International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Online International Journal Available at http://www.cibtech.org/jet.htm
2012 Vol. 2 (2) April-June, pp.39-48/Kumar et al.
Research Article

ASSESSMENT OF OVERALL EQUIPMENT EFFECTIVENESS, EFFICIENCY AND ENERGY CONSUMPTION OF BREAKFAST CEREAL

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ABSTRACT
For a good manufacturing plant, the most recommended thing is quality and efficiency. These two parameters depend on the function of equipment used in the industry. In the current global competitive environment it is of immense importance for manufacturing companies tokeep track of, and improve the production performance of their production systems. Production failure includes many reasons. Among them improper maintenance and equipment performance are the eye catching reasons. Overall Equipment Effectiveness (OEE) calculation of a machine will result in final conclusion of point where rectification should be done and proper maintenance of machines in near future. One of the most widely used performance measures is OEE, a powerful tool for production development if used correctly. This OEE includes analysis of repair data and failure over a line of process.Nowadays due to raise of electricity price, industries are in a struggle to utilize and pay for the energy which they utilize. So estimation of consumption of energy byeach equipment of a plant should be noted for further rectification steps. If capital investments are implemented it is often necessary to justify these in terms of cost-benefit, which means quantized overall energy has to be used by a piece of equipment and likely savings. Energy management is one of the essential steps that should be maintained in industries to make cost benefit. This paper investigates the utilization of OEE measure for efficient management of improvement in production performance and calculation of efficiency and energy consumption of the equipments used in cereal processing industry.

Key Words: *Effectiveness, Equipment, Production Performance, Improvement, Production Failure, Efficiency, Energy Consumption*

INTRODUCTION
This OEE study is done in an industry where cereals are processed and packed using the machines like Roaster, Destoner, Pulveriser and Packaging machine. To avoid wastage of money due to false decision of equipment condition this OEE calculation is done in a cereal processing industry. This OEE calculation quantifies how well a manufacturing unit performs relative to its designed capacity during the periods where it is scheduled to run. OEE defines the expected performance of a machine, measure it and provides a less structure for analysis, which leads to improvement. It can be used as a tracking measure to see if improvement is to be sustained. This paper investigates OEE calculation of three equipments (Roaster, Destoner, Pulveriser) by taking readings directly and hence the performance of the equipment is analysed. The efficiency and energy consumption is also measured for the three machines. Efficiency is calculated by measuring the output power under no load and full load. This shows the real condition of each equipment and hence necessary steps can be taken to improve OEE of each equipment. This paper investigates the OEE analysis, energy consumption and also efficiency. Efficiency differs from OEE. Overall utilization of power of a whole processing plant for the specific period of time is determined **(**Ahuja *et al.*, 2008**)**. If the machine runs under no load, it leads to great energy loss. The cost of power and hence the energy is high and there is a high crisis for power generation. So rectification of this problem can be done with OEE analysis and additional improvement for the plant also can be done.

MATERIALS AND METHODS

Definition of OEE

OEE is a measure of total performance of equipment. This OEE includes three parameters. They are availability, performance and quality.

Availability

Availability takes into account Down Time Loss, which includes any Events that stop planned production for an appreciable length of time (usually several minutes – long enough to log as a trackable Event). Examples include equipment failures, material shortages, and changeover time. Changeover time is included in OEE analysis, since it is a form of down time. While it may not be possible to eliminate changeover time, in most cases it can be reduced. The remaining available time is called Operating Time.

Performance

Performance takes into account Speed Loss, which includes any factors that cause the process to operate at less than the maximum possible speed, when running. Examples include machine wear, substandard materials, misdeeds, and operator inefficiency. The remaining available time is called Net Operating Time.

Quality

Quality takes into account Quality Loss, which accounts for produced pieces that do not meet quality standards, including pieces that require rework. The remaining time is called Fully Productive Time. Our goal is to maximize Fully Productive Time.

In this article,calculation of OEE has done for three main plant equipments that are used in breakfast cereal processing plant.

Equipment selected for OEE analysis

Equipment selected for OEE calculation are as follows.

- Sand roaster
- De-stoner
- Packaging machine.

***Sand Roaster**:*

Moist conditioned grains are fed to the inner section where they are enveloped by hot sand resulting in heat and mass transfer. Roasting has to be done in an optimal range (distinctly different for different grains) to get the desired quality of parboiling. Degree of roasting depends on parameters like, moisture content of the feed material, ratio of feed material to heat transfer medium, particle size of sand, temperature of sand – process temperature, rate of heat input, feed rate and speed of roaster drum apart from the variety of grain being roasted. Large variations in the product temperature (5-10^{o}C) were observed in the manual type unit that resulted in non-uniformity of products. It is recommended to roast cereals at 140°C for about 10 minutes and pulses, legumes, oilseeds at 170°C for about 15 min. Roasting loosens the seed coats, making them easy to remove before the product is ground. Although roasting is one of the least expensive cooking processes, it is limited to whole grains and products with uniform piece sizes. Roasting dries grains and destroys much of the surface microflora.

Procedure for Sand Roasting the Cereals

- Ensure the machine is clean before starting the work. Ensure the level of diesel and fill upto 150 liters.
- Switch on the blower valve, through burner hole fire using a cotton rolled in a long rod.
- Depending upon the temperature adjust the blower and diesel valve.
- Switch on the machine. After 30 – 45 minutes for the roaster drum become heat. The roaster drum temperature is adjusted depending upon the material to be roasted in the thermometer.
- When the roasting drum reaches 100^{0}C 80Kg of sand is loaded slowly in the conveyor and switch on the conveyor.
- When the sand reaches the drum check the temperature in the thermometer is correct for the material to be roasted using the chart. The temperature varies for different material.

- Allow the material to be roasted slowly in the conveyor bait and switch on the shaker. If the material is roasted dark color, then reduce blower and diesel valve and increase the speed of the conveyor and vice versa.
- Once in 15 days clean the machine thoroughly. Rotating drum is fully cleaned once in 6 months. Once in 3 months the burner is cleaned thoroughly.
- Air blower is cleaned once in 2 weeks. Sieve net are cleaned once in 6 months. The roasted material is collected in the main bag.

Figure 1: Sand Roaster

Ideal production rate of roaster is 1150-1200 kg/hr. The horse power of this equipment is about 12.6 HP. The system response was found to be quick and linear.

Destoner

A destoner is a machine that can be used to remove stones from cereals, grains, seeds, etc. Destoner works effectively to separate debris which are heavier than the product. Destoners are manufactured using heavy gauge steel. Superior quality of grain separator machine is reciprocating screen type cleaner cum grader with a feed regulatory arrangement. A vacuum type aspiration system is provided for precision control. An inter changeable screen has a proper arrangement for taking care of all kind of pulses and guar. The screen is mounted on strong and a sturdy support by using appropriate steel (M.S.) structure. Here the DE stoneranalyzed is of construction with a top hopper where the grains will be unloaded by a bucket elevator, which connects with roaster machine. Then grains are dropped into the vibrating steel which moves larger sized grains backward and small size frontwards. Depending on the mesh size, grains will get separated from stones and other larger particles which are collected at sides of machine. Then sieved grains are dropped into rotating drum for further removal of tiny dust particles. Final collection is done at the end of machine. Collected grains are stored in sacks for further processing of pulverizing. Aspirator is also fitted with this destoner which removes away the light impurities from grains. Air is blown at hopper which takes away the light impurities with them.

Procedure for Destoning the Roasted Grains:

- Switch on the machine. According to the material to be sieved the mesh net is fixed to the machine.
- The mesh is cleaned before fitting into the machine.
- The material to be sieved is in loaded in the drum.
- The sieved powder is collected in a clean tub.
- The material is labeled and passed to the packing section.

This equipment is of capacity 13HPand the production rate is of 400-500 kg/hr.

The data for calculation OEE for destoner machine is collected or different PPT time intervals. The corrected readings are tabulated as shown in table 2. Data of destoner shows that estimated OEE is at average of 69.79%. Further improvement in equipment is need. While comparing with roaster, it has downtime much more comparatively. For 300mins production time the OEE is observed as 67.929% and 74.999%. This fluctuation in OEE is also depends on the same ideal run rate and downtime loss of 10, 9 and 8, 6 respectively. At 390 minutes of production time, downtime is same but the ideal run rate differs each other. It is inferred that OEE can fluctuate by changing ideal run rate alone. OEE depends not only on PPT but also on IR and DT. When PPT is set to 390 mins and DT is happened to be 10 mins, OEE differs as IR is not constant.

Figure 2: Destoner

Packaging Machine:

These machines are for packing the whole grains or powder materials into open mouth packs. They are mostly ideal for the food industries, or for any other application requiring high precision in weighing and ease of cleaning when changing product. These machines are designed to achieve the total absence of inside corners where any product remains can accumulate to cause possible cross-contamination. The measured dispensing system is made up of a product dosing screw controlled by a variable speed motor that allows the dispensing cycle to be carried out in two phases (fast and fine-tuned loading), thereby optimizing speed and accuracy. The measured dispensing assembly can be completely dismounted at the back. This moves together with a product collection tray. The dosing screw and its support are completely accessible for cleaning. They include sealed adjustment, closure and quick connection systems The flour is loaded into a drum which consists of screw conveyor that drops the grained flour into a hopper. This hopper decides the weight to be dropped into pouches as per our feed instruction. Pouches are carried and air is blown into the pouches. Then by sensing the opening, the material is dropped into the opened pouches. Sealing take place at last at a temperature of 130^0c. This machine is of ideal run rate at 11-20 units/min and HP of 16. Air compressor is also connected with this packaging machine.

METHODS

Calculation of OEE is based on three parameters. They are same availability, performance and quality. They are same availability, performance and quality. These based on the time period calculation ad production unit. Other than those three, six big losses also take into account. Those losses includes as follows.

- Downtime losses

- Breakdown losses
- Setup losses
- Speed losses
- Small steps losses
- Quality losses

Figure 3: Packaging Machine

Simple OEE Terminology:
This section describes the various plant manufacturing terms that make up Simple OEE and the three metric values (Availability, Performance, Quality) used in the calculation of Simple OEE (Louglin *et al.*, 2003/2004).

- *Runtime* (Availability Metric) - The total production time that the machine hasbeen running and producing parts. (t_r)
- *Setup time* (Availability Metric) - The period of time on the machine required foran operator to perform all the necessary tasks to produce the first good part.(t_s)
- *Down time* (Availability Metric) - The period of time the machine is not availablefor production due to maintenance or breakdown(t_d)
- *Total time* (Availability Metric) - The total accumulated machine time of RunTime + Down Time + Setup Time.(t_t)
- *Target counter* (Performance Metric) - the number of parts or cycles thatshould be completed at a particular point within the shift, day, or production run.(n)
- *Total count* (Performance & Quality Metric) - The total number of parts, goodand bad, that are produced on a machine.(n_t)
- *Good count* (Quality Metric) - The input count for any part produced toManufacturing specifications on the machine.(n_g)

Formula for OEE calculation
OEE calculation includes a basic formula. This formula is based on three parameters and six big losses. OEE can be assessed with three measuring metrics:

- Availability
- Performance
- Quality

These metrics help measure plant’s efficiency and effectiveness and categorize these key productivity losses that occur within the manufacturing process.

By definition, OEE is the calculation of Availability, Performance, and Quality.

Metric 1: Availability

Availability = Operating time/ Total production Time

Metric 2: Performance

Performance= (Total Pieces / Operating Time) / IdealRun Rate

Metric 3: Quality

Quality = Good Count / Total Count

OEE = Availability x Performance x Quality

Definition of formula:

Operating time is the time where the production process is done. This time period minuses downtime from total planned production time(Muchiri et al.,2008)**.** Setup time and break should be excluded for this planned production time. Downtime is the time loss due to repair of fault in equipment. Ideal production rate is the production per minute in specified equipment.

Availability:

Availability takes into account **Down Time Loss**, which includes any **Events** that stop planned production for an appreciable length of time (usually several minutes – long enough to log as a trackable Event)**(**Nakajima**)**. Examples include equipment failures, material shortages, and changeover time. Changeover time is included in OEE analysis, since it is a form of down time. While it may not be possible to eliminate changeover time, in most cases it can be reduced. The remaining available time is called **Operating Time**.

Performance:**Performance** takes into account **Speed Loss**, which includes any factors that cause the process to operate at less than the maximum possible speed, when running. Examples include machine wear, substandard materials, misfeeds, and operator inefficiency. The remaining available time is called **Net Operating Time**. (Williamson)

Quality:

Quality takes into account **Quality Loss**, which accounts for produced pieces that do not meet quality standards, including pieces that require rework. The remaining time is called **Fully Productive Time**. Our goal is to maximize **Fully Productive Time.**

Efficiency:

Efficiency can be defined as the ratio between input power and output power of the equipment. This output power is calculated using grip on ammeter. High efficiency is useful in the design of systems that can operate from batteries. Inefficiency requires weighing the cost of the required power supply) against the cost of attaining greater efficiency (through choosing different components or redesigning the system)(Narayan, et al., 2003)**.** Also, any difference in the input and output power probably produces heat within the system (although noise and other mechanical vibrations involve at least theoretically separate and generally negligible inefficiencies), and that heat must be removed from the system if it is to remain within itsoperating temperature range. If the system is in a climate-controlled environment, like a home or office, heat generated may reduce heating costs or increase ventilation and air conditioning costs and are quick to run out.

$$\% \textbf{ EFFICIENCY} = \frac{\textbf{OUTPUT POWER}}{\textbf{INPUT POWER}} \times 100$$

Here the output power can be calculated by using the name plate details that has been attached to the equipment. Input power is calculated by using the current measuring devices. Grip on ammeter is used here to collect the reading of three phases.

Energy consumption:

Total consumption of equipment energy is to be calculated. By calculating each equipment energy, we can calculate the whole industry consumption of energy.

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Energy consumption (kwhr) = power x time consumption.
Thus to derive power the formula that used
Power (kw) = √3*current*voltage*power factor/1000.

Data collection:

This calculation of OEE is based on the original input parameters from the process flow. They are calculated manually during the process of product and usage of equipment. This collection includes the breakdown time, speed loss, minor stoppage. Analysis of this parameter is directly noted down and OEE is calculated by substituting in the formula mentioned above.OEE,energy consumption and efficiency are calculated separately for the Roaster, Destoner, Pulveriser, and Packaging machine as per the formula. Every time period losses are noted for OEE and power is determined for energy consumption and efficiency. The tabular column which shows the collected data is shown below in tables.

Data analysis:

Data for OEE are calculated and tabulated in given tables. For each equipment, OEE are tabulated separately. Using the above said formula OEE are measured.

Calculations for OEE:

Table 1

ROASTER OEE DATA

SI. No.	PPT (min)	DT (min)	OPT (min)	A%	TPU (kg)	IR (kg/min)	P%	TGP (kg)	Q%	OEE%
1.	75	3	72	96	1000	15	92.59	979	97.9	87.019
2.	75	2	73	97.333	2500	35	97.85	2450	98	93.333
3.	180	5	175	97.22	4350	26	95.60	4298	98.80	91.82
4.	176	4	180	97.77	3100	18	97.853	3030	97.74	93.506

From OEE calculations for it is found that at constant planned production time of 75 mins(table1), OEE gets differ. Thus it is inferred that OEE depends not only on ideal run rate but also on downtime. OEE gets varied because of ideal run rate and downtime.

Table 2

DESTONER OEE DATA

SL. No.	PPT (min)	DT (min)	OPT (min)	A%	TPU (kg)	IR (kg/ min)	P%	TGP (kg)	Q%	OEE%
1.	300	8	292	97.333	2050	10	71.180	2010	98.048	67.929
2.	300	6	294	98	2050	9	77.475	2025	98.75	74.999
3.	390	10	380	97.435	2550	10	67.105	2512	98.50	64.40
4.	390	10	380	97.435	2550	9	74.561	2522	98.90	71.849

Table 3

PACKAGING MACHINE OEE DATA

SL. No	PPT (min)	DT (min)	OPT (min)	A%	TPU (kg)	IR (kg/min)	P%	TGP (kg)	Q%	OEE%
1.	380	10	360	94.75	5624	19	82.22	5575	99.12	77.217
2.	420	25	395	94.041	6010	19	80.079	5825	96.92	73.63
3.	240	15	225	93.75	2435	15	72.14	2382	97.82	66.15
4.	245	22	223	91.080	2806	15	83.886	2689	95.830	73.21

From the above tables it is found that at constant planned production time, OEE gets differed. Thus it is inferred that OEE depends not only on ideal run rate but also on downtime. OEE gets varied because of ideal run rate and downtime.

Sample calculation of OEE for roaster equipment:

Data,
PPT-planned production time(mins)
DT-downtime (mins)
OPT- operating time (mins)
A%- availability %
TPU- total produced unit (kg)(pieces in case of packaging)
P%- performance%
TGP- total good products (kg)(pieces in case of packaging)
Q%- quality %
OEE%- Overall Equipment Effectiveness

Table 4

Planned Production Time	= Shift Length - Breaks = 210-30 = 180 minutes
Operating Time	= Planned Production Time - Down Time = 180-5 = 175 min
Good Pieces	= Total Pieces – Rejected Pieces =4350 -52 = 4298 pieces
Availability	= Operating Time / Planned Production Time = 175 minutes / 180 minutes

	=97.22
Performance	= (Total Pieces / Operating Time) / Ideal Run Rate = (4350 pieces / 175 minutes) / 26 pieces per minute = 0.9560
Quality	= Good Pieces / Total Pieces = 4298/ 4350 pieces =0.9182
OEE	= Availability x Performance x Quality = 0.9722*0.9560*0.9182 =0.9182 or 91.82%

Calculation of efficiency and energy consumption:
Name plate details of Roaster, Destoner and Pulveriser are as follows.

Table 5

Equipment	Amps	HP	Volts	Hz
Roaster	12.6	12	230	50
Destoner	5	9	230	50
Pulverisizer	92.8	35	230	50

Data For Effeciency And Energy Calculation
I – current (amps)
V- Voltage (volts)
IP- input power (kw)
OP- output power (kw)
T- Time of running period (h)
EC – energy consumption

Efficiency that has been calculated is of minor variation. Power consumption of equipment on the processes changes on both load and unload conditions. There are variations of power utilization is found at load and no load process of equipment. Running of machine without load results in wastage of energy. Due to this there will be a loss of money to the manufacturing industry. Proper raw material supply without of shortage of time should be needed to avoid this wastage. Difference in energy consumption is getting vary at ±0.1 or ±0.2. Power factor is 0.8 in calculation of power. While comparing pulveriser with roaster and destoner, pulveriser utilizes heavy current. Because the HP of this pulverizer is about 60. Heavy current has got consumed by this machine.

Table 6

PULVERISER Efficiency and Energy Consumption							
I_{phase} (amps)	I_{line} (amps)	V_{line} (volts)	P_{output} (kw)	P_{input} (kw)	T (hrs)	EC (kwh)	EFFICIENCECY%
31.1	53.86	230	17.166	25.742	10	171.661	66.685
31	53.692	230	17.110	25.742	8.5	145.44	66.47
31.1	53.86	230	17.166	25.742	7.5	128.74	66.68
31.1	53.86	230	17.166	25.742	8	137.32	66.68

ROASTER Efficiency and Energy Consumption							
I_{phase} (amps)	I_{line} (amps)	V_{line} (volts)	P_{output} (kw)	P_{input} (kw)	T (hrs)	EC (kwh)	EFFICIENCECY%
12.1	20.957	230	6.6787	8.826	8	53.4299	75.67125
12.0	20.784	230	6.6236	8.826	8	52.9888	75.04658
12.3	21.303	230	6.7890	8.826	7.5	50.9175	76.92058
12.1	20.957	230	6.6787	8.826	3	20.0362	75.67125

Sample calculation for Efficiency and energy consumption:
Below table shows calculation of one reading of destoner equipment:

Table 7

Output Power	**1.732*230*0.8*Iline**	**1.732*230*0.8*17.14 =5.64 kw**
I line	**1.732* I phase**	**1.732*9.9 = 17.14amps**
Input power	**Name plate details (HP*735.5/1000)kw**	**9*735.5/1000 =6.619kw**
EFFECIENCY	**OUTPUT POWER/ INPUT POWER**	**0.8258 or 82.58%**
Energy consumption	**Output power * time consumption**	**40.983 kwh**

RESULTS

From the analysis the data that has collected, it is found that packaging machine is of less OEE while comparing other two. Packaging is the final step and this should be done at higher rate to compensate the production. So improvement of this equipment's OEE should be considered and necessary steps should be taken. For zero breakdowns we can follow the following steps.

- Maintain basic equipment conditions,
- Adhere to proper operating conditions
- Restore deterioration
- Correct design weakness
- Improve operating & maintenance skill

The only reason to measure and analyses anything is to improve it. If we are not going to use the whole improvement cycle there is no point in measuring OEE. It tells us nothing we do not already know. At a gross level all OEE tells you is how much you made compared to what you wanted to make, and any schedule adherence measure would tell you that already. Averaging OEE's over whole plants or time periods just hides issues – OEE is a specific measure for use in specific improvement projects. The biggest misuse of OEE is to use it to compare different processes, plants or machines. It is not even a very useful operational measure. It is an improvement measure, for people who want to improve their equipment performance.

Conclusions

Implementing OEE is not a difficult task. However, it requires some customized training in order to succeed. The results of implementing an effective program in terms of increased plant efficiency and productivity are outstanding. It should be acknowledged that an OEE implementation is not a short-term fix program. It is a continuous journey based on changing the work-area, then the equipment so as to achieve a clean, neat, safe workplace. Significant improvement can be evident within six months.

At this crucial point of global competition, the implementation of OEE not a matter of liking it or following the fashion. While OEE was in the 60's, just an innovative thing, today it has turned into a survival strategy. OEE is capable of bringing a machine back to original condition and even better. The cost of postponing a decision of implementing OEE, that have to make sooner or later, can be excessive. It is convincing that the losses for each day of delay are out of imagination.

Apparently, successful OEE implementation can achieve better and lasting result as compared to other isolated program because there is an ultimate change in people (knowledge, skills, and behavior) during the progress. Efficiency calculation and energy calculation is also one of the essential implementation work in this competitive global. Most of industries are doing this work, but not in daily shift. Implementation and working with these on daily bases can result in positive improvement of industry and lead to good position.

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