Automated S.M.A.R.T Mill'S Algorithms with Internet of Thing (IOT)

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INTRODUCTION

Palm oil mills (POM) in Malaysia are still backward in embracing new technologies compared to other key economic sectors such oil and gas, automotive, construction, etc. despite being one of the major oil palm producer in the world and core income in Malaysia under National Key Economic Area (NKEA). Process automation is one of the hurdles in productivity as it is rarely seen in place or if it is installed, the capability of the instrument is not fully maximised.

Majority of POM intervention process is manually operated and despite its dynamic process; it is heavily dependent on labour in managing process control and quality. Insufficient process and engineering knowhow and insufficient manual data logging contributed to low productivity, significant negative environment impact due to black particles and smoke, foul smell and oil losses to environment in uncontrollable manner.

It is Government's aspiration to transform the industries towards digitalisation via high technology advancement innovation to boost POM productivity, environment protection and less dependency on foreign labour under Industrial Revolution 4.0 (IR4.0). However, there is a huge gap in implementing economically feasible, robust automation system, computers and electronic devices *i.e.* IR3.0 before IR4.0 as shown in *Figure 1*. Equipments and machines need to communicate with each other via Internet of Things (IoT) based on pre-determined set-points or desired values. Machines and equipments will learn over time based on statistical data and adjusting themselves regardless of the weather or type of crops towards the pre-determined setpoints. Thus, we would reduce the dependency on labour in carrying out repetitive and routine procedures (*Economic Transformation Programme; Chapter 9*).

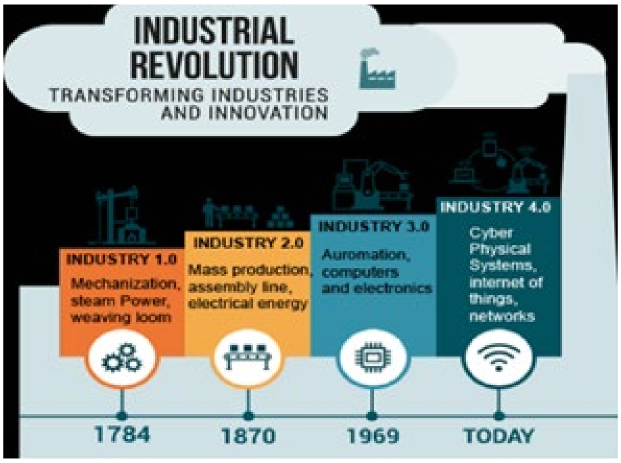

Figure 1. World industrial revolution.

PROBLEM STATEMENT

This article aims to attract readers' attention to look into minimising palm oil losses in the oil room and effluent emission such as bad odour, wastewater, greenhouse gases (GHG) that are uneconomical and has adverse effect on the environment if they are not efficiently managed by employing proven advanced technology leverages such as from oil and gas upstream (offshore operations) sector. Oil and gas upstream have vast similarities palm oil industry. For information and comparison, oil loss in offshore operation shall not exceed more than 100 ppmV or 0.01%, which is equivalent to 0.1 g for every 1 kg water discharged to open sea.

Figure 2. Typical offshore oil production platform operations.

In upstream offshore oil production (*Figure 2*), hydrocarbon produced from oil and gas wells consist of hydrocarbon gas, crude oil and free water, along with some fine sand that flow up to the surface of the topside facility via well heads and separated via separation vessels. Upon separation of hydrocarbon gas, crude oil is separated from free water in few stages until it meets the required basic sediment and water (BS&W) quality measurement which is similar to moisture and impurity (M&I) in POM. Due to the nature of the oil and gas industry that deals with flammable hydrocarbon, the technology employed need to be robust and reasonably accurate to ensure high safety integrity. Therefore, equipment and technology from automation that links to the communication network to ensure erratic and dynamic process to be predictively controlled in efficient manner. The equipment and technology needs to be selected so that the desired output is safely achievable at minimal operating cost, environmental- friendly and required minimal trained personnel on site.

Majority oil loss in POM comes from empty fruit bunch (EFB), pressed cake fibre and clarifier's underflow (Othman and Ng, 2013). Minimising oil loss in oil room indirectly means improving the oil extraction rate (OER) of the mill. *Figure 3* shows the integrated operation systems adopted from oil and gas offshore (upstream) practice in reducing oil loss (Othman and Ng, 2013; Andrew, 2006; Ropandi *et al*., 2017) odour (Andrew, 2018), black emission (Environmental Quality Act 1974) and untreated water discharge in POM in order to overcome the problem statements.

The output of the OER Based Algorithm and Mass Balance Automation (OBAMA) -6 is to ensure minimum oil loss in wet basis in the heavy phase and pressed fibre, minimal water released to the environment (hence zero discharge), minimal greenhouse gas (GHG) emission and foul odour. Oil is further extracted from water and recycled into oil room. Meanwhile trace of oily water is leached (Perry and Green, 1997; Coulson *et al*., 1999; Donald, 2009) and treated by using excess heat from boiler via Waste Heat Recovery Unit (WHRU) (Perry and Green, 1997; Coulson *et al*., 1999; Donald, 2009; McCabe *et al*, 1993; Ravi, 2015 and later cooled down as distilled water condensate. Recovered distilled water is later sparged into exhaust of hot flue air to recover CO_2, PM 2.5 and PM 10. Excess recovered water can be used for process and utility consumption.

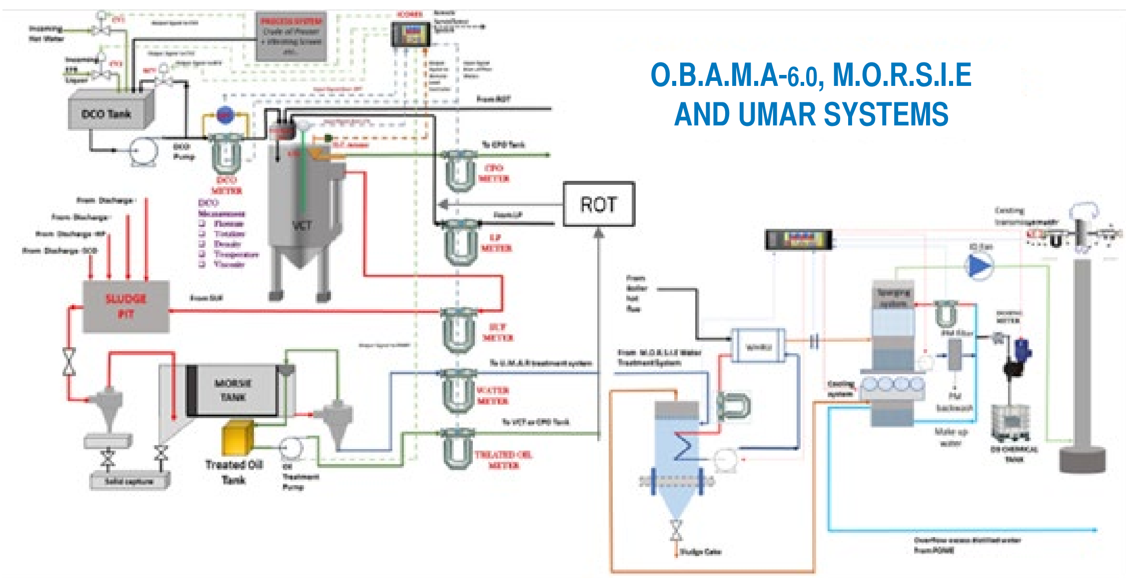

Figure 3. Integrated operations in reducing oil loss, foul odour, black emission and clean water recycling.

What is A.S.M.A.W.I?

Automated	:	operated by large automatic equipments.
S.M.A.R.T.	:	specific, measurable, achievable, realistic, timebound.
Mill's	:	referring to palm oil mill (POM).
Algorithms	:	processes or set of rules to be followed in calculations or other problem-solving operations, by programmable logic controller (PLC).
IoT	:	IoT is a system of interrelated computing devices, mechanical and digital machines, objects and people provided with unique identifiers (UIDs) and the ability to transfer data over a network or internet without requiring human-to-human or human-to-computer interaction.

The flow chart of control algorithms embedded in the PLC to calculate various measurement devices and command controlling devices to desired set-points for OBAMA-6+ is shown in *Figure 4*.

OBJECTIVES

The Government through its special agency has set some key performance index (KPI) to boost the oil palm industry via NKEA 2.0 initiative. However, despite its size in economy's contribution, Government also recognised the adverse effect of the industry on the environments. Therefore, the objectives of our innovations (A.S.M.A.W.I) are:

a. To improve palm oil's productivity by improving its OER to 23% by 2020.
b. To reduce GHG or methane formation by palm oil mill effluent (POME).
c. To reduce emission of black smoke and particle by mills to environment by June 2019 according to Ringlemann Chart 1 and below 150 ppmV.
d. To reduce odour released by microbes' activities in anaerobic pond below 12 000 OU number.

A.S.M.A.W.I addresses the above objectives with targeted deliverables of S.M.A.R.T mill concept (high productivity, environmental friendly and technology spearhead) (*Figure 5*) consisting of few integrated operations (IO) systems namely:

a. OBAMA-6 (OER Based Algorithm and Mass-balance Automation).
b. MORSIE (Mobile Oil Recovery System in Effluent).
c. UMARS (Unwanted Matters in Air Recovery System).

OBAMA CASE STUDY

The primary objectives of the case study are:

To regulate the dilution water to the required density and viscosity at operating temperature. To manage OIWB in underflow to below 6.5%.

The focus of this article is to discuss the OBAMA system that has been installed at 13 locations nationwide.

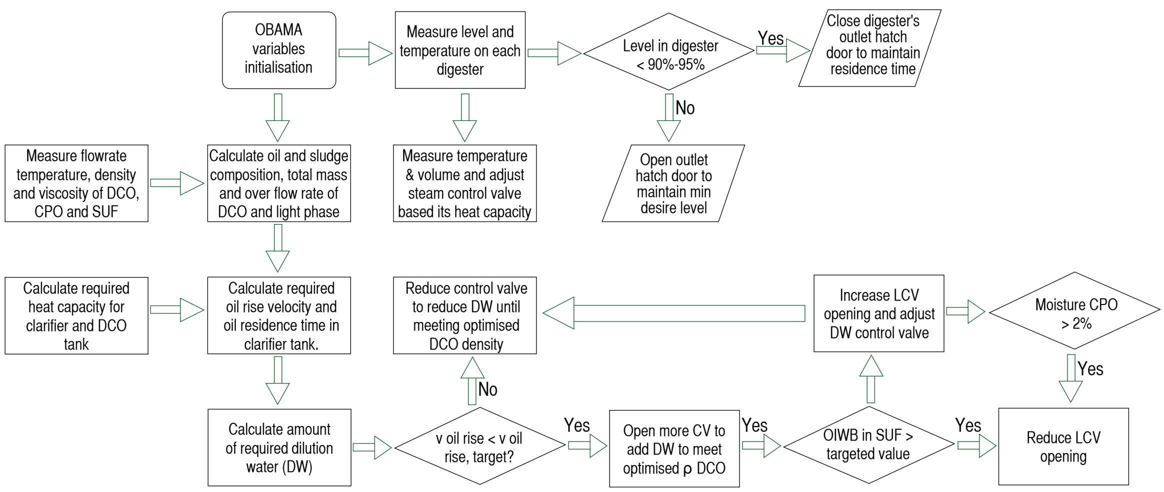

Figure 4. Flow Chart of the OBAMA-6 Control Algorithms.

Figure 5. A.S.M.A.W.I deliverables are addressing environment issues, oil loss reduction and enhancing productivity via IR4.0.

It has evolved to the 6^{+} version, also known as OBAMA-6^{+}, addressing stand-alone automated process control system in oil room without the need for dedicated control room but rather mobile devices such as laptops, tablets or handphones by capitalising mobile internet network that is accessible anywhere to notify operators or management team while the system is controlling, monitoring and generating the big data. *Figure 6* shows one of the integrated OBAMA panel with field mounted display equipped with uninterrupted power system and internet connection.

Site display for operator to interface with the OBAMA panel as in *Figure 7*.

Figure 6. OBAMA panel at one of the site.

OBAMA-6+ is a series of algorithms that integrates with few operations across digesters, diluted crude oil tanks (DCOT) and clarifier tanks that are backed by real time OER based heat and mass-balance algorithms. *Figure 7* shows a typical Human-Machine Interface display on site and *Figure 8* depicts the key process equipment installed across a digester. *Figure 9* shows the typical equipment installed on a clarifier tank.

Fluid and heat transfer across inlets and outlets of clarifier tank(s) are measured and analysed by a few equipments connected to a PLC and interfaced to operators and other equipments via SCADA software. From SCADA, data is transmitted out via modem through internet service provider to an external secured server (VPN or cloud computing) and further analysed through a customised

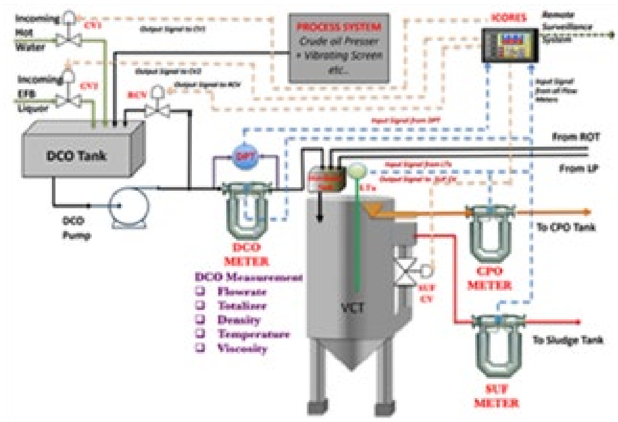

Figure 7. OBAMA panel at one of the site.

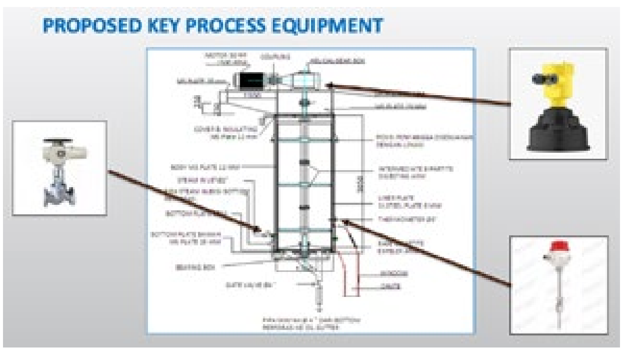

Figure 8. Typical installation of the devices within a digester unit.

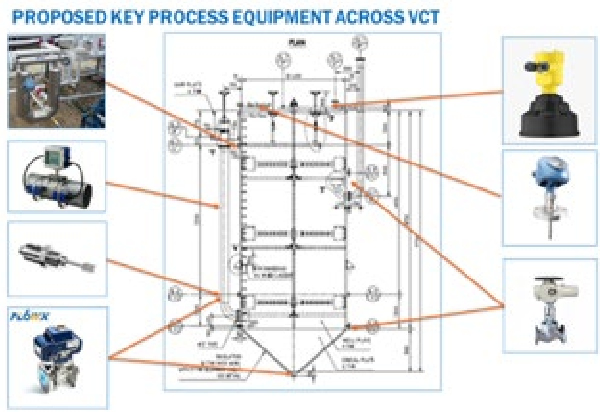

Figure 9. Typical equipment installed within a clarifier tank.

Figure 10. Remote monitoring system accessible via internet connection where instantaneous and cumulative data can be monitored and extracted.

dashboard management as shown as in *Figure 10*.

OBAMA-6 is specifically designed to manage mechanics and thermodynamics of the fluid within the clarifier tank where:

a. dilution water meet required density and viscosity,
b. constant overflow rate into clarifier tank,
c. minimal oil in wet basis (OIWB) in underflow,
d. less than 2% moisture in crude oil,
e. oil layer control to prevent sludge/ water to oil tank,
f. heat capacity via steam management,
g. hold-up volume in the clarifier for constant overflow rate,
h. heat and mass balance across clarifier tank.

whereby, additional features of OBAMA-6+ compared to OBAMA-6 are:

a. digester volume hold up control.
b. digester steam management.

METHODOLOGY

A case study for OBAMA system was carried out at a 45MT hr^{-1} capacity POM with small DCOT (2.24 m^3) and 30 m^3 horizontal clarifier. The mill acquired fresh fruit bunch (FFB) from surrounding areas and weather alternated between hot and rain alternately.

The baseline was set based on two sets of OIWB% in underflow recorded using POM's lab data. One baseline set was set up without OBAMA system (August 2020) and another set was set up with OBAMA system but without any controls by OBAMA system. The baseline study was made for a week in March 2021. The purpose study was to compare the baseline made by the system against lab data. Mean or average of both OIWB% data in sludge underflow (SUF) was determine by carrying out Standard Distribution analysis.

Study in August 2020 (*Figure 11)* showed that OIWB% in underflow were in the region between 9.54%-14.64% with average about 12.09% (*Figure 12)* while 20% of data sampled (OIWB% in underflow) were in the region between 4.44%-9.54%.

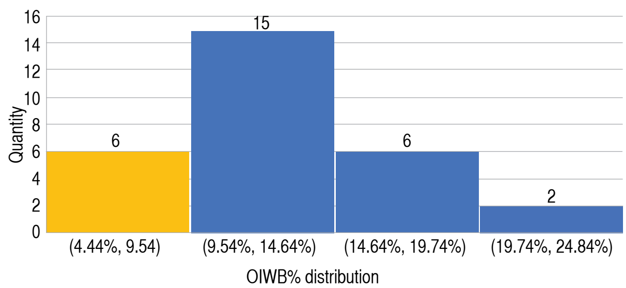

Figure 11. Clustered distributed data of OIWB % in SUF in August 2020.

Another round of baseline analysis using lab data on OIWB% in underflow was carried out after commissioning of OBAMA system for a week without any controls from the system. The OIWB% data showed an uptrend with average OIWB% in underflow at 11.58% (*Figure 13*).

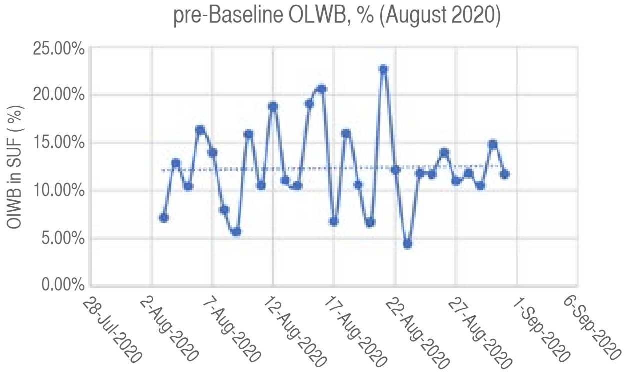

Figure 12. OIWB data in August 2020 prior to installation of OBAMA system.

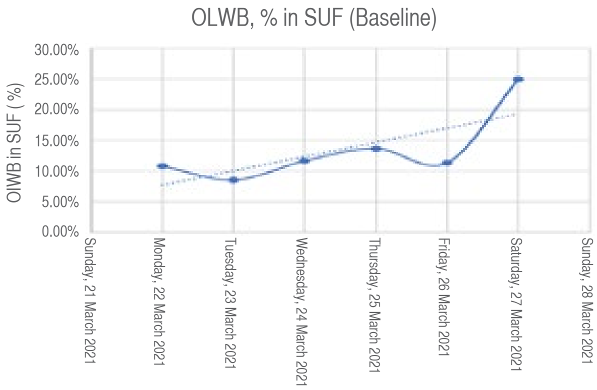

Figure 13. Second baseline without OBAMA system's control.

Upon activating the control system, the OIWB% in underflow showed downtrend (*Figure 15*) but *Figure 14* shows the increment in population of the OIWB% in SUF at the lowest range *i.e.* 5.25%-9.65%.

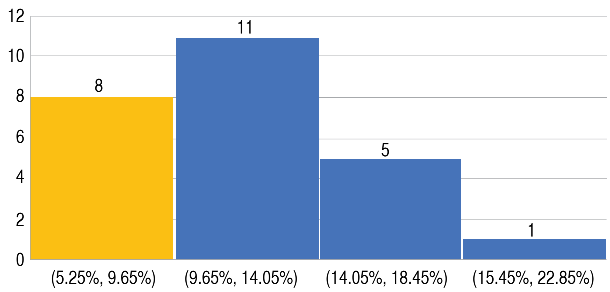

Figure 14. Clustered distributed data of OIWB% in SUF in April 2021.

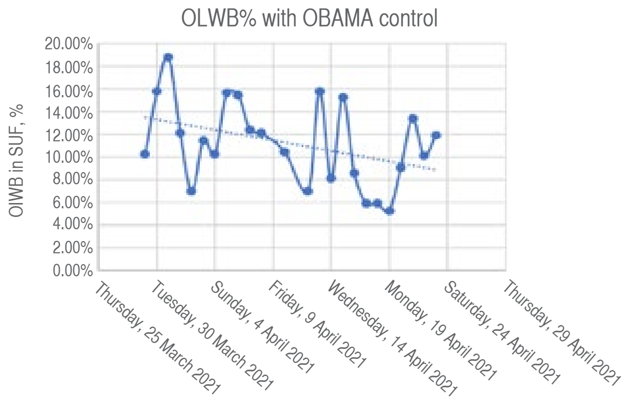

Figure 15. OIWB% in SUF population in April 2021.

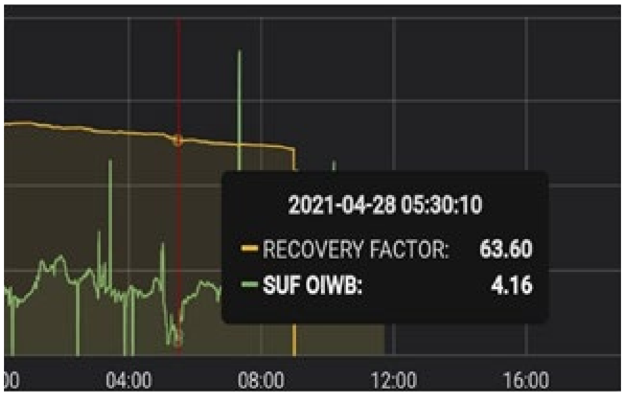

Figure 16. Reduction in OIWB% in SUF is possible down to less than 5%.

Data on April 2021 showed that OIWB% in underflow distributed mostly in the region between 9.65%-14.05% (*Figure 14*) with an average of 11.03%. 32% of data sampled was in the region of 5.25%-9.65% (*Figure 14*).

Although OIWB reduction from 11.58% to 11.03% in SUF seemed insignificant, however, initial oil loss reduction (recovery) in underflow equivalent to 0.2% OER was observed, hence reducing oil loss at SUF (*Figure 16*). Further process tuning and external factors management will further enhance the oil recovery.

However, some external factors need to be managed separately, which includes:

1. Manual intervention in:
   i. oil skimming activity
   ii. opening bypass valve
2. High mill's throughput up to 75MT hr^{-1} beyond clarifier capacity.
3. System familiarisation from manual to automation.

Therefore, as machine learns in due time, further improvement of OIWB in SUF could bring less oil loss and therefore improving the OER when:

a. Controlling layer is much tighter *i.e.* less manual intervention.
b. Constant over flowrate (OFR) proportionates to clarifier's dimensions.
c. Sufficient amount of dilution water in accordance to separation requirement *i.e.* Stoke law.

DISCUSSION

Key challenge in oil room area is controlling the dilution water regardless of the number of operating digesters/ pressers, origin of crops and crops quality as well as source of hot water or/ and oily water (steriliser condensate oil or/ and empty fruit bunch (EFB) liquor) against dynamic undiluted crude oil and non-oily solid (NOS) flow rate. Although there is a rule of thumb for fluid composition as undiluted crude oil (UCO) and diluted crude oil (DCO) as mentioned by Stork (1960) and Mongana Report (1955) however, process dynamic in a POM is unique from one to another (Adzmi *et al*., 2012; Andrew, 2006; Othman and Ng, 2013).

Clarifier tanks are designed to separate oil from its sludge gravimetrically and exits as underflow rich in water and NOS. The intent was to minimised oil loss in underflow to as minimal as possible. Thus, fluid mechanic and thermodynamic aspects within clarifier tank are critical to ensure optimum oil separation in hindered settling process condition (Sulaiman, 1998).

To attain optimum oil terminal velocity within clarifier tank and its composition which relates to its density and viscosity at specific operating temperature, it is important to be predetermined according to clarifier tank's dimension at constant overflow rate so that it is within its residence time (Sulaiman, 1998; Perry and Green, 1997; Coulson *et al*.,1999).

Temperature also played an important role in breaking up the surface tension between oil and water, especially in tight emulsion and therefore heat supplied by steam needs to be regulated without overboil to prevent water boils up and created vortex movement inside the clarifier tank (Perry and Green, 1997; Coulson *et al*.,1999). Usage of designed ionic wetting agent or surfactant promoted the acceleration of interfacial surface tension break up.

To attain optimum separation of oil from sludge in clarifier tank, a steady over-flowrate (OFR), density and viscosity at specific operating temperature or heating capacity is required to optimise oil rise velocity with minimal oil loss to sludge underflow of the vertical clarifier tank (VCT).

OBAMA-6 primarily functioned to determine the diluted crude oil (DCO), sludge under flow (SUF) and purified crude palm oil (CPO) mass rate, analysing the composition (oil, water and non-oil solid (NOS), temperature, density and viscosity via mass balance.

Additional dilution water will be consumed and controlled by control valves in accordance to Stoke Law' (Equation 1) with optimum oil rise velocity (Perry and Green, 1997; Coulson *et al*.,1999). *Figure 17* shows typical dilution water supply into the system that managed the dilution, either via EFB liquor (condensate) or hot water.

Figure 17. Dilution water control valves regulate accordingly to process requirement as computed in OBAMA panel.

Figure 18. Recycle valve to manage constant over flow rate (OFR).

The constant overflow rate (OFR) will be managed by a recycle valve back to DCO tank as shown in *Figure 18* to ensure consistent feeding to clarifier tank and heat distribution.

Key parameters such as density, viscosity and temperature of fluids under assessment were manually measured for baseline as shown in *Figure 19*.

$$v = \frac{d^2 . (\rho_{DCO} - \rho_{oil}) . g}{18\mu_{DCO}} \quad \text{(Equation 1)}$$

where;

d	=	diameter of pure oil molecule
ρ_{DCO}	=	density of diluted crude oil (DCO) at operating temperature
ρ_{oil}	=	density of pure oil (CPO)
g	=	gravitational force
μ_{DCO}	=	viscosity of diluted crude oil (DCO) at operating temperature

These parameters were measured and analysed by a few equipments installed at specific locations across clarifier tank and computed by PLC to determine the required amount of dilution water.

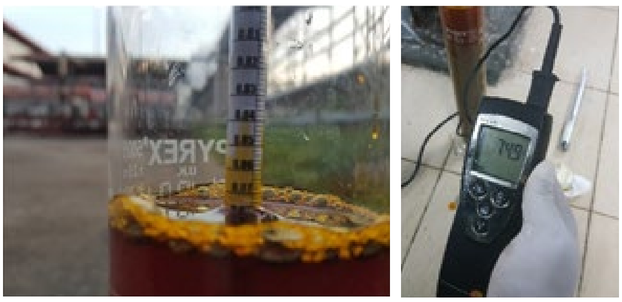

Figure 19. Field test and data acquisition at site on temperature and density on various process points.

Apart from managing dilution water to ensure spot on density and viscosity of DCO is achieved so that optimum oil rise terminal velocity in clarifier, residence time of the clarifier was controlled via oil in underflow measurement by regulating level control valve as shown in *Figure 20*. Concurrently, oil layer was measured by an interface level transmitter to feedback to level control valve to be regulated accordingly to its predetermined oil layer.

Interface level transmitter for measuring oil-water contact closely

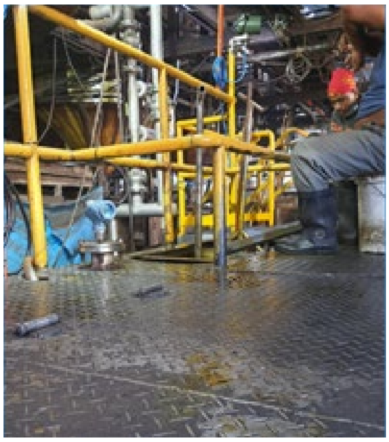

Figure 20. Strategic location of the interface level transmitter to control OIWB and oil layer in clarifier.

The level in the clarifier was further balanced by using Bernoulli equation (Equation 2) across the clarifier (Perry and Green, 1997; Coulson *et al.,*1999; McCabe *et al.,* 1993).

$$P_1 = P_2 \; ; \; \frac{F_1}{A_1} = \frac{F_2}{A_2} \; ; \; \frac{m_1 g}{A_1} = \frac{m_2 g}{A_2} \quad \text{(Equation 2)}$$

where;

P	=	Pressure of load in the clarifier
F	=	Force applied by load onto the surface sectional area
A	=	surface area where force is applied perpendicularly
m	=	mass of load where force is applied on the area
g	=	gravitational force

As oil in wet basis was calculated by PLC OBAMA panel, oil layer/band was optimally controlled to ensure low moisture CPO exit the clarifier tank. In the event where moisture in CPO exceeding 2%, oil layer was increased by closing the control valve as shown in *Figure 21*. Subsequently, as the valve closed, residence time in clarifier was prolonged, hence less oil exit via underflow.

Figure 21. Level control valve at the SUF line responding to interface level transmitter.

To ensure good separation break-out in emulsion, steam supplied to the clarifier tank were distributed to open and close the loop system at the bottom and at the middle of the clarifier tank. The steam supplied was controlled based on latent heat capacity calculation (Equation 3) of the steam where heat was measured by flowmeters that equipped with built in thermocouple (Perry and Green, 1997; Coulson *et al*.,1999; Donald, 2009; McCabe *et al*., 1993).

Amount of steam used was registered to enable user to determine clarifier tank's steam consumption timely.

$$Q = m.\ Cp.\ \Delta T = \lambda T \qquad \text{(Equation 3)}$$

where;

Q	=	heat capacity of the fluid or steam
M	=	mass of liquid (CPO and SUF)
Cp	=	heat capacity of the liquid (CPO and SUF)
ΔT	=	change in temperature
λ	=	latent heat of evaporisation
T	=	temperature of supplied steam

PLC received output of mass rate, liquid composition and temperature of SUF and CPO exiting the clarifier from the flowmeters installed (*Figure 23*). Based on the difference between setpoint and the measured temperature, demand of heat capacity across the clarifier was calculated to determine the amount of steam supplied to each open and close loop as shown in *Figure 22*.

Figure 22. Steam supplied based on heat capacity required by regulating steam control valve into the system computed by OBAMA system.

Figure 23. Vertically mounted flowmeters to promote self-draining effect measuring mass rate and fluid properties.

Maintaining active hold up volume is crucial to ensure sufficient retention/ residence time of fluid. Any excessive sludge build up at the bottom of the clarifier tank would increase the residence time for oil separating from water, causing CPO impurity or excessive OIWB in SUF. Thus, having an active level measurement on solid build up at the bottom of the clarifier tank would be able to discharge solid via control valve to prevent heat loss and loss of active separation volume/ space.

Figure 24. Position of discharge control valve to evacuate sludge at the bottom conical.

CONCLUSION

Implementing automation and link up to IoT facility would be able to accelerate the industry from IR2.0 to IR4.0. Availability of big data equipped process engineer and mill's operations and advisors with information to further improve productivity by minimising oil loss.

By employing automation, repetitive actions such as sampling, dilution control, oil layer control, steam management and desanding can be automated with less dependency on labour.

Dilution required to carry out separation in the clarifier tank was accurate and responsive regardless of the number of pressers and digesters in operations, weather, crops quality as well as the dilution water added with respect to composition of undiluted crude oil or pressed juice.

Oil layer was managed by a couple of controlled algorithms where optimum oil layer is built up in the clarifier to maintain the CPO quality more than 98% pure thus giving ample residence time for oil to rise up and minimising OIWB in underflow.

Steam supplied to the system will be automatically adjusted to ensure sufficient heat to break the surface tension between oil and water in emulsion by employing thermocouple sensor in the flowmeters and actuated globe valve.

With Government incentive and financial supports via its agencies such as MIDA, automation can be rolled out to improve mill's processing efficiency and productivity in embracing IR4.0 with minimal dependency on foreign labour, thus empowering profitability with less adverse environment impact.

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