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PRESIDENT MESSAGE

I am delighted to announce the start of Nova Cast, a computer simulation software training, at our Foundry Service Center at UET in May 2018.Foundrymen can now view their casting results right on their computer screens before actually casting them on the shop floor.

Potential casting defects can now be observed, gating systems can be changed, and shrinkages can be eliminated or reduced at the stage of technology development before casting. The best news for the industry is that casting simulation-Nova cast software will be available FREE for use by the foundries who will get their staff trained at Foundry Service Center. Our foundries will benefit a great deal from this access to technology.

We are grateful to the team of Qadri Group who explained the simplicity of use and staff required for the use of this software in awareness seminar on Casting Simulation Technology at UET. The awareness session was largely attended by the member of PFA and removed a lot of misunderstands on complexity of use in their minds.

As we prepare for the upcoming change in metal casting industry with CPEC, Pakistan Foundry Association (PFA) have formulated a delegation to participate in METAL CHINA Expo 2018 on May 16-19, 2018 at Beijing, China. Tianjin Foundry Association and Foundries are also included in visit. Our delegation will visit Tianjin Foundry Industries and meet the relevant industrial authorities who are planning to shift their business to Pakistan under joint venture or re-locations. I look forward to some very encouraging results from this effort.

This year, Pakistan Foundry Association (PFA) will hold 7th International Foundry Congress & Exhibition (IFCE) on 14-15th November, 2018 at Pearl Continental Hotel Lahore-Pakistan. I urge all PFA members to join hands and welcome all foundrymen in Pakistan and international foundry friends to participate in IFCE-2018.

Sikandar Mustafa Khan
President - PFA

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MODERN FOUNDRY PERFORMANCE MANAGEMENT USING (INTERNATIONAL) KEY PERFORMANCE INDICATORS.

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Abstract:

Foundry technology is the backbone of industrial growth in developing economies. At the same time, international market has become highly competitive and thus warrants operational excellence. A set of Key performance indicators developed by the World Bank while studying the foundry industry in Developing Country have been published in their benchmarking study. These KPIs and the drivers of operational excellence are very practical, highly relevant and provide excellent guidelines to the Foundry Businesses in Pakistan. In this document we will discuss the performance management (measurement) criteria, the drivers of operational excellence - their definition and contents and some guidelines for achieving operational excellence. Each foundry aspiring to benchmark itself can suitablymodify the parameters according to the technology employed, processes deployed and the customer requirements at each location.

Of the total potential for better resource management and efficiency, roughly 50 percent can be achieved solely through the implementation of low-cost initiatives and improved management practices: the remaining half requires some capital expenditure or refurbishment.

Foundries can achieve optimum potential - in terms of resource efficiency, competitiveness, and profitability by measuring and monitoring operational excellence KPIs,related to:

A. People - motivation, attitude, skills and knowledge,

B. Processes - built around lean, optimization and effectiveness,

C. Technology - designed to deliver capacity, capability and ease of use.

According to leading consultants one third of change-management programs success depends on the behavior and motivation of individuals. Establishing an environment conducive to the implementation of optimum resource efficiency depends notonly on setting key objectives and determining progress but also a mechanism to continuously monitor and gauge trends and effectiveness.

Setting up a dedicated project team (with both internal and external specialist advisors) can be a good first step here: the involvement of external experts acts as a catalyst in eradicating redundant processes and habits, as well as generating new ideas.

Benchmarking using industry best practices is one of the options readily available and it through this article it is emphasized that the implementation of this approach the operational excellence can be achieved.

About the author:

This report has been compiled by Ghazanfar Ullah Khan who is a management trainer and consultant in the local and International market in manufacturing arena related to the industry. He has to his credit the privilege of having worked in international foundries - Pakistan, Germany and China, and to have developed, installed and commissioned a large brownfield lost wax steel casting Foundry. Management of such a complex operation gives him the rare insight into the foundry practices prevailing in Germany, and P.R. China.

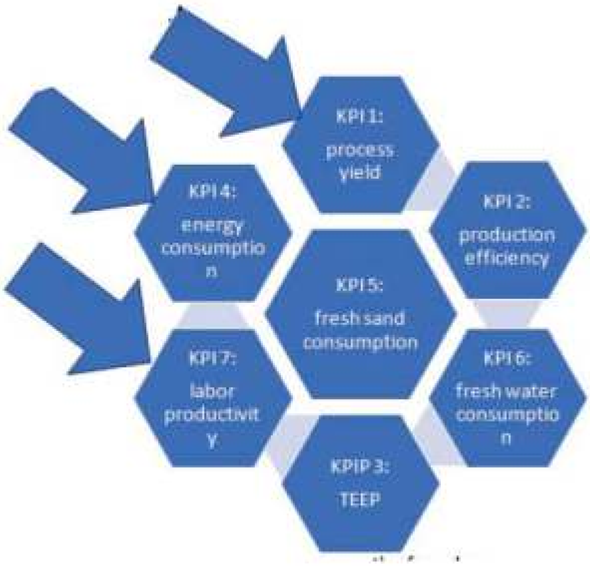
The following KPIs are essential to clearly depict the resource utilization efficiency and to monitor the operational excellence within a foundry.

KPI 1 "Process Yield."
KPI 2 "Production efficiency"
KPI 3 "Capacity utilisation"
KPI 4 "Energy consumption"
KPI 5 "Sand consumption"
KPI 6 "Fresh water consumed"
KPI 7 "Labour productivity"

KPI 1 Process Yield

This KPI consists of four sub-indicators:

a) KPI 1.1 melting loss (%)
b) KPI 1.2 pig and spillage (%)
c) KPI 1.3 runners & risers (%)
d) KPI 1.4 scrap & rejects (%)



KPI No. 1.1, "Melting loss"

"Melting loss" is 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. The melting loss includes:

- a "necessary" loss, to achieve the required chemical composition for the desired alloy properties;
- an "unnecessary" loss, resulting from sub-optimal material qualities, production processes, and technology.

The impacts of melting loss on the performance of a foundry include:

- A direct impact on the consumption and cost of raw materials.
- A direct impact on energy costs (since the lost metal has been melted).

In case the melting capacity is a bottleneck in the foundry:

- an impact on capacity utilisation (capital costs);
- an impact on labour costs (productivity).

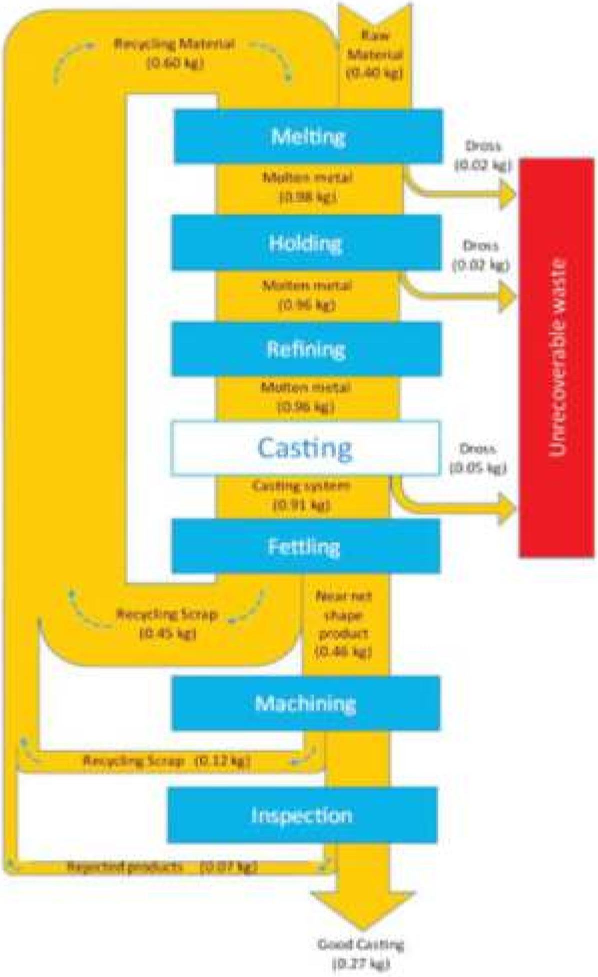
Excessive Melting loss depends on:

I. the quality of charged material;
ii. the sequence of charged material;
iii. holding time at high temperatures;
iv. incorrect on inferior refractory application;
v. poor slag chemistry control;
vi. inadequate melting equipment.

To Improve KPI 1.1 "Melting Loss"

To reduce "Melting loss:" select charge material of the correct quality. The composition of the "cold set-up" of raw materials must fit the required final cast material specification, to:

a) avoid the later addition of missing alloy/trim additions;
b) avoid additional metallurgical steps to reduce elevated chemical elements;
c) Ensure the raw material is kept dry and purchase alloy additions with a low content of chemically bond water inside:
d) humidity causes chemical reactions resulting in oxidation and hydration, as well as losses of various important chemical elements;



I. moisture influences the consumption of elements initially provided to compose the required specification;
ii. ensure the raw material is kept free from dirt such as oil, grease, sand, rust, etc.: dirt of this kind is weighed and charged but does not contribute to the amount of liquid metal: it must therefore be replaced by additions;
iii. the emission of oxygen or other gases in the melt leads to increased burn-off or excessive slag;

Follow the optimum sequence when charging material:

- avoid incorrect cold set-up sequence will lead to inhomogeneous melt, which finally results in higher burn-off (stirring by overheating and convection);
- avoid non-metallurgical overheating and extended holding times:
- higher temperatures and longer periods of time rapidly increase losses;
- melt as quick as possible and accomplish the necessary overheating;
- avoid high corrections between melting and tapping by adjusting the metal analysis in the charge preparation.
- apply the correct refractory (lining of the furnace);
- if the melt and refractory do not fit together the melt will chemically react with the refractory, leading to elevated slag, burn-off, and conglomerates.

Control slag chemistry carefully:

- if slag control is poor some important elements may be trapped in the slag and need to be replaced later.
- Use appropriate melting technology:
- for each melting system (induction, cupola, arc, etc.) the melting loss is fixed within a certain range. Despite this, losses can be reduced by upgrading equipment to state-of-the-art technology;

Modern state-of-the-art equipment has improved performance in the following ways:

- higher-energy density increases the melting rate and reduces losses over time;
- better heat-exchange processes allow much higher energy transfer effectiveness and thereby reduce losses over time.

KPI 1.2 "Pig and spillage" refers to the amount of liquid metal tapped from the furnaces (and which does not get poured into moulds), expressed as a percentage of the liquid metal tapped. The impact of pig and spillage loss on the performance of a foundry is as follows.

a. About 5- 10 % of pig and spillage is lost material and must be disposed of; such material cannot be recycled since it contains ingredients which are not required in the next scheduled charges.

b. The remaining 90-95 % of material can be recycled but:

i. further losses occur with melting loss;

ii. it is necessary to add further alloys or trimming additions;

iii. further energy is required for melting;

iv. further melting capacity and labour are required at the melt shop;

v. if the melt shop is the bottleneck, further plant capacity and labour are consumed.

Losses incurred through pig and spillage vary:

- depending on the melting process;
- in relation to moulding technology: the hand-moulding process always involves excess molten metal, necessary to avoid insufficient metal available especially for large castings.

Reasons for excessive pig and spillage loss include:

a. incorrect metal analysis;

b. incorrect metal temperature in the ladle;

c. moulding line breakdown after tapping;

d. inadequate pouring technology and procedures.

How to improve KPI 1.2, "Pig and spillage:"

a) Release melt for pouring only in line with correct metal analysis:

- install test equipment at the furnaces for:
  - o thermal analysis;
  - o wedge test;
  - o spectrometer;

b) Ensure the correct metal temperature in the ladle:

- use preheated ladles;
- measure temperature beforetapping;
- closely synchronise tapping with progress at moulding.

c) Minimise moulding line breakdown time:

- Develop comprehensive patterns maintenance strategy;
- Maintain all equipment in good working condition. Manage proper spares;

d) A robust and synchronised production plan should be:

- Ensured throughout the entire manufacturing system (including the melting, moulding, cores, and pouring functions);
- sufficiently flexible to allow alterations without the need to change melt batches.

e) Ensure adequate pouring technology and procedures:

- choose an appropriate pouring technology, from:
- manual ladle pouring for medium-sized (mechanised moulding) to largecastings (manual moulding);
- automatic pouring (auto-pour) for castings on automated moulding lines;

f) update and maintain appropriately skilled manpower;

More castings are produced for the same amount of liquid metal, resulting in:

- savings in energy consumption;

- savings in labour;
- improved capacity utilisation;
- savings in the cost of materials (alloy and trimming additions).

KPI 1.3 "Runners and Risers"

The losses arising from runners and risers vary in accordance with:

- casting materials (designed to material-specific properties such as volume deficit (cubic contraction, micro-porosity, macro-porosity, shrinkage, etc.);
- the type of product (large-series castings will be optimised whereas in small series and single castings a sub-optimum is acceptable);
- the type of process (mould rigidity);
- the geometry of castings: this also influences the proportion of runners and risers

Reasons for low box yield include:

- runners too large for the size of castings;
- feeders larger than is necessary;
- large pouring cups;
- an insufficient number of impressions per mould;
- size of moulding box inappropriate for casting size.

How to improve KPI 1.3, "Runners and risers:"

a) Redesign the running system (runners, feeders), including:

- balance systems;
- use of insulating and exothermic sleeves;
- use of predictive solidification simulation packages (mainly for steel).

b) Optimise the dimensions of pouring cups:

- ensure the pouring cup is of the smallest size possible, consistent with the speed of metal delivery;
- where, appropriate an auto-pour system allows the size of the pouring cup to be minimised.

c) Improve mould utilisation:

- use appropriate mould packages of a size appropriate to the size of the casting;
- improve mould utilisation by increasing the number of impressions per mould;
- ensure adequate mould rigidity

KPI 1.4 "Scraps and Rejects"

This KPI monitors the weight of scrap castings (including customer returns), expressed as apercentage of the weight of gross castings produced.

The scrap and general quality requirements based on Western specifications and customer requirements should be used as benchmarks;

The impact of reducing the volume of scrap and rejects on the performance of a foundry is as follows.

a. More good-quality castings are produced in proportion to the same volume of gross castings, resulting in:

- savings in energy consumption;
- improved labour productivity;
- improved capacity utilisation;
- savings in material costs (alloy and trimming additions);

b. better relationships with customers, leading to fewer losses through customer returns. The losses connected to scrap and rejects vary in relation to:

c. material applications (e.g., X-ray requirements for oil-related steel castings);

d. the size of the series run (higher series have lower scrap levels).

There are many reasons for excessive scrap castings and high scrap levels, but they generally involve:

- insufficient process controls;
- incorrect metallurgy;
- sand-related problems;
- casting design;
- incorrect manufacturing processes.

How to improve KPI 1.4, "Scrap casting and rejects:"

a) Use a systematic approach to identifying potential causes, and set clear priorities:

b) investigate scrap levels by weight, volume, and cost;

c) identify high scrap items by product type, individual castings, and defect causes;

d) implement an improvement programme targeted at the highest scrap values.

e) Implement product process control procedures and data collection, to include:

f) manufacturing process control data (e.g., analysis and temperature controls, etc.);

g) metallurgical requirements (e.g., microstructure, hardness, etc.);

h) sand properties;

I) customer requirements on casting quality (acceptance standards).

j) Carry out continuous improvement and updating of process control data.

k) Ensure all design is conducted based on optimum manufacturing efficiency

l) Re-equip the foundry with production processes and/or equipment most suitable for the castings being produced.

2. KPI 2 Production Efficiency

"Production efficiency" refers to the utilisation of the time available for production. Production efficiency ("Overall equipment efficiency" (OEE)) refers to the utilisation of the time available for production. It refers to the time used to produce good-quality castings, expressed as a percentage of the planned time available. This KPI comprises four sub-indicators:

a) KPI 2.1: Down time (%);

b) KPI 2.2: Slow running (%);

c) KPI 2.3: Bad moulds (%);

d) KPI 2.4: Scrap castings (%).

This KPI has an impact on:

- increased labour productivity;
- improved capacity utilisation.

KPI No. 2.1, "Down time" (moulding)

The time lost due breakdowns or other operational reasons, expressed as a % age of the total available time. It impacts:

- More gross castings are produced during the same time, resulting in:

o better labour efficiency;

o better capacity utilisation.

However, the losses due to downtime differ according to moulding technology:

- manual moulding (less complicated equipment, with fewer breakdowns);
- mechanised moulding lines (more breakdowns due to more equipment involved, and downtime for virtually all breakdowns).
- automatic moulding lines have higher breakdown risks and but have better early warning systems in place.
- Within automatic and mechanised moulding differences in performance relate to different types of moulding processes:

o high-pressure boxed (green sand);

o flaskless vertically parted (green sand);

o mechanised pattern flow .

Reasons for excessive downtime include:

a) mechanical and electrical stoppages;

b) waiting periods and delays for metal or sand;

c) a high number of pattern changes;

d) operational and/or organisational inefficiencies;

e) poor scheduling.

How to improve KPI 2.1, "Downtime (moulding):"

a. Use a systematic approach to identify the main causes of downtime:

- investigate stoppage times by cause;
- identify incidences of high or frequent stoppage and rectify these;
- structure and classify the reasons for downtime, in terms of:

o equipment failures;

o inadequate support services (waiting for metal, sand, cores, etc.);

o organisational shortcomings (scheduling, pattern changes, etc.);

b. inadequate management control. Implement a sound maintenance strategy to reduce breakdowns:

- define maintenance strategy in terms of:

o targeted equipment;

o preventive maintenance, predictive maintenance;

o monitoring of the condition of plant and equipment;

- maintain adequate spare parts to support maintenance strategy;
- develop trained and skilled maintenance teams.

c. Ensure adequate supplies of metal, sand, and cores to moulding lines:

- organise the production processes;
- eliminate bottlenecks.

d) Reduce the impact of pattern change through improved scheduling.

e) Ensure adequate staffing levels and ensure personnel are fully trained, with the correct professional attitude.

2.2 KPI 2.2, "Slow running"

This KPI monitors the production time lost through the operation of a moulding facility below design capacity or calculated output, expressed as percentage of the net operating time.

The impact of reducing slow running in foundry is more gross castings are produced over the same period, resulting in:

- improved labour productivity;
- better capacity utilisation.

The losses connected to slow running vary in accordance with moulding technology:

- the manual moulding rate is controlled by people and production rates fall below standard easily;
- in mechanised and automatic plants, the moulding speed is machine controlled but can be stopped or slowed by personnel;
- within automatic and mechanised moulding, the differences in performance relate to the type of moulding process in accordance with production parameters, affecting both mechanised and automatic lines, including:
  - core setting requirements;
  - casting cooling requirements;
  - residual stresses;
  - pouring rate.

Reasons for excessive slow running include:

a) difficulty in casting to mould in normal machine cycle time;

b) a series of small stoppages occurring and not recorded as downtime;

c) individual operations not synchronised with moulding operations;

d) long pouring times for very heavy castings;

e) poor supervision.

How to improve KPI No. 2.2, "Slow running" (moulding):

a) Monitor any incidences of slow running, investigate the reasons for this, and rectify them.

b) Among the large variety of solutions, three categories are evident:

- organisational improvements which can be influenced by management, such as:
  - the unauthorised reduction of moulding speed, or stoppages by personnel;
  - downtime not recorded as such;
- production restrictions which usually cannot be improved without investment, such as:
  - moulding and core setting not possible within machine cycle time;
  - long pouring times for heavy box weights;
  - inadequate supervision:

In the above-mentioned cases it is important to ensure employees carry out the required operations within stipulated time periods.

Impact on the bottom lineresults in:

- improved labour productivity, since reduced productivity on the moulding line can have implications throughout the production chain;
- better capacity utilisation, because capacity utilisation on the moulding line is often the decisive capacity, insofar as slow running on the moulding line reduces the output of the total plant, and that the correlating equipment costs are wasted.

2.3 KPI 2.3, "Bad moulds"

This KPI monitors the number of moulds produced that are not poured: it is expressed as a percentage of the total number of moulds produced. The impact of fewer bad moulds on the performance of a foundry is:

- More gross castings can be produced over the same period, resulting in:
  - better labour productivity;
  - improved capacity utilisation;
  - the potential saving of cores placed in bad moulds.

The losses arising from bad moulds vary according to the moulding technology:

- manual moulding: bad moulds can sometimes be repaired;
- at mechanised and automatic plants, only minor defects can be rectified.
- Within automatic and mechanised moulding, the differences in performance relate to the various types of moulding processes:
  - high-pressure boxed (green sand);
  - flaskless vertically parted (green sand);
  - mechanised pattern flow.

Reasons for excessive bad moulds include:

a) the condition of the sand used;

b) the condition of the patterns used;

c) problems in moulding machine alignment;

d) non-poured moulds.

How to improve KPI 2.3, "Bad moulds":

Ensure appropriate sand conditions:

a) monitor and investigate appropriate sand properties and adjust to required level.

b) ensure pattern equipment and tooling are properly maintained;

c) put in place a comprehensive procedure for the inspection of pattern equipment and tooling:

- after every production all pattern equipment, core boxes, and tooling must be cleaned, polished, and checked;
- dimensional checks should be carried out on pattern equipment, and castings produced on a regular basis ;

d) improve the design and construction of tooling:

- ensure appropriate core print fit, radii, draft angle, etc.;
- ensure appropriate tooling relative to production volumes.

e) Ensure correct moulding machine alignment:

- measure the position of the pattern plate bolster to the squeeze plate;
- check the stripping action of the pattern, relative to the bolster;
- measure the position of the pattern plate relative

to the mould box closure system (check castings for mismatch);

- for automatic moulding lines, implement frequent checks of test pieces;
- rectify and adjust the moulding line accordingly.

f) Avoid producing moulds which are not poured.

Impact on the bottom line.

The major impact of reducing the frequency of bad moulds will be in making possible the production of more gross castings during the same period.

Other benefits include:

g) improved labour productivity, since greater productivity on the moulding line (due to fewer bad moulds) will ensure production is maintained at the intended output levels;

h) improved capacity utilisation, because capacity utilisation on the moulding line is often the decisive capacity (since other bottlenecks are assumed to have been eliminated): reducing the production of bad moulds here will reduce waste in correlating equipment costs and wasted core.

3. KPI 3 Capacity Utilization

Total effective equipment performance (TEEP) measures overall equipment effectiveness (OEE) in terms of calendar hours - i.e., 24 hours per day, 365 days per year. Total effective equipment performance per annum is expressed as a percentage of total plant capacity, assuming operation for 24 hours per day, 365 days per year.

Improving a foundry's TEEP will result in:

- a better return on overhead costs;
- more effective utilisation of capital employed.

Total effective equipment performance varies in accordance with various factors.

- Moulding technology:
- the higher the capital investment, the greater the capacity utilisation required.

- In automatic and mechanised moulding, differences in TEEP in connection with OEE performance relate to various types of moulding processes:

- high-pressure boxed (green sand);
- flaskless vertically parted (green sand);
- mechanised pattern flow

Reasons for low TEEP include:

- a low level of OEE;
- insufficient orders;
- limited access to electrical power; excessively high electricity tariffs during peak hours.

How to Improve KPI 3, "TEEP:"

Total effective equipment performance is driven by loading, multiplied by OEE. Since "loading" (the percentage of total calendar time that is scheduled for operation) will usually be limited by the orders a foundry can produce, three scenarios need to be considered, as follows.

If a foundry is not subject to any limitation in respect of orders (such that the foundry could produce maximum volumes within its existing installed capacity and operational performance standards), then:

- eliminate all technical bottlenecks that reduce capacity (e.g., limitations in power supply, ancillary departments, etc.);
- restructure the organisation and the workforce to operate at maximum capacity: for example, increase the working schedule from two shifts (i.e., in operation for 16 hours a day) to three shifts (in operation 24 hours per day), and from five days per week to seven;
- increase OEE;
- If a foundry is suffering from insufficient orders, take measures to increase these:

- If a foundry is currently seeking new customers in export markets improve skills in operations about customer requirement standards and improve sales and marketing skills to develop international business.
- If there is no intention of increasing sales volumes at all, then downsize (after due consideration of all financial implications). This will ultimately result in a more competitive plant, operating at a higher level of capacity utilisation:

- through the removal of excess capacity at all levels of the plant (or group of plants), including moulding, melting, workforce, overheads, etc.;
- because of consolidation within the foundry sector (through the disposal and outsourcing of foundries within vertically integrated enterprises, and through mergers and acquisitions, etc.), as has happened and continues to occur throughout Europe.

The major impact of improved TEEP is:

- better utilisation of capital employed. The capital invested in allowing the foundry to operate at the intended capacity should be utilised to the greatest possible extent, to ensure that the cost of such capital is not wasted;

- better utilisation of overheads
- better capacity utilisation need not, necessarily, involve higher overheads if the additional volumes produced are within an existing product category.

4. KPI 4Energy Consumption

KPI 4.1 "Energy consumption in melting"

KPI 4.2 concerns "Energy consumption in foundry,"

The KPI 4.1 "Energy consumption in melting" ("Melting efficiency"), monitors the furnace power consumption (kWh) divided by the tonnage of metallic material charged to the furnaces. Increasing melting efficiency has the effect of reducing energy costs. Energy consumption varies in accordance with induction melting:

- iron castings: by alloy type and manufacturing process;
- steel castings: by alloy type;

Reasons for low energy efficiency in melting include:

a) holding liquid metal for long periods of time;
b) electrically inefficient equipment;
c) outdated processes for operating the melting process (specific to arc furnaces);
d) low power density of some furnaces, causing long tap-to-tap times (specific to arc furnaces).

KPI 4.2 "Energy consumption in foundry"

	Europe		Developing Country	
kWh/ton of good casting	Best practice	Average	Best practice	Average
Grey iron	1000-1305	1169-1483	1521-4533	2939-5428
Ductile Iron	1284-1566	1744-1758	2344-3539	3322-5016
Steel	1165-2088	1391-2676	2874-6996	3285-7464

Raw materials and energy constitutes one of the most important cost factors in a foundry's operations: the energy involved in melting can often be a factor in limiting capacity.

KPI 4.2 concerns "Energy consumption in foundry,"

This KPI monitors total energy consumption (kWh) across various foundry departments, divided by the tonnage of net good castings produced. Decreasing energy consumption in a foundry has the effect of reducing energy costs. Energy consumption within a foundry varies in accordance with:

- the material, alloys, and processes involved in melting;
- other additional factors, including:

o variations in process yield;
o variations in heat treatment operations

Reasons for high total energy consumption include:

a. inefficient melting plant;
b. extensive heat treatment cycles;
c. inefficient heating and ventilation systems;
d. insufficient awareness of energy efficiency.

How to improve KPI 4.2, "Energy consumption in foundry:"

a. Improve "Energy consumption in melting;"
b. Check the condition and efficiency of heating, ventilation, and extraction systems, and rectify as necessary;
c. Inform and educate employees on energy efficiency and conservation.

The sand used in making moulds should be recycled and regenerated as far as possible. A perfectly designed and effectively operating sand regeneration plant will reduce the costs of buying sand and will also improve the quality of castings.

KPI 5.1 "Fresh Sand consumption"
(tonne sand used/tonne of core produced)

	Europe		Developing Country	
	Best practice	Average	Best practice	Average
Grey Iron	0.160-0.87	0.19-0.98	0.22-1.22	0.52-2.60
Ductile Iron	0.17-0.37	0.20-0.41	0.25-0.51	0.33-1.10
Steel	0.17-0.87	0.19-0.96	0.24-4.37	0.51-5.39

KPI 5.1, "Fresh sand consumption" monitors the weight of new (fresh) sand used, divided by the volume (tonnes) of net good-quality castings produced. This indicator includes the sand used in moulding as well as sand used in the production of core.

KPI 5.2, "Rate of sand regeneration" monitors the percentage of sand that is re-used in each moulding cycle (expressed as an average of all moulding cycles included in the sampling period).

KPI 5.1 "Fresh sand consumption"

Reducing the consumption of fresh sand has the effect of reducing material costs. Consumption of fresh sand varies in accordance with:

- product type, and the extent and complexity of core-making requirements;
- the extent of recovery of core material before shaking out (e.g., engine blocks).

Reasons for excessive consumption of new sand include:

a. large or intensive core-making requirements;

b. a low sand-to-metal ratio, causing high sand burn-out;

c. poor-quality sand (roundness, size distribution, refractoriness, pH, etc.).

How to Improve KPI 5.1, "Fresh sand consumption:"

a. Where possible, use hollow and/or back-filled cores.

b. Improve sand-to-metal ratios to reduce high sand burn-out. Note:increasing sand-to-metal ratios (and hence improving rates of sand consumption) should not be carried out at the expense of reducing the box yield and, subsequently, the process yield.

c. Improve the quality of sand purchased.

d. Improve system sand properties (compactability, shatter, etc.): refer to process control measures elsewhere in this document.

e. Review shake-out operations:

- check the separation of core sand if possible;
- ensure system sand is not carried out with castings;
- check all processes to insure sand is not lost at shake-out.

Impact on the bottom line. Reducing fresh sand consumption reduces the costs of raw materials.

Improving KPI 5.2, "Sand regeneration"

KPI 5.2 "Sand regeneration"				
Moulding process	Europe		Developing Country	
	Best practice	Average	Best practice	Average
Automatic	92-98%	91-97.5%	9398.4%	91.8-96.6%
Mechanised	88-98%	84-95%	84.2-97.6%	74.7-93.6%
Manual	84-98%	82-95%	82.2-95.3%	79.3-91.8%

regeneration"

This KPI monitors the percentage of sand that is re-used in each moulding cycle (expressed as an average of all moulding cycles included in the sampling period).

Sand regenerationshould be carried out at an optimum level for individual products and processes, bearing in mind certain factors, including the following:

- core intensity;
- the addition of new sand. Additions must be made at a minimum of 10 percent of the metal weight if the appropriate weight of cores is not added; if this is not carried out the system sand will become unusable;
- increasing the rate of sand generation does not necessarily represent an improvement in performance.
- The rate of sandregeneration differs in accordance with:
- the type of system sand used (green sand or chemical-bonded);
- the extent of core requirements and complexity;
- the moulding process.

Reasons for low rates of sand regeneration include:

a. high core usage;

b. high burn-outlevels;

c. poor sand quality;

d. the choice of resin binder system (e.g., for the same volume of base sand a furan binder will reclaim at a higher rate than an alkaline phenolic system);

e. the surface requirement of the casting, resulting in the need for a separate facing sand.

To improve KPI 5.2, "Sand regeneration:"

a) Regarding burn-out levels and sand quality issues:

b) Review the selected binder system in chemical-bonded plants:

- investigate alternative binder systems that have greater potential for reclamation;
- mixed binder

mixed binder systems tend to have greater potential for reclamation than mono-systems.

c) The same factors that reduce new sand consumption will also improve sand regeneration levels. Impact on the bottom line. The better a foundry's sand regeneration the lessnew sand must be bought.

KPI No. 6, "Fresh water consumption"monitors the fresh water consumed per unit of product (e.g., per tonne of net good castings produced). Reducing fresh water consumption has the effect of reducing utility and service charges for water. Volumes of fresh water consumption vary in accordance with:

- the moulding medium used (green sand, chemical-bonded sand, etc.);
- systems and cooling requirements;
- equipment cooling requirements;
- heat treatment cycles that have a quench requirement.

KPI 6 "Fresh water consumption"				
m3/ton good castings	Europe		Developing Country	
	Best practice	Average	Best practice	Average
Grey Iron	0.60-1.10	0.78-1.25	2.5-25.5	5.0-218.7
Ductile iron	0.60-0.81	0.71-1.06	6.4-59.2	54.7-435.6
Steel	0.60-1.50	0.76-1.77	2.5-27.3	10.6-234.1

Reasons for high levels of fresh water consumption include:

a. heat treatment cycles involving water quench;
b. excessive green sand temperatures requiring high cooling rates by evaporation;
c. process water for green sand systems;
d. general evaporative loss from cooling systems;
e. low efficiency of cooling systems;
f. the use of water-based dust cleaning systems

To improve KPI 6, "Fresh water consumption:"

1. Some reasons for high levels of water consumption cannot be changed:

heat treatment is necessary to reach required properties;

- in areas of high ambient temperature/humidity more water is required for evaporative cooling.

b) Reduce sand cooling requirements by reducing sand temperature:

increase the storage volume of sand in the sand system, thus increasing the dwell time before sand re-use and thereby reducing cooling requirements; this may also have the additional benefit of improving the overall sand quality;

- reduce sand-to-metal ratios, thereby reducing sand temperature and thus reducing cooling requirements. Note: increasing sand-to metal ratios (and hence improving rates of sand consumption) should not be carried out at the expense of reducing the box yield and, subsequently, the process yield.

c) Maintain correct sand properties (particularly moisture/clay relationships) as this will avoid producing sand that is too wet.

d) Reduce cooling water requirements for ancillary plant:

- ensure all cooling systems are operating effectively, and replace defective systems;
- replace water-based dust collection systems with dry-bag filters (this replacement will be necessary at some point in any case, to meet environmental standards).

e) Where possible, replace fresh water with collected surface water (rain water) instead of taking water from the distribution network. Impact on the bottom line. The financial impact of reducing fresh water consumption is lower utility and supply costs.

KPI No. 7 Labour productivity

Comparative results for KPI No. 7, "Labour productivity"

KPI 7, "Labour productivity" monitors the total number of man-hours worked (excluding management and supervisory hours) divided by the tonnage of net good castings produced. Improving labour productivity has the effect of: reducing direct labour costs;

potentially reducing certain related indirect overhead costs. Labour productivity varies in accordance with:

- manufacturing processes (automatic, mechanised, or manual);
- the volumes produced (volume regression effect);
- the degree of automation (e.g., block grinder, rotary grinder for discs, etc.);
- the extent of process requirements on casting type (e.g., the greater degree of processing involved in steel castings).
- (man-hours/tonne of good castings)

(man-hours/tonne of good castings)				
Moulding Process	Europe		Developing Country	
	Best practice	Average	Best practice	Average
Automatic	5-25	10-34	19.7-89.8	36.2-173.9
Mechanised	12-27	19-37	16.1-101.7	31.9-162.7
Manual	22-30	24-40	24.0-114.2	52.9-234.7

Reasons for low labour productivity include:

a. over-manning;
b. low standards of automation;
c. poor management of certain business processes and operational practices;
d. poor performance levels of production equipment.

To improve KPI 7, "Labour productivity:"

1. Conduct a full review of manning levels:

2. identify and clarify the roles and responsibilities of all personnel (both on the shop floor, and in management);

3. establish clear staffing levels for each department within the plant:

- based on existing equipment;
- based on increased automation following investment.

4. Develop a new and improved manning strategy: "

5. reduce manpower consistent with a) above; "

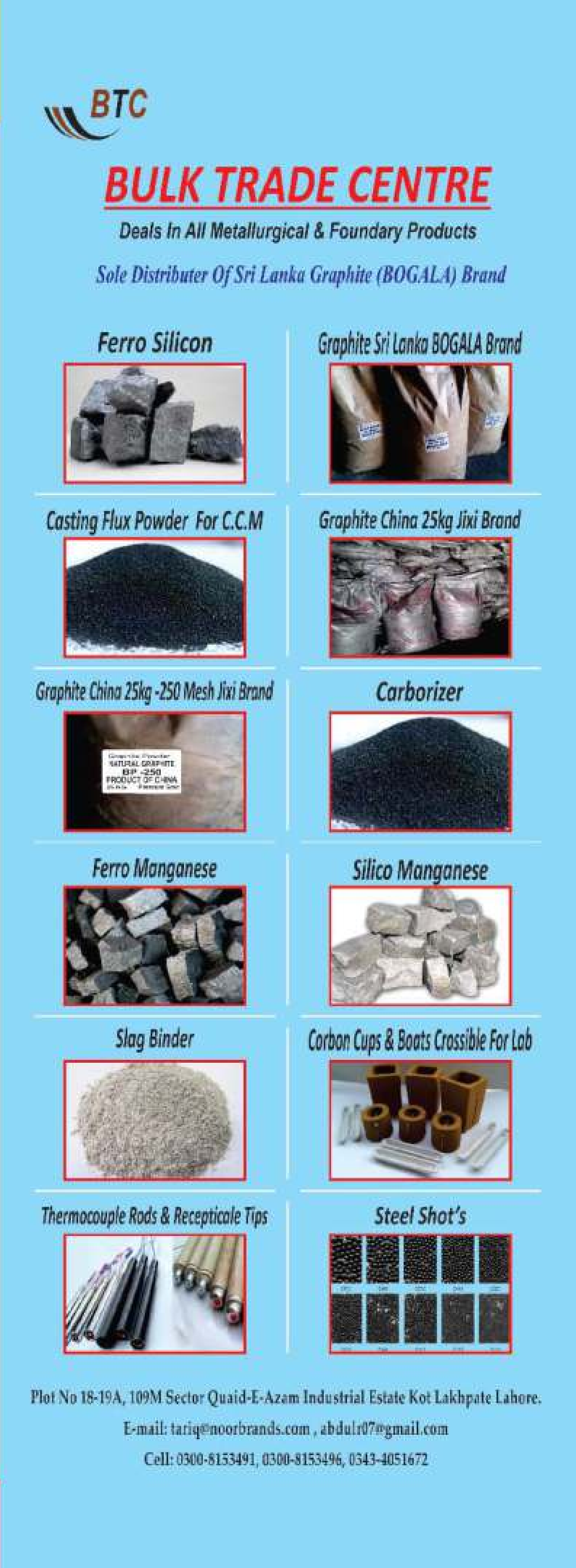
6. where manpower reductions are not possible develop an investment programme to increase automation levels (e.g., using materialshandling equipment, etc.); "

7. conduct training sessions (for shop floor employees and management) to familiarise the workforce with any necessary changes in working practices.

Before investing in greater automation existing equipment should be made to operate more effectively wherever possible.

Impact on the bottom line. The major impacts of improved labour productivity are: " lower direct labour costs; " potentially lower related indirect overhead costs.

Overall Foundries Key Performance Indicators Iron and Steel	Europe	Developing country
	Overall weighted	Overall weighted
	Average performance	Average performance
1.Process yield (%) from four sub-indicators)	69.4	62.5
melting loss (%)	5.2	4.6
pig and spillage (%)	3.0	3.3
runners & risers (%)	24.0	29.9
scrap & rejects (%)	5.4	6.7
2. OEE (moulding) (%) (from four sub-indicators)	77.5	48.4
downtime (%)	14.2	22.7
slow running (%)	6.7	20.3
bad moulds (%)	1.1	5.6
scrap & rejects (%)	5.4	6.7
3. TEEP (%) Capacity utilisation	63.0	32.8
4. Energy consumption (kWh per te produced) for melting (kWh/te melt)	880**	1184**
for casting (kWh/te cast)	1483	4800
5. Sand consumption (per ton good casting)		
Fresh sand (te sand/te cast)	0.348	1.282
Sand regeneration (%)	84.0	58.2
6. Fresh water consumed (m3 per te good casting)	0.80	144.58
7. Labour productivity (man-hr/te good casting)	21.5	76.2



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Three part no bake alkyd
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Phenolic urethane gassing cold box
Hot box system for ferrous & non ferrous
Furan no bake (steel, SG, CI, NF)
CO_2 cured phenolic
Inorganic no bake system

Coatings

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Graphite spirit/water based
Alumino-silicate mix refractory spirit/water based
Magnesite spirit based
Graphite water base for metallic trough
Bismuth base coating
Coating for lost foam process
Tellurium base coating
Sulphur blocking coating

Other Foundry Consumables

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Release agents
- Release agent for green sand mould
- Release agent for alkaline phenolic no bake system
- Release agent for cold box
- Parting agent for shell (water / solvent based)
- Aluminium based release for no bake system

Core joining paste

- Hot to hot
- Cold to cold
- Cold to cold (ultra fast)

Collapsible agent for silicate
Mould sealing rope
Surface hardner for green sand mould
Sealing compound for mould and core
Silicon carbide, zirconia foam filters
Ceramic sand
Chromite sand
Slag coagulant (perlite ore)
Sand Additives (Sphereox) of Chesapeake Specialty Products, USA
Furnace & refractory cleansing fluxes of ASI International, USA
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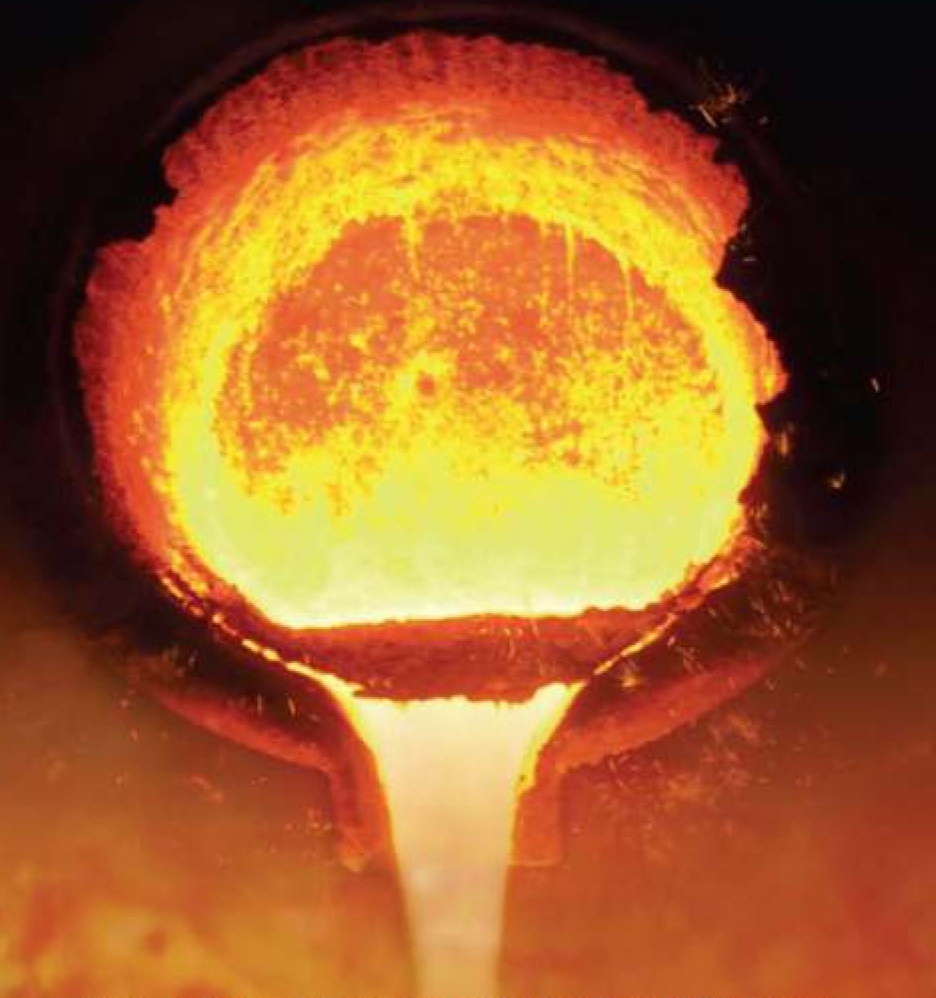


DESIGNING CASTING METHODS USING 3D MODELS

J.F. Meredith
Casting Solutions Pty Ltd
Courtesy: Metal Casting Magazine

Introduction

One of the most fundamental problems facing the foundry engineer is developing an adequate design and position of risers for feeding a casting.Most alloys contract as the liquid metal cools and solidifies, and this contraction must be compensated for by providing risers (or "feeders"). The riser is essentially a reservoir of molten metal which flows into the casting cavity as the casting allo cools and contracts, thus preventing shrinkage porosity from forming with in the casting and ensuring a sound part. The approaches taken by foundries to design adequate risers vary widely. Some rely on exper ence and instinct, which takes the design process essentially into the realm of art.Others rely on calculations to determine riser size and location. The classical approach to estimation of riser size is to calculate the volume and cooling surface area of various parts of the casting. The ratio of volume to cooling surface area (V/CSA) is known as the modulus, and is generally expressed in centimetres. Regions of the casting which have the lowest modulus values solidify first, while those parts of the casting which have the highest modulus solidify last. According to Chvorinov's Rule, which has been in use for many years in the foundry industry, solidification time is proportional to the square of the calculated geometric modulus value.

Using these facts, one can fairly easily derive a few simple design rules. Since the riser must be able to provide feed metal, it should remain liquid longer than the region of the casting to which it is attached. This means that the riser should have a higher modulus than this region, so that it freezes later. Also, to provide progressive feeding from thinner sections to thicker sections, a casting should ideally be designed such that section thicknesses (and modulus) increase progressively from the thinner sections to the thickest sections where the risers are to be attached.

Another consideration in riser design has to do with the volume of feed metal required. The volume of metal which a casting requires is a function of the amount of total contraction that it undergoes from pouring to solidification. The volume of metal which a riser can provide is a function of the volume of the "pipe", i.e., the void which represents the amount of liquid drained from the riser. This pipe is deeper and more pronounced in open-top risers which are not sleeved; in these risers, less of the total volume of the riser is available as feed metal. In risers which are sleeved and/or hot-topped, more of the metal tends to remain liquid during the solidification process, so more of the total riser metal is available to feed. The amount of metal required by the casting must be equal to or exceeded by the amount that the riser can deliver, or shrinkage porosity will likely form.

In general, in heavy-section castings, the modulus values govern the design of the riser; in "rangy" castings (those with large dimensions but thinner wall sections), the volume consideration often is the governing factor. While these concepts are relatively simple and straightforward, their implementation in casting design is not. This is primarily due to the difficulty in calculating volumes and surface areas for complex, real-world castings. The approach which has been taken by most foundry engineers is similar to that of weight calculation; the

THE RATIO OF VOLUME TO COOLING SURFACE AREA (V/CSA) IS KNOWN AS THE MODULUS, AND IS GENERALLY EXPRESSED IN CENTIMETRES. REGIONS OF THE CASTING WHICH HAVE THE LOWEST MODULUS VALUES SOLIDIFY FIRST, WHILE THOSE PARTS OF THE CASTING WHICH HAVE THE HIGHEST MODULUS SOLIDIFY LAST.

castingisarbitrarilybroken into anumberofpieces, and each of these pieces is approximated by a simplegeometricshapeforwhichsurfaceareaand volume can be calculated. Several software programs and worksheets for performing these calculations are currently in use. In practice, however, this process is cumbersome and inexact;thearbitrarinessofapproximatingacasting shape with a series of simple shapes reduces both repeatability and accuracy. Another intrinsic problem with this method is that it is based only on geometry, and does not directly take into account thermal effects such as specific properties of chilling or insulating materials and heat saturation of cores or various areas of the mould. Some factors have been proposed for correcting for these effects,but the introduction of such factors only increases the uncertainty surrounding the accuracyofresults.

A new approach

In recent years, computer simulation of the casting process using accurate three dimensional models has become in creasingly widespread.Suchsimulations can,in manycases,very accurately predict the progressive solidification of the casting and its rigging system,along with the potential for for mation of various casting defects. However, one of the significant drawbacks of casting simulation is that it requires an initialdesigntosimulate.Itis ironicthatmostfoundries, even those using the most advanced simulation tools, still use a traditional approach to developing the initial design to submit for simultion.

Since most new casting designs are available today in 3D CAD format from the casting buyer, it seemed that it should be possible to develop a methodology for riser calculations that is both more accurate and more automated than those used by the industry today. The starting point for this development was the idea that the modulus approach is essentially an attempt to estimate the solidification times of various parts of the casting prior to attaching the rigging. However, using modern casting simulation software,the solidification time of every point with in a casting can be calculated very quickly, and does not need to be estimated. It is often the case that, having downloaded a 3D CAD model by email, it is possible to run a simulation of the casting with in just a few minutes, using the Finite Difference Method, to obtain solidification time information throughout the casting.

The next question was how to relate this information to potential risers of various sizes and type swhich might be attached to the casting. At this point,having simulated only the casting with no risers,we can not directlycompare the solidification time of any arbitrary riser with the casting. The answer to this question was the development of a calculation which could convert the solidification times in the casting to equivalent thermal modulus values. This would allow theusertodirectlycompareariserwiththecasting, since a modulus value for a riser can generally be calculated easily. In order to develop such a procedure, it was necessary to devise a formula which would take into account the wide range of properties of the diverse array of casting alloys which are poured today, so that the resulting modulus values would be accurate no matter what alloy was being poured.

IN RECENT YEARS, COMPUTER SIMULATION OF THE CASTING PROCESS USING ACCURATE THREE-DIMENSIONAL MODELS HAS BECOME INCREASINGLY WIDESPREAD. SUCH SIMULATIONS CAN, IN MANY CASES, VERY ACCURATELY PREDICT THE PROGRESSIVE SOLIDIFICATION OF THE CASTING AND ITS RIGGING SYSTEM, ALONG WITH THE POTENTIAL FOR FORMATION OF VARIOUS CASTING DEFECTS.

Another question to be answered was whether, given an array of modulus values with in the casting, a system could be devised which would recognise separate feeding areas within the casting and thus give advice as to how many risers would be required,and where they should be located. This has been accomplished by development of pattern- recognition software which is able to locate isolated areas of high modulus values, which are essentially "hot spots" in the casting which need to be fed. In some more rangy castings, there may be many such areas; therefore the system must be able to discriminate between very small areas which don't need feeding, and larger areas which do. The level of discrimination can be set by the user, by adjusting a "slider bar" from a "Less Sensitive" position to a "More Sensitive" position.

Once the individual feed areas are identified, an appropriate modulus value and the volume of each feeding area is known, it is relatively simple to apply known rules (as discussed above) to calculate the correct size riser for each area. Also, by plotting the location of the maximum modulus values within each feeding area, we can pinpoint the required attachment point for each riser. Of course, the actual attachment point is subject to considerations such as parting line location, ease of removal, machine locating points and other practical issues.

Using this methodology, what amounts to an almost automatic calculation of required risering for a casting is achieved. The starting point is a 3D model of the casting, which can be transmitted from a CAD system. Then, the alloy and mould material are selected and a simulation with no risers is run. With a few clicks of the mouse, the system then analyses the simulation results, calculates modulus values, and suggests the number and location of required risers. The details of each riser are then provided by calculations which embody riser design rules based on modulus and volume requirements.

There are many reasons that such an approach provides more accuracy than traditional design calculations. One is the accuracy

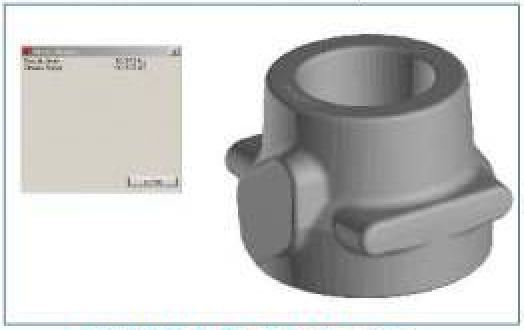


FIGURE 1. Model of casting.

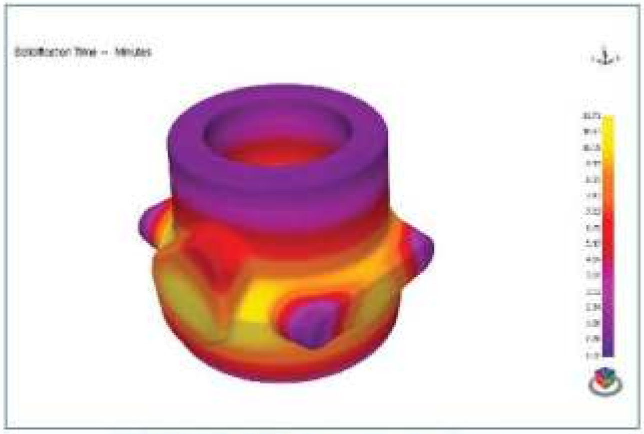


FIGURE 2. Plot of solidification time.

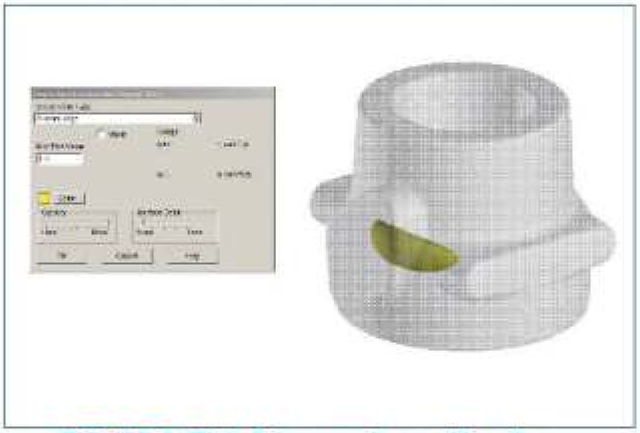


FIGURE 3. Plot of riser number and location.

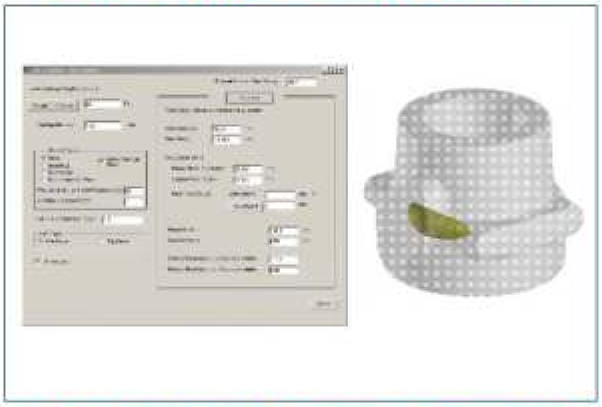


FIGURE 4. Riser size calculation based on 2 castings per riser.

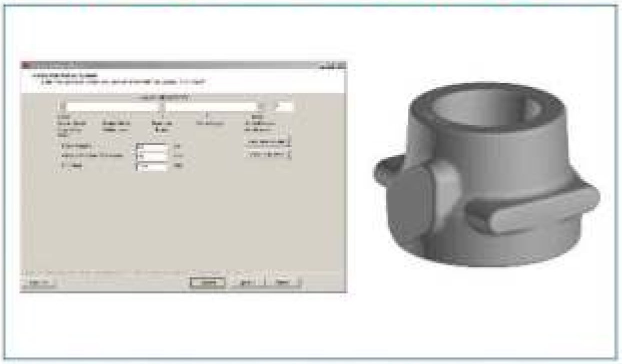


FIGURE 5. Determination of gating requirements.

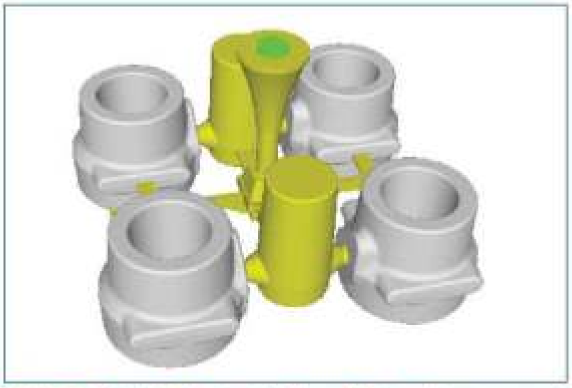


FIGURE6. Model of fully rigged design with 4 castings per mould.

of the 3D model, which provides more exact geometry than is usually considered. Another is that, by running a simulation, thermal effects such as heat saturation of cores are accounted for explicitly.It would also be possible to place chills on the casting model, and even gating for a mould-filling simulation which would accommodate the effects of heat loss during filling. All of these effects are difficult to account for explicitly when performing traditional design calculations. It is generally recommend that, after a rigging design is completed using this procedure, a verification simulation be run with the actual geometry of the calculated risers. However, it is expected that the percentage of "first-time" simulation successes would be considerably higher using this approach.

As an example of how this approach might be applied, consider the casting model shown in Figure 1. Designing the risering for this casting begins with selecting the casting alloy and mould material, which in this case are ductile iron and green sand. A Finite Difference mesh is generated, and a simulation is run with no risers attached. The result of this simulation is shown in Figure2 as a plot of solidification time throughout the casting. The next step is to apply the formula which converts the simulation data to modulus values.This is done simply by clicking a button, as shown in Figure 3. This operation calculates a modulus value for each point within the casting. After this calculation is performed, the pattern-recognition algorithm is then applied to the modulus values,so that individual feeding areas within the casting can be identified and the result is a display which in dicates the number of suggested risers to produce this casting. In this case, the system has suggested a single riser in the position indicated in Figure 3. The modulus data and the volume of each of the feeding areas can be displayed, based on the results of the modulus and pattern calculations. Along with consideration of the metal chemistry and temperature as well as mould type, the dimensions of a riser for each area can be determined. The system is also capable of determining gating requirements based on determination of an optimum fill time for the casting in question. Figure 5 shows the determination of optimum fill time based on 4 castings per mould.Using this information, the suggested risers and gating is added to the casting model and a verification simulation run. This is an important step, as it must be realised that the riser size calculations are approximations and cannot take into account all of the complex thermal interactions which occur in a fully-rigged casting. The fully rigged casting assembly is shown in Figure6, and the simulation results, are as shown in Figures 7, 8 and 9. The macro-porosity prediction (the yellow area in Figure 9) shows clearly that the volume provided by the risers was sufficient to feed the casting without formation of internal shrinkage porosity in the castings.

THERE ARE MANY REASONS THAT SUCH AN APPROACH PROVIDES MORE ACCURACY THAN TRADITIONAL DESIGN CALCULATIONS. ONE IS THE ACCURACY OF THE 3D MODEL, WHICH PROVIDES MORE EXACT GEOMETRY THAN IS USUALLY CONSIDERED.

Conclusion

Thus, within a time span of just a few minutes it was possible in this case to fully design adequate risering for this casting, given a CAD file transmitted from the customer. The user's effort to perform these calculations is minimal, primarily just clicking on a few menu items and buttons on the screen. There are a number of issues in confluence today which make such an approach critical for a foundry to consider. First is the requirement by customers for shorter lead times as well as pressure to reduce cost and casting prices, meaning that getting the casting process designed correctly and quickly is imperative. Second is the wide availability today of 3D CAD models for most new castings. Third, and not the least in importance, is the fact that many experienced foundry engineers are nearing retirement age, and they are being replaced by younger people without the years of experience needed to develop a "feel" for the casting design process. Providing an automation tool to these younger engineers can dramatically increase their productivity in designing casting processes.

JUST A FEW MINUTES IT WAS POSSIBLE IN THIS CASE TO FULLY DESIGN ADEQUATE RISERING FOR THIS CASTING, GIVEN A CAD FILE TRANSMITTED FROM THE CUSTOMER.

FIGURE 7. Mould filling showing temperature distribution.

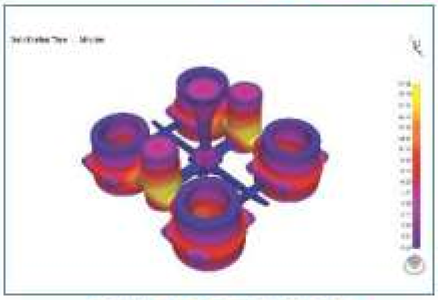


FIGURE 8. Solidification simulation.

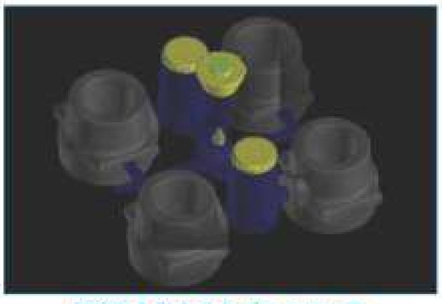
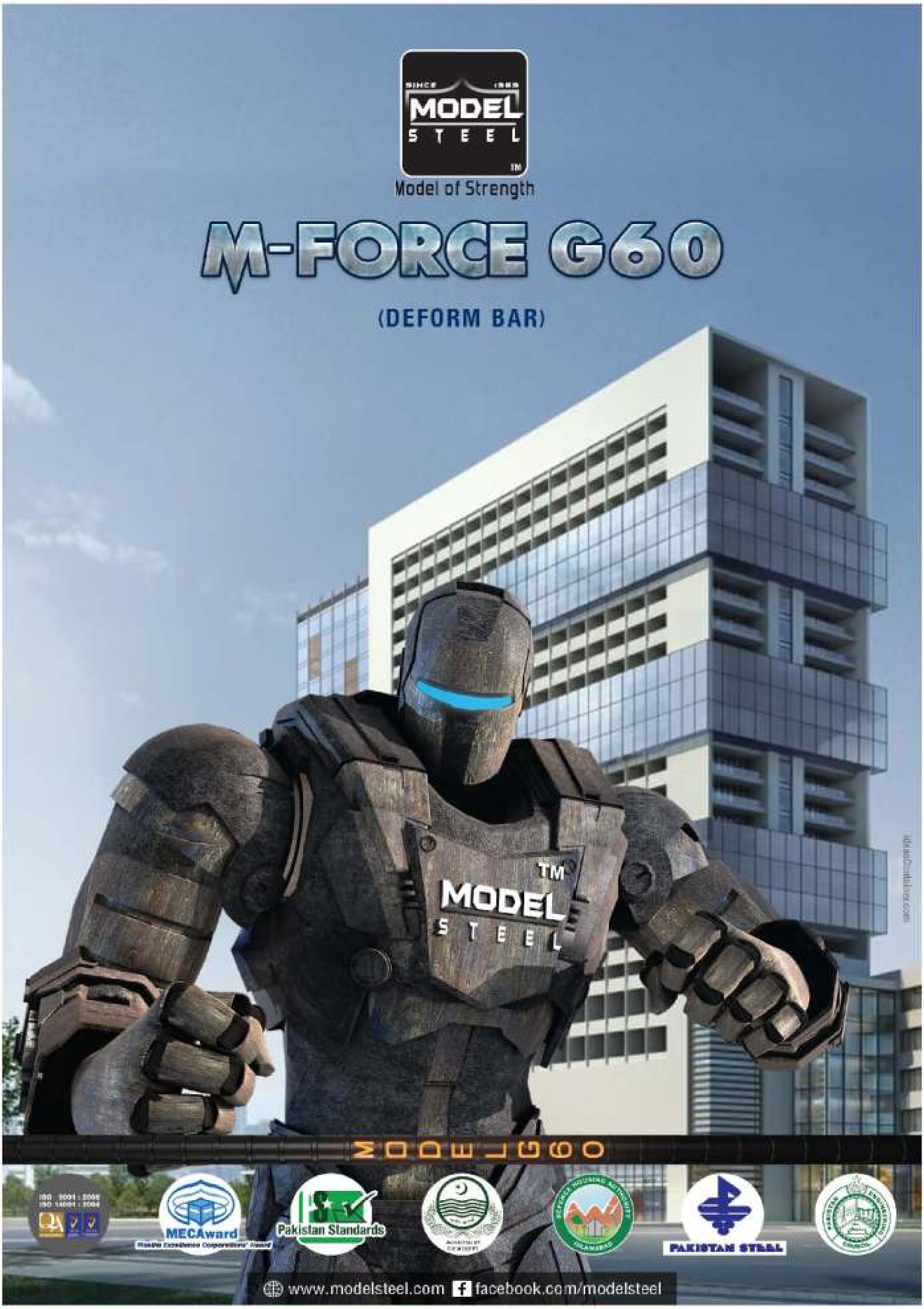


FIGURE 9. "X-Ray" plot of macro-porosity.



MELT SHOP WITH CUPOLA AS MELTING MEDIUM – ENERGY EFFICIENCY DESIGN & OPERATION

S.SKarkhanis
Foundry Consultant & Member,
Panel of Experts, IIF-NCTS

Introduction

In India, 90% of iron foundries use cupola as a melting unit. As the cost of energy skyrockets, more and more attention is paid to energy-efficient cupola, by improving the combustion reactions, prolonging the heat time or by using additional external energy. These modifications are mainly, equi-blast, auxiliary blast, oxygen enrichment, water cooling, hot blast and divided blast cupolas. Cupolas are also modified to work on gas (called coke-less cupola) and there is also the plasma cupola. Under present Indian conditions, divided blast cupolas working on coke are found to be the most energy- efficient melting unit.

What is divided blast cupola?

Divided blast cupola is a modified version of the conventional cupola (Fig. 1). The divided blast cupola has one additional wind box over the normal wind box of the conventional cupola. Single fan type, high discharge pressure blower supplies air to both the upper and the lower wind boxes through two pipes. The blast pipes are fitted tangentially to the respective wind boxes. As far as possible, bends are avoided in the wind pipes.

Both the upper and lower pipes are fitted with a butterfly valve to control air passing through it. Separate air blast volume meter and pressure gauge are fitted in each pipe to record the air volume and pressure passing through each of the pipes. This air further passes through the upper and lower row of tuyers connected to respective wind boxes. The air distribution through upper and lower pipes is 30:70 per cent, 40:60 per cent or 50:50 per cent, depending on various factors of furnace design. The distance between the upper and lower row of tuyers is about one metre. The coke bed height is about 90cm above the upper row of tuyers.

As the air passes through the upper row of tuyers, additional coke is needed for preparing coke bed. The coke bed height of the divided blast cupola is about one metre higher than that of the conventional cupola.

Divided blast cupola (DBC) is an energy-efficient and economical unit, operation training of which can be imparted very conveniently. As the main principle is to divide the air between upper and lower tuyers, measurement and proper monitoring of air volume and pressure at both the pipes is essential.

To get the desired results viz (1) Metal temperature (2) Melting rate (3) Coke: Metal ratio (4) Trouble-free cupola operation, it is necessary to design the DBC taking into consideration of all the technical aspects very meticulously.

Advantages of divided blast cupola

- Reduction in coke ratio.
- Rise in tapping temperature.
- Increase in melting speed.
- Increase in steel scrap.
- Reducing the sulphur pick-up in metal.
- Lowering the temperature of exhaust gases.

In the conventional cupola lining, burn out is deep, whereas in the divided blast cupola, as the blast is divided, the penetration of the blast is less, and hence, there is less consumption of refractory. (Figs 2 & 3).

Fig 1: Divided blast cupola (DBC)

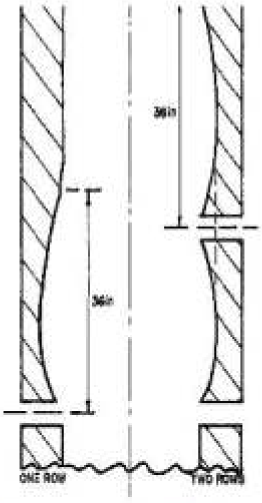


Fig 2: Pattern of lining burn out with single blast and divided blast cupola

Significance of divided blast cupola

There are two points of view, as mentioned below. Secondary air blast is provided above the main tuyer to burn CO gas coming up in the de-oxidation zone and to use the combustion heat. This may result in the following:

(1) Metal pre-heating in the pre-heating zone is enhanced. Or

(2) The melting zone is expanded, the melting position is raised a little, the falling distance of molten drops is increased and furnace temperature is raised to increase melting and super-heating effects.

In a divided blast cupola, position of the upper tuyer and ratio of blast volume of the upper and lower tuyers are to be determined according to the purpose.

- When pre-heating solid metal, upper tuyers shall be provided in places at a distance of 2 to 3 times the furnace diameter from lower ones and their blast volume may be 15% of the total volume, when the amount of CO gas in flowing gas in the pre-heating zone is estimated to be 13% to 15%.
- While expanding the melting zone, ensure sufficient super-heating of molten drops. Upper tuyers shall also be provided in the coke bed; they shall be at a height of 1.0 to 1.2 times the furnace diameter from the level of lower tuyers. The blast volume through upper tuyers is considered adequate to be equal to lower ones.

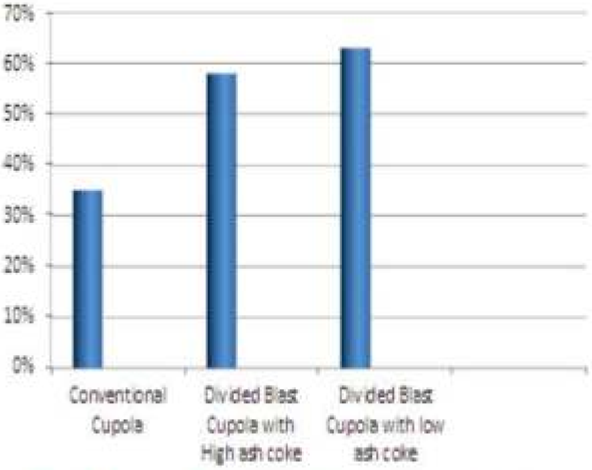


Fig 3: Energy efficiency of different types of cupola

Factors responsible for increasing the energy efficiency of the divided blast cupola Effluent Gases:

- 1. The total air has to be divided and blown in separately through two sets of wind belts and tuyers at different levels. The vertical distance between two rows of tuyers is 1 metre. Pressure and volume of air is measured separately by two sets of manometers and volume flow meters. In front of the lower tuyers, the combustion is oxygen- deficient and therefore, a large amount of CO is formed ($2C+O_2=2CO$). Conventional cupola has about 10%-12% CO in exhaust gases. The sole purpose of secondary air through the upper tuyers is to burn this CO to CO2 and utilise the full energy of carbon to burn to CO2 (Fig 4).

The above procedure leads to coke savings, ranging between 20% and 45% (Figs 5 & 6).

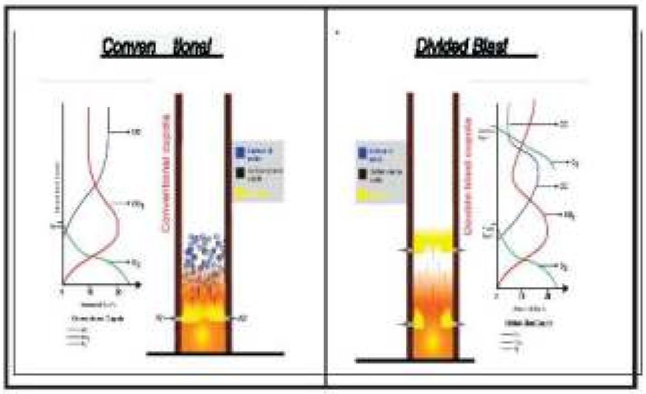


Fig 4: Comparison of effluent gases

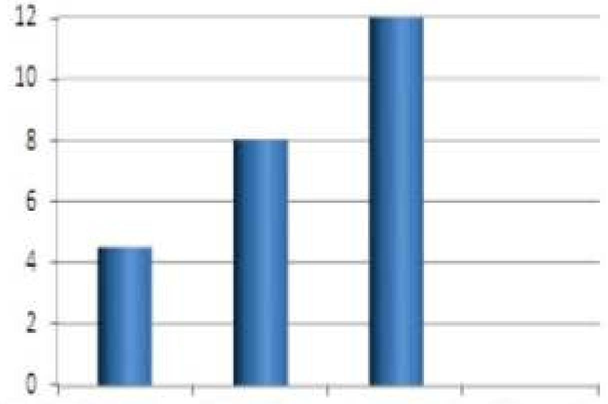


Fig 5: Comparison of Fuel consumption (kg Melt / kg coke)

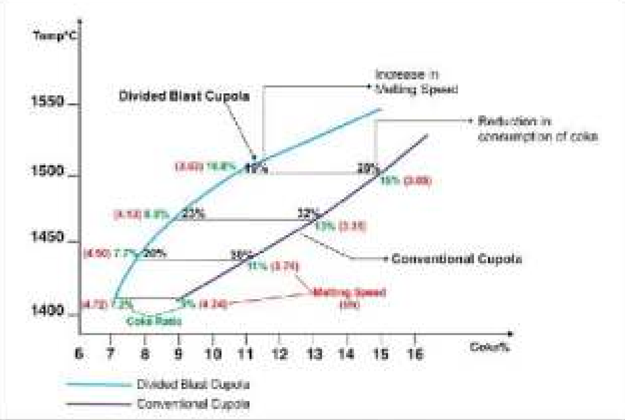


Fig 6: Comparision of coke consumption

2. As the effluent gases contain less amount of heat-laden gases, the temperature of flue gases is about 150 C as against 800 C of short conventional cupolas (lower shaft height).

3. The volume of gases increases exponentially. With reduction of the temperature of the exhaust gases, the volume of outgoing gases is drastically low for the divided blast cupola, and hence, handling of exhaust gases is easy.

4. With less amount of exhaust gases, the size of the pollution control equipment reduces.

Thermal balance between conventional cupola and divided blast cupola is shown in Fig 7.

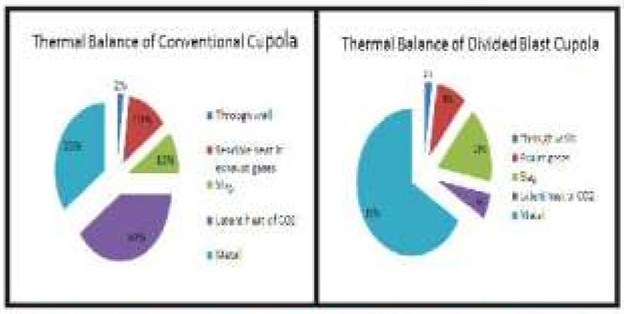


Fig 7: Thermal balance of conventional & divided blast cupola

Energy Savings of DBC over Conventional Cupola

Savings in coke	10%-15%
Savings in refractory	20%
Silicon manganese loss	5% as compared to 15% in case of conventional cupola
Carbon gain	20% better than conventional cupola
Rise in metal temperature	50°C
Reduction in pollution	30%
Cupola operation	Operation friendly with no poking of tuyers

Case Study

For a typical foundry, cupola of capacity 2 tonnes per hour, melting 20 tonnes per heat, and fired 12 times per month, the coke savings per month will be 6 tonnes ie 72 tonnes/annum; and emission reduction will be 13.2 tonnes CO_2/annum.

Practical tips for efficient cupola operation

- Coke bed - Unless the bed is properly put in, there will be problems during the entire campaign. There should be written procedures and checklists for this operation.
- Refractory repair - After the bottom is dropped, the lining must be cleaned and repaired. Unless the lining is properly repaired, operational problems will occur. Unfortunately, repairs are done when there is little or no supervision. This operation should be carried out as per written procedures and proper training.
- Coke - Keep it dry! Wet coke makes calculation of the correct charge weight difficult. Over-coking or using extra bumps to compensate occurs. This increases the coke consumption.
- Dirt, small metallics, rust etc should not be charged. The charge is to be screened over a ½ inch screen. The screen needs to be clean and in good condition. This reduces the requirement for additional limestone or supplemental fluxes, decreases refractory attack and avoids excessive back pressure.
- Thin, leafy (tin can) steel should not be charged. It oxidises quickly and readily picks up sulphur. Railroad tie plates, spikes etc should not be charged, because they are usually highly oxidised. Highly oxidised scrap, regardless of price, is very expensive! Dirty, rusty scrap will increase slag generation and reduce overall metal handling efficiency.
- Very large pieces of metallics should not be charged ie over 1/3 the cupola diameter. These pieces disrupt the entire operation of cupola. Very large pieces invite disaster!
- Coke breakage should be avoided - Easy to

say but hard to accomplish. Coke will be weaker in the future! Rough handling will cause serious breakage.

- Coke size is important. Larger is not always better. Coke size should be 1/10-1/12 the diameter of the cupola when it is added at the charge door. Buying large-size coke (knowing some will end up as fines during handling) creates a mixture of large and small sizes, reducing combustion efficiency.
- The ½ inch x down coke fines should be screened out. If the bottom is dropped after a short period, going to longer campaigns is to be considered. Refractory suppliers may be of considerable assistance.
- Cupola has to be kept full - no excuses!
- The ideal melting rate for the cupola is to be determined. This is calculated by determining the cross sectional area of the tuyers, the hearth and the blast rate. If the numbers indicate an imbalance, they should be corrected. This may require a larger blower, different diameter tuyers, etc., but making the changes will increase the efficiency of the cupola. The sales department should be aware of the ideal number. This figure is as important as the ideal production of moulds per hour, the core making capacity, etc.
- New and better refractories come into the market everyday. Living with refractory problems is to be avoided.
- Cupola stack height must be sufficient to ensure pre-heating of charge and to reduce exit flue gas temperature.

- Weight of a single piece of metal should be limited to 1% of the hourly melting rate.

Role of air control instrumentation

To attain maximum efficiency of cupola, it is essential to measure pressure and volume of the air blast (Fig 8). The pressure decides penetration of the blast in the coke bed, horizontally as well as vertically. The coke bed height is a direct function of the air pressure. Cupola blast volume is calculated by considering the coke charge weight. It is the desired volume of air supplied to the cupola. If the air volume is low, the operation will be deficient of air, not all the coke will be burnt, resulting in increase in coke bed height, and thereby producing cold metal. On the other hand, if the air is in excess, it will oxidise the metal lower the bed height and again produce cold metal. If desired air pressure and air volume is supplied, the cupola works most energy efficiently. With minimum coke, it will produce maximum heat in the coke bed. This will improve the metal and slag temperature. The fluid slag will not adhere to the lump of coke. This will expose maximum coke. The fluid slag will carry more sulphur, producing metal with less sulphur, ending in producing the hottest metal.

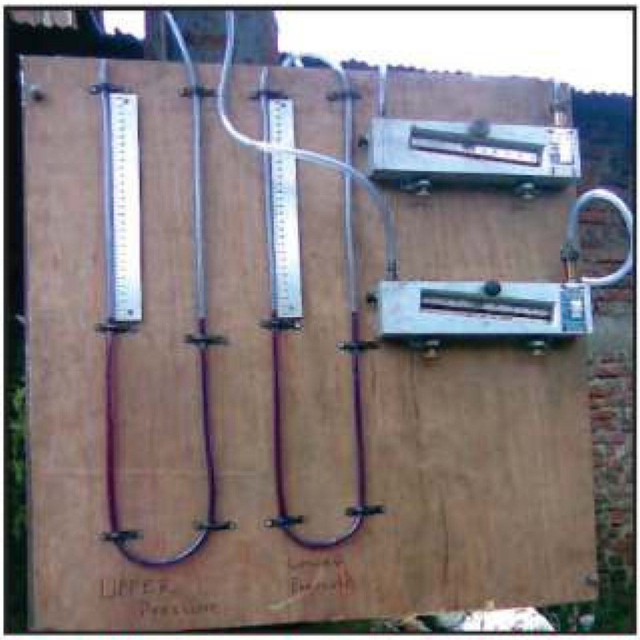


Fig 8: Air Pressure gauge and volume meters for divided blast cupola

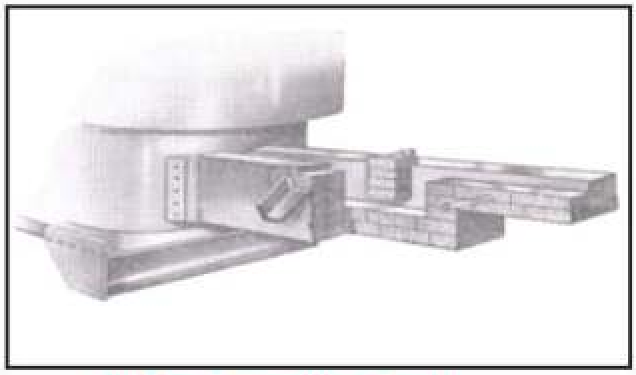


Fig 9: Front slagging cupola spout

Role of front slagging spout ((Fig 9) in increasing energy efficiency of cupola

- Saves bed coke substantially.
- Improves metal temperature.
- Reduces sulphur content of the metal.
- Avoids blocking of the slag hole due to sticky slag and enlargement of slag hole.
- Avoids blocking of the tap hole, during longer time intervals between the tapping.
- There will be no leakage of air through tap

hole, thus reducing temperature losses and improving the energy efficiency.

Refractory Lining

Types of Cupola Refractories (Bricks)

S No	Quality	Specifications						Fire brick application area
		Al_2O_3%	Fe_2O_3%	A.P.%	BD Min Gms/cc	CCS Kg/cm²	RUL(TA) °C	
1	IS 6	30	3.5	28	2	250	1300	Cupola stack, Cupola outer layer
2	IS 8	40	2.5	26	2.1	250	1350	Cupola preheating zone
3	High Duty	40	3	24	2.3	300	1400	Cupola melting zone, back-up layer
4	Super Duty	60	1.5	20	2.5	450	1600	Cupola melting zone, cupola well

AP - Apparent porosity; BD - Bulk density; CCS - Cold crushing strength

Longer the duration of heat, lesser the coke consumption, cupola becomes more energy-efficient. For longer duration of heat, it is necessary to use better refractories.

Requirements of the Right Refractory

General requirements of a refractory material can be summed up as:

- Its ability to withstand high temperature and trap heat within a limited area like a furnace.
- Its ability to withstand action of molten metal, hot gases, slag erosion etc.
- Its ability to withstand load in service condition.
- Its ability to resist contamination of the material with which it comes into contact.
- Its ability to maintain sufficient dimensional stability at high temperature and after/during repeated thermal cycling.
- Its ability to conserve heat.

For hotter metal and increased melting rate, it is essential to use a better quality refractory. For cupola operation up to 2 days, use of high alumina bricks (70% alumina) is recommended in the melting zone and in the hearth. For even longer duration of heat, use of silicon carbide bricks is recommended.

Charge Composition

For energy-efficient cupola operation, it is necessary to maintain desired density of metal, coke and flux. The weight of a single piece of scrap should be no more than 10% of the charge weight. Desired coke size is 15% of the cupola diameter. The flux size should be 2" for smaller cupola and 3" to 4" for bigger cupolas. The correct size and weight of the material gives good permeability to upward moving gases.

Important steps towards energy savings

When the cupola blast is put on and if the charged material is cold then the heat produced is consumed in preheating the charge material. Further, part of the heat from the molten metal is taken by the refractory to raise its temperature. Hence, to reduce the initial spell of the cold metal, the following steps are advised:

- Always pre-heat the charged material before starting the heat. After charging is started waiting is to be done for 40 to 60 minutes to get the material pre-heated properly.

- During this pre-heating period, it is necessary to keep all the tuyer covers fully open. If the tuyer covers are closed, draft will not enter into the cupola stack and pre-heating will not take place.

- For pre-heating the refractory lining, at least two hourstime is to be allowed for the entire coke bed to become red hot. The entire coke bed should be added in three instalments (50%, 30% and 20%). This ensures that the entire coke bed is red hot and no black spots are left.

- To completely avoid the initial cold metal, if the cupola is run in the morning, then the bed is to be prepared in the evening (about 8 hours prior to starting of the blower). Wood is to be fired, 40% of the coke bed is to be put. Now all the tuyers and the service door have to be closed. Only the tap hole is to be left open. Let the coke burn slowly and thoroughly, throughout the night. In the morning, bed coke is to be added as per procedure.

" Another procedure that can be adopted is to keep the initial 5-6 metal charges low ie coke: iron ratio - 1:8. It is important to keep the coke charge the same and lower the metal charge.

Cupola Standardisation and log book

For efficient cupola operation, as many factors as possible of the operation are to be standardised. It is necessary that the same results are duplicated day after day. The reason for any deviation of the operation should be known quickly so that it can be rectified.

A copy of the cupola log book is given in the Annexure-1. Filling of log book should be obligatory.

At the end of the operation, it is essential to record and register the inputs and outputs of the heat.

The log book for the input-output is also given in Annexure-2.

Annexure-1

Cupola Melting Log Sheet

Name of Company:

Cupola Type: **Size :** **Date**

Sr. No.	Time Record AM/PM		Sr. No.	Misc. Record	
1.	Bed Lighted At		A	Total Bed Coke Sr. No. (2+3+4)	kg
2.	Bed coke part I (kg)at		B	Coke bed height	Inch
3.	Bed coke part II (kg)at		C	Total blaston Sr.No. (8-6)	Hrs Min
4.	Bed coke Part III at(kg)		D	Downtime (if any)	Hrs Min
5.	Charging started at		E	Total No. of charges	Nos
6.	Blast on at		F	Total tonnes melted	T
7.	Metal at spout		G	Tonnes melted /hour F/(C-D)	T/Hr
8.	Blast off at		I	Coke: Metal Ratio	

Comparison of parameters with optimum (as standardised)

Sl No	Parameter	Optimum	Actual
I	Bed preparation time		
II	Bed height		
III	Bed weight		
IV	Weight of metal charge		
V	Weight of coke charge		
VI	Melting rate		
V VI	Blast volume-upper		
VII	Blast volume-lower		
VIII	Blast pressure-upper		
IX	Blast pressure-lower		

Annexure-2

Signature of the furnace in-charge

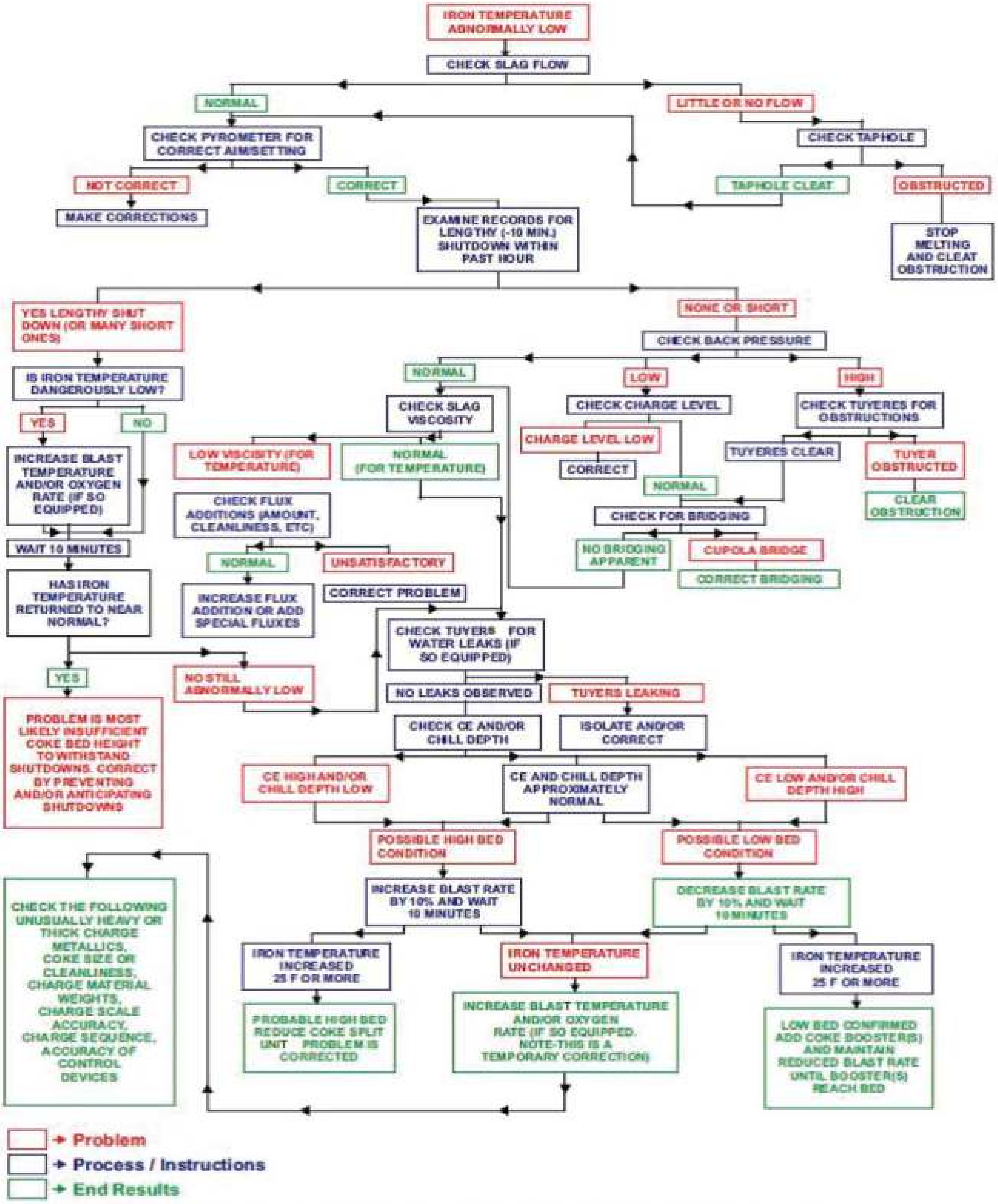
Cupola Record

Cupola Input

Sr. No.	Item	Weight/Charge	Specifications	Total Weight Heat
1	Pig iron			
2	Scrap			
3	Steel scrap			
4	Coke			
5	Limestone			
6	Ferro silicon			
7	Ferro manganese			
8	Any other alloy			

Sr. No.	Item	Quantity
1	Total molten metal	
2	Total slag	
3	Burnt coke	

CUPOLA OPERATOR'S DECISION CHART
COLD IRON



REF. : GRAY IRON RESEARCH INSTITUTE, COLUMBUS, OHIO

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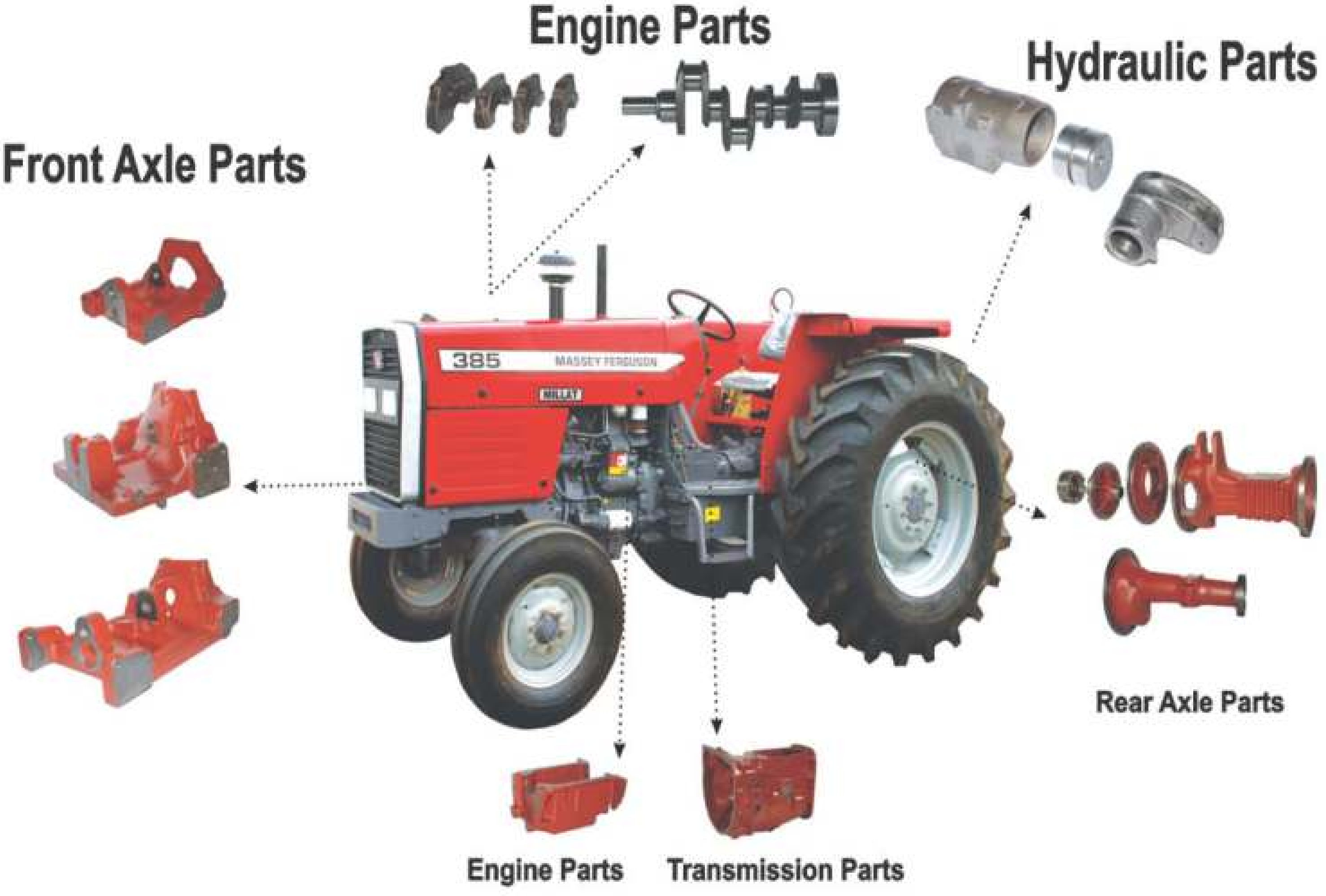

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NOVA CAST AWARENESS SESSION

Abdul Rashid,
Secretary-PFA

Casting Simulation is based on the process of modelling a real phenomenon with a set of mathematical formulas. It is essentially, a program that allows the user to observe an operation without actually performing it. This means foundrymen can now view their casting results right at their computer screens without actually going at the shop floor. Potential casting defects can now be observed, gating systems can be changed, and probability of micro-shrinkage and micro-porosity could be verified.

A number of simulation programs are available today to visualize mold filling and casting solidification. Such virtual trials save the time and production resources otherwise required for shop-floor trials. The simulation results provide the necessary insight to determine the cause of past defects or prevent future defects. The methods design is reiterative, modified and simulated till the desired quality and yield are achieved. The simulation programs are also useful for checking the cast ability of a part design, early in its lifecycle, when it is easier to modify and achieve significant cost reduction. Most of these programs claim to be versatile, intelligent, accurate, user-friendly and cost-effective.

Pakistan Foundry Association (PFA)in collaboration with University of Engineering & Technology (UET), Lahore conducted an awareness seminar on Casting Simulation Technology. The seminar was presided by worthy Vice Chancellor UET Prof. Dr. Fazal Ahmad Khalid. CEO Millat Group/President- PFA. Mr. Sikandar Mustafa was the chief guest.

The awareness session on Nova cast was largely attended by the member of PFA i.e. Bolan casting, Karachi shipyard, Atlas Engineering, KSB Pumps Company Ltd., Ravi Spherocast (Pvt.) Ltd, Qadri Group of Engineering, Infinity Group of Engineering, Matchless Engineering (Pvt.) Ltd., Zaid Products (Pvt.) Ltd. and Heavy Mechanical Complex - I (HMC-1) etc.He feels that our foundrymen can benefit from the casting simulation software installed in Foundry Service Center and can improve the quality of casting productions to meet international standards.

The session was conducted by the team of Qadri Group, who are already using simulation software and shared their real life cases of improvements in casting using simulation software with the participants.Mr. Asim Qadri in a simplified method highlighted the advantage and uses of Simulation Software. He realized the participants that it is easy to use with lot of benefits to improve quality and quantity of casting production. Most important service of casting simulation-Nova cast software has been installed at Foundry Service Centerto facilitate foundrymen.

PFA will organize a training session through Nova cast for a group of Engineers who will further train the foundry Engineers working on the shop floor. In the next stage they will conduct classes of students and foremen to dissimulate the knowledge of Software. PFA will alsoarrange a one day training session for entrepreneurs, GM, CEO's and decision makers.

Dr. Fazal Ahmed Kahlid, VC- UET Lahore wrapping up the session remarked that it is first time that industry and academia are working together and it should be continued in the future too. He thanked Mr. S.M khan, Mr. Asim Qadri, Mr. Iqbal Khalid and all participants who help in the organization of this session. He specially thanked Mr. Abdul Rashid, Secretary-PFA for his efforts to gather such a big audience from Karachi to Islamabad.

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