Energy Audit Report

of **GHATGE PATIL,**
KOLHAPUR

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Prepared By: M B Associates, UK

Under the Joint Initiative of WB-GEF (BEE) and Institute for Industrial Productivity

CONTENTS

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.

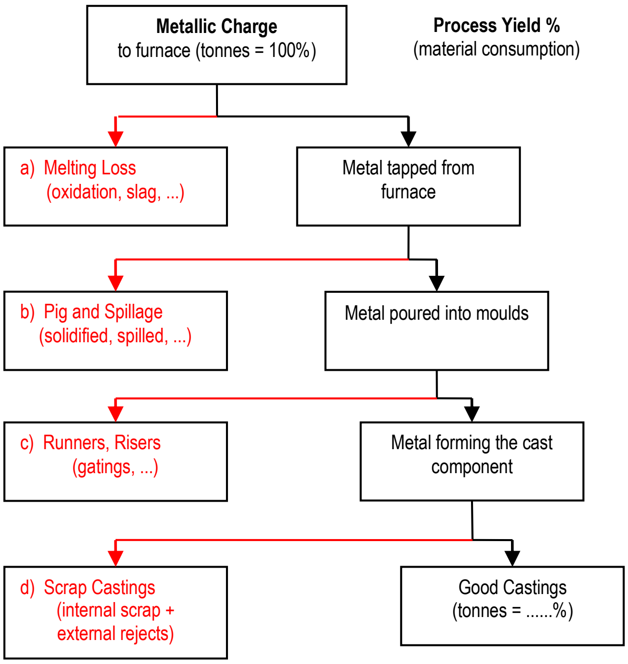
The analysis and the recommendations made in this report are based on the audit data provided by Shivaji University and the information provided by the foundries themselves and observations made during the field visits undertaken in November 2012.

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 (%)

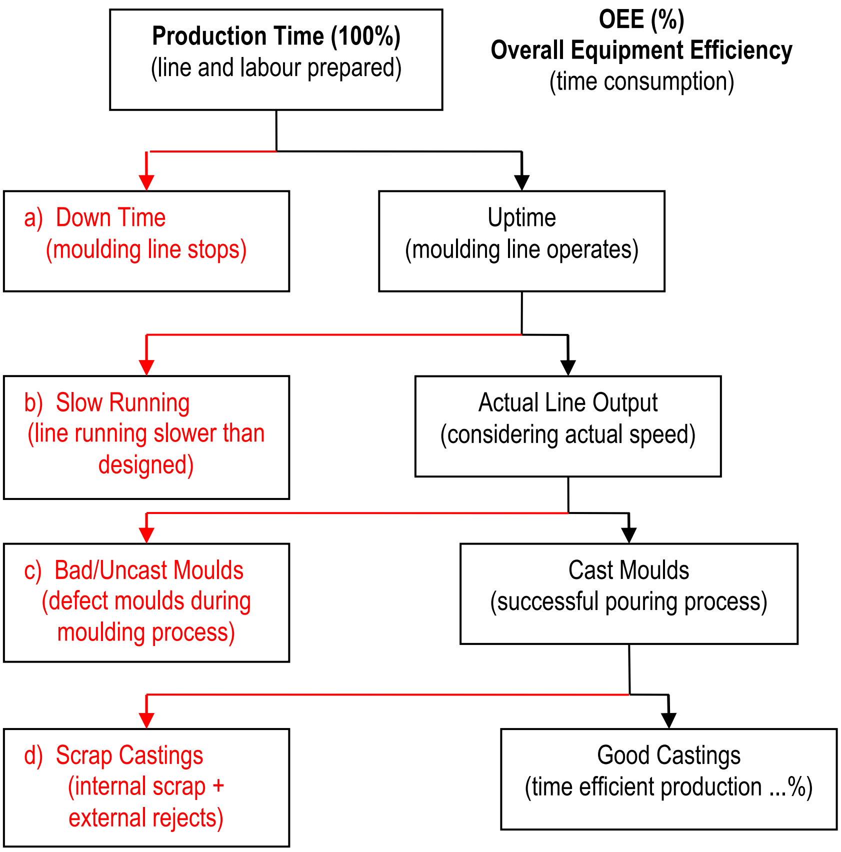
Formula:
KPI 1 = (1-a) x (1-b) x (1-c) x (1-d) x 100%

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 GHATGE PATIL

2.1 General Description

Annual Tonnage – 42,000 tonnes per annum.

Primary melting is carried out by means of three divided blast cupolas of 54" diameter. This metal is then duplexed into four induction furnaces, each of 4.5 tonne capacity. In order to increase the melting capacity, these induction furnaces are also charged with steel scrap and some returns. Conversion to ductile iron is carried out using a GF converter. Metal is poured into moulding boxes using an auto pour system.

Moulding is carried out using a Kunkel Wagner high pressure squeeze system on an automated greensand line. The box size is 1,150 x 750 x 400/350 mm. Cores are produced using semi-automatic cold box or shell machines.

The plant operates continually for 24 hours per day, 6 days per week.

2.2 Product Mix

The 42,000 tonnes per annum produced by Ghatge Patil can be divided into three production categories as follows:

GABH (Grey Iron Blocks and Heads)	–	1,260 tonnes (3.0%)
GAAG (Grey Iron Agricultural)	–	38,640 tonnes (92.0%)
DAGE (Ductile Iron Agricultural and General Engineering)	–	2,100 tonnes (5.0%)

An explanation of the categories is given in Figure 1.

2.3 Audit Results

2.3.1 Process Yields

During the audit period some 81,700 kg of metallic was charged either to the cupola or to the induction furnaces. The coke charged during this period represented 10.7% of the metallic material charged to the cupola. Allowing for a proportional allocation of the bed coke, the total coke consumed was 11.8% of the metallic material charged to the cupola.

Some 77,100 kg of molten metal was produced which equates to a melting loss of 5.6%. Metal poured into the moulds was not recorded, neither was the box yield of the castings produced.

However, the gross castings produced were 51,063 kg. The average scrap rate of 7.5% results in a net good saleable casting weight of 47,233 kg.

Thus some 57.8% of the weight of the material charged to the various furnaces resulted in castings that could be sold. A representation of the calculation of the Process Yield – where data is available – is given below.

Process Yield Calculation

Material Charged	81,700	100%	100%
Metal Loss	4,600	5.6%	
Liquid Metal	77,100	94.4%	94.4%
Pig and Spillage	N/R	N/R	
Metal in Moulds	N/R	N/R	///
Runners & Feeders	N/R	N/R	
Gross Castings	51,063	N/R	62.5%
Scrap & Rejects	3,830	7.5%	
Net Good Castings	47,233	92.5%	57.8%

Process Yield – 57.8%

2.3.2 Effective Production

The design capacity of the moulding line is 83 moulds per hour. Therefore during the period of the audit – some 5.25 hours – a total of 436 moulds could have been produced. No breakdowns or stoppages were reported.

During the audit period a total of 330 moulds were produced. This represents only 75.7% of the potential available. The moulding line is normally deliberately run slowly due to a general shortage of metal versus the line requirements.

Bad moulds were reported at 3.0% and the scrap level was 7.5% – see above.

Therefore the Effective Production for the plant was 67.9%. This means that the plant produced saleable castings for only 67.9% of the available moulding capacity operating time. The calculation of Effective Production is given below:

Effective Production Calculation

Production Time	436	100%	100%
Downtime	0	0%	
Operating Time	436	100%	100%
Slow Running	106	24.3%	
Moulding Output	330	75.7%	75.7%
Bad Moulds	10	3%	
Good Moulds	320	97.0%	73.4%
Scrap Castings	24	7.5%	
Good Production	296	92.5%	67.9%

Effective production – 67.9%

2.3.3 TEEP

The plant operates for some 300 days per annum for 24 hours per day. This equates to 7,200 hours or a plant utilisation of 82.2%.

However, when the plant is operating the Effective Production is only 67.9%. Thus the real plant utilisation or TEEP (Total Equipment Effective Production) is only 55.8% (82.2% x 67.9%). This means that the plant operates in such a way that it only uses 55.8% of its total capacity.

2.3.4 Energy

i) *Melting* – the cupolas consumed coke at the rate of 11.8% of the charged weight. Coke with an ash content of 12% ash has an energy equivalent of 7,966 kWh per tonne. Therefore the coke consumed during melting is equivalent to 940 kWh per tonne charged. As 62.27 tonnes of metallics was charged to the cupola during the audit period, this is equivalent to 58,534 kWh.

The electricity consumption – mainly for the induction furnaces – during the same period was 87,492 kWh.

Therefore the total energy consumed can be expressed as follows:

Cupola Coke	58,534 kWh
Electricity	87,492 kWh
	146,026 kWh

The total material charged to both the cupolas and the induction furnaces was 81.7 tonnes. Therefore the energy consumption per tonne charged equates to 1,787 kWh/tonne.

ii) *Overall Consumption* – during the time of the audit 47.233 tonnes of net good castings were produced giving a total energy consumption of 3,092 kWh per tonne of good castings.

2.3.5 Sand

New sand consumption was 0.23 tonnes per tonne of good castings. No figures were obtained for core sand usage or for moulding sand production and reclamation.

2.3.6 Productivity

No figures for manning levels or productivity were recorded during the audit.

2.4 Comparison of Results

In order for Ghatge Patil 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 Ghatge Patil audit data is compared to the average of all of the Kolhapur audit results.

Ghatge Patil vs. Kolhapur Cluster		
	Ghatge Patil	**Kolhapur Cluster**
Melting Loss	5.6%	6.8%
Pig & Spillage	N/R	4.6%
Runners & Feeders	N/R	19.7%
Scrap & Rejects	7.5%	4.6%
Process Yield	57.8%	68.1%
Downtime	Nil	Nil
Slow Running	24.3%	50.0%
Bad Moulds	3.0%	2.4%
Scrap & Rejects	7.5%	4.6%
Effective Production	67.9%	46.6%
TEEP	55.8%	28.8%
Energy Consumption Per Tonne Melted	1787 kWh	1057 kWh
Per Tonne Good Castings	3092 kWh	1770 kWh
Sand Consumption New Sand/tonnes castings	0.23 t	0.50 t
Cores/tonnes castings	N/R	0.08 t
Sand Reclamation	N/R	59.0%
Productivity Man hours/tonnes castings	N/R	48.9
Direct Ratio	N/R	4

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

2.4.2 Similar Foundries

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

Ghatge Patil Performance Comparison

	Ghatge Patil	Developing Countries		Western Europe	
		Average Performance	Best Practice	Average Performance	Best Practice
Melting Loss	5.6%	4.0%	2.8%	2.0%	1.0%
Pig & Spillage	N/R	3.9%	2.5%	2.0%	1.6%
Runners & Feeders	N/R	37.0%	30.6%	30.4%	25.5%
Scrap & Rejects	7.5%	5.6%	0.8%	2.5%	2.0%
Process Yield	57.8%	54.9%	65.2%	65.2%	71.1%
Downtime	Nil	33.9%	15.1%	15.0%	11.6%
Slow Running	24.3%	20.5%	2.0%	0.6%	0.3%
Bad Moulds	3.0%	1.7%	0.7%	1.0%	0.5%
Scrap & Rejects	7.5%	5.6%	0.8%	2.5%	2.0%
Effective Production	67.9%	48.8%	82.4%	81.6%	85.9%
TEEP	55.8%	18.4%	23.2%	62.7%	77.5%
Energy Consumption Per Tonne Melted	1787 kWh	1407 kWh	757 kWh	551 kWh	541 kWh
Per Tonne Good Castings	3092 kWh	4595 kWh	4422 kWh	1264 kWh	1088 kWh
Sand Consumption New Sand/t castings	0.23 t	0.52 t	0.43 t	0.30 t	0.27 t
Cores/t castings	N/R	N/R	N/R	N/R	N/R
Sand Reclamation	N/R	92.2%	95.3%	95.0%	96.0%
Productivity Man hours/t castings	N/R	38	20.6	10.6	9.1
Direct Ratio	N/R	N/R	N/R	N/R	N/R

The data above applies to large foundries with automated moulding facilities producing blocks and heads, other automatic and agricultural castings in both grey and ductile iron. 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 UK or Germany.

2.5 Conclusions and General Comments

2.5.1 Process Yield

The combined melting loss of cupola and induction furnaces was 5.6% compared to the Kolhapur average of 6.8% for the plants audited. However, the majority of plants in the Kolhapur Cluster are only cupola melting whereas Ghatge Patil operates a duplexing system with additional material being melted in the induction furnaces. Figures for the melting loss for similar plants in other parts of the world would be 4.0% for developing countries and 2.0% in Western Europe. The main reason for such a high melting loss figure is considered to be associated with the cupola operation:

- incorrectly designed DB cupola (wrong size and spacing of tuyeres)
- Blast rate and fan pressure not matched to cupola diameter and wind belt size.

The above two issues are also responsible for the slightly high charge coke consumption of 10.7%. A properly designed cupola would reduce the coke usage by some 15%.

Scrap and reject levels for the plant is 7.5% compared to the average for the Kolhapur Cluster of 4.6%. This difference probably reflects the more demanding and sophisticated market served by Ghatge Patil compared to other foundries in the cluster. The equivalent levels for similar foundries elsewhere would be 5.6% for developing countries and 2.5% in Western Europe.

The overall process yield figure for Ghatge Patil of 57.8% compares favourably with similar foundries in other developing countries (54.9%) but is less than would be expected in a Western Europe foundry (65.2%) producing similar castings.

2.5.2 Effective Production

No downtime was recorded for the plant. The moulding line is rated to produce 83 moulds per hour, but the plant is deliberately slowed down because of an overall shortage of melting capacity. During the 5.25 hours of the audit period, some 436 moulds could have been produced if the moulding line was operating at design capacity. In the audit period 330 moulds were produced. This represents only 75.7% of the potential plant capacity

There was a measured Bad Moulds figure of 3.0% (10 from 330) which is considered to be a little high for this type of facility. This compares to an average of 2.4% for Kolhapur Cluster, 1.7% for developing countries and 1.0% for Western Europe.

Taking into account the scrap level, the Effective Production of the plant is 67.9% which compares well with other foundries in the Kolhapur Cluster (average 46.6%) and with similar foundries in other developing countries (48.8%). Similar plants in Western Europe would operate at an average Effective Production Level of 81.6%.

2.5.3 Other Parameters

The energy consumed during melting was 1,787 kWh/tonne which compares with the Kolhapur average of 1,057 kWh/tonne. Plants that operate a duplexing system would be expected to have a slightly higher energy consumption, but not by this amount. The equivalent figure for other developing countries would be 1,407 kWh/tonne and for Western Europe 551 kWh/tonne. An important factor in the high energy consumption for melting is the incorrect design of the cupola and its ancillary plant as indicated above.

The overall energy consumption per tonne of finished castings is very high at 3,092 kWh/tonne compared to the remainder of the Kolhapur Cluster which has an average of 1,770 kWh/tonne. Ghatge Patil has much more equipment to operate than other foundries in the cluster and has additional energy losses in their auto pour and ductile iron nodularisation plant. However, this figure still appears to be quite high, even after taking these considerations into account. A similar foundry in Western Europe would operate at an average of 1,445 kWh/tonne of castings.

There were no sand reclamation or productivity figures quoted during the audit. Ghatge Patil should compare their own operational data to that for other parts of the world shown in the comparison above. The level of Effective Production has an impact on the plant's real capacity as is illustrated by considering the TEEP value which shows that Ghatge Patil only operates at a plant utilisation of 55.8% of its moulding capacity. This is, however, much higher than other foundries in the cluster which only average 28.8%. TEEP for Western Europe would average at 62.7% plant utilisation.

2.6 Potential Improvements

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

- reduce coke consumption
- reduce melting loss
- improve metal temperature
- increase melting rate
- reduce scrap levels

- reduce overall energy consumption per tonne of finished castings.

Since material costs represent 60% of the total operating costs of the foundry, a reduction in melting loss of 2% represents a reduction in total operating costs of 1.2%.

From the figures provided, coke appears to contribute some 6% of the operating costs so at the same time a reduction in coke consumption of 15% would reduce the total operating costs by 0.9%.

Thus improving the design of the cupola can add a minimum of 2.1% on the bottom line, which for a foundry of this type probably doubles the profit margin.

Ghatge Patil should investigate the provision of additional melting capacity in order to allow the moulding line to operate at design capacity. A resulting improvement in the Effective Production would take Ghatge Patil from a three shift operation to a two shift working pattern 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