Energy Audit Report

Of **ABHIJEET CASTINGS,**
KOLHAPUR

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1.0 INTRODUCTION

In November 2011 MB Associates assisted a series of audits of operation – with a view to reducing energy consumption – in the Kolhapur foundry cluster. The audits were carried out by Shivaji University personnel as part of a World Bank-GEF-BEE initiative. MB Associates' role was to assist the Institute for Industrial Productivity (IIP) to provide industry specific technical guidance before and during the audits.

The objective of the project was to develop an understanding of the overall performance of the Kolhapur Cluster, carry out a comparison of that performance and provide guidance as to the methods required for improvement. This should enable the foundries to check and improve their efficiency and consumption of resources and energy.

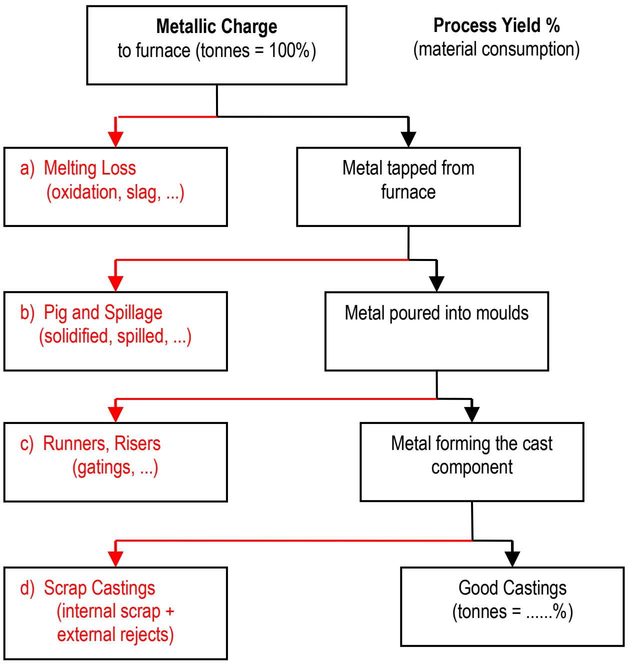
The analysis and the recommendations made in this report are based on the audit data provided by Shivaji University and the information provided by the foundries themselves and observations made during the field visits undertaken in November 2012.

In order for the individual units to better understand the energy audit results and the recommendations made thereof, a brief explanation is provided about Key Performance Indicators (KPIs) in a foundry.

1.1 Key Performance Indicators (KPIs)

1.1.1 Process Yield

This KPI monitors how much of the material processed ends up as good saleable castings. As most of the material which does not end up as good castings is recycled, the loss of material is of minor importance. Much more important is the loss of energy, labour time, and capacity for processing material which does not end up as a saleable product. See below:



Performance:
Tonnes of Good Castings divided by tonnes of liquid melt processed;

This KPI is comprised from 4 sub-indicators
a) KPI 1.1 – Melting loss (%)
b) KPI 1.2 – Pig and spillage (%)
c) KPI 1.3 – Runners and risers (%)
d) KPI 1.4 – Scrap castings (%)

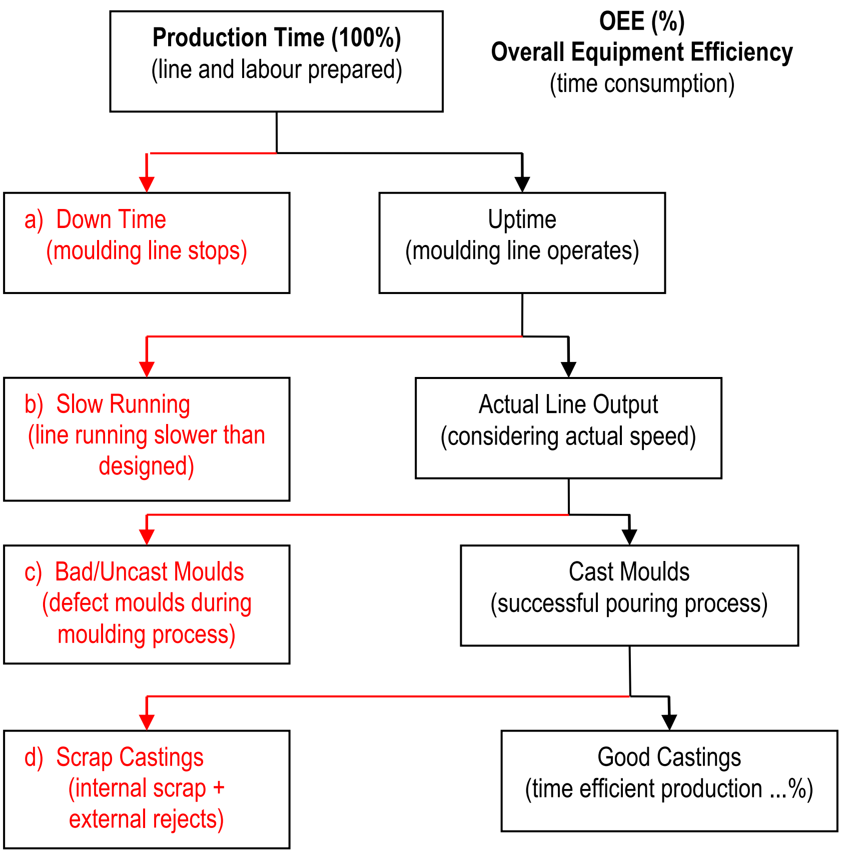
Formula:
KPI 1 = (1-a) x (1-b) x (1-c) x (1-d) x 100%

No	KPI	Definition
1	Process Yield (%)	Material consumption based performance. The weight of net good castings produced as a percentage of the metallic material charged to the melting furnaces; comprised from 4 performance indicators.
1.1	Melting Loss (%)	The material lost during melting (either by oxidation or incorporation into the slag) expressed as a percentage of the metallic material charged to the melting furnaces.
1.2	Pig and Spillage (%)	The amount of liquid metal tapped from the furnace which does not get poured into moulds expressed as a percentage of the liquid metal tapped.
1.3	Runners and Risers (%)	The weight of liquid metal poured into the mould which does not form a casting expressed as a percentage of the liquid metal poured into that mould.
1.4	Scrap Castings and Rejects (%)	The weight of scrap castings (including customer returns) expressed as a percentage of the weight of gross castings produced.

1.1.2 Effective Production (OEE)

Time consumption based performance also known as Overall Equipment Effectiveness indicates the gap between actual and ideal performance.

The time during which the plant produces good saleable castings expressed as a percentage of the time that the plant was available for production. See below:



This KPI is comprised from 4 sub-indicators

a) KPI 2.1 – Down Time (Moulding) (%)
b) KPI 2.2 – Slow Running (%)
c) KPI 2.3 – Bad Moulds (%)
d) KPI 2.4 – Scrap and Rejects (%)

Formula:

KPI 2 = (1-a) x (1-b) x (1-c) x (1-d) x 100%

No	KPI	Definition
2	OEE (%) – Overall Equipment Efficiency	Time consumption based performance. The time during which the plant produces good saleable castings expressed as percentage of the time that the plant was available for production; comprised from 4 performance indicators.
2.1	Downtime (Moulding) (%)	The time that a moulding facility is not operating due to breakdowns or operational reasons expressed as a percentage of the total time available for production (often called the net operating time).
2.2	Slow Running (%)	The production time lost by operating a moulding facility at a speed below the design capacity or calculated output expressed as an equivalent percentage of the net operating time.
2.3	Bad Moulds (%)	The number of moulds that are not poured expressed as a percentage of the total number of moulds produced.
2.4	Scrap and Rejects (%) (internal scrap and external rejects)	The weight of scrap castings (including customer returns) expressed as a percentage of the weight of gross castings produced.

1.1.3 TEEP (Total Effective Equipment Performance)

No	KPI	Definition
3	TEEP (%) – Total Effective Equipment Performance	Time based capacity utilisation. Total effective equipment performance (TEEP) measures OEE effectiveness against calendar hours, i.e. 24 hours per day, 365 days per year. Total Effective Production per annum expressed as a percentage of the total plant capacity if operating for 24 hours per day, 365 days per year.

1.1.4 Energy Consumption

The KPIs referring to energy consumption are monitored for two levels as some 75% of total energy consumption is usually consumed already only in the melting plant and measures for improvement can be concentrated on this department:

- KPI 4.1 – energy consumption in melting
- KPI 4.2 – energy consumption in foundry

The energy consumption includes all types of energy such as electric power, coke (i.e. when combustion melting in cupola furnaces), gas and oil. The energy consumption is expressed in kWh.

No	KPI	Definition
4	Energy Consumption	Energy is one of the most important cost factors apart from raw material and in melting the energy supply often is a limiting capacity factor.
4.1	Energy Consumption in Melting (Melting Efficiency) (kWh/tonne melt)	Furnace power consumption (kWh) divided by the tonnage of metallic material charged to the furnaces *(the melting consumes some 75% of the total foundry energy demand; a good performance of the melt shop saves money and capacity).*
4.2	Energy Consumption in Foundry (kWh/tonne good castings)	Total power consumption (kWh) in the foundry departments divided by the tonnage of net good castings produced *(the cost impact of energy consumption is a competitive mark)*.

1.1.5 Sand Consumption

The performance of sand consumption is monitored with 2 KPIs:

- new (fresh) sand consumption per tonne of good castings (indicates design of casting process)
- rate of sand regeneration (indicates how much sand must be dumped)

No	KPI	Definition
5	Sand Consumption	The sand utilised for making the moulds is supposed to be recycled and regenerated as much as possible. A perfect designed and operated sand regeneration plant will reduce costs for sand purchase and also improve quality of castings.
5.1	Fresh Sand Consumption (tonnes sand/tonnes good castings)	The weight of new (fresh) sand used divided by the tonnage of net good castings produced. This indicator includes sand for moulding as well as sand for core making.
5.2	Rate of Sand Regeneration (%)	The percentage of sand that is re-used at each moulding cycle (as an average of all moulding cycles included in the sampling period).

1.1.6 Labour Productivity

No	KPI	Definition
6	Labour productivity (man hours/tonnes good castings)	Apart from the overall productivity a lean organisation and a high grade of automation have the impact on labour productivity. The total number of man hours worked (excluding management and supervisory hours) divided by the tonnage of net good castings produced.

2.0 ABHIJEET CASTINGS

2.1 General Description

Annual Tonnage – 3,000 tonnes per annum.

Melting is carried out by means of a divided blast cupola of 24" diameter.

Moulding facilities consist of 3 pairs of jolt-squeeze machines with pin lifts.

All cores are bought in as there is no core making facilities on site. The majority of cores appeared to be shell.

The plant operates for 3 shifts per day, 6 days per week. Moulding and melting operations are carried out on alternate days.

2.2 Product Mix

All of the 3,000 tonnes per annum produced by Abhijeet Castings are covered by the category GMGE – grey iron general engineering and automotive castings. An explanation of the categories is given in Figure 1. Within this classification the approximate product split is as follows:

General Engineering	–	85%
Automotive	–	15%

An explanation of the categories is shown in Figure 1.

2.3 Audit Results

2.3.1 Process Yield

During the audit period some 12,950 kg of metallics was charged to the cupola. The amount of coke charged during this period was 975 kg (7.5%). Allowing for a proportional allocation of the bed coke, the total coke consumed was 1,136 kg (8.8%).

Some 11,830 kg of molten metal was produced which equates to a melting loss of 8.6%. Metal poured into the moulds was 11,622 kg so that there was 208 kg lost to pig and spillage (1.8%).

The average box yield of the castings produced was 86.6%, giving a gross castings weight of 10,065 kg. The average scrap rate of 3.1% resulted in a net good saleable castings weight of 9,753 kg.

Thus some 75.2% of the weight of the material charged to the cupola resulted in castings that could be sold. A representation of the calculation of the Process Yield is given below.

Process Yield Calculation

Material Charged	12,950	100%	100%
Metal Loss	1,120	8.8%	
Liquid Metal	11,830	91.2%	91.2%
Pig and Spillage	208	1.8%	
Metal in Moulds	11,622	98.2%	89.6%
Runners & Feeders	1,557	13.4%	
Gross Castings	10,065	86.6%	77.6%
Scrap & Rejects	312	3.1%	
Net Good Castings	9,753	96.9%	75.2%

Process Yield – 75.2%

An explanation of the categories is given in Figure 1.

2.3.2 Effective Production

The plant moulds and pours on alternate days. At the time of the audit some 484 moulds had been produced the previous day and no breakdowns or stoppages had been reported.

The plant has 3 pairs of jolt-squeeze pin-left moulding machines, each of which is quite capable of producing 50 moulds per hour. Thus in 24 hours of production the number of moulds that could be produced is 3,600. The 484 produced therefore represents only 13.4% of the potential available.

No bad moulds were recorded and the scrap level was 3.1% – see above.

Therefore the Effective Production for the plant was 13.0%. This means that the plant produced saleable castings for only 13.0% of the available operating time. The calculation of Effective Production is give below.

Effective Production Calculation

Production Time	3,600	100%	100%
Downtime	0	0%	
Operating Time	3,600	100%	100%
Slow Running	3,116	86.6%	
Moulding Output	484	13.4%	13.4%
Bad Moulds	0	0%	
Good Moulds	484	100%	13.4%
Scrap Castings	15	3.1%	
Good Production	469	96.9%	13.0%

Effective production – 13.0%

2.3.3 TEEP

The plant operates for some 900 shifts per annum, with moulding and pouring on alternate days. Therefore the moulding plant operates for some 450 shifts or 3,600 hours. This equates to a plant utilisation of 41.1%. However, when the plant is operating the Effective Production is only 13%. Thus the real plant utilisation or TEEP (Total Equipment Effective Production) is only 5.3% (41.1% x 13.0%). This means that the plant operates in such a way that it only utilises 5.3% of its total capacity.

2.3.4 Energy

i) *Melting* – the plant consumed coke at the rate of 8.8% of the charged weight. Coke with an ash content of 11.5% has an energy equivalent of 8,012 kWh per tonne. Therefore, the coke consumed during melting is equivalent to 705 kWh per tonne charged.

ii) *Overall Consumption* – during the audit period the energy consumption was as follows:

Melting	9,130 kWh
Other Operations	84 kWh
	9,214 kWh

During this time 9.753 tonnes of net good castings were produced giving a total energy consumption of 945 kWh per tonne of good castings.

2.3.5 Sand

New sand consumption was 400 kg or 0.04 tonnes of sand per tonne of good castings. Of this, 273 kg was as cores. The sand consumption figures indicate a sand reclamation level of 75.3%.

2.3.6 Productivity

Using the shift patterns and manning levels provided, it has been calculated that the level of productivity in the plant is such that it requires 70.2 man hours (direct labour) to produce one tonne of good castings.

2.4 Comparison of Results

In order for Abhijeet Castings to obtain the maximum benefit from the audit, their data will be compared below to other foundries.

2.4.1 Kolhapur Cluster

In the table below the Abhijeet Castings audit data is compared to the average of all of the Kolhapur audit results.

Abhijeet Castings vs. Kolhapur Cluster		
	Abhijeet Castings	**Kolhapur Cluster**
Melting Loss	8.6%	6.8%
Pig & Spillage	1.8%	4.6%
Runners & Feeders	13.4%	19.7%
Scrap & Rejects	3.1%	4.6%
Process Yield	75.2%	68.1%
Downtime	Nil	Nil
Slow Running	86.6%	50.0%
Bad Moulds	N/R	2.4%
Scrap & Rejects	3.1%	4.6%

Effective Production	13.0%	46.6%
TEEP	5.3%	28.8%
Energy Consumption		
Per Tonne Melted	705 kWh	1057 kWh
Per Tonne Good Castings	945 kWh	1770 kWh
Sand Consumption		
New Sand/tonnes castings	0.04 t	0.50 t
Cores/tonnes castings	0.03 t	0.08 t
Sand Reclamation	75.3%	59.0%
Productivity		
Man hours/tonnes castings	70.2	48.9
Direct Ratio	1.4	4

However, the above table compares the Abhijeet Castings performance with other foundries in the area which have different products and production methods. To gain a more realistic guide as to the Abhijeet Castings performance, it must be compared to that of similar foundries.

2.4.2 Similar Foundries

In the table blow the Abhijeet Casting performance data is compared to that of similar foundries in other parts of the developing world (both average and best practice) and Western Europe.

Abhijeet Castings Performance Comparison

		Developing Countries		Western Europe	
	Abhijeet Castings	Average Performance	Best Practice	Average Performance	Best Practice
Melting Loss	8.6%	5.1%	2.8%	2.0%	1.0%
Pig & Spillage	1.8%	2.8%	1.0%	3.5%	2.6%
Runners & Feeders	13.4%	30.3%	13.1%	30.0%	27.5%
Scrap & Rejects	3.1%	8.4%	0.5%	5.0%	4.0%
Process Yield	75.2%	58.9%	83.2%	62.9%	67.1%
Downtime	Nil	27.2%	4.3%	15.0%	13.4%
Slow Running	86.6%	21.4%	0.0%	5.0%	4.5%
Bad Moulds	N/R	1.9%	0.5%	1.0%	0.9%
Scrap & Rejects	3.1%	8.4%	0.5%	5.0%	4.0%
Effective Production	13.0%	51.4%	94.7%	75.9%	78.7%
TEEP	5.3%	28.2%	65.5%	46.7%	51.9%
Energy Consumption Per Tonne Melted	705 kWh	1285 kWh	543 kWh	600 kWh	580 kWh
Per Tonne Good Castings	945 kWh	2948 kWh	1521 kWh	1424 kWh	1235 kWh
Sand Consumption New Sand/t castings	0.04 t	1.18 t	0.37 t	0.19 t	0.16 t
Cores/t castings	0.03 t	N/R	N/R	N/R	N/R
Sand Reclamation	75.3%	92.7%	97.6%	95.0%	98.0%
Productivity Man hours/t castings	70.2	162.7	37.6	25	20
Direct Ratio	1.4	N/R	N/R	N/R	N/R

The data above applies to mechanised moulding, small greensand foundries producing grey iron automotive and general engineering castings. The term “Developing Countries” applies to countries such as Brazil, Russia and Mexico.

It should be noted that scrap levels are quoted in terms of the quality standards prevailing in the country of the foundry concerned. For instance what is a good casting in Kolhapur may not be a good casting in the UK or Germany.

2.5 Conclusions and General Comments

2.5.1 Process Yield

The melting loss experienced in the cupola was quite high at 8.6% and compares to a value of 6.8% for the average of the plants in Kolhapur that were audited. Figures for the melting loss for similar plants in other parts of the world would be 5.1% for developing countries and 2.0% in Western Europe. The main reasons for such a high melting loss figure are considered to be:

- incorrectly designed DB cupola (wrong size and spacing of tuyeres)
- blast rate and fan pressure not matched to cupola diameter and wind belt size
- low consumption of coke
- cupola stack level running very low therefore high oxidation and little pre-heating of charge material
- very large limestone being used.

2.5.2 Effective Production

No downtime was recorded for the moulding machines. A pair of jolt-squeeze machines can easily produce 50 moulds per hour. Therefore with three pairs of machines and 24 hours available, some 3,600 moulds could have been produced. In the 24 hours before the audit some 484 moulds were produced. This represents only 13.4% of the moulding machine capacity.

The moulding machines concerned is all of the “pin-lift” type which means that half moulds have to be lifted off the machine and then transported away. During this time the moulding machines cannot be operated. These machines should be converted to “roller-lift” whereby the half moulds could be rolled off the moulding machine onto a small section of roller track and handled elsewhere. This would allow the moulding machine to continue operating within its own cycle time.

Taking into account the scrap level, the Effective Production of the plant is only 13.0% compared to 46.6% for the Kolhapur Cluster, 51.4% for developing countries and 75.9% for Western Europe.

2.5.3 Other Parameters

The energy consumed during melting was 705 kWh/tonne which compares well with the Kolhapur average of 1,057 kWh/tonne. The equivalent figure for Western Europe would be 600 kWh/tonne.

The overall energy consumption per tonne of finished castings is very low at 945 kWh/tonne. This figure is lower than that recorded for the most efficient foundries in the world. This figure mainly results from the very high box yield (86.6%) quoted by Abhijeet Castings. If this is correct, then the foundry is operating very well in this area. Most foundries in this category would operate with a box yield of around 70.0%.

The sand reclamation figure of 75.3% is quite low for a greensand plant and compares poorly against 92.7% for developing countries and 95.0% for Western Europe.

The productivity level of 70.2 man hours per tonne is high, largely because of the low Effective Production level. This is illustrated by considering the TEEP value which shows that Abhijeet Castings only operates at a plant utilisation of 5.3% of its moulding capacity against 28.8% in other Kolhapur foundries.

Similar foundries in Western Europe would operate at a productivity level of 25 man hours per tonne on average with the better foundries operating as low as 20.

2.6 Potential Improvements

A re-design of the cupola and blowing systems would:

- reduce melting loss
- improve metal temperature
- improve melting rate
- reduce scrap levels
- reduce overall energy consumption per tonne of finished castings

Since material costs represent 77.4% of the total operating costs of the foundry, a reduction in melting loss of 3.5% (8.6% to 5.1%) represents a reduction of total operating costs of 2.7%.

Similarly, the energy costs would be reduced by some 0.3%. Thus improving the efficiency of the cupola operation reduces operating costs by 3%.

Only a small improvement in the Effective Production (as indicated by introducing a small amount of handling equipment and converting the moulding machines to roller-lift) would take Abhijeet Castings from a three shift operation to a two shift operation for the same output. This would reduce the labour and energy costs considerably. Alternatively, it would give the opportunity to expand the existing production levels.

Figure 1 Product and Manufacturing Method Classification

Grey iron product categories

Automatic moulding

GABH = automotive engine blocks and cylinder heads
GAAO = automotive other
GAAG = agriculture
GAMI = mining

Mechanised moulding

GMBH = medium sized engine blocks and heads (energy generation)
GMAG = agriculture
GMMI = mining
GMGE = general engineering

Manual (hand) moulding

GHBH = large size engine blocks and heads (energy generation)
GHMI = mining
GHGE = general engineering

Ductile iron product categories

Automatic moulding

DAAU = automotive other
DAGE = general engineering

Mechanised moulding

DMAU = automotive
DMGE = general engineering

Manual (hand) moulding

DHEN = energy generation components
DHCO = compressor components
DHGE = general engineering

Steel product categories

Automatic moulding

SARC = railway components (c)
SAMM = mining components (m)
SAAC = commercial vehicles (c)
SAGC = general engineering

Mechanised moulding

SMRC = railway components (c)
SMMM = mining components (m)
SMPC = pumps and valves (c)
SMPS = pumps and valves (s)
SMGC = general engineering (c)
SMAC = commercial vehicles (c)

Manual (hand) moulding

SHMM = mining components (c)
SHPC = pumps and valves (c)
SHEA = energy components (a)
SHGC = general engineering (c)

c = carbon steel, s = stainless steel
m = manganese steel, a = high alloy steel