Feature Article

Diesel Power Plant

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INTRODUCTION

Almost all palm oil mills have stand by diesel electricity generator sets (DGS). There are alternating views by mill managers on what criteria to adopt when choosing the capacities of these DGS. It is quite obvious that the mill managers did not spend enough time to analyse the requirements in more details when requesting for diesel sets for their mills. The selection of a steam power plant is relatively simple compared to DGS. Let us look at the mill requirements when the mill is not in operation. In the daytime, electricity is needed for the operation of office equipment, office and mill lighting. In the night time, the security lighting and domestic load will add on to the load. After midnight, the domestic load will drop until early morning.

SELECTION CRITERIA FOR DGS

It will be a good exercise for all palm oil mills to record hourly loads as accurately as possible for a full year so that it can cover the periods of low crop, normal crop and peak crop. This exercise will help the new engineers to gain considerable knowledge on how to scientifically rate the DGS they want for their mills. Currently some of the mills have assorted inventory of DGS with improper ratings. It is useful to enter the data in a table to enable them to make a good decision. Samples of the data needed are shown in *Table 1*. The figures given are not actual readings and not to be used for real assessments as they are only examples. Based on the figures compiled in *Table 1*, we can easily size the steam turbine requirement with sufficient provision for 10% additional load as it is normal for such expansion. If a single turbo alternator is using a 1250 kW, it would be a good choice. However, it is prudent to choose two units so that in case of a major breakdown the mill can still satisfy part of the process requirement. In this case, two 700 kW would be a good choice. The selection is very much a subjective issue. There are many options to choose from based on specific requirements.

Now for the DGS although many mill managers may select two units of say 250 kW or slightly different combinations, the reason being that the two units it can supply at least half the electrical load in case the turbo alternator breaks down. This does not

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TABLE 1. DATA NEEDED FOR DIESEL GENERATOR SET SELECTION FOR A 60 TPH MILL

No	Electric load demand by	kW	% to total	Time (hr)	
a	Mill: 60 tph@ 18 kW t^{-1}	1 080	95	20	Based on maximum load (B) 1 135
b	Only nut station operation 25%	270	23.8	Off-days	
c	Non- processing: base load: (4 hr)	40	3.5	4 am-8 am	
d	Off-day: maintenance load	40	3.5	7 am-3 pm	
e	Compound lighting	10	0.9	7 pm-7 am	
f	Mill lighting	5	0.45	7 pm-7 am	
g	Office lighting/air conditioner	15	1.3	8 am-5 pm	
h	Domestic load- say 120 personnel	40, 20	3.5/1.7	7 pm-11 pm	
	TOTAL LOAD (approximate)				
A	Day: 7 am- 7 pm	1 080			
B	Evening: 7 pm- 12 pm (40kw) (maximum)	1 135			a+ e+f+h+1 080+10+5+40 = 1 135
C	Night: 12 pm- 7 am (20kw)	1 115			a+ e+f+h+1 080+10+5+20 =1 115
D	Maintenance day	40			d
E	Non-processing hours	40			
F	Public holidays (Evening+ night)	40			

Note: tph – tonne per hour.

seem to be a good selection criteria when we consider the breakdown of a single turbo alternator as then the entire process steam will have to issue out of a pressure reducing valve without any work output by the steam. It will be better to have additional steam turbine (third unit) as standby than too many DGS.

In this case, the DG'S capacity can be reduced to a single unit of 80 kW that can operate between 52 kW to 56 kW. This is all we need. No additional units are required. The best efficiency for a DGS is at about 65% to 70% loading. If the unit is well maintained, it will last for a long time. Since the DGS are not operated while the steam power plan is in operational, there is ample time to maintain it in good condition. The diesel consumption also will drop to 3 kWh per litre diesel at the optimum load of 65% to 75%. A suggested selection is shown in *Table 2*.

DGS COMPONENTS

Apart from the engine, the associated other components that make up the whole plant are some additional equipment also used for improving the quality of exhaust gases to comply with the Department of Environment's (DOE) requirements:
- air intake system comprising air filter, ducting and turbo-chargers.
- fuel supply system comprising diesel storage tank, flow meter, pipe work, pumps, strainers, day tanks and float level indicator. The fuel pump with common rail and fuel injection nozzles.

TABLE 2. A SIMPLE METHOD FOR THE SELECTION OF BOILERS AND POWER PLANT

Type of electric generators	No	Maximum load	
Steam turbo alternators 700 kW	2	1 135 kW	Normal operation for 60 tph
Steam turbo alternators 700 kW	1	700 kW	Stand by unit
Diesel generator set 80 kW	1	80 kW	Back-up – non-processing and off-days hours
Boiler 20 tph	2	40 tph	Capable of generating up to 1 500 kW
Boiler 20 tph	1	20 tph	Capable of generating 750 kW / 40 tph FFB

Note: FFB – fresh fruit bunch. tph – tonne per hour.

- exhaust system with turbo-charger, silencers and ducts.
- cooling systems comprising water circulating pumps, radiators, cooling towers, water treatment system and pipes.
- lubricating system comprising lubricant circulating pump, oil tanks, oil filters, oil purifiers and air compressor.
- the dedicated alternator.
- armoured feeder cables to control panel bus bar.
- electric control panel with relevant instrumentation and synchroniser.
- noise insulation system for the whole engine so that the noise levels comply with the DOE's set limits.
- warning signs for visitors to use ear plugs, safety shoes and helmets.

FUEL CONSUMPTION

Diesel consumption may be roughly taken as 0.304 kg per kWh or 0.42 litre per kWh (at a diesel specific gravity of 0.73kg per litre). For a 75 kW cummins engine, it is given as 0.37 litre per kWh. The specific fuel consumption for different capacities and fractional loads are given in the Datasheet of this bulletin. If the palm oil mill generator sets in Malaysia consume more diesel than say 0.5 litre per kWh, the mill engineers are advised to conduct an investigation to rule out the possibility of diesel leakage from submerged pipe joints as I personally experienced such a catastrophe in one of the mills.

THERMODYNAMIC FUNDAMENTALS

There is a distinct possibility for some mill engineers to forget the basic fundamentals related to diesel engines and that should not be the case. There are many areas of mill operations where the mill engineers will get the thrill of intellectual interaction with thermodynamics especially with wet steam. When we deal with steam we get an opportunity to remember and experience the application of the two laws of thermodynamics, the impact of Dalton's law of partial pressures during sterilisation process and the Rankine cycle during power generation. In a palm oil mill, the engineers have a great opportunity to work with all the facets of mechanical engineering, generous amount of electrical engineering, control systems, civil engineering, accountancy, human resource management, environmental protection and sustainability issues. A good combination of this proportion is not offered by most other industries.

THE AIR STANDARD CYCLE FOR DIESEL PLANT

The diesel cycle was created by Rudolph Diesel in 1892 and in the original engine powdered coal was blasted using compressed air and using hot bulb, the fuel was ignited unlike spark plug ignited petrol engines operating on Otto cycle. The cycle used was called Diesel cycle comprising an isentropic compression followed by a

reversible constant pressure heating, isentropic expansion during which the work was done and a reversible constant volume cooling (*Figure 1*). In this case, the ignition took place when the piston reached the top dead center (TDC) but now the diesel engines have undergone changes from the original concept of firing only during the constant pressure combustion.

Contrary to popular belief the diesel engines do not operate on diesel cycles anymore. The cycle is a combination of diesel and Otto cycle as shown in *Figure 2*. The engine based on this cycle called dual combustion cycle was invented by Ackroyd-Stuart in 1888. It is rather unfortunate that despite the fact that he formulated the dual combustion cycle four years before Diesel presented his diesel cycle his name never came to the fore front but faded away from history. In this cycle, the firing takes place during the constant volume operation indicated by 2 to 3 as well as during the constant pressure operation represented by 3 to 4. In this cycle there is a compression ratio v_1 / v_2, an expansion ratio v_3 / v_2 as well as a pressure ratio p_3 / p_2.

Heat supplied is given by the equation
$H_{input} = m_{in}\{ c_v (T_3 – T_2) + c_p (T_4 – T_3)\}$

Heat rejected by exhaust gases = $m_{ex}\{ c_v (T_5 - T_4)\}$

Where,

c_p and c_v are specific heats at constant pressure and constant volumes respectively;

min_{in} and m_{ex} are masses of fuel air mixture injected at inlet and exhaust gases respectively.

Two-stroke internal combustion engines are mechanically simple compared to their four-stroke engines but are more complex in thermodynamic and aerodynamic terms, according to Society of Automotive Engineers (SAE) definitions. In a two-stroke engine, the four fundamental operations of the engine comprising air intake, compression, ignition and exhaust occur in one revolution of the crank shaft *i.e.* 360 mechanical degrees, while in a four-stroke engine these operations are done in two complete revolutions or 720 mechanical degrees. In a two-stroke engine, more than one function occurs at any given time during the engine's operation. The advantages and disadvantages of the two stroke engines are given in *Table 3*.

- air intake takes place when the piston approaches the bottom dead center (BDC) through the ports provided in the cylinder wall with or without valves. All two-stroke diesel engines need either an artificial aspiration system like a mechanically

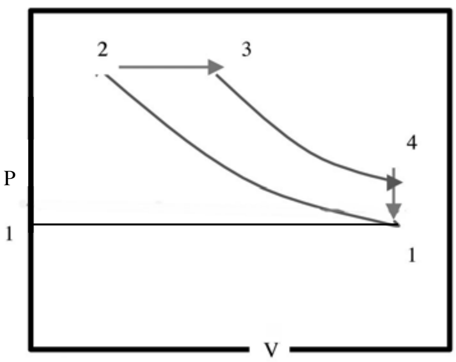

Figure 1. Diesel cycle (1892).

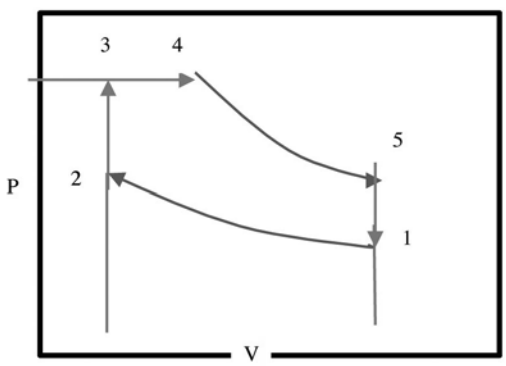

Figure 2. Dual combustion cycle (replaced diesel cycle).

TABLE 3. THE ADVANTAGES AND DISADVANTAGES OF TWO-STROKE ENGINES

POSITIVE	NEGATIVE	INTERESTING
Do not have valves, simplifying their construction.	Two-stroke engines don't live as long as four-stroke engines. The lack of a dedicated lubrication system means that the parts of a two-stroke engine wear-out faster. Two-stroke engines require a mix of oil in with the gas to lubricate the crankshaft, connecting rod and cylinder walls.	The following comments are from Columnist Michael Harrison of Deep Science: • Most of what is written on advantages and disadvantages of two-stroke vs four-stroke are not actually correct. • The comparisons are often made based on unequal basis. A two-stroke motor cycle engine that mixes the lubricant with the fuel cannot be compared with a four-stroke power plant prime mover. • It should be compared to a unit equal in size any large Caterpillar, or Detroit two-stroke they have conventional oil sumps, oil pumps and full pressure fed lubrication systems and they are also two-stroke. • The ports of two-stroke is claimed to be inefficient in scavenging exhaust gases compared to the valves of four-stroke engines but the same valve system can be incorporated in two stroke engines. The emission quality of some two-stroke engines are as good as four-stroke engines like Surrich/ Orbital two-stroke design that Mercury outboards are using - this is as clean burning as four-stroke.
Fires every revolution (four-stroke engines fire once every two revolution). This gives two-stroke engines a significant power boost.	Two-stroke oil can be expensive. Mixing ratio is about 1:40 (burning about 2 lit/1000 km).	
Two-stroke engines are lighter and cost less to manufacture.	Cannot use fuel efficiently, gets less km per lit.	
Two-stroke engines have the potential for about twice the power in the same size because there are twice as many power strokes per revolution.	Two-stroke engines produce more pollution from: • The combustion of the oil in the gas. • The oil makes all two-stroke engines smoky to some extent, and a badly worn two-stroke engine can emit more oily smoke. • Each time a new mix of air/fuel is loaded into the combustion chamber, part of it leaks out through the exhaust port.	

driven motor or a turbo-charger to charge the cylinder with air. During the aspiration phase, the residual exhaust gas of the previous charge is also expelled out.

- as the piston rises, the intake charge of air is compressed. Fuel is injected near the TDC to initiate the combustion as the compressed air temperature would be high enough to ignite the fuel. The high compression of the air is accomplished by the downward movement of the piston. As the piston moves downward in the cylinder it will reach a point where the exhaust port is opened to expel the high pressure combustion gases. Currently the concept has undergone some changes as now the cylinder wall body ports have given way to poppet valves and improved exhaust gas evacuation. As the piston moves downward, the air intake ports will be exposed in the cylinder wall and the cycle will start again.

- the scavenging ports are symmetrically set to open from 45° before BDC to 45°

after BDC whereas the exhaust port settings being based on maximum exhaust gas evacuation does not have to be symmetrical. A single camshaft operates the poppet-type exhaust valves with the special injector systems using three lobes: two for exhaust valves (either two valves on the smallest engines or four valves on the largest; and the third for the injector system).

There are hardly any major variations in the operational features of most of the engines. The discharge ports can either open at 45^{o} or before the piston reaches the TDC. The scavenging ports are set to open at any point from 45^{o} before BDC to same angle after BDC to keep it symmetrical. The exhaust valves are set to allow maximum air intake. According to Caterpillar's Electro-Motive Diesel known widely as EMD, it uses the following specifications for its two-stroke engine operation system.

The power stroke begins at 0^{o} TDC. Fuel injection will start 4^{o} before TDC 356^{o} in order to ensure that fuel injection is completed by the time the piston reaches the TDC or slightly after. This is followed by the fuel ignition and exhaust gas expulsion when the exhaust valves are opened causing a reduction of combustion gas pressure and temperature. The duration of the power stroke is about 103^{o}.

- the scavenging will begin 32^{o} later or at 135^{o} (103+ 32), or 45^{o} before the BDC having a duration of 90^{o} ending at 225^{o} (135 + 90). The delay of 32^{o} is for the scavenging ports to open and another 16^{o} delay after the scavenging ports are closed (thereby initiating the compression stroke), maximises scavenging effectiveness, thereby maximising engine power output, while minimising engine fuel consumption.

- towards the end of scavenging, all products of combustion have been forced out of the cylinder, and only 'charge air' remains (scavenging may be accomplished by Roots blowers, for charge air induction at slightly above ambient, or EMD's proprietary turbo-compressor which acts as a blower during start-up, and as a turbo-charger under normal operational conditions and for charge air induction at significantly above ambient, and which turbocharging provides a 50% maximum rated power increase over Roots-blown engines of the same displacement).

- the compression stroke begins 16^{o} later at 241^{o} (225+16), to begin the compression stroke having a duration of 119^{o}. By then the piston will be at 360^{o} (241+119).

- in present day engines with electronic fuel injection systems, the electronically-controlled unit injector is used. But they are actuated mechanically, the amount of fuel fed into the plunger-type injector pump is under the control of the Engine Control Unit replacing the Woodward governor or similar units or conventional unit injectors specific to General Motors (GM) two-stroke engines.

- the same procedure is followed by the GM/EMD 567 and the GM/Detroit Diesel 6-71 engines as they were designed and developed by the same team of engineers. Turbocharging provisions were an optional extra in some of the EMD and Detroit Diesel engines that employed turbocharging like for hybrid turbo-compressor system with inter cooling. For conventional units, Roots blowers were used for scavenging as a hybrid turbo-compressor would elevate the cost of the engines.

Some of the performance characteristics of EGT 6 truck are given in *Table 4*. The negative temperature at zero throttle opening shows that the drop in temperature of the exhaust at inlet was faster than the gas turbine outlet as the gas picked up heat from residual heat from the turbine casing.

TABLE 4. SHOWS THE PERFORMANCE OF A 'POWER STROKE OF EGT 6 TRUCK'

	At gas turbine inlet		At gas turbine outlet		ΔT	TPS	MPH
RPM	Turbine-in temp (F)	Turbine-in temp (^{0}C)	Turbine-out temp (F)	Turbine-out temp (^{0}C)	Temperature difference in-out (F)	Throttle position sensor (%)	Miles (hr)
3 900	950	510	720	382	128 (230)	22	55.7
3 800	1 060	571	740	393	178 (270)	57	53
2 500	1 030	554	760	404	150(270)	60	53.8
2 500	660	349	540	282	67 (120)	0	44.4
2 400	980	527	750	399	128 (230)	55	52.4
1 700	1 040	560	800	427	133 (240)	48	54.1
650 (Idle)	690	366	705	374	-8 (-15)	0	65.8

Fuel savings in terms of efficiency, the diesel engines fair better than gas engines mainly due to the higher calorific value of the diesel oil (7% higher) but some diesel engine manufacturer's claim of 30% increase in efficiency needs verification.

DIESEL ENGINE IMPORTANT MAINTENANCE TIPS

As diesel engine works on the principle of compressing the air that is drawn into the cylinder during the suction stroke so that the compressed air temperature is sufficient to ignite the fuel injected into it at close to the TDC, there is no need for any electrical components like the spark plugs or induction coil.

In diesel engines, the cylinder walls are thicker than petrol engines due to the high compression ratio. The temperature is also high resulting in additional demand for an efficient cooling system that has to be closely monitored. Abnormal temperature rise should be avoided in order to ensure prolonged engine life and to prevent engine getting seized or gasket get damaged. Gasket must be replaced as a set.

IMPORTANT TIPS ON BASIC DIESEL ENGINE MAINTENANCE

Sometimes the gas engines will get overheated due to poor coolant performance or continuous overloading of the engine. In such instances, the mill engineers seldom have a clue as to how the problem can be resolved. The right thing to do is to give it a break for a few minutes and restart when the temperature comes back to normal. The use of a fan will be of great help and as such it is prudent to have a fan permanently stationed near the gas engine. This may even prevent the occurrence of overheating. Overheating of a diesel engine should never be allowed even for short periods.

If a temperature rise is observed on a diesel engine, take any precaution that can prevent such occurrence as once it happens there is a good possibility for the cylinder gaskets to be damaged. Now let us look at some of the measures that would help the preventions of such catastrophe. The use of fan can be tried out but if the temperature rise cannot be arrested check the cooler tubes to remove any scales. If that does not bring the desired results, the best solution

would be renewal of cooler tubes with bigger tubes or add another cooler in series or parallel based on the available space. This should solve the problem amicably.

In order to safeguard the engine parts, it is usual to have filters on the run line to separate any dirt accumulated in the coolant while it circulates through the engine cooling circuit. Some engine manufacturers also provide coolant purification system so that the possibility of damage to engine parts by the coolant contaminants is effectively eliminated. Some of the coolant filters carry out multiple functions specially designed to protect the engines but they all add to the cost.

It is not a common practice in palm oil mills to assign an engineer or artisan to monitor the condition of the diesel engine and this weakness has been responsible for many costly engine breakdowns. If the mill engineers had been marine engineers before joining palm oil mills, they would have known how to maintain diesel power plants. Regular check on all the bolts and nuts to ensure the recommended torque is the starting point as over a period of time we can expect the nuts to work itself loose setting in motion a series of problems culminating in overheating and damage of gaskets. When this happens immediate attention should be given to change as a set to prevent further damage to the engine.

Great care must be directed to the condition of the oil filter. In palm oil mills, additional care will be needed and as such it is advisable to implement more than the manufacturer's recommendation based on the operating hours as the environment in the palm oil mill is very dusty and a shorter period would be more appropriate.

Ensure that the diesel fuel storage is done according to prescribed methods. It must be enclosed in a concrete tank having a volume equivalent to the storage tank so that in case of a leak through a leak or otherwise the escaping diesel oil can be contained without getting it into the monsoon drain. The day tank also must have the same provision. Both the storage tank and the day tank must have level indicators with identification signage and statement on the tank capacity. It is preferable to install a flow meter or a remote flow recorder close to the engine with isolating valves and a filter.

Ensure that all spare parts used for the engine are original parts. Imitation parts can damage the engine.