system. Determination of BOD - COD, oil and grease, and pH were carried out in accordance with the standard method - the examination of water and wastewater.

The characteristic of fresh POME is tabulated in Table 5. It was found that POME contains high BOD and COD with values of 44 818 mg litre⁻¹ and 85 300 mg litre⁻¹ respectively with high total solids and SS. The high BOD and COD values showed that the POME had high organic matter. These will result in significant environment problem if there is proper disposal. Most of the palm oil mills in Malaysia practice biological treatment method and it is quite inefficient for effluent treatment. The system is capable of producing a final discharge with BOD of less than 100 mg litre⁻¹. Table 5 shows that POME is acidic with pH at 4.5. Typically POME is low in pH ranging from 4 to 5. The low pH could be as a result of the presence of phenolic acids and oxidation of
other organic acids. The oil residue was in the range of 0.4% to 1.0% which depends very much on the quality of fruits, process control and machine efficiency.

Density of a typical POME sample from a palm oil mill located in Rantau, Negeri Sembilan is 1012.65 kg m\(^{-3}\) at room temperature of about 25°C measured in MPOB laboratory as shown in Table 6. The temperature versus density is shown in Figure 5.

Total protein content was also present in POME powder in the range of 10% to 12%. This protein can be isolated as an animal feed and further work can be done to find cheaper method of isolating protein from POME powder. The calorific value of POME powder is about 17 742 kg kg\(^{-1}\). This makes it potentially interesting for animal feed. Apart from the organic composition, POME powder is also rich in mineral containing appreciable amount of N, P, K and Mg.

### TABLE 5. CHARACTERISTIC OF FRESH PALM OIL MILL EFFLUENT (POME) AT RANTAU PALM OIL MILL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (mg litre(^{-1}))</td>
<td>44 818</td>
</tr>
<tr>
<td>COD (mg litre(^{-1}))</td>
<td>85 300</td>
</tr>
<tr>
<td>TS (mg litre(^{-1}))</td>
<td>41 022</td>
</tr>
<tr>
<td>SS (mg litre(^{-1}))</td>
<td>18 980</td>
</tr>
<tr>
<td>Oil and grease (mg litre(^{-1}))</td>
<td>2 151</td>
</tr>
<tr>
<td>pH</td>
<td>4.5</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>96.32</td>
</tr>
</tbody>
</table>

Note: BOD – biological oxygen demand.
COD – chemical oxygen demand.
TS – total solid.
SS – suspended solids.

### TABLE 6. THE DENSITY OF PALM OIL MILL EFFLUENT (POME) AT VARIOUS TEMPERATURES

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Calibration value</th>
<th>Weight of POME (g)</th>
<th>Density (g cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>50.210366</td>
<td>50.2143</td>
<td>1.0126</td>
</tr>
<tr>
<td>35</td>
<td>50.227850</td>
<td>50.6911</td>
<td>1.0092</td>
</tr>
<tr>
<td>45</td>
<td>50.247028</td>
<td>50.4754</td>
<td>1.0045</td>
</tr>
<tr>
<td>55</td>
<td>50.253944</td>
<td>50.1357</td>
<td>0.9976</td>
</tr>
<tr>
<td>65</td>
<td>50.256413</td>
<td>49.7273</td>
<td>0.9895</td>
</tr>
<tr>
<td>75</td>
<td>50.261900</td>
<td>49.1675</td>
<td>0.9782</td>
</tr>
</tbody>
</table>
Figure 5. Plot of density vs. temperature.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>4.5</td>
</tr>
<tr>
<td>Crude protein</td>
<td>10 - 12</td>
</tr>
<tr>
<td>Oil</td>
<td>11.11 - 17.73</td>
</tr>
<tr>
<td>Ash</td>
<td>14.0</td>
</tr>
<tr>
<td>P</td>
<td>0.62</td>
</tr>
<tr>
<td>K</td>
<td>3.55</td>
</tr>
<tr>
<td>Mg</td>
<td>1.17</td>
</tr>
<tr>
<td>Ca</td>
<td>1.25</td>
</tr>
<tr>
<td>Calorific value (kg kg⁻¹)</td>
<td>17 742</td>
</tr>
</tbody>
</table>

### DISCUSSION AND CONCLUSION

The study results show that POME could be spray dried to produce POME powder which is rich in nutrient. The powder has good aroma smell but yet to have any market value which may be a vital positive impact factor in the process economic. POME powder can be used as a fertiliser and animal feed as it contains high nutrient value. It can also be used as fermentation media to produce antibiotic and bioinsecticide, solvents, polyhydroxyalkanoate and organic acids.

Thermal efficiency is an expression of spray drying performance. Dryer design is directed towards achieving desired dried product properties at the highest possible thermal efficiencies. The calculations above show that thermal efficiency can be increased by increasing the temperature of the air entering the chamber and operating the dryer at an outlet temperature as low as the process allows. However, there are limitations due to the dryer design. Heat input is proportional to the evaporation rate which is greatly affected by the solid content in the dryer feed.

Maximum thermal efficiency is obtained by exhausting the drying air in a saturated state. Overall thermal efficiency is defined as the fraction of the total heat supplied to the dryer used in the evaporation process. Evaporative efficiency is defined as the ratio of the actual evaporative capacity to the capacity obtained in the ideal case of exhausting air at saturation. Degree of heat loss to evaporation determines the heat losses from chamber and product heating (Master, 1991).

The enforcement of Environmental Act
is becoming a high priority for the palm oil industry. New technology for effluent treatment is urgently needed to overcome the effluent problem. The purpose of zero waste from palm oil industry incorporating production of valuable POME powder can attract the mills to invest in the efficient effluent treatment. Thus, the spray drying of POME could be an alternative treatment method which would eliminate the requirement of effluent digestion ponds.

**ACKNOWLEDGEMENT**

Special thanks are recorded to Rantau Palm Oil Mill, Negeri Sembilan for the POME samples used in this work. Also thanks to Ir Ravi Menon for his assistance in the project implementation and Zaid Yasir, Izzat Zainal Abidin (Universiti Malaya) and Norain Mohamed (Universiti Teknologi Mara) for technical assistance.

**REFERENCES**


## NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Particular</th>
<th>SI Unit</th>
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<tbody>
<tr>
<td>$A$</td>
<td>area</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$BOD$</td>
<td>biochemical oxygen demand</td>
<td>-</td>
</tr>
<tr>
<td>$Ca$</td>
<td>calcium</td>
<td>-</td>
</tr>
<tr>
<td>$c_C$</td>
<td>humid heat</td>
<td>J[kg °C]$^{-1}$</td>
</tr>
<tr>
<td>$COD$</td>
<td>chemical oxygen demand</td>
<td>-</td>
</tr>
<tr>
<td>$F$</td>
<td>mass flow rate</td>
<td>kg hr$^{-1}$</td>
</tr>
<tr>
<td>$G_a$</td>
<td>air flow rate</td>
<td>kg hr$^{-1}$</td>
</tr>
<tr>
<td>$H_u$</td>
<td>absolute humidity</td>
<td>%</td>
</tr>
<tr>
<td>$H_w$</td>
<td>humidity at the saturated surface</td>
<td>%</td>
</tr>
<tr>
<td>$H_i$</td>
<td>humid water content in feed</td>
<td>kg kg$^{-1}$</td>
</tr>
<tr>
<td>$H_o$</td>
<td>humid water content in exhaust</td>
<td>kg kg$^{-1}$</td>
</tr>
<tr>
<td>$K$</td>
<td>potassium</td>
<td>-</td>
</tr>
<tr>
<td>$K_s$</td>
<td>mass transfer coefficient</td>
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</tr>
<tr>
<td>$Mg$</td>
<td>magnesium</td>
<td>-</td>
</tr>
<tr>
<td>$M_r$</td>
<td>dryer feed rate</td>
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<tr>
<td>$P$</td>
<td>phosphorus</td>
<td>-</td>
</tr>
<tr>
<td>$P_L$</td>
<td>partial pressure of the solvent vapour</td>
<td>Nm$^{-2}$</td>
</tr>
<tr>
<td>$P_r$</td>
<td>pressure</td>
<td>Nm$^{-2}$</td>
</tr>
<tr>
<td>$Q_a$</td>
<td>air enthalpy</td>
<td>Jkg$^{-1}$</td>
</tr>
<tr>
<td>$Q_s$</td>
<td>slurry enthalpy</td>
<td>Jkg$^{-1}$</td>
</tr>
<tr>
<td>$T_a$</td>
<td>air temperature</td>
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</tr>
<tr>
<td>$T_f$</td>
<td>total solid content in feed</td>
<td>%w</td>
</tr>
<tr>
<td>$T_p$</td>
<td>total solid content in spray dried powder</td>
<td>%w</td>
</tr>
<tr>
<td>$T_w$</td>
<td>wet bulb temperature</td>
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</tr>
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<td>specific surface heat loss</td>
<td>Jm$^{-2}$</td>
</tr>
<tr>
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<td>kg hr$^{-1}$</td>
</tr>
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<td>kg</td>
</tr>
<tr>
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<td>water content in the feed</td>
<td>kg kg$^{-1}$</td>
</tr>
<tr>
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<td>water content in the dried POME</td>
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<tr>
<td>$h_c$</td>
<td>heat transfer coefficient</td>
<td>J[m$^2$ s °C]$^{-1}$</td>
</tr>
<tr>
<td>$m$</td>
<td>droplet mass</td>
<td>kg</td>
</tr>
<tr>
<td>$t$</td>
<td>time</td>
<td>s</td>
</tr>
<tr>
<td>$w_s$</td>
<td>molecular weight of the solvent</td>
<td>-</td>
</tr>
<tr>
<td>$w_m$</td>
<td>molecular weight of the drying medium</td>
<td>-</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>latent heat of evaporation</td>
<td>Jkg$^{-1}$</td>
</tr>
<tr>
<td>$\Delta T$</td>
<td>temperature difference between inlet and outlet</td>
<td>°C</td>
</tr>
</tbody>
</table>
EQUATIONS DESCRIBING THE PHYSICAL PROPERTIES OF MOIST AIR

Water Vapour Pressure

In a closed container partly filled with water, there will be some water vapour in the space above the water. The concentration of water vapour depends only on the temperature. It is not dependent on the amount of water and is only very slightly influenced by the presence of air in the container. The water vapour exerts a pressure on the walls of the container. The empirical equations given below give a good approximation to the saturation water vapour pressure at temperatures within the limits of the earth’s climate. Saturation vapour pressure, \( p_s \), in pascal:

\[
p_s = \frac{17.2694 t}{610.78e^{t/238.3}} \quad (A1)
\]

where \( t \) is the temperature in degrees Celsius. The saturation vapour pressure below freezing can be corrected after using the equation above, thus:

\[
p_{s, ice} = 4.86 + 0.855p_s + 0.000244p_s^2 \quad (A2)
\]

The next formula gives a direct result for the saturation vapour pressure over ice:

\[
p_{s, ice} = 28.906 - \frac{6140}{t + 273} \quad (A3)
\]

The SI unit of pressure is Nm\(^{-2}\) and 1 Pa = 1 Nm\(^{-2}\). Atmospheric pressure is about 100 000 Pa (standard atmospheric pressure is defined as 101 300 Pa).

Water Vapour Concentration

The relationship between vapour pressure and concentration is defined for any gas by the equation:

\[
pV = nRT \quad (A4)
\]

where \( p \) is the pressure in Pa, \( V \) is the volume in cubic metres, \( T \) is the temperature in degrees Kelvin (degrees Celsius + 273.16), \( n \) is the quantity of gas expressed in molar mass, \( R \) is the gas constant: 8.31 Jmol\(^{-1}\)m\(^3\).

To convert the water vapour pressure to concentration, \( c \) in kg m\(^{-3}\):

\[
c = \frac{0.018p}{8.31(t + 273.16)} = \frac{0.002166p}{t + 273.16} \quad (A5)
\]

where \( p \) is the actual vapour pressure. It is sometimes convenient to quote water vapour concentration as kg kg\(^{-1}\) of dry air. This is used in air conditioning calculations and is quoted on psychrometric charts. The following calculations for water vapour concentration in air apply at ground level. Dry air has a molar mass of 0.029 kg. It is denser than water vapour, which 0.62 \( \times \) 10\(^{-5} \) \( p \) has a molar mass of 0.018 kg. Therefore, humid air is lighter than dry air. If the total atmospheric pressure is \( P \) and the water vapour pressure is \( p \), the partial pressure of the dry air component is \( P - p \). The weight ratio of the two components, water vapour and dry air is:

\[
\text{kg water vapour/kg dry air} = 0.018p/(0.029(P - p)) = 0.62p/(P - p) \quad (A6)
\]

At room temperature \((P - p) = P\), which at ground level is close to 100 000 Pa, so, approximately:

\[
\text{kg water vapour/kg dry air} = 0.62 \times 10^{-5} p \quad (A7)
\]

Wood Equilibrium Moisture Content Table

The Wood Equilibrium moisture content is given by:

\[
M = \frac{1800}{W} \left[ \frac{K}{(1 - KH)} + \frac{(K, KH + 2K, K_2H^2)}{(1 + K, KH + K, K_2H^2)} \right] \quad (A8)
\]

where:

\[
M = \text{moisture content (%)}, \quad K = 0.791 + 0.000463T - 0.000000844T^2
\]

Appendix 1

Feature Article
TABLE A1. EQUILIBRIUM MOISTURE CONTENT TABLE

<table>
<thead>
<tr>
<th>RH (%)</th>
<th>Ambient air temperature - degrees Fahrenheit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>1.4</td>
</tr>
<tr>
<td>10</td>
<td>2.6</td>
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<tr>
<td>15</td>
<td>3.7</td>
</tr>
<tr>
<td>20</td>
<td>4.6</td>
</tr>
<tr>
<td>25</td>
<td>5.5</td>
</tr>
<tr>
<td>30</td>
<td>6.3</td>
</tr>
<tr>
<td>35</td>
<td>7.1</td>
</tr>
<tr>
<td>40</td>
<td>7.9</td>
</tr>
<tr>
<td>45</td>
<td>8.7</td>
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<tr>
<td>50</td>
<td>9.5</td>
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<tr>
<td>55</td>
<td>10.4</td>
</tr>
<tr>
<td>60</td>
<td>11.3</td>
</tr>
<tr>
<td>65</td>
<td>12.4</td>
</tr>
<tr>
<td>70</td>
<td>13.5</td>
</tr>
<tr>
<td>75</td>
<td>14.9</td>
</tr>
<tr>
<td>80</td>
<td>16.5</td>
</tr>
<tr>
<td>85</td>
<td>18.5</td>
</tr>
<tr>
<td>90</td>
<td>21.0</td>
</tr>
<tr>
<td>95</td>
<td>24.3</td>
</tr>
<tr>
<td>98</td>
<td>26.9</td>
</tr>
</tbody>
</table>

Note: RH – relative humidity.

\[ H = \frac{\text{relative humidity (\%)}}{100} \]
\[ K_1 = 6.34 + 0.000775T - 0.0000935T^2 \]
\[ W = 330 + 0.452T + 0.00415T^2 \]
\[ K_2 = 1.09 + 0.0284T - 0.0000904T^2 \]
\[ T = \text{temperature (\textdegree F)} \]

Relative Humidity

The relative humidity (RH) is the ratio of the actual water vapour pressure to the saturation water vapour pressure at the prevailing temperature.

\[ \text{RH} = \frac{P}{P_s} \] (A9)

RH is a ratio but usually expressed as a percentage rather than as a fraction. It does not define the water content of the air unless the temperature is given. The reason RH is so much used in conservation is that most organic materials have an equilibrium water content that is mainly determined by the RH and is only slightly influenced by temperature. Notice that air is not involved in the definition of RH. Airless space can have a RH. Air is the transporter of water vapour in the atmosphere and in air conditioning systems, so the phrase RH of the air is commonly used, and only occasionally misleading. The independence of RH from atmospheric pressure is not important on the ground, but it does have
some relevance to calculations concerning air transport of works-of-art and conservation by freeze drying.

The Dew Point

The water vapour content of air is often quoted as dew point. This is the temperature to which the air must be cooled before dew condenses from it. At this temperature, the actual water vapour content of the air is equal to the saturation water vapour pressure. The dew point is usually calculated from the RH. First one calculates $p_s$, the saturation vapour pressure at the ambient temperature. The actual water vapour pressure, $p_a$, is:

$$p_a = p, \text{RH} \quad (A10)$$

The next step is to calculate the temperature at which $p_s$ would be the saturation vapour pressure. This means running backwards the equation given above for deriving saturation vapour pressure from temperature:

$$\text{Dew point} = \frac{238.3w}{17.294 - w} \ ; \ w = \ln \left( \frac{p_s}{610.78} \right) \quad (A11)$$

This calculation is often used to judge the probability of condensation on windows and within walls and roofs of humidified buildings. The dew point can also be measured directly by cooling a mirror until it fogs. The RH is then given by the ratio:

$$\text{RH} = 100 \frac{p_s}{p_\text{ambient}} \quad (A12)$$

The Psychometer

The psychrometer is the nearest to an absolute method of measuring RH that the conservator ever needs. It is more reliable than electronic devices, because it depends on the calibration of thermometers.
or temperature sensors, which are much more reliable than electrical RH sensors. The only limitation to the psychometer is that it is difficult to use in confined spaces (not because it needs to be whirled around but because it releases water vapour). The psychrometer, or wet and dry bulb thermometer, responds to the RH of the air in this way: unsaturated air evaporates water from the wet wick. The heat required to evaporate the water into the air stream is taken from the air stream, which cools in contact with the wet surface, thus cooling the thermometer beneath it. An equilibrium wet surface temperature is reached which is very roughly half way between ambient temperature and dew point temperature. The air potential to absorb water is proportional to the difference between the mole fraction, $m_a$, of water vapour in the ambient air and the mole fraction, $m_w$, of water vapour in the saturated air at the wet surface. It is this capacity to carry away water vapour which drives the temperature down to $t_{w}$, the wet thermometer temperature, from the ambient temperature $t_a$:

$$ (m_w - m_a) = B(t_a - t_w) $$

(A13)

where $B$ is a constant, whose numerical value can be derived theoretically by using physics. The water vapour concentration is expressed here as mole fraction in air, rather than as vapour pressure. Air is involved in the psychrometric equation, because it brings the heat required to evaporate water from the wet surface. The constant $B$ is therefore dependent on total air pressure, $P$. However, the mole fraction, $m$, is simply the ratio of vapour pressure $p$ to total pressure $P$: $p/P$. The air pressure is the same for both ambient air and air in contact with the wet surface, so the constant $B$ can be modified to a new value, $A$, which incorporates the pressure, allowing the molar fractions to

Figure A2. Psychrometric chart.
be replaced by the corresponding vapour pressures:

\[ p_w - p_a = A(t_a - t_w) \]  

(A14)

The relative humidity as already defined above is the ratio of \( p_w \), the actual water vapour pressure of the air, to \( p_s \), the saturation water vapour pressure at ambient temperature.

\[ \text{RH\%} = \frac{100(p_w - A(t_a - t_c))}{p_s} = \frac{100(p_w - 6300(t_a - t_c))}{p_s} \]  

(A15)

The constant \( A \) changes to 56 when the wet thermometer is frozen (Wylie and Lalas, 1985).

### Thermal Properties of Damp Air

Moist air is a mixture of dry air and water vapour. In atmospheric air, water vapour content varies from 0% to 3% by mass. The heat content, usually called the air enthalpy, consists of sensible heat and latent heat, rises with increasing water content (Table A2). Enthalpy is used to calculate cooling and heating processes. This hidden heat has to be supplied or removed in order to change the relative humidity of air, even at a constant temperature. This is relevant to conservators. The transfer of heat from an air stream to a wet surface, which releases water vapour to the air stream at the same time as it cools it, is the basis for psychrometry and many

<table>
<thead>
<tr>
<th>Temperature ( t ) (°C)</th>
<th>Density ( \rho ) (kg m(^{-3}))</th>
<th>Specific heat capacity ( c_p ) (kJ/kg.K)</th>
<th>Thermal conductivity ( \lambda ) (W/m.K)</th>
<th>Kinematics viscosity ( \nu \times 10^3 ) (m(^2)s(^{-1}))</th>
<th>Expansion coefficient ( b \times 10^{-3} ) (1/K)</th>
<th>Prandtl’s number ( Pr )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-150</td>
<td>2.793</td>
<td>1.026</td>
<td>0.0116</td>
<td>3.08</td>
<td>8.21</td>
<td>0.76</td>
</tr>
<tr>
<td>-100</td>
<td>1.980</td>
<td>1.009</td>
<td>0.0160</td>
<td>5.95</td>
<td>5.82</td>
<td>0.74</td>
</tr>
<tr>
<td>-50</td>
<td>1.534</td>
<td>1.005</td>
<td>0.0204</td>
<td>9.55</td>
<td>4.51</td>
<td>0.725</td>
</tr>
<tr>
<td>0</td>
<td>1.293</td>
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<td>0.0243</td>
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</tr>
<tr>
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<td>0.0257</td>
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<td>3.43</td>
<td>0.713</td>
</tr>
<tr>
<td>40</td>
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<td>3.00</td>
<td>0.709</td>
</tr>
<tr>
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<td>0.0299</td>
<td>20.94</td>
<td>2.83</td>
<td>0.708</td>
</tr>
<tr>
<td>100</td>
<td>0.946</td>
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<td>0.0314</td>
<td>23.06</td>
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</tr>
<tr>
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<tr>
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<td>0.0343</td>
<td>27.55</td>
<td>2.43</td>
<td>0.695</td>
</tr>
<tr>
<td>160</td>
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<td>0.0358</td>
<td>29.85</td>
<td>2.32</td>
<td>0.69</td>
</tr>
<tr>
<td>180</td>
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<td>0.69</td>
</tr>
<tr>
<td>200</td>
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<td>0.0386</td>
<td>34.63</td>
<td>2.11</td>
<td>0.685</td>
</tr>
<tr>
<td>250</td>
<td>0.675</td>
<td>1.034</td>
<td>0.0421</td>
<td>41.17</td>
<td>1.91</td>
<td>0.68</td>
</tr>
<tr>
<td>300</td>
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<td>1.047</td>
<td>0.0454</td>
<td>47.85</td>
<td>1.75</td>
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</tr>
<tr>
<td>350</td>
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<td>0.0485</td>
<td>55.05</td>
<td>1.61</td>
<td>0.68</td>
</tr>
<tr>
<td>400</td>
<td>0.524</td>
<td>1.068</td>
<td>0.0515</td>
<td>62.53</td>
<td>1.49</td>
<td>0.68</td>
</tr>
</tbody>
</table>
Figure A3. Drying curve for APV laboratory spray dryer model MAL 150 at a constant outlet temperature 90°C.

The enthalpy of dry air is not known. Air at zero degrees Celsius is defined to have zero enthalpy. For air temperature between -100°C and 100°C the specific heat capacity, \( c_p \), can be set to 1.006 kJ/kg°C. The enthalpy known as sensible heat, in kJ kg\(^{-1}\), at any temperature, \( t \), between 0°C and 60°C is approximately:

\[
h_a = c_p t = 1.006t - 0.026 : t \geq 0°C \quad \text{and} \quad h_a = \frac{1.005t}{1.005} : t < 0°C
\]

The assumption that air enthalpy is 0 kJ kg\(^{-1}\) at 0°C is not correct according to the definition of enthalpy in thermodynamics. Thus, an approximate corrective factor has been included. For practical purposes in air psychrometrics this assumption is good enough since our interest is the enthalpy difference. The enthalpy of liquid water is also defined to be zero at zero degrees Celsius. To turn liquid water to vapour at the same temperature known as heat of evaporation, \( h_v \) is 2501 kJ kg\(^{-1}\) at 0°C. For water vapour the specific heat capacity, \( c_v \), can be set to 1.84 kJ/kg°C. Thus, at
temperature \( t \) the specific enthalpy of water vapour known as latent heat is:

\[
h_w = h_v^e + c_v^e t = 2501 + 1.84t \quad (A17)
\]

Notice that water vapour, once generated, also requires more heat than dry air to raise its temperature further: 1.84 kJ/kg°C against about 1 kJ/kg°C for dry air. Specific enthalpy of moist air is defined as the total enthalpy of the dry air and the water vapour mixture per unit mass of moist air. The enthalpy of moist air, in kJ kg\(^{-1}\), is therefore:

\[
h = h_a + x h_w = (1.006t - 0.026) + [0.62 \times 10^{-5} p (2501 + 1.84t)] \quad (A18)
\]

due to the humidity ratio, \( x \), is approximately \( 0.62 \times 10^{-5} p \) as shown in the equation (A7). Common properties for air are indicated in Table A2.

**REFERENCE**

WARNING NOTICE

Malaysia Patent No: MY 137253-A
Recovering Oil From Palm Mesocarp Fibre

THE TRADE AND PUBLIC are hereby informed EONCHEM TECHNOLOGY SDN. BHD. of
PLO 525, Jalan Keluli 9, Pasir Gudang Industrial Estate, 81700 Pasir Gudang, Johor, Malaysia is
the owner of Malaysian Patent No. MY- 137253 -A in respect of recovering oil from palm
mesocarp fibres.

The Patent claims a process and assembly of apparatus to extract remaining oil from mesocarp
fibres of oil palm after initial extraction of oil. Flow chart of the process is shown below:

NOTICE is hereby given that, any person who, or firm or company which imports, exports,
manufactures, offers for sale, sells or uses the process and/or the assembly of apparatus as claimed in
the MY-137253-A Patent which does not originate from EONCHEM TECHNOLOGY SDN. BHD.
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(Registered Patent Agent for EONCHEM TECHNOLOGY SDN. BHD.)
SYNOPSIS

This topic is indeed a long one and probably can be written as a complete book if an attempt is made to cover all aspects of oil palm development in detail. In this article, the author purposely wanted to unveil to the palm oil community a glimpse of the historical past on the development of the industry. Many countries for whom oil palm was totally foreign have now emerged as giants of the industry making the countries from where it originated fading into oblivion during the past few decades. In the beginning, oil palm was only considered to be a decorative palm meant for gardens but today it has become a formidable commercial crop growing very fast throughout the world. A glimpse of all the latest technologies of recent origin is also discussed in this article, although it is possible some others could have been left out. The palm oil development in recent times had been quite rapid and probably in a decade or two, faster development is anticipated in the field of biodiesel, oleochemicals and some health products.

HISTORICAL BACKGROUND

The centre of origin of the oil palm is the tropical rain forest region of West Africa mainly in a 200 - 300 km wide western coastal belt stretching from Gambia to Angola. The oil palm is indigenous to Africa and palm oil extraction dates back to about 3000 B.C. according to Friedel (1897). It grew on its own accord without being cultivated at the sites of homesteads that generally followed the trade routes and settlements of slaves. The Deli Dura was introduced into East Asia in 1875.

STAGES IN PLANTATION DEVELOPMENT

The development of the oil palm industry in Peninsular Malaysia can be subdivided into three stages.

First Stage

This stage occupied 1875 to 1916 when oil palm seeds were introduced in Singapore (Zeven, 1965). The government conducted studies on the suitability of oil palm cultivation in Malaya and the planting of oil palm for decorative purposes. From 1903 onwards, the Department of Agriculture imported seeds to Batu Tiga Experimental Plantation and to the Public
Gardens in Kuala Lumpur. The testing of oil palm was transferred to Experimental Plantation where 6 ha of oil palm planted in 1912 with seedlings selected from the Public Gardens. The origin of the seeds was not known except that it is of the Deli type as recorded by Milsun (1921). Three varieties from Nigeria – microsperma, normal Dura and mantle fruited were also planted in the Experimental Plantation in 1914 (Jouge, 1952).

In 1911, Henri Fauconier, a Frenchman, visited Tanjong Morowa Kiri Tobacco Estate near Medan in Sumatra and purchased Deli seeds. He planted them at Rantau Panjang Estate near Kuala Selangor. In 1912, he obtained more seeds from the same source with the help of Adrian Hallet, who selected the seeds from the best selected palms (Barnes, 1924). The seeds were planted at the Rantau Panjang Estate Entrance and the Rantau Panjang Estate bungalow known as La Mansion des Palmes. Oil palm and rubber were introduced into Malaya at the same time. Malaya became the largest world producer of rubber, but the oil palm industry was yet to grow on a commercial scale probably due to its lesser world demand at that time.

At the same time, in Netherlands East Indies, commercial planting of oil palm started a decade earlier mainly due to the efforts of Adrian Hallet, a Belgian, who set the oil palm industry going. Malaya had to wait until 1917 when Henri Fauconier, a friend of Hallet, planted the oil palm in Tennamaram Estate in Selangor, having obtained the seeds from Rantau Panjang Estate. While Fauconier was planting oil palm for decorative purposes, Tennamaram Estate, nearby, was being opened up for coffee planting. The coffee experiment was a failure and as a result oil palm was tried out as an alternative having brought the seeds from Tanjong Rantau Avenue. Thus, Tennamaram Estate became the first commercial oil palm plantation in Malaya, marking the beginning of the oil palm industry.

Second Stage

This stage comprises along period stretching form 1917 until 1961, considered to be an exciting stage laying the foundation for the rapid expansion in the 1960s.

The second commercial oil palm plantation, was developed at Elmina Estate. It was opened up in 1919 and the first 16 ha planted in 1920, growing to 2332 ha in 1922 and 4000 ha by the end of 1923. The progress was slow due to the renewed demand for rubber in 1925 following the introduction of the Stevenson Scheme for promoting rubber. However, there was a marked increase in oil palm cultivation from 1926, when large areas of land in Johor were alienated for oil palm cultivation on very generous terms. By 1925, the 8000 ha expanded to 50 000 ha in 1930 and three years later to 63 000 ha. In 1940, the total acreage was 77 000 ha. Despite the low palm oil prices, the expansion in oil palm cultivation continued, although not dramatically. In 1940 – 1941, Malaya exported 51 000 t of palm oil contributing to 12% of the world production being the fourth largest producer. The Japanese occupation during 1941 to 1945 resulted in the neglect of the crop but picked up after the war as the palm oil prices soared to 4 - 5 times higher than pre-war days. This further encouraged the cultivation of oil palm in Malaya and by 1960 the total area under oil palm cultivation was 54 540 ha (135 000 ac).

Third Stage

The need for diversification was emphasised by the World Bank mission and Malaya continued its expansion programme of oil palm cultivation until what it is today - an oil palm land bank of nearly 4 million hectares producing about 14 million tonnes of palm oil.
PROCESSING MILESTONES

This is discussed in three stages. The first stage covers from the time immemorial until the technology received colonial attention for mechanisation forming stage two of the development. The third stage covers the current rapid technology modernisation.

Stage 1 - Production Technology 3000 years

This technology for the production of two types of popular oils called hard and soft oils developed in Africa was presented in a paper by Nwanze (1942). For both soft and hard oils, fresh fruit bunches (FFB) is cut into sections, watered, covered with leaves and left for two to four days to ferment. Both methods, since the very early days, used crude hand or foot methods to extract oil and kernel. The kernels were separated and sun dried. After drying the nuts they are hand cracked and the kernels hand picked and sun dried again. These crude palm oil extraction methods, probably originated 5000 years ago, still continue in some part of Africa until the present day and the oil serves as part of the people’s staple diet. The oil is not used as a frying medium but consumed as an additive to their rice, garri or pounded yam and for this the free fatty acid (FFA) must necessarily be high. For example in the Delta area of Nigeria, the banga soup requires an oil of over 10% FFA while in Sierra Leone the taste of the palaver soup depends on an oil of over 20% FFA. These were probably the equivalent of KFC, McDonalds, Coca Cola or Pepsi Cola of those days!

**Soft oils.** The fruits are hand plucked (stripping) and boiled in water for 4 hr (digestion) and boiled fruits pounded (pressing) in pits or drums. The oil is then skimmed out (clarification) and heated again in shallow pans to remove (purification/drying) moisture. Product quality: FFA: 5%-12%, extraction efficiency: 40%-50%, suitable for bangga soup.

**Hard oils.** The hand plucked fruits are placed in a long canoe, covered with leaves and left for three days. Fruit is vigorously trodden with foot (pressing) and left for three days to allow oil to flow out. Water is then added and a second treading done (double pressing) and oil skimmed off (clarification), followed by further skimming and heating (dryer) in shallow pans to remove moisture. Product quality: FFA: 30%-50%, extraction efficiency: 20%-30%, suitable for palaver soup.

Both these methods were very labour intensive requiring 420 man-days for the production of soft oil and 133 man-days for the production of hard oil. This includes harvesting, fruit preparation, depulping, extraction and others. Although this system is still practiced in some places, the screw press was accepted by the small scale processing industry mainly due to the savings in labour.

Stage 2 - Mechanisation of Processing Technology

The first screw press, Miller press or the Deutscher press as it was known was introduced into palm oil processing in 1930. It comprises a central screwed steel shaft, permanently fixed in the centre of a base plate. The ram head and the turning arms are attached to the central shaft and are free to move vertically. The cage is a circle of wooden laths about 3 mm apart banded with two steel rings. Macerated fruit is fed to the cage and oil is expressed as pressure is exerted by screwing the ram head down. The press is essentially of the curb type normally used for the extraction of juices from soft pulpy fruit. Limitations on the working press make it unsuitable for efficient oil extraction of palm oil and its extraction efficiency seldom exceeds 65%.

The hand operated screw press was superceded by the oriental press which was used from the time of the Greeks and
the Romans until the 17th century. This single screw press, essentially similar to the cage press was used in the 17th and 18th centuries after which period was replaced by the hydraulic press for oil pressing, first patented by Joseph Bromah in 1795. Both these methods are still in use.

The manually operated hydraulic press was designed for pressing small quantities of fruit. One such press designed by the Dutch was tested by the West African Institute for Oil Palm Research (WAIFOR) and gave it an extraction efficiency of 90% to 98%. The press combined with locally designed and fabricated ancillary equipment gave an overall efficiency of 85% to 90%. However, the average throughput was limited to 0.625 t hr⁻¹. The maximum throughput attained so far for a mill using hand operated press at the Nigerian Institute for Oil Palm Research (NIFOR formerly WAIFOR) was 4.7 t hr⁻¹ (Nwanze, 1942). The equipment used were three open fired sterilisers with a capacity of 1 t of cut up bunches each, two stripped-fruit heating drums (capacity 2 t of sterilised fruit) and two macerated fruit re-heating drums. Bunch boiling usually commences on Sunday evenings and continues until Saturday mornings thus loosing two processing days per week. In this process, the losses were as follows:

Sterilisation oil loss: 0.51%
Clarification oil loss single drum: 3% - 5%
Clarification oil loss double drums: 0.8% - 1.0%
Moisture/dirt content: 0.01% - 0.01%

The mechanical milling of oil palm started in Africa before the First World War and the mills were far from perfect. At that time the development of a de-pulping system was the main focus resulting in a delay in the progress of designing large size processing plants using existing system until 1919 when a large power-operated mill was set up in Sumatra followed later by Malaya. The first power driven machinery for cracking nuts is reported to have been introduced into West Africa in 1877 by A C Moore of Liverpool (Ministry of Agriculture, 1877) being devised by Mather and Platt Ltd of Salford. In 1901, a German colonial committee wanting to develop a good machinery for palm oil extraction awarded the assignment to a firm - Haake of Berlin leading to the erection of plants at Mamfe and Victoria in the West Cameroon. At the same time, a French firm set up a plant at Contonou to press the fruit as whole, the precursor of the present milling concept. Two pressing methods slowly evolved from the Contonou concept.

In the first, the fruits after stripping were sterilised for 15 min to 30 min by steam heating followed by hydraulic pressing. Double pressing was done with inter-stage heating with nut separation done in rotating drum followed by nut cracking in a centrifugal cracker. This plant was constructed by the firms - Louis Labarre and Paulmier.

Digestion was first undertaken in a stamping mill in a plant of German design in Togoland. The entire spikelets were cut off and subjected to digestion so that fruit loosening and pulp crushing were done in one operation. The digested mash was pressed and the nuts cracked in a Haake centrifugal cracker.

The second method of press extraction was developed by Haake. Even though the hydraulic press was doing a good job, many German, British and French firms continued stubbornly to persist in developing the de-pulping technology. Haake’s system
was the outcome of the development of pressing after de-pulping. The de-pericarper consisted of a shaft carrying triangular metal blades rotating within a cylinder, which was itself rotating in the same direction have differential speeds. Two British companies, Culley Expressors Ltd and Manlove, and Alliot of Nottingham also supplied machinery for this plant.

Meanwhile, Lever Brothers in Zaire (now Republic of Congo) and other concession in Africa were also actively engaged in the development of processing plants but its progress was not publicised. Lever Brothers used centrifugal extraction in their mill in Zaire in 1916, developed by Manlove, Alliot and Co.

Apart from that the only pre-war mill of any size was built at Maka in the Cameroons for the Syndikat fur Oelpalmen Kultur by German firms. This mill consisted of six hydraulic presses for pressing before de-pulping. Stripping was done by hand. The capacity was 525 t of FFB per week with 24 hr operation. The oil extraction rate (OER) was 18.5% with kernel extraction rate (KER) at 6.9%. The press was manufactured by Krupp.

Centrifuge extraction proved well suited for the African grove fruit with its thin layer of mesocarp and became the standard extracting equipment in Malaya during the first 10 - 15 years of its industry’s life. The first Manlove type mill was constructed at Tenamaram Estate in 1923. But by early 1930s, the hydraulic press was beginning to displace the centrifuge in Malaya although the centrifuge was entirely a new modern method of extracting oil from fruit or seeds and which was considered to be a highly successful invention. In Sumatra, the first mills followed the Maka pattern and the hydraulic press developed by Konrad Loens, Krupp and later by Gebr.

Stork of Amsterdam was also active in developing palm oil extraction technology and set up a large mill at Pulu Radja Estate in 1921, a design by Dr Fickendey and constructed by Krupp.

The present milling technique took its shape after the First World War after the idea of depericarping was thrown out of favour. As such, centrifuges and hydraulic presses dominated the industry and most of the installations in Africa were done by Lever Brothers and their successors Unilever Ltd. In the early days, steam engines transmitted the power by long transmission shafts driving the individual machinery by pulley and beltings, a practice that continued in Malaya until about 1978.

**Stage 3 - Modern Technology**

It is now in the hands of Malaysians and the Indonesians to pursue the innovations to improve the milling technology further to keep pace with technologies used in other food-based industries especially the supporting infrastructures computer-based technologies. The vast gap between the techniques still employed in the milling process and other food processing industry makes the oil palm industry look very primitive and obsolete although the millers may not be able to see them. Even though there is no denial that the palm oil industry has made some strides in terms of improving the processing capability of mills, there are still some shortcomings in terms of improving the process efficiency and reducing the labour force. Any innovation for the industry must take into consideration the current processing problems faced by the industry such as:

- labour shortage;
- low oil extraction rate; and
- necessity to improve product quality due to increasing world demands.

MPOB’s research projects are based on the industry’s requirements and are tailored towards achieving these objectives. Unfortunately, the progress appear to be rather slow in this direction due to the favourable commodity prices. We shall
look at the whole scenario and discuss the achievements as well as the weaknesses in the industry under each section.

**Fresh Fruit Bunches Reception and Cage Filling Operation**

This does not seem to have made any inroads for the past three decades in terms of progress except for the introduction of a long conveyor that now fills the cages at only one or two points. The continuous sterilisation system in combination with the conventional sterilisation system requires by-passing fresh fruit bunches (FFB) from the FFB conveyor to the continuous sterilisation feed line as in the case of Palm Oil Mill Technology Centre at Labu. In mill with continuous sterilisation, the FFB can be fed directly into the continuous sterilisation plant. The old system of manual loading into individual cages from every hopper is labour intensive but now this can be done without any operator. This satisfies the present day requirement of labour reduction.

**Continuous Sterilisation**

Although attempts were made in 1952 to develop a continuous steriliser at Mongana, MPOB developed a new type of continuous sterilisation system using steam at atmospheric pressure for cooking. I will only touch on the milestones leading to the present level of continuous sterilisation development in Malaysia. This concept has its origin with the Mongana trials way back in 1952 and is well documented in their research report which was published in 1953, although the project did not take off the ground. They tried out prolonged storage of fruit bunches under water at high temperature and found that spikelets stripped completely. This property was used for designing the continuous sterilisers. Mongana trials also established some fundamental characteristics related to bunch stripping: (a) bunches soaked in hot water at 100°C for approximately 1 hr virtually did not strip at all, and (b) spikelets treated the same way stripped completely. The reason was that the air occluded in the bunches slowed down the heat transfer rates. Heat penetration also could be improved further by de-aeration or increased sterilisation temperature. Soaking of bunches in water under a pressure of 1.5 kg cm² for 90 min. This led to a stripping efficiency of 98%. Addition of surfactants likewise allowed a faster degradation of the bunches resulting in better heat transfer.

Using these findings Mongana designed a continuous steriliser in the form of a giant U-tube filled with hot water injected at the bottom of the U-tube so that the pressure at that point was about 1 kg cm² capable of a temperature of 120°C. The U-tube branches had a height of 10 m and 0.6 m diameter. Nut cracking was found to be more effective than if the bunches were sterilised with live steam at atmospheric pressure. Whatever the reasons, the project was not accepted commercially. Anyway, this was the precursor of the successful continuous steriliser developed by MPOB after a period of nearly half a century!

The Mongana scientists did not attempt to crush the bunches and subject them to sterilisation even though they knew that heat transfer and stripping were better if they sterilised the spikelets and not the bunches as a whole. Kumpulan Guthrie also conducted successful trials on effective sterilisation in 1990s after crushing bunches followed by sterilisation in conventional
sterilisers at atmospheric pressure but the system was still a batch process. The present continuous sterilisation system is the outcome of a combination of many trials with the important addition of making the system continuous. The system comprises of a bunch crushing operation followed by steam sterilisation at atmospheric pressure in a closed chamber through which the crushed bunches travel at very low velocity and return to the same level as the entry after making a U-turn at the end of the conveyor. In terms of bunch stripping, the sterilisation performs satisfactorily as almost all bunches are stripped efficiently. However, the choice of a horizontal digester instead of the well-proven conventional vertical digester appears more for the sake of a change than for improving the process operation. There are many advantages when vertical digesters are used that are absent in the horizontal units like the fruit weight acting on the mash at the bottom and drainage.

Currently, there are only some minor problems to be resolved. One is the insufficient nut conditioning arising from the lack of inadequate sterilisation temperature that the nuts are now subjected to. This can be done by additional nut drying to reduce the kernel moisture level within the nut to about 14% so that the kernel recovery station will function satisfactorily like conventional mills. This is being implemented in new mills under construction. Already a number of mills are in operation but most of them are in Indonesia. An interesting mill, probably the only one of its kind in the world built by CBIP using the continuous sterilisation principle is in operation in Riau Province, eastern Sumatra in Indonesia. This mill built on a floating platform about 3 m deep is made up of 14 steel pontoons linked together giving a base dimension of 60 m by 17.5 m. The only land connection is the elevator that feeds empty fruit bunches (EFB) into the incinerators. This mill uses seven workers per shift and operates non-stop for 24 hr a day at 12 t hr⁻¹ throughput even though designed for 10 t hr⁻¹. Hardly any supervision is needed for its operation. In case some of you get excited and get a burning desire to build a mill on a pontoon, please take note that this mill was so built because the entire plantation covering some 80 000 ha is located on high peat soil and the thousands of kilometres of canals replace the plantation roads there. The FFB cages sitting on pontoons are towed to the mills by motor boats.

Looking at this peculiar mode of FFB delivery, I must admit that I did get some funny (or stupid?) brain waves. If the width of the mill foundation pontoon is reduced to say 10 m the mill will be able to sail through the large canals that are 26 m wide leaving sufficient room for other boats to travel along. Then the mobile mill can travel to the estates rather than the other way round. A number of such mills could travel to whichever field that has the crop ready for processing. The only infrastructure needed is the incinerator at each milling port. Another advantage is that the effluent can also be discharged to different fields. This will solve the problem of having to discharge the effluent into the canals as is the practice now.

The problem associated with the slightly high oil loss in the fibre is not a big issue as some conventional mills also give the same results mainly due to operational defects like improper digester drainage. The mills having good digester drainage system is unlikely to face this problem. An additional digester would also improve oil recovery as in which case most of the oil bearing cells can be ruptured before pressing. It is agreed that some teething problems do exist but they can be addressed and continuous sterilisation is expected to be adopted by the industry in coming years after the initial resistance as is the usual case with all new
inventions. One important advantage in adopting this system is the ease with which the operation can be automated.

**Vertical Sterilisers**

This again is the offshoot of Mongana trials. The system tried out in Mangana had serious shortcomings like dropping FFB from a height without anything to cushion the free fall. Unloading was not only slow but required a great deal of labour. The vertical sterilisers use a very different concept capable of full automation. According to the manufacturers, the 20 t vertical vessel fitted with automated hydraulically operated doors can be charged or emptied in about 20 min unlike the Mongana trial units. The slanting bottom hidden within the chamber poses no problem for bunch discharge through the small chamber outlet and bunch discharge is aided by a motor driven augur with its shaft running along the free vacant space to the drive system located outside the chamber wall. The augur has large diameter to ensure efficient bunch evacuation needing no labour. A complete 30 min sterilization cycle including charging and evacuation is reported to be about 70 min and cooking is done at 3 barg pressure. At this pressure, bunches are conditioned sufficiently for efficient kernel recovery operation. No further treatment is necessary as the fruits are well cooked similar to the conventional system. The design has now undergone many changes after writing this article.

The secret of effective cooking and stripping using low sterilisation cycle in this system is the complete and efficient evacuation of air or the creation of a partial vacuum in the chamber. This is accomplished by filling up the chamber with water and as bunches fall into the chamber they displace the air trapped within bunches. The fall also is well cushioned by the water. Once the chamber is filled with bunches and water, the air bubbling out is effectively removed. After closing the feed door, the water is drained of from the bottom enabling the chamber to have a partial vacuum. Now when steam is injected, the heat transmission is more effective in the absence of air which is a constant curse in conventional sterilisers. In theory, the system is technically very sound but we do not have any trial data to assess its performance in real life. It is rather unfortunate that most of the innovations done in Malaysia find actual application outside Malaysia. The weakness of the industry in Malaysia is its tendency to shy away from anything new.

**Automation of FFB Cage Handling - The Indexer System**

Although well-known to other industries, this system is relatively new to the palm oil milling industry. It is all a question of an automated system for the continuous movement of the cages in and out of the sterilisers. It is indeed a surprise why it took the industry this long to adopt it as the technology has been well established and tested in a number of industries. The winches, ropes, tractors, etc. moving all over the place on a dirty and unsightly sterilisation bay must be very homely to some millers who like to maintain that culture like keeping vintage cars but some daring millers with good foresight ventured out and set up useful systems. The indexer system is one of them capable of reducing labour to a great extent. No high technology invention is involved in this except putting together some hydraulic components with a few mechanical components. Boustead has already installed this system in some mills and the feedback is very positive like very clean mill, much reduced labour force, no breakdowns fully automated system, etc.

This system is dependant and hence is more reliable and comprises of the following:

- hydraulic power packs;
- indexer frame with rollers;
hydraulic slave cylinders;
- electrical systems, sensors; and
- PLC/microprocessors and related equipment.

This can be used for steriliser drawbridges, transfer carriages, tippers, steriliser doors and any other operation. The different operations can be interlocked for safety like steriliser charging/discharging operation linked to drawbridge and the indexer operation. Cage marshalling can be done more efficiently including mechanical attachment and detachment of cages. Indexer system offers a number of useful features that will help to implement the mill wide automation leading to a significant reduction in labour. The actual data on the cost of installation, maintenance, etc. are not yet available to make a comparison.

Mill Wide Automation Trials in POMTEC

It has been the dream of the millers for nearly half a century to automate the processing operation not merely for labour reduction but for improving process efficiency. The current research on mill automation mainly focuses on process monitoring from a control room which only allows process operation and alarm circuit activation. The system developed is a precursor to mill wide automation in the absence of a feedback loop or any power aided slave mechanism for controlling the individual process machinery. A CCTV system is also used to monitor operations for the mill security surveillance but are yet fully functional. The present system is designed to operate the whole mill with just two operators and a maximum crew of eight field operators to communicate using walkie-talkies. In addition, a communication network interconnects all work stations and PLC systems in accordance with 10/100 Mbps Ethernet protocol.

The HMI/SCADA (human-machine interface/supervisory control and data acquisition) software communication with the installed PLC has features for historical data analysis, statistical process control and formatting of printed reports. The CCTV system used in the mill is designed to facilitate monitoring using computers connected to the same network as the SCADA system together with four analogue PTZ cameras, 33 analogue fixed cameras and four network video servers to provide a comprehensive CCTV solutions.

It is difficult to cover all the related activities in this article and if anyone is interested to gain an in-depth knowledge on POMTEC automation trials they are requested to read papers presented in the Proc. of the 2006 National Seminar on Palm Oil Milling, Refining Technology, Quality and Environment.

Renewable Energy

In future, palm oil milling may have to be renamed as palm oil milling and green energy plant as the vast renewable energy resource available at the mill may have to be converted to electricity for grid connection. I am sure that the current spiralling of fossil fuel prices do make an impact on all of us. At the current pricing probably it is not serious enough but if the price of petrol reaches RM 10 per litre then renewable energy production in Malaysia is likely to develop quite fast. At any rate the day is not far off and we have to make an effort to develop the best technology to face the impending fuel crisis. There are many methods available for energy conversion from biomass to electricity and it is not possible to cover all of them in this article. However, the article on bio-methanation will discuss some of the latest developments on energy conversion.

Bio-methanation technology deals with the conversion of any organic matter into biogas like methane. Once in gas form it can be used in internal combustion engines like gas engines or external combustion
plants like boilers or gas turbines. If all the biomass is converted to biogas in a converting plant the gas can be used for a number of purposes.

Methane production from effluent digestion ponds is also gaining momentum. There are various technologies available for harnessing it for green energy production. There is also a fund available from Global Environment Facility (GEF) administered by United Nations Development Project (UNDP) for harnessing and power production of methane generated by the effluent ponds. One plant in Malaysia had been producing it for more than 20 years and is used as fuel in boilers. The conversion of methane to carbon dioxide can reduce the harmful effect of methane as a greenhouse gas by 21 times! There is much potential for millers to pursue methane tapping and energy conversion as at the same time methane is converted to less harmful carbon dioxide as part of Clean Development Mechanism (CDM).

**Alfa Laval Decanter and Separator System (ALDASS)**

Any technology that can reduce water consumption during processing will be most welcome to the milling industry as there are two distinct advantages: (1) the reduction in the effluent production, and (2) simplification of milling process. It has to be noted that whatever the water added during the processing has to be eventually removed at the end of the processing operation. Hence, the less the water added the simpler the operation.

As all of you are aware, the conventional separators suffer from the problem of high water usage except for the stork-based designs that could operate satisfactorily with less water. This new decanter design by Alfa Laval is reported to cater for the specific requirement of the press liquor with the winning point that no additional water is necessary. It makes use of the water present in the process material itself together with whatever water is added upstream like during sterilisation and clarification. The system essentially comprises of a three phase decanter and a nozzle separator with a small clarifier. The heavy phase is claimed to have oil loss in the region of 8% similar to that of the clarifier underflow. The heavy phase is again subjected to high G-force centrifugal separation in a nozzle separator. The light phase oil does not have to be purified further and may be channelled straight into a vacuum dryer. The results will be given by Alfa Laval after intensive field trials in a palm oil mill.

**Nut Cracking Machines**

Nut crackers have undergone significant changes in recent years. The centrifugal crackers have more or less become extinct now for no apparent reasons. These crackers demanded only one extra condition for efficient nut cracking, i.e. drying nuts before cracking. This required large nut silos but the millers somehow were quite unanimous in disposing of the silos and embrace ripple mills, which were not satisfactory in many ways compared to the centrifugal crackers. The large quantities of kernel churned by these crackers were not detected as it was not easily detectable. The millers believed these crackers were doing a fine job and remained comfortable. Thereafter, new versions of the crackers made their debut in the industry, some with minor changes while others deviated wide away from the original cracking principle of ripple milling.

Machine evolution must be based on a clear and well-defined objectives like improving the product quality or efficiency. If there are no improvements then the new design was a waste of time. In the case of Rolek, the objective was the driving force behind the design, i.e. production of shell-free or least shell kernel with minimum kernel breakage. This will improve the quality of kernel cake rendering it penetrate niche markets that commands higher price.
Another objective was to be able to crack all the hard *Dura* nuts that the millers were finding it difficult to perform in conventional crackers.

The first Rolek crackers when it made its debut a few years ago had three cracking rings within the same machine. The outer cracking pair of rods can handle the large nuts such as *Dura* and the inner ones for medium and small nuts. The cracking is performed by the interaction of a pair of rods; one stationary and the other dynamic. The high wearing rods are sleeved so that the base rods remain intact. In addition, the inter-gaps can be customised for cracking nuts of any size. The full cracking and kernel recovery system comprises three nut graders, three winnowing columns and associated Rolek crackers for dealing with all types of nuts including dry separation columns for cracked mixture separation. This topic will be dealt with in detail in this session.

**THE FUTURE**

It is not possible to cover everything in this article but the major ones were discussed. Looking at the future there are a lot more to be done. This is just the beginning of a long journey towards perfection. As you can see the present achievement is still rudimentary in nature. In the immediate future you will be able to assess the exact oil extraction rate of a specific load of FFB in a lorry using computer analysis backed by sophisticated instrumentation that can conduct accurate analysis of the crude oil after a set time lapse co-relating to the specific FFB load.

It is difficult to visualise what is in store for us in the future in terms of process evolution. Perhaps the whole load of FFB can be churned into a paste and a combined oil extruded in a simple plant. The oil is fractionised into different grades that can be re-combined according to the customer requirement. This idea is not new as it was widely discussed at one time but did not take off due to resistance. It is possible it may yet reappear when the time is ripe as the concept is good. This system allows the option to remove the harmful fractions as defined by the nutritionists from time to time on the harmful effects of certain fractions of edible oils.

**REFERENCES**


Bunch growth depends very much on the transfer of carbohydrates produced by the leaves. Chlorophyll diminishes significantly by the 17th week after anthesis and mesocarp oil formation commences with the help of sugar brought in together with phloem sap (Henson, 1993).

It is estimated that a gramme of oil requires about 3.33 g of glucose and 1 g of non-oily dry matter will require 1.37 g of glucose for their production. Glucose to dry matter ratio for an average bunch is about 2.31 (Penning de Vries et al., 1983). The trunk contains large quantities of free sugar and poly-saccharine, some of which are imported.

The period from anthesis to harvesting in Malaysia ranges from 140 to 160 days (Hartley, 1977) but oil accumulation is usually confined to about 35 days before harvest. The development of the fruit will continue up to about 160 days. Mesocarp mass per fruit is variable and may decrease when the number of fruit per bunch increases. It is believed that kernel takes precedence over the mesocarp for assimilates (not yet proven). The number of fruits in a bunch is proportional to the number of female flowers and the pollination efficiency.

There is no evidence to show that the oil to bunch follows any specific trend (Corley and Gray, 1976) but pollination efficiency can have seasonal variation due to the impact of heavy rain that could discourage weevils from active pollination. Water deficit can shorten the period of bunch maturation resulting in reduced oil to bunch due to the lower oil in mesocarp (Ochs and Daniel, 1976).

**Causes for Low Extraction Rate**

The actual players seldom highlighted are:

- poor quality crop;
- insufficient loose fruits recovered;
- excessive trash in consignment;
- long stalks;
- wet bunches;
- rat infested bunches; and
- milling losses.

Out of the seven contributors only one is from the mill. The individual losses can

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be roughly estimated on very conservative figures as shown in Table 1.

**ANALYSIS OF FIELD LOSSES**

**Poor Quality Crop**

- This happens when the crop goes through the hands of the fresh fruit bunches (FFB) merchants who certainly want to make some money in trading FFB. The best way for them is adding sand and water or even empty fruit bunches (EFB).
- The unripe crop are kept by the merchants for a few days to get the desired loose fruits so that they are qualified to be ripe with low oil content.
- Over-ripe crop. This is common in Sabah as the plantation cannot deliver the crop when there is rain in the afternoon. The bunches together with the loose fruits will be immersed in water – sometimes even for days.
- Mills are supposed to use a specific sterilisation regime for each category of crop, viz. unripe, ripe and over-ripe. However, the consignments are always a mixed lot so nothing can be done.

The impact of the above: oil loss not less than 2%.

**Action: OER Booster No. 1: Get the FFB Quality Right**

**Contamination - entry points.** This also happens when the crop goes through the hands of the FFB merchants who certainly want to make some money in trading FFB.

They carry out a special treatment on the crop by adding:
- sand;
- water;
- trash; and
- or even empty fruit bunches (EFB).

Would merchants wish to stop this practice? The answer is NEVER!

<table>
<thead>
<tr>
<th>Factors affecting OER</th>
<th>Estimated loss %</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor quality crop</td>
<td>1.0</td>
<td>Under-ripe crop will not have the same quantity of oil as ripe crop. Over-ripe crop would have shed some of the fruits in the field. Both these could easily contribute towards a drop in OER of say 1%.</td>
</tr>
<tr>
<td>Insufficient loose fruits collected</td>
<td>1.5</td>
<td>If every 1% loose fruit not collected contributes 0.3% OER depression, then for say 5% loose fruit not collected = 1.5%.</td>
</tr>
<tr>
<td>Excessive trash in crop</td>
<td>1.0</td>
<td>Trash can sometimes be as high as 10%. But let us take a small figure of only 5% then the OER depression could be 1% based on 600 t fresh fruit bunch (FFB) processed with an OER of 20%.</td>
</tr>
<tr>
<td>Long stalk</td>
<td>0.1</td>
<td>Assuming 5% has long stalk and it causes the bunch weight to increase by 10% i.e. 30 t x 1.1 = 33 t (600 t per day processing mill). So without the extra stalk the FFB processed would have been 597. The actual OER = 1 (120/597)% = 20.1%.</td>
</tr>
<tr>
<td>Wet bunches</td>
<td>1.0</td>
<td>Here the bunch weight can escalate by 10% on a rainy day. But let us assume it is 5%. The OER drop in the same case would be 21%-20% = 1%.</td>
</tr>
<tr>
<td>Rat infested bunch</td>
<td>0.5</td>
<td>Here again let us assume a very low figure of 0.5%.</td>
</tr>
<tr>
<td>Total field losses</td>
<td>5.4</td>
<td>This is only a conservative figure.</td>
</tr>
<tr>
<td>Milling losses</td>
<td>0.3</td>
<td>This can be split into controllable and uncontrollable losses 0.3% and 1.5% respectively assuming a total losses = 1.8%.</td>
</tr>
</tbody>
</table>
Action: OER Booster No. 2: Strict Enforcement - Revoke License if Necessary

**Excessive trash in FFB.** They comprise of the following:

- sand;
- calyx leaves;
- EFB;
- grass;
- FFB net;
- foreign objects, and
- anything under the sun (animal carcass, empty bomb shells, etc.).

Let us see its impact on the mill’s OER when processing 1000 t FFB per day having a moderate 10% trash in the consignment. Mill’s OER was found to be 20%.

So the absolute oil produced = 200 t.

But the actual FFB delivered (minus trash) was: 900 t.

So the actual OER = 22.22%.

So OER depression amounted to 2.22% !!!

Action: OER Booster No. 3: Do Not Accept Trash with FFB

**Unripe crop.** Rejected crop can be confiscated and destroyed (in force now).

But generally this is confined to own estates (large plantations).

But the merchants will not deliver such crop (from smallholders) to the mills until they are given special treatment.

- They are kept by the merchants for a few days in their yard.
- Until they get the desired loose fruits.
- So that they are qualified to be ripe.
- But … with low oil content. Say 15%?

What happens to the loose fruit? Is it separately sold at a high price?

Win-loose situation.

OER Booster No. 4: Need Strict Enforcement

**Long stalk.**

- This will absorb oil from crude palm oil (CPO).
- Long stalk is like blotting paper.
- CPO absorption by stalk will reduce mill’s OER.
- Stalk should be as short as possible.

Action: OER Booster No. 5: If Not, Such Bunches should be Rejected, Confiscated and Processed by the Mill under Unaccounted Crop

**Over-ripe crop.**

- This is very common in Sabah and also in Peninsular.
- Plantation unable to clear harvested bunches.
- This is due to rain in the afternoon, which is common.
- The bunches together with the loose fruits will be immersed in water.
- Even for days with great loss of loose fruits.
- Some bunches have no fruits at all but still find their way to the mill.

Action: OER Booster 6: Do Not Wait for Bunches to be Over-ripe

**Mixed crop.**

- Over-ripe, ripe and under-ripe are mixed and sent to the mill.
- Mills can use a specific sterilisation regime for each category of crop, viz: unripe, ripe and over-ripe.
- But the consignments are always a mixed lot.
- So nothing can be done?
- What is the solution? Harvest bunches when they are just ripe.
- Is this possible? Need to keep on trying.
Feature Article

Action: OER Booster No. 7: Harvest When Bunches are Just Ripe

Loose fruits not collected (Shawaluddin, 1998).

- Every 1% loose fruit not collected from the field, the mill’s OER drops by 0.3%.
- Remember this and also tell your plantation friends.

Action: OER Booster No. 8: Collect All Loose Fruits Irrespective of the Cost

Wet bunches.

- This can easily elevate the bunch weight by about 10%.
- Previously some plantation companies had provision to reduce this amount for the bunch weight so that the OER is more realistic.
- The FFB merchants sometimes spray water and sand into the bunches to elevated the FFB weight.
- This is difficult to monitor or control.

Action: Per Booster No. 9: Strict Monitoring and Enforcement

Rat infestation.

- Too much of rat infestation could bring down mill’s OER.
- For young palms producing 25 t ha⁻¹ yr⁻¹ the crop loss due to loose fruits consumed by rats were quantified as 10%.
- For higher yielding field the loss is lower at about 7% to 8% (Liau, 1990).
- Overall OER loss was estimated to be 0.6% with moderate rat damage to crop.

Action: OER Booster No. 10: Rat Elimination Using Barn Owl

Milling losses. The approximate milling losses are shown in Table 2. In mechanical oil extraction processes some losses are inevitable unlike in the case of solvent extraction

Oil loss in FFB

Oil loss in EFB comprises of the following:

- Fruit trapped in EFB = 0.02%
- Un-striped bunches = 0.05%
- Oil absorbed by EFB = 0.45%

Total in EFB = 0.52%

Action: OER Booster No. 11: The Following Actions would Help

- The oil absorbed by EFB can be reduced by adopting regimes to prevent overcooking FFB.

### Table 2. Oil Loss during Processing

<table>
<thead>
<tr>
<th>Areas where oil losses are</th>
<th>Losses as a % to empty fruit bunches (FB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit trapped in empty fruit bunches (EFB)</td>
<td>0.02</td>
</tr>
<tr>
<td>Un-striped bunches</td>
<td>0.05</td>
</tr>
<tr>
<td>Oil absorbed by EFB</td>
<td>0.45</td>
</tr>
<tr>
<td>Condensate from sterilisation</td>
<td>0.10</td>
</tr>
<tr>
<td>Nut surface after pressing</td>
<td>0.05</td>
</tr>
<tr>
<td>Oil loss in mesocarp fibre</td>
<td>0.55</td>
</tr>
<tr>
<td>Oil loss in sludge separator</td>
<td>0.45</td>
</tr>
<tr>
<td>Oil loss during spillage/washing, etc.</td>
<td>0.10</td>
</tr>
<tr>
<td>Total</td>
<td>1.77</td>
</tr>
</tbody>
</table>

Source: Ng, S B (1993).
Not overloading the thresher as bunches should not fall on each other something.
That over-feeding can cause.
Over-cooking over-ripe crop will impart oil into other bunches, thereby increasing EFB absorption.
Loose fruits should never be subjected to unnecessary threshing operation. Segregate loose fruits and let them bypass thresher. This way the oil absorbed by EFB can be brought down significantly.

Oil Loss in Mesocarp Fibre

This is one of the main constituents of milling losses and can be reduced by ensuring:

- proper sterilisation of the crop;
- proper digestion of the mash;
- proper drainage of oil from the digester;
- proper cone pressure on the press cake;
- right temperature of the mash; and
- proper sterilisation of the crop.

Lack of understanding of the sterilisation process has probably set in motion the emergence of a series of alternate sterilisation techniques that defies established norms founded on sound engineering principles.

If sterilisation is done according to proper methods based on thermodynamics, a single threshing operation is all that is required to attain 100% stripability. Un-stripped bunches arise from erratic processing operation and nothing else not even hard bunches.

The use of bunch crusher is like fighting the consequences of an erratic cause rather than the cause itself.

Proper Sterilisation of the Crop

We need to go back to basics now as engineers and inventors seem to have lost track of it. Let us have a good look at Dalton’s Law of Partial Pressures.

In an enclosed vessel containing a mixture of steam and air, the effective pressure is equal to the sum of the partial pressures of steam and air when they occupy the whole vessel independently.

What does this mean? Take an example:

The steriliser pressure shown on the pressure gauge is 4 bar-g. This is the pressure of steam and air not steam alone. It contains 50% steam and 50% air.
If steam occupied the whole steriliser the steam pressure would be 2 bar-g. The air inside will have a pressure of 1 bar-g (1 atmosphere). So the partial pressure of steam would be
\[ \frac{2 \times 4}{2+1} = 2.7 \text{ bar-g} \]

The saturation temperature of steam at 4 bar-g = 143.6°C.

But the steam pressure is only 2.7 bar-g at saturation temp: 130°C and not 143.6°C as you would have thought!

Impact of Air

- You have now identified the air as the culprit.
- This means half the battle is won.
- How do you get rid off as much air as possible from the steriliser?
- Air is a very poor conductor of heat.
- As steam condenses, it releases about 2171 kJ kg\(^{-1}\) of heat at 27 bar-g steam pressure.
- At 4 bar-g pressure, it is actually lower at 2134 kJ kg\(^{-1}\).
- Discharge continuously the air released by the bunches.
- Install a 50 mm condensate by-pass line that is kept open throughout the sterilisation programme.
• Monitor your stripping efficiency. If not satisfactory, air evacuation had been inefficient.

Impact of Steriliser Designs

• Some steriliser designs are specially designed to overcome the partial pressure problems.
• If a steriliser can produce a vacuum within it, the effective steam pressure in it will not drop as it contains only steam and it is possible to attain a temperature equal to the saturation temperature of steam at 4 bar-g (i.e. 143.6°C).
• The water-filled vertical steriliser can do this when the water is discharged from the bottom. A partial vacuum is possible. It is also possible to get 100% stripping.
• The only problem is the production of a large quantity of effluent. All engineers are requested to wake up!
• Need to pursue this closely by you!!

Action: OER Booster No. 12

Fruit Digester - Function

• The correct art of operation is lost now. Millers seem to have lost the fundamentals again in here.
• The function of a digester is to convert the cooked fruit to a digested mash containing ruptured cells which is ready to release most of the oil in the digester and the rest is extracted during pressing operation.

Fruit Digestion - Requirements

For this to happen efficiently it must satisfy the following conditions:

• the mash temperature must be between 90°C to 95°C.
• the stirrer blade tip clearance should be as low as possible (say 6 mm if possible).
• the digester drainage must be extremely efficient.
• re-design the digester drainage system. About 95% of the mills do not have proper digester drainage.
• the digester liner renewal causes distortion of digester body as the liner plates are welded. It is no more circular to maintain 6 mm blade tip clearance. It is worthwhile to fit the liner as one piece. For this the digesters should be away from the presses.

Action: OER Booster No. 13: All the Above

Digester Dynamics

• The mash temperature is critical.
• Do not let this drop below 90°C.
• Digester power consumption is related to mash temperature.

PRESSING OPERATION

• If most of the oil has drained off from the digester the press has very little job to do.
• But millers impose an excessive cone pressure on the mash within the press often exceeding 60 bar-g with the

TABLE 3. DIGESTER TEMPERATURE AND MOTOR POWER CONSUMPTION

<table>
<thead>
<tr>
<th>Volume</th>
<th>Temperature (°C)</th>
<th>Power consumed (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>¼ full</td>
<td>71 to 72</td>
<td>6 – 4</td>
</tr>
<tr>
<td>½ full</td>
<td>71 to 70</td>
<td>11 – 9</td>
</tr>
<tr>
<td>¾ full</td>
<td>70 to 72</td>
<td>16 – 13</td>
</tr>
<tr>
<td>Full</td>
<td>69 – 71</td>
<td>22 – 18</td>
</tr>
<tr>
<td>Full</td>
<td>95 - 96</td>
<td>14 - 12</td>
</tr>
</tbody>
</table>

Source: Dato’ Beck Nelson.
consequence the nut breakage in press is too high. This may even reach an alarming 35%.

- Some of the nuts are also broken in the digester when the clearance between the expeller arm and the bottom perforated plate is erratic. This clearance is critical. It should not allow nuts to lodge in the space and get broken.

Action: OER Booster No. 14: The Above

Oil Loss in Wastewater

- As you dilute the press liquor, it becomes more viscous.
- At 50% water addition the separation of water and oil will be the least.
- In their clarifier mills add about 41% water to CPO.

- This is done to make the press liquor flow out from the gutter, sacrificing good separation.
- If you want good separation, do it with zero dilution.

Action: OER Booster No. 15

Oil Loss in Wastewater

The best separation is at zero dilution. In sludge separator the oil loss is directly proportional to the dilution water.

Proof.

- The oil loss ex-centrifuge is always fixed at about 0.3%.
- If 100 litres of sludge water is processed the absolute loss is 100 x 0.3% = 0.3 litres.

![Viscosity vs. Setting for CPO ex-press](image)

*Figure 1. Press juice viscosity vs. settlement.*

**TABLE 4. OIL DILUTION METHOD USED BY MOST MILLS NOW**

<table>
<thead>
<tr>
<th>Components</th>
<th>From press (%)</th>
<th>Dilution water</th>
<th>Final condition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>55</td>
<td>Add 41% water = 41 + 35 = 76%</td>
<td>39</td>
</tr>
<tr>
<td>Water</td>
<td>35</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Solids</td>
<td>10</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Note: The normal dilution system adopted by almost all mills do not follow the recommendations given by Mongana Research Report (*Figure 1*) but most mills add 41% dilution water which is a deviation from Mongana Research Station recommendation (*Table 4*).
• If it is diluted 100%, the absolute loss is 200 x 0.3% = 0.6 litres.
• Does this make sense? This is twice the loss.

Action: OER Booster No. 16: Do Not Dilute Excessively

**OER measurement – on-line in real time.**
In order to monitor the performance of smallholders and even divisions of an estate there is a new technique available now. The individual batches will be processed. The OER will be plotted and average value calculated so that justice is done to good performers. The bad performers will then try to emulate the good ones and improve their OER.

**OER in Real Time will Improve OER of Smallholders**

• Hand over consignment note to weighbridge clerk.
• Weighing done and data transferred to a magnetic disc.
• FFB cages sterilised with the disc (maximum temperature 160°C).
• At exit starting time entered into the disc.
• Time duration until CPO exit ex-press is previously established.
• The CPO ex-press is analysed continuously by a near infra red analyser and recorded by interfacing data with a computer.
• If it is x min, the data analysed belongs to the batch in question.
• If one owner gets 16% OER and another one 24% won’t the lower OER supplier try to improve his crop by applying more fertiliser?

Action: OER Booster No. 17: OER Measurement in Real Time

If you agree please try to implement some of them.

**REFERENCES**


INTRODUCTION

This topic is not new to a lot of us, but there is an inherent failure in us to understand the basics of the terminology.

DEFINITIONS

Maintenance is defined as the act of maintaining something. The basis for maintaining is to keep, preserve and protect. That is to keep something in an existing state or preserve it from failure or decline.

Reliability is defined as the ability of an item to perform a required function under a stated set of conditions for a stated period of time.

I have chosen, very early in this article to clearly define the two items as the terminologies are sometimes interchanged.

Let us examine some commonly used terms when we need to approach this.

But, first let me declare what that I am about to prescribe is not ‘alien’ technology or something that is too difficult to practice or is just another ‘fad’, it is something which have already been in practice a long time ago, but over the course of time, has just been forgotten. This is merely the basics and the proper foundation required for us before we attempt to make our journey towards reliability.

SETTING STANDARDS

Firstly, ‘...we cannot manage something which we cannot measure...’- Edward Deming.

Therefore let us set some measurable standards to achieve world class maintenance. These are given in Table 1.

The standards defined above are the norms and may be used as a guideline to form the basis of our maintenance and reliability culture. In the palm oil industry, cost variances vary depending on the accounting methods. It generally make up of fixed and variable cost, and seldom takes into account capital funds allocated for repair type jobs, for instance the replacement of a thresher, which is a repair job, but is still nevertheless capitalised. So
for the basis of our discussions in setting standards, the maintenance cost which is referred to, does include capital repair type jobs and also those routine maintenance cost for the plant.

Let us now define a few of the maintenance methods.

**Planned Maintenance**

It is a combination of preventive and predictive maintenance.

- **Reactive maintenance** – characterised by practices such as failure to run, breakdown and emergency maintenance. Its common characteristics are that it is unplanned and urgent. A more stringent view of reactive maintenance - the maintenance team did not schedule a repair on a particular pump for Monday but had to do it before Monday morning.
- **Preventive maintenance** (time-based) – characterised by practices that are periodic and prescribed. Examples are annual overhauls, quarterly calibrations, monthly lubrication and weekly inspections.
- **Predictive maintenance** (condition-based) – characterised by practices that are based on equipment condition. Examples include changing a bearing long before it fails based on vibration analysis; changing lubricants based on oil analysis showing excess wear particles; replacing steam traps based on ultrasonic analysis or even replacing a cutting tool based on deterioration in product quality.
- **Pro-active maintenance** (root cause-based) - characterised by practices that focus on eliminating the root cause of the maintenance requirement or that seeks to extend equipment life, mitigating the need for maintenance. These practices use the maintenance knowledge-based knowledge about what was going wrong with equipment to make changes in the design, operation or maintenance practices or some combination and seeks to eliminate the root cause of the problems.

Having worked in quite a few locations in the region, I have noticed an almost

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**TABLE 1. COMPARISON OF TYPICAL ACHIEVEMENTS AGAINST AND WORLD CLASS STANDARDS**

<table>
<thead>
<tr>
<th>Performance measure</th>
<th>Typical</th>
<th>World class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant uptime</td>
<td>70% - 80%</td>
<td>90% - 95%</td>
</tr>
<tr>
<td>Maintenance cost per RAV*</td>
<td>3% - 6%</td>
<td>1% - 3%</td>
</tr>
<tr>
<td>Breakdown production loss</td>
<td>5% - 10%</td>
<td>&lt; 1% - 2%</td>
</tr>
<tr>
<td>Planned maintenance</td>
<td>50% - 70%</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Reactive maintenance</td>
<td>45% - 55%</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Overtime</td>
<td>10% - 20% or higher</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Stores value per RAV</td>
<td>1% - 2% or higher</td>
<td>&lt;0.25% - 0.5%</td>
</tr>
<tr>
<td>Training (RM yr⁻¹)</td>
<td>1 - 1.5 K</td>
<td>2 - 3 K</td>
</tr>
<tr>
<td>Training (hr yr⁻¹)</td>
<td>20 hr</td>
<td>40 hr</td>
</tr>
<tr>
<td>Lost time accidents (per 200 K hr)</td>
<td>0.2 - 0.5</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Recorded injuries (per 200 K hr)</td>
<td>5 - 10</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

Note: RAV* is defined as replacement asset value or how much will it cost to rebuild a similar size plant or insured value of the plant or a combination of the two.
consistent slip in the maintenance strategies employed by the sites. The following are the common problems which I have encountered and continue to persist.

- Lack of skilled crafts – (maintenance fitters, electricians).
- Lack of proper record keeping.
- Lack of properly defined standards to guide the site teams – this is from not having proper standards and processes based on actual data, rather than having to ‘shoot from the hip’ or ‘rule of thumb’ numbers – which are not a good indicators as there will always be peculiarities between different locations.
- Poorly trained manpower from managers to operators.
- Increased cost of operations – which has led to increased automation, but with reduction in site skills, also resulted in poor maintenance planning to address the defects. When breakdowns occur, it is often outsourced and certain maintenance functions – even the basics are now done by non-plant personnel. I know of some companies which employ contractors to carry maintenance and repair (M&R) but works on their main chain conveying system.
- Introduction of so called quick fixes like software to aid maintenance - CMMS, although this is a workable solution provided the basics and the general M&R in the plant is well done, but sadly this is not the fix the industry needs at the moment.

So what is the main area which needs improvement?

The answer is actually quite simple, but difficult to have it seen through as it involves an increase in cost from the time of the implementation to at least 24 months. Most site management teams will not be too pleased to accept this. But this is nevertheless required, so as to undo some of the mistakes of the past.

The increase in cost will come mainly from the following areas:

- training – if we put a ringgit value on our training cost – how much do we actually spend on our people – our most important asset? This could include cost to bring in subject matter specialist to provide specialised training to the maintenance teams, etc.
- re-design – this is undoing some of the poorly designed equipments, this comes into realm of pro-active maintenance. This may also come from capital injection to renew defective or poorly designed equipments.
- purchase of special tools – this is in the form of procuring special tools which can be used for basic trend monitoring over two main areas in the plant, temperature and vibration.

Finally, the most important aspect of success in this will be to remind everyone to go back to the basics. Basics here are defined as having the following measures done.

**Asset register.** All plants regardless of the size have quantities of assets which have to be properly defined and recorded. In almost all plants and companies which I have worked with, some being large MNC and also reputable Malaysian companies, these data are either not available or is partially available, and also lacks accuracy. So is this true in your plant? What do you need to get your asset register up to date?

**Asset type.** If example is pump.

- make;
- model;
- mechanical seal size and type;
- pulley size;
- v-belt type;
- bearing type; and
- equipment history card for maintenance.
**Breakdown frequency and specifics.** Do we know what caused the breakdown, do we know the actual loss (financial)?

**Inventory levels.** Depending on the complexity and criticality of the asset, maintaining stock levels may be necessary for particular machinery.

**Criticality ranking of assets.** This is done mainly to focus our limited resources and scheduling work towards our most critical assets.

Once the assets have been defined, then we can proceed to do a physical inspection on these assets, this entails what I refer to as an asset walk-down. Here we physically inspect the asset and ascertain its condition. This could be done through the use of special tools, maintenance data (on breakdowns and types of repairs incurred – if the records exist).

A maintenance strategy can be formulated based on what type of maintenance is to be done, either it is preventive, predictive or pro-active.

The above methodology is not something new, but these are the basics and even this is not properly done.

We need to look into ways and means to address these shortfalls and look into improving the maintenance set ups at our sites.

Many will say that they are able to do it with their existing personnel at site, but based on experience, the sites seldom push hard on these issues as they may feel this is or will be another management type push from the top. So the system would eventually fail.

The challenge will be to educate the people and to have a consistent drive from management for change and to have greatness achieved within their respective organisations.

To quote Jim Collins – ‘Good is the Enemy of Great’.

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**Feature Article**

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**PALM OIL ENGINEERING BULLETIN NO. 100**
Steam Traps

Steam traps in most of the palm oil mills are not doing their designated tasks. They are seen to merrily steaming away and the captains of the mills do not seem to be concerned about this. But please remember that steam is a greenhouse gas and its release to atmosphere is not a friendly act in terms of environment. Apparently no one takes the trouble to open their steam traps and rectify any defect in them. It is quite easy to do and there must be a routine maintenance for this like opening up whenever steam is found blowing out.

* Malaysian Palm Oil Board, P. O. Box 10620, 50720 Kuala Lumpur, Malaysia.
E-mail: nravi@mpob.gov.my
Direct Action Float

In Figure 1, the condensate will initially fill up the steam trap so that the stopper attached to the bucket will keep the condensate from discharging out. As the condensate start building-up in the trap, it will spill over to the bucket until the buoyancy is sufficient to move the bucket downwards, thus releasing the stopper causing the condensate to blow out through the central discharge pipe by the steam pressure. In this trap, there will always be some condensate in the trap and the condensate release is intermittent. It is possible to have various configurations using this principle. This type is protected from dirt and is suitable for low to moderate pressures.

Inverted Bucket or Bell Trap

In this float (Figure 2), there is no danger of the collapse of the bucket. Initially the built-up condensate allows the inverted bucket to float in the water which rises around it. When the steam inside the bucket condenses coupled with the air release through the orifice on top of the bucket, the condensate level within the inverted bucket rises causing the bell to sink thus opening the discharge opening. The incoming steam entering under and inside the bucket blows out the water and discharges it through the trap outlet causing the bell to retain its original floating position.
HEAT CONTAINED IN WATER AT DIFFERENT PRESSURES

Heat content from 0°C (32°F)

<table>
<thead>
<tr>
<th>Pressure psi-g</th>
<th>Water temperature Fahrenheit</th>
<th>Heat content BTU lb⁻¹</th>
<th>kJ kg⁻¹</th>
<th>Sp.Volume Cft lb⁻¹</th>
<th>m³ t⁻¹</th>
<th>Density lb Cft⁻¹</th>
<th>t m⁻³</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>212</td>
<td>180</td>
<td>419</td>
<td>0.01672</td>
<td>1.04</td>
<td>59.83</td>
<td>0.96</td>
</tr>
<tr>
<td>5</td>
<td>227</td>
<td>195</td>
<td>454</td>
<td>0.01684</td>
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<td>0.95</td>
</tr>
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<td>10</td>
<td>239</td>
<td>207</td>
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<td>59.1</td>
<td>0.95</td>
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<td>259</td>
<td>227</td>
<td>528</td>
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<td>30</td>
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<td>243</td>
<td>565</td>
<td>0.01721</td>
<td>1.07</td>
<td>58.1</td>
<td>0.93</td>
</tr>
<tr>
<td>40</td>
<td>286</td>
<td>256</td>
<td>595</td>
<td>0.01733</td>
<td>1.08</td>
<td>57.7</td>
<td>0.92</td>
</tr>
<tr>
<td>50</td>
<td>297</td>
<td>267</td>
<td>621</td>
<td>0.01742</td>
<td>1.09</td>
<td>57.4</td>
<td>0.92</td>
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<tr>
<td>60</td>
<td>307</td>
<td>277</td>
<td>644</td>
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<td>57.1</td>
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<td>70</td>
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<td>56.8</td>
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</tr>
<tr>
<td>80</td>
<td>324</td>
<td>294</td>
<td>684</td>
<td>0.01770</td>
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<td>56.5</td>
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</tr>
<tr>
<td>90</td>
<td>331</td>
<td>302</td>
<td>702</td>
<td>0.01778</td>
<td>1.11</td>
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</tr>
<tr>
<td>100</td>
<td>338</td>
<td>309</td>
<td>719</td>
<td>0.01786</td>
<td>1.11</td>
<td>56.0</td>
<td>0.90</td>
</tr>
<tr>
<td>110</td>
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