Feature Article

Thermodynamics Applied to Palm Oil Milling

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INTRODUCTION

Most of the mill engineers, in particular the mechanical engineers, may be quite familiar with the engineering thermodynamics associated with the biomass fired boilers that they operate daily in a palm oil mill. The heat content in the biomass fuel expressed usually as the calorific value is transferred to the water in a boiler to generate the steam which in turn operates the steam turbine wheels when undergoing an approximate isentropic expansion. As the alternator is coupled to the turbine shaft through a gear box, it can generate electricity that is sufficient to operate all the mill machinery as well as the domestic supplies if worker's quarters is located nearby.

As the energy produced is from biomass, the mill operation is completely powered by renewable energy (RE). Palm oil mills had been (say for the past 100 years) and still are processing fruit bunches using the self-generated RE. The staff and worker's quarters and in some cases the estate worker's quarters also use the RE generated by the mill, so RE is not something new for the palm oil industry. The palm oil mills also have diesel operated power plants as a back-up for use during non-processing hours for security lighting, office equipment, workshop operation and domestic consumption. The diesel generator set load is considerably low compared to the full load demand during processing hours that may vary from 1 to 1.5 MW in a mill capable of processing 60 t fresh fruit bunches (FFB) per hour (usually called 60 tph mill).

The RE is also known as green energy. Many people seem to be confused with the term RE. When the by-products of the processing operation like the biomass are burnt, it still produces identical carbon dioxide (CO_2) that the fossil fuels produces when combusted. It is exactly the same molecule having one carbon atom combined with two oxygen atoms. It certainly does not exhibit green colour and its greenhouse gas (GHG) impact on the environment will remain exactly the same as that being generated by other means. It will be helpful to emphasis this because some non-technical decision-makers seem to think that the CO_2 released by the

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combustion of biomass and fossil fuel have different molecular structure!

The biomass has heat energy which we do not feel when we touch them. The heat value of a biomass can be easily ascertained using calorimeters. There are many types of calorimeters known as solution calorimeter, differential scanning calorimeter (DSC), titration calorimeter, gas calorimeter and reaction calorimeter for different applications. But generally for evaluating the calorific values of biomass a bomb calorimeter is used. In a bomb calorimeter made of a steel chamber, a small sample of the fuel is combusted in an atmosphere of oxygen at high pressure. The steel chamber is immersed in another closed chamber containing water so that the heat can be absorbed by the water during the complete combustion of the sample of the fuel. During the combustion process, the chamber pressure and temperature may reach very high values and as such the chamber must be able to withstand the required conditions.

The calorific values of raw biomass is very much lower than that of fossil fuels like coal as for example, the moisture content of empty fruit bunches (EFB) can be as high as 70% and that of fibre which has about 40% moisture. Reduction of the moisture content of 15 t of EFB from 70% to 30% by drying would entail evaporation of 6 t of water per hour at atmospheric pressure. As the enthalpy of evaporation (latent heat) at atmospheric pressure is 2258 $kJ\ kg^{-1}$, the drying of EFB to make it a usable fuel will need approximately 13.5 MJ of heat per hour! This factor alone will make EFB one of the worst fuels in the world. The cost of transportation of the water in the EFB will not make it financially viable if we consider transporting the EFB from several mills to a central power station for grid connected power generation. The relevant authorities or investors, who want to venture into power generation using EFB, should consider these crucial issues as they may only focus on the mass of EFB available rather than its heat content. Some of the salient points associated with palm oil biomass-based power generation as compared to conventional power stations are discussed in this article.

POWER PLANTS IN POWER STATIONS *vs.* PALM OIL MILLS

There is a vast difference between the heat content of palm oil biomass and the fossil fuel that is used in power plants belonging to the Tenaga National Berhad (TNB) or Independent Power Plants (IPP). Although the palm oil mill power plant (POMPP) may look like a toy when compared to the TNB or IPP, the fundamental principles of power generation remains very much the same except perhaps the palm oil mill managers have a much wider scope of responsibilities than just operating the power plant.

As I had the opportunity to work in both the Lembaga Letrik Negara (LLN) now renamed as TNB thermal power stations and the palm oil mills, I may be in a position to draw some comparisons between the two systems based on my specific scope of work. This is purely a subjective discourse based on my experience with events that took place about half a century back in time at LLN and the current experience in the palm oil mills. Some of the comparative responsibilities of a mill manager and a station superintendent are given in *Table 1*.

Mill Manager's Responsibilities

As can be seen in *Table 1*, the mill managers have a number of additional responsibilities compared to their counterparts in power plants. The palm oil millers use the steam not only for power generation but for processing the crop as well. The operational system comprises an assortment of processing stages before the final product is ready for shipping. Most of the miller's time and energy are focussed on refining the processing techniques as the product quality is an important target for marketability of the products.

TABLE 1. RESPONSIBILITIES OF PALM OIL MILL MANAGERS AND POWER STATION SUPERINTENDENTS

No.	Events	Palm oil mills	National electricity board
1	Overall in charge	Mill manager	Station superintendent
2	Wages computation/payment	Mill manager	Chief clerk and staff
3	Power plant	Mill manager	Operational engineer
4	Operation	Mill manager	Operation staff
5	Maintenance	Mill manager	Maintenance engineer
6	Product quality	Mill manager	-
7	Product sale/shipment	Mill manager	Grid demand (automatic)
8	Duty time coverage 24 hr	Mill manager	Shift charge engineer
9	Water treatment	Mill manager	Chemist
10	Dispute settlement	Mill manager	Human resources department
11	Crop purchase	Mill manager	-
12	DOE compliance (boiler fuel gas)	Mill manager	Chemist
13	DOE compliance (effluent)	Mill manager	-
14	Sustainability	Mill manager	-
15	Output	Palm oil, palm kernel, biomass, electricity	Only electricity
16	Product market	Overseas (90% of the oil)	Within Malaysia
17	Location	Remote area with poor roads	Mostly urban or close to it
18	Workers benefits	No pension or special benefits	Pensionable in most cases

Note: DOE – Department of Environment.

It is possible that about 90% of all millers' attention will be directed towards product quality, process losses, environment issues, sustainability issues and social welfare. As a consequence, the efficient utilisation of steam and power generation aspect of the milling operation in a palm oil mill takes the backstage leading to the pathetic abuse of energy in palm oil mills.

THERMODYNAMICS APPLIED TO PROCESS OPERATIONS

Energy Wastage

As mentioned earlier, the steam utilisation segment of a palm oil mill is a grossly under-explored area and is likely to remain so based on the attitude of the mill owners or top management. It is not difficult for a thermodynamist to fathom the criminal waste of steam in certain stages of the process line. The areas that offer great opportunities to save the wasted steam and use it for the benefit of humanity are still awaiting the right opportunity for the right Malaysian investor to coordinate with our competent steam engineers and set up energy saving systems before someone from some remote corner of the earth start selling the product to Malaysia.

Application of Thermodynamics

Application of engineering thermodynamics in a palm oil mill are seen in the

POMPP, sterilisation station and other heat exchange equipment like kernel silo heater, oil tanks, process water tanks, sludge oil storage tanks, crude palm oil storage tanks, *etc.* This clearly indicates that the mill engineers should be fairly well-versed with engineering thermodynamics associated with steam, a very interesting part of mechanical engineering. Currently the mill engineers are expected to process whatever crop contaminated with stones, sand and other trash that accompany them are brought to the mill and try to extract more oil than what the fruit bunches contain. The demand for increasing the oil extraction rate (OER) of the mill by the mill owners or the top management is exerting an unreasonable pressure on the mill personnel as OER is solely dependent on the oil content of the bunches that is clearly under the jurisdiction of the plantation managers.

Steam Leakage

The mill engineers should also try to improve processing techniques associated with steam by applying the thermodynamic principles wherever it is required. A mechanical engineer with sound knowledge of thermodynamics will not allow steam to blow out of steam joints or the steam traps. When the MPOB code of practice (CoP) auditors audit the mills, a common sight in almost all mills is the free issuance of steam from steam traps. When the auditors query on whether the steam traps are working, the answer is always "yes" based on the considerable amount of steam visibly seen blowing out of the steam traps! This certainly is a sad state of affairs as the engineers do not seem to know how to diagnose the defect in a faulty steam trap. They do not even realise the fact that the function of a steam trap is to trap the steam and allow it to blow out freely.

Apart from the steam trap losses a significant amount of heat is wasted from the leaky steam pipe joints in palm oil mills and this will paint a poor picture of our mill engineers who do not seem to be interested in tapping this large potential of energy. If a mechanical engineer from overseas visit our palm oil mills and observe a substantial amount of steam blowing out of steam traps, leaky seam joints, isolating valves and relief valves he will certainly have a bad impression of the professionalism of the engineers operating the mills. Most of these leaks can be easily prevented by tightening the nuts on the flange coupling and yet these are not attended resulting in unnecessary waste of steam.

Lack of Preventive Maintenance

Our observation of the maintenance work carried out on steam traps in palm oil mills are as follows. None of the mills we visited had a routine maintenance programme associated with steam traps. Most of the steam traps were never overhauled ever since the mills were commissioned. Common sense dictates that any mechanical machinery must be maintained on a routine basis at least once a year, if we want the machinery to perform efficiently. If the mill personnel have no time to carry out this one day job they may outsource experts to carry out this job. It is worth the while as a lot of steam can be saved, bearing in mind that to produce steam which itself is a GHG the biomass combustion involved for its production also releases CO_2, which also is a GHG.

Energy Wastage Evaluation

Even the exhaust steam released from the steriliser that is responsible for causing so much of noise pollution reaching perhaps 200 decibels can be effectively curtailed. For this, the exhaust may be re-routed through the condensate line or discharged into an open chamber from where its enthalpy of condensation could be recovered for product drying operations. The blown out steam from the sterilisers still has a sizable quantity of heat that is currently discharged functioning literally as a device meant for district heating, which we can do without as we are already blessed with an abundant supply of sun's heat throughout the year.

Let us now make some quantitative analysis of the heat lost in the steam exhaust in a 60 tph mill steriliser with an operating cycle spanning 90 min (door close pressure cook and door open time) similar to the home pressure cooker. For the purpose of simplification, the calculation is based on an hourly data as shown in *Table 2*.

This is a criminal waste of steam that no one seem to worry about. This is indeed a steam engineer's dilemma. The reasons are easy to find. The progressive thinking of the human race and their genuine concern on diminishing fuel reserves, conservation of energy, global warming leading to adverse GHG impact on environment are in place. There are also a number of successfully established mechanisms for monitoring and enforcing the major well known and popular energy guzzlers and pollution generators like power stations and transport industry. However, the odd ones like the non-efficient steam generation and its usage in palm oil mills, being not widely established, may not appear in the global energy abuse radar screen. In such situations, the monitoring mechanisms must necessarily evolve locally as global bodies will only look at common issues such as sustainability and environmental impact but steam wastage and its efficient utilisation in specific applications like palm oil industry will be left out for the local industry management to handle.

But a specialised body is yet to evolve for addressing such issues either in Malaysia or Indonesia who are the major producers of palm oil. Most developing countries find it easy to copy systems prevailing in developed nations as then we do not have to re-invent the wheels. That is fine but the question arises as to why the developed nations should make efforts to develop something that they do not need. In such cases, we have to take the initiative and move forward. Based on the current discussion, the palm oil industry in Malaysia must establish a centre to address the important issues related to upgrading milling operation so that they are on par with other food processing industries from all angles including efficient and profitable use of resources.

MASTERING *MONGANA REPORT*, A COMPETENT MILLER BORN?

A palm oil miller's encyclopedia is the *Mongana Report*, a very useful report that was published in 1955 (it is now the property of MPOB, a gift from Lever Brothers). This magnificent report is the outcome of a research project conducted by a team of scientists from the Institute for

TABLE 2. THE ENERGY LOST FROM THE STERILISER DURING EXHAUST BLOW-OFF OPERATION

Wasted energy calculation	
FFB processed	60 tpm
Steam consumption (say at 40% of FFB processed)	24 tph
Steriliser condensate produced (20% of FFB processed)	12 tph
Steam used for deaeration (say 5%)	3 tph
Steam blown out during exhaust (15%)	9 tph
Total steam blown out	12 tph
Heat contained in saturated steam at 4 bar_a (steam table)	2.739 MJ kg^{-1}
For 18 000 kg steam per hour (energy lost in blown out steam)	32 860 MJ hr^{-1}

Note: FFB - fresh fruit bunch. tpm – total productive maintenance. tph – tonne per hour.

the Advancement of Scientific Research in Industry and Agriculture (IRSIA) during 1952 till 1955 organised by Congopalm, a cooperative registered in Congo to establish parameters for optimum palm oil processing operations. The research findings originally presented in French have not undergone any appreciable changes even after 60 years and the mill engineers still hold on to this report with great respect. There is a good reason for it. It comes in two volumes and it is very comprehensive as it contains every aspect of the palm oil mill processing in very great detail. That is why it is apt to declare that 'When someone masters the *Mongana Report*, a competent miller is born'. It is difficult for palm oil mill engineer who has not digested the contents of the *Mongana Report* to become a competent miller. But they can go beyond being a competent miller to become an expert miller or a consultant with a good back-up of engineering thermodynamics.

HISTORIC AND CURRENT REQUIREMENTS

The early boilers were functioning as a steam generator cum incinerator purely to save money for transporting the surplus biomass to a suitable dumping site. The biomass, in the most unwanted list, was the wet shell amounting to 2.4 tph (about 4% of the 60 tph FFB processed) that had to be transferred out for laterite road surfacing or dumping in an allocated site. In the early days, all mills had incinerators for partial combustion of EFB whose production rate was 13.8 tph (23% of 60 tph). The bunch ash produced was a useful potash source for the oil palm nursery. These incinerators frequently used to be choked up due to overloading and were not designed to combust kernel shell to produce charcoal, a good commercial product of good value.

The situation now has changed with the spiraling price of fossil fuel and the steadily increasing use of biomass fueled boilers. In addition, the recent interest in alternate use of biomass like biodiesel production, eco mat, RE power generation, *etc.* has encouraged the millers to conserve the biomass for sales and for the generation of additional revenue. The current requirements of the millers with steam generation and its application are closely linked to efficient use of biomass and the steam. However, despite being aware of the need for a paradigm change the mill owners have done very little to call it a breakthrough in this direction.

Now, let us examine the reasons and conditions prevailing at the time when the horizontal steriliser (wrong name given for a pressure cooker) made its debut about a century ago. The requirement was to pressure cook the fruit bunches satisfying the two basic conditions of deaeration and maintaining three bar steam pressure for 30 min. The recommended pressure cooking temperature was found to be 130°C, a temperature that was and still is sufficient for the steam to penetrate the bunch and condition the mesocarp so that the fruit cells are ready to release oil as well as partially dry the kernel within the nut.

It will be of interest to note that the pressure cooking (sterilisation) of bunches using low pressure steam radically differs from the normal process heating performed in other food processing industries. In the pressure cooking operation, the sterilisers are first charged with the fruit cages laden with 20 to 30 t of FFB after which the doors are closed and steam at 3 bar is admitted in two peaks with intermittent blow off for deaeration followed by the third peak where the pressure is held for approximately 30 min. During each peak comprising steam is admitted causing a pressure rise followed by blow-off with each peak being higher than the preceding one.

The efficiency of the steriliser deaeration process is riddled with many hurdles as it is not actually possible to completely remove all the air from the steriliser chamber even with multiple peaks. Some of the problems stem from the miller's poor knowledge of thermodynamics. The sterilisers of all palm oil mills are fitted with pressure gauges that generally give a satisfactory reading of three bar if the boiler capacity is sufficient to cater for the mill. When anyone taking a quick look at the steam table and see the saturation temperature corresponding to this pressure as 143.6°C, he has good reason to be satisfied as the optimum required temperature is 130°C. If a thermometer had been installed on the sterilisers the engineers would have realised that something was not right. The temperature shown corresponds to a much lower steam pressure as the air content in the steriliser has reduced the effective steam pressure and its corresponding saturation temperature according to Dalton's Law of Partial Pressures. The mills must find an effective way to reduce the air contained in a steriliser so that the sterilisation temperature remains above 130°C.

THE STEAM TURBINE

The mills usually use a non-condensing steam turbine with a single Curtis wheel that receives steam at 20 bar or 30 bar and discharges it at about 3 bar. This low pressure steam can be used for process heating. The turbine nozzles are located within the turbine casing at the steam inlet chamber and the pressure drop is accompanied by the rise in kinetic energy that drives the Curtis wheel. The nozzle may be placed in nozzle groups of two or three with separate isolating valves or can be distributed equally in circular formation. The steam exhausting out of this turbine still has considerable amount of energy and this is used for process heating with very little condensate return.

The thermal efficiency of the power plant seldom exceeds 3% to 4% as the exhaust steam still carries most of the heat. As the turbine efficiency is dependent on the maximum isentropic expansion of the steam within the turbine, the existing Rankine cycle does not cater for high power generation coupled with low specific steam consumption.

There are many options available in this area. Boilers may opt for medium pressures like 50 bar or even higher with high super heat of say 500°C so that the Rankine work done by the turbine exceeds 10 MW in a 60 tph mill. This is possible and at higher superheat temperatures the specific steam temperatures can drop to even 5 kg steam per kWh compared to the 25 kg kWh^{-1} in the conventional non-condensing turbines currently used in palm oil mills.

There will be some changes in the design of the turbines as the single Curtis wheel will be replaced by a six stage reaction turbine. Adequate steam bleeding points also will be needed with steam re-heating if necessary, to shift the superheat state point towards far right so that after the isentropic expansion the exhaust state point is out of the wet region. There are many ways to achieve the industries' objectives.

However, the most important consideration for Malaysia is not to be influenced by the strategies used by other industries when they set up RE power plants overseas. They may set them up near a place where the grid connection is convenient so that the transmission cost is low. But in the case of the Malaysian palm oil industry, we should always think about an industry moving close to the mill.

There are two great advantages:

- low grid connection cost (if the grid connection point is far the transmission cost could exceed the cost of the RE plant); and
- low price for the land close to the mill compared to urban area.

PROCESS HEAT REQUIREMENTS

Processing operations will require about 65% by weight of the FFB processed. The individual plant requirements are listed in *Table 3*.

TABLE 3. APPROXIMATE STEAM UTILISATION BY PROCESSING PLANTS

Process plant	Requirements	% to FFB	tph
Sterilisation	Cook FFB, direct steam injection, Δ T= 95°C	40	24
Digester	Direct steam injection, Δ T= 20°C	6	3.6
Diluted crude oil tank	Direct steam injection, Δ T= 10°C	3	1.8
Clarifier (C.S) tank	Closed coil and direct injection, Δ T= 10°C	2	1.2
Pure oil tank	Closed coil, Δ T= 10°C	2	1.2
Sludge tank	Closed coil, Δ T= 10°C	2	1.2
Process water	Direct steam injection, Δ T= 50°C	6	3.6
CPO storage tank	Closed coil, Δ T= 10°C	4	2.4
	Total	65	39

Note: Δ T - temperature rise. FFB – fresh fruit bunch. CPO – crude palm oil. tph – tonne per hour.

Palm Oil Mill Heat Balance

The turbine exhaust steam is admitted to a steam receiver drum having a diameter of about 2 m and a length of about 6 m having a volume of 18.84 m^3. However, considerable variations can be seen in different mills. The 40 t of steam exhausting form the turbine at 4 bar_a will have a specific volume of 0.4623 m^3 kg^{-1} occupying a volume of 18.49 m^3. The steam receiver volume is just sufficient to receive the exhaust steam form the turbine when the mill is processing 60 tph of crop. When there is a mill breakdown and the mill throughput drops to half there will be a corresponding drop in generator load. But if the mill continues to operate the sterilisation station at full capacity, the steam pressure will drop resulting temperature drops in all stages of processing ending up in process loss.

Let us now look at the influence of thermodynamics in this application. Efficient utilisation of heat and steam were deliberately ignored in the case of seam generation, turbine selection and operation, and conservation of fuel. Low boiler efficiency was preferred as that would assist in the evacuation of biomass waste compared to its costly transportation to the dumping site. The system of steam exhausting to the atmosphere as chosen at that time was the cheapest way to dispose it. Noise pollution from factories was not an unusual phenomena or a Department of Environment (DOE) issue at that time. Now requirements have changed but the millers are not ready yet to responding fast enough to the new requirements.

Palm oil mills in Malaysia are slow to embark on projects that will improve the efficient utilisation of heat. A good example

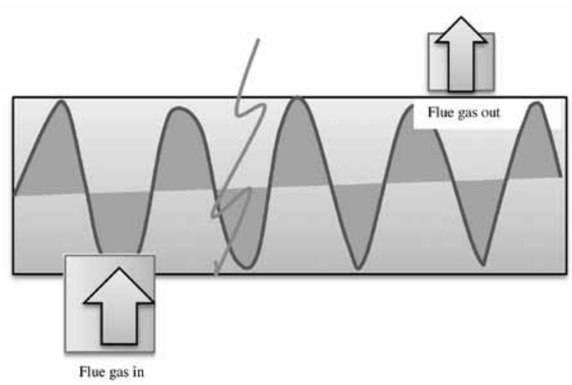

Figure 1. Heat transfer in shaft-less screw conveyor via counter flow direct contact with flue gas. Conveyor length: 20 m, conveyor diameter: 50 mm.

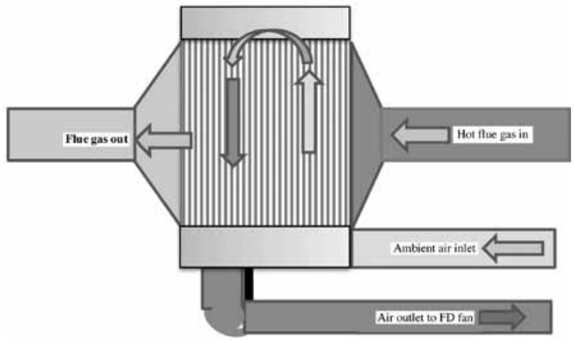

Figure 2. Air pre-heater.

is the heat lost in the flue gases from the stack. Assuming it is 280°C and if some of the heat is used back for either heating the feed water, air or fuel there is not only a good opportunity to generate more money by selling the surplus biomass, the boiler performance should also increase in terms of particulate emission and black smoke. The investment cost also need not be high. The advantages are discussed in *Table 4* for a 60 tph mill, under different options.

Heating mesocarp fibre contains about 40% moisture which is on the high side for good boiler performance. If we can bring this down to say 30% the performance of the boiler would certainly improve resulting in better combustion. As the heat exchangers mentioned in all cases are not under pressure the fabrication cost is expected to be low. This can be fabricated in the mill workshop.

TABLE 4. SIMPLE METHODS OF WASTE HEAT RECOVERY

Options	Heating purpose	Achievement	Remark
Mesocarp fibre	Reduce moisture content from 40% to 30%. Heater type: scroll type. Expected cost of heat transfer equipment: RM 150 000	Better combustion	P
		Reduced black smoke	P
		Reduced particulate emission	P
		Some investment cost is involved	N
Feed water	Economiser: tubular type. Heat the feed water from ambient 34° C to say 80°C. Expected cost of heat transfer equipment: RM 150 000	Reduced fuel consumption	P
		Improved combustion efficiency	P
		Reduced black smoke	P
		Reduced particulate emission	P
		Some investment cost is involved	N
Decanter cake	Reduce moisture level from 80% to 40%. Expected cost of heat transfer equipment shown in *Figure 1*: RM 150 000	Reduced fuel consumption	P
		Improved combustion efficiency	P
		Reduced black smoke	P
		Reduced particulate emission	P
		Some investment cost is involved	N
Combustion air	Air pre-heater shown in *Figure 2*. Tubular type. Heat the air from ambient 34°C to say 100°C. Expected cost of heat transfer equipment: RM 150 000	Better combustion	P
		Reduced black smoke	P
		Reduced particulate emission	P
		Improved boiler efficiency	P
		Reduced fuel consumption	P
		Some investment cost is involved	N
Sludge evaporation	Scroll type or drum type. Evaporate part of the liquid sludge to reduce effluent discharged and recycle evaporated water for process operation. Expected cost of heat transfer equipment: RM 500 000	Reduced fuel consumption	P
		Improved combustion efficiency	P
		Reduced black smoke	P
		Reduced particulate emission	P
		High investment cost is involved	N

Note: P – positive. N – negative.