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Cleaner production for environmental conscious manufacturing in the foundry industry

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Abstract

Purpose – The purpose of the paper is to illustrate application of the cleaner production concept so as to incorporate environmental protection into business performance. The study analyses areas pertaining to the foundry industry that impact negatively on the environment leading to unsustainable resource utilisation and suggests options for promoting sustainable development within the industry, with specific focus on a foundry in a lower income country (LIC).

Design/methodology/approach – Data were collected using the cleaner production (CP) Methodology. Pre-assessment and assessment was carried out and options generated. The options included both low cost and capital intensive approaches.

Findings – The paper finds that the CP approach adopted provides clear guidance for generating options and can be used as a practical basis for managerial decision making and policy formulation. Of major concern is resource depletion and pollution associated with the foundry processes. Used resin sand contains toxic chemicals cause leaching and as such, reclamation of resin sand is suggested. There is need for low income countries (LIC's) to identify the best available technologies (BAT's) that are available within the foundry industry and take these aboard or better still improve on them.

Research limitations/implications – This research developed environmental options that can be applied in the foundry industry. However, it can be said that the findings may have limited global application since the analysis was carried out at one Foundry Company.

Practical implications – The paper focuses on a single foundry factory, since the case study approach was used. As such, environmental indicators and options may vary, since the processes from one foundry to another are bound to differ.

Originality/value – This paper is an attempt at combining theoretical and practical ideas to cover the scope of sustainable manufacturing in the setting of a developing country with a view to identify the lessons that can be learnt and to identify the points of departure when compared with studies done elsewhere. The work informs cleaner production assessment at any level, with a focus of production experiences in the foundry industry in a lower technology, developing economy that is less industrialized. The paper establishes a framework of options that can be applied in the foundry industry and other pollution-intensive industries.

Keywords Foundry engineering, Environmental management, Sustainable development, Pollution control

Paper type Case study

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Introduction

Foundry industry provides products, which are widely used in agricultural, mining and manufacturing industry, as well as other industries. Recently, there are many foundry companies whose annual production exceeds million of tons. The contribution of this industry to the world over is vital and crucial to many economies. However, the foundry industry is one of the industries, which consumes large amounts of water and energy and produces numerous organic pollutants causing serious contamination.

With the growing awareness on environmental problems, issues about the pollution caused by the foundry industry have to be seriously and urgently reviewed. Mitigation of pollution becomes a top priority for management in this sector. Cleaner production (CP) is useful in addressing pollution during industrial production. Those companies who deal directly with the public, and in particular manufacturing companies whose production processes involve potentially harmful emissions, are more likely to come under public scrutiny, and are therefore, more likely to set and achieve realistic emission reductions. Government and non-governmental organisation regulation has had more significant success with these companies than with those businesses who do not have a significant public profile (Kolk and Pinkse, 2006).

The aim of the study was to assess CP options in the foundry industry and maximise resource utilisation whilst minimising waste generation within the confines of international protocol as well as emerging green markets, thus ensuring new business opportunities, security of markets and improvement of business profile.

Analysis of the developments during the past years shows a paradigm shift in the disposition of governments and industry with regards to industrial operations. CP refers to how goods and services are produced with limited effects on the environmental under present technological and economic challenges.

CP is not against industrial development and expansion, but emphasizes that development and expansion be sustainable. Besides, being an environmentally oriented approach, CP also relates to economic issues as well. Each effort to minimize consumption of materials and energy, and to prevent or reduce waste generation, can boost productivity as well as result in economic benefits to the company. CP is a two proned approach. In addition to protecting the environment, the consumer and the worker in improves industrial efficiency as well as competitiveness. The approach also invariably leads to increased profits for any organisation that embarks on such an effort.

The definition of CP that has been adopted by the United Nations Environment Programme (UNEP) is as follows:

> Cleaner Production is the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment.

Sustainable development (SD) is a development path along which the maximisation of human well being for today's generation does not lead to declines in future well being. Increasing environmental problems related to the increase in production and consumption have contributed to the development of the concept of SD (Fortunski, 2008).

SD implies a broad view of human welfare, a long-term perspective about the consequences of today's activities, and global co-operation to reach viable solutions. CP can be viewed as a subset of the concept of SD. Industrial ecology is an emerging framework adopted in the manufacturing, construction and process industries to provide innovative solutions in strategic planning, leading to cleaner operation and production (Basu, 2006).

CP, according to Schnitzer (1995) can only be a partial utopia within the SD framework and answers for CP to the requirements of sustainability are based on two principles:

(1) Avoiding discussion of symptoms (solid waste, emissions, waterwaste, noise, odour, etc.) but proceeding to the sources.
(2) Making it clear that minimization of waste and emissions can only be obtained through a higher degree of the utilisation of the input materials.

There are limits to what the environment can take, and people needs to ensure that development today does not result in negative environmental impacts that compromises future development. Many issues need be considered here but industry's role in industrial pollution is apparent. Industrial systems and individual companies will need to make changes in order to enable future generations to meet their own needs. SD is thus the long-term goal of individual companies rather than a business practice as pointed out by Berthon and Lowitt (2009). Srivastava and Srivastava (2003) quoted by Mohan *et al.* (2006) point out that deepening environmental concerns and perceptions of increased risk to health and safety of community residents from industrial activities have led to a significant increase in interest in research at the interface of environmental management and operations of industries.

Metal yields may be reduced in a number of areas in the foundry process. The benefits that could be gained by implementing improvements will vary between foundries. Therefore, it is important for companies to undertake their own mass balance for metal, to identify the true cost of metal loss to the company and the key sources that can be addressed most effectively. Improving metal yield often requires an integrated approach to ensure that improvements in one area lead to an overall improvement in operational efficiency. The Energy Efficiency Best Practice Program in the UK has prepared a publication titled "Achieving high yields in iron foundries" (DETR, 1999). The publication points out that the major areas of metals losses in foundry work are melting, pouring and fettling processes.

A number of researches have been done with respect to the application of environmentally friendly technologies as getaway to environmental conscious manufacturing in the context of developing economies. For instance, Pal *et al.* (2008); investigated the application of cleaner technologies in the foundry industry. However, the investigation did not carry out a plant wide assessment but instead focussed on the development of an energy efficient divided-blast cupola furnace (DBC) and the use of a pollution control device. They showed that any energy saving of more than 40 per cent could be achieved by migrating from the traditional Cupola to the DBC. The pollution control device enabled suspended particulate matter (SPM), to be reduced from 2,000 mg/Nm^3, to below 70 mg/Nm^3, well within the emission limit.

A study in Finland by Lilja and Liukkonen (2008) showed that the amount of foundry dust fluctuate between 46 and 460 t/a but showing a steady decrease in more recent years. He carried out a study on the reduction of hazardous waste (HW) in several industries. The foundry industry was one of the functional groups they studied. They pointed out that one reason for the declining trend they had observed with HW may have been the increased recycling of foundry dusts back to the process. Daniels (2005) demonstrated that going green by adopting a green techno-economic paradigm (TEP) in developing countries (DCs), provide for resource efficient gains. He points out the aspects that needed to be addressed in order to create an enabling environment for the installation of material and energy saving regimes. He concluded that a green TEP could be panacea for better environmental performance in low income countries.

Wijayatunga *et al.* (2006) focussed on the barriers to Cleaner Technologies in Sri Lanka. He cited the unavailability of financial initiative; resource unavailability; unclear policies on the part of government and policy makers as some major issues in as far as implementation of CP in the Sri Lankan perspective. Sekhar and Mahanti (2006) point out that traditional practice in India focus on the aspects of profit making without environmental considerations. They also investigated the possibilities of improving the performance of the Venturi scrubber using a six sigma approach and simulation; demonstrating that particulate emissions (PM) ca be reduced from 200 to $<20\,mg/m^3$ and SO_2 and 45 to $<4.5\,mg/m^3$.

Fatta *et al.* (2004) researched on industrial pollution and control measures for a foundry in Cyprus and developed guidelines for application of best available technologies (BATs) for 14 industrial categories; with the foundry as one of them. The emissions from the Cyprus foundry cupola oven flue gas flacuated around $350\,mg/m^3$. They pointed out that air emissions of particulate matter should be below $20\,mg/m^3$, where toxic metals are present and $50\,mg/m^3$, in other cases. This would correspond to a total dust emission of 0.5 kg/tonne of molten metal.

Deng and Tikalsky (2008) looked at the properties of what he termed waste foundry sand (WFS); through a test program of WFS samples from a wide variety of sources; the incorporation of WFS samples into flowable fills was validated from both a technical and environmental perspective. A starting or scouting mixing formulae was suggested. Foundries have recycled and reused for quite some time now; when sand can no longer be recycled; it is termed spent foundry sand (SFS) and it can be used in controlled low strength materials. Siddique and Noumowe (2008) presents an overview of some research published on the use of SFSs. Dungan *et al.* (2009) looked at sand resin in the USA; focusing on polychlorinated dibenzo-p-dioxin (PCDDs) and polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs). These are largely released into the environment during combustion processes. By testing several samples, they concluded that (PCDDs); (PCDFs) and (PCBs), can be detected in SFSs but in low concentrations to cause a risk to environmental receptors when beneficially used in soil related applications.

Resource Recovery Corporation (RRC), located in the West Michigan town of Coopersville was created in 1990 to enhance the competitive advantage of West Michigan foundries through safe, dependable, and economic management of foundry residuals (EPA, 2002). RRC encourages participating foundries to increasingly employ sustainable business principles including reduction in use of materials entering the process residual stream, reclamation for internal reuse and source separation to facilitate processing for beneficial use in other industries. Beneficial use of foundry sand and other process residuals diverts materials from disposal in general refuse landfills and into other uses where they replace virgin resources. However, foundry sand is generally not suitable for reuse immediately after leaving foundry operations. To this end, RRC operates a sand processing facility where it reduces mold and core sand lumps, removes fines, recovers metallics and screens the material to a specified particle size distribution. RRC also accumulates foundry slag at a site in nearby Muskegon, Michigan for crushing and subsequent use in the production of asphalt (EPA, 2002).

Cleaning of casting loads the environment with dust, noise and waste. All casting must undergo cleaning before they undergo machining operations and surface treatments. To limit the load on the environment, extraction and filtering of dust generated during the cleaning process may be undertaken. When pouring and solidification takes place in CO_2 hardened moulds, CO is effectively the only gas released. There is a limited amount of dust generated from mixing of the moulding sand and during removal of the cast component from the mould. Dust is also generated during the mechanical reclamation of the used moulding sand.

With regards to energy use in foundries, energy consumption can be as low as 550 kWh/tonne but these figures are achieved only with high utilisation factors and for higher-frequency furnaces (Taft, 1995). Figures of around 650-750 kWh/tonne are more typical (Jain, 1986). In comparing the overall efficiency of these systems with that of fuel based furnaces, it should be remembered that the electricity has to be generated and even modern power stations do not reach a 40 per cent efficiency, which means the overall fuel consumption is well over 2,000 kWh/tonne (Powell, 1992).

As the above review of literature reveals, relatively few studies have focussed on the plant wide application of CP approach to the foundry industry in the context of the developing world. The current paper seeks to investigate the drive towards environmental conscious manufacturing using a CP approach in a DC with particular reference to the foundry industry.

The rest of the paper is divided into the following parts. An overview of the CP approach is given as applied to the study company. The next section describes the problem statement, followed by a brief background of the company highlighting the moulding process and the underlining the areas of environmental concern. The next section outlines and discusses the findings of the study before the paper is concluded by summarising the lessons learnt and potential areas of environmental performance improvements.

CP approach – an overview

Industry and businesses operations are affected by many factors, external and internal. As such they respond in such a manner so as to mitigate those signals that tend to be negative and to reinforce the positive aspects. It is this combination of positives and negatives that dictate the corporate performance. To achieve the efficient use of raw materials, conservation of water and energy and reduce/minimize the generation of pollution and waste, among the concepts being implemented right now are CP, total quality environmental management, eco-efficiency and lean production (Rao, 2004). The CP assessment methodology is used to pinpoint critical areas in industry as well as streamline the various available options and facilitate their implementation in industries.

CP assessment is most often divided in five phases; planning and organisation, pre-assessment, assessment, feasibility analysis and implementation and continuation (UNEP, 1997).

CP as a tool for SD

Three elements are crucial to achieving more environmentally sound industrial development. First, environmental considerations must be incorporated into all aspects of planning for new industry. Second, techniques must be developed which more easily and flexibly control pollution within a legal framework which provides strong incentives, particularly economic incentives, to minimize the release of pollutants and the production of waste, and which places greater emphasis on the "polluter pays" principle. Third, producers of hazardous products should be required to be responsible for these products "from cradle to grave", i.e. from production to safe disposal. The approach to comprehensive control of industrial environmental hazards is being promoted as "cleaner production" (UNEP, 1997).

CP is recognized as a tool that can contribute to the sustainable forms of economic development, as endorsed in Agenda 21 adopted by the United Nations Conference on Environment and Development (UNCED, 1992). CP is a strategy that protects the environment, the consumer and the worker while improving the industrial efficiency, profitability and competitiveness of enterprises.

CP, pollution prevention, etc. are all subsets of the concept of SD, which states the basic problem that the other concepts attempt to address:

CP, according to Schnitzer (1995), can only be a partial utopia within the SD framework and answers for CP to the requirements of sustainability are based on two principles:

(1) Avoid discussion of symptoms (solid waste, emissions, waterwaste, noise, odour, etc.) but proceed to the sources.

(2) Make it clear that minimization of waste and emissions can only be obtained through a higher degree of the utilisation of the input materials (learn more about less).

There are limits to what the environment can tolerate, and society needs to ensure that development today does not cause environmental degradation that prevents development tomorrow. There are many issues here but the role of industry and industrial pollution is obvious. Industrial systems and individual companies will need to make changes in order to prevent future generations from being unable to meet their own needs. SD is thus the long-term goal of individual companies rather than a business practice according pointed out by the International Institute for Sustainable Development (1992) in conjunction with Deloitte & Touche and the World Business Council for Sustainable Development.

Research approach

The approach used during the research is as shown in Figure 1. Having appreciated the need for CP and obtaining the management support, a pre-assessment exercise was carried out followed by an assessment. Options were generated at the pre-assessment phase and the assessment that was also the basis for the recommendations. The four R's were considered in option generation. The concept of the 4R's, reduce, re-use, recycle and recover was used as a basis of coming up with CP options. The Four R's are the foundation of the waste hierarchy which itself has become the cornerstone of sustainable waste management setting out the order in which waste management should be considered based on environmental impact. Waste reduction at source is the most straightforward and effective of the approaches: if waste is not created in the first place, the waste control problem is not created either reuse simply means using objects or materials again enabling continual benefits prior to recycling. Recycling conserves resources by keeping them in

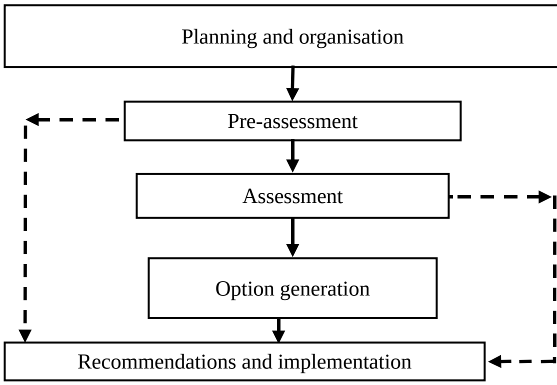

Figure 1.
CP research methodology

circulation, reducing the depletion of non-renewable materials and energy such as fossil fuels and mineral ores used to manufacture products from new. Recovery of materials or energy can take numerous forms such as materials recovery and energy recovery. The recovery of waste materials leads to their eventual recycling rather than being sent to landfill

The planning and organisation phase was aimed at obtaining management support and convincing everyone that there was a need to prevent waste or at the very least reduce it and making them aware of the potential benefits of the CP approach. The pre-assessment sets priorities for waste prevention as well as identify low cost options that can have immediate application. The assessment phase analysed the environmental concerns more rigorously and options for mitigating these are generated. The options identified may be numerous and thus prioritisation has to be done. The high priority; feasible options can then be implemented and this sets the tone for an on-going prevention programme.

Problem statement of foundry industry

Foundry is one of the basic material industry in most national economies. However, foundry industry has been proved as one of the industries, which consumes large amount of water and energy and produces numerous organic pollutants, causing serious contamination.

Overview of the study factory

The study was done on a foundry company based in Gweru, situated in the Portland Heavy Industrial Sites in Gweru and that was established in the 1960s. The present plant was commissioned in 1981. The company is into a variety of foundry products that include agricultural implements amongst others and specializes in casting of malleable iron, grey iron. Ni-hard 20, SG iron 42, high silicon grade steel, high chrome molybdenum steel and high silicon grade steel. The company faces various challenges that can be addressed by undertaking CP options. Some of the problems include the seasonal rise in the underground water table. This causes flooding of the low-lying conveyor belts tunnels and this has resulted in the stoppage of production, as water has to be pumped out occasionally. There is also the problem of poor lighting and ventilation such that the health of the workers is endangered due to presence of dust particles and gas fumes releases during the manufacturing process. A lot of income is also being lost due to the non-reclamation of sand. Other environmental issues associated with the operations of the facility are: solid waste – resulting from the disposal of non-reclaimed sand, slag and off-specification moulds and cores; and *Air emissions* – odours resulting from alkaline phenolic resins

Figures 2 and 3 show flow charts illustrating the material and energy flow. At each moulding unit, used sand is transported by a conveyer belt to a recycling unit which mixes the sand with new sand and this is returned to the moulding units. After a while the sand loses its initial properties and is dumped within the company premises and latter on to municipal dumps. Melting is done using an electric arc furnace and transportation to pouring points is by way of crucibles on rails. The casting is recovered at the shakeout area where the risers and gates are removed and returned to the furnace; whilst the casting is forwarded to cleaning and finishing shop. A generalized block flow diagram of the sand casting process at the company is shown in Figure 5.

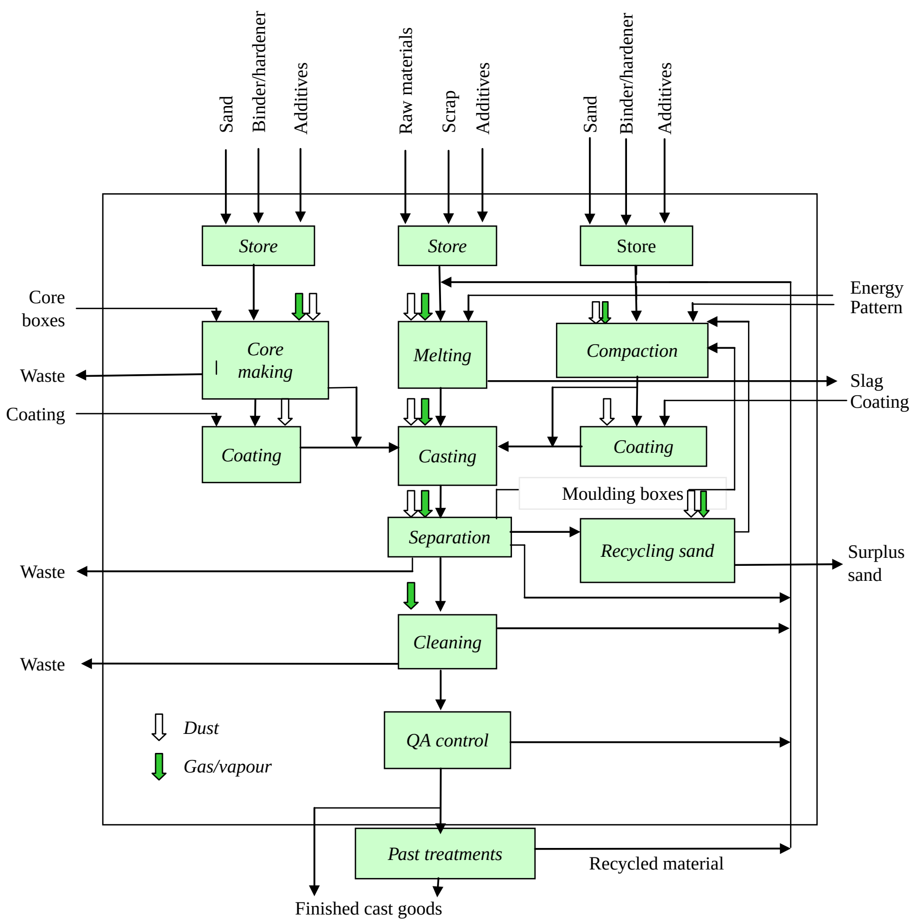

Figure 2.
Foundry flow diagram

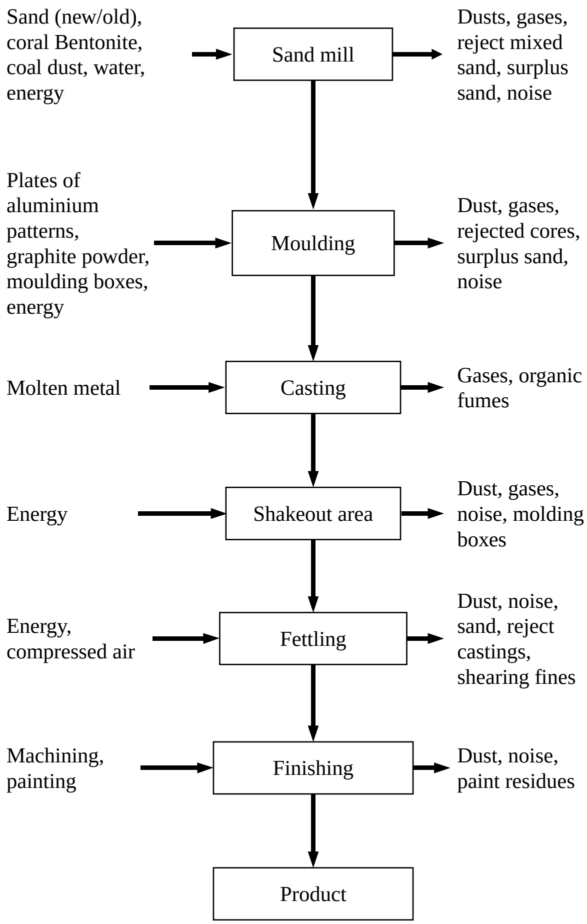

Figure 3.
Inputs and outputs

The different inputs at the various stages of production are shown in Figure 3. This figure forms a basis for the material mass balances in the effort of identifying areas that represent wastages and that give rise to environmental concerns.

Findings and discussions

Emission factors for fugitive PMs

The total PMs for each process are broken down to amounts emitted to the work environment and the residual amounts emitted to atmosphere. The major fractions of emissions remain in the work environment. A foundry's most concentrated source of emissions is its melting operation. Fugitive emissions from furnaces were found to occur during charging, back-charging, alloying, slag removal, oxygen lancing (in the case of steel melting furnaces) and tapping operations when the furnace lids and doors are open. Controls for furnace emissions (non-fugitive) during the melting and refining operations when the furnace lids and doors are closed focus on venting the furnace gases and fumes directly to a collection and control system Toxic gases may be emitted from the use of heat-cured and no-bake binders and the handling and storage of catalysts in moulding and core making operations requiring containment and venting from the building. Control of the emissions may be required depending on the nature and concentration of the contaminants and regulatory agency requirements.

Table I to shows the aspects and impacts of the sand casting process; this further develops on Figure 3; illustrating the effects of the various particulate and gas emissions on the environment. Of concern is the health hazard presented to the workers. There is also the issue of surrounding air pollution and the effects on the nearby communities. Further to that; the land is affected due to waste sand disposal. The spillages contribute to material waste as well as energy as the spillages have to be recovered after solidification.

Sand used at the company can basically be divided into two: green sand and chemically-bonded sand. Green sand makes up more than 85 per cent of the sand and it is clay bonded. Chemically bonded sand is rarely used save for special jobs requiring high strength cores. Owing to the make-up of the sand; the gasses given in Table II are emitted and are cause for concern. The different chemical binders used also contribute to environmental concerns. These contribute to leaching when the sand is washed away from the stockpile.

Emission factors for fugitive PMs for the foundry are shown in Table III. The range of PM emitted to the atmosphere varied from 0.1 to 1.5 kg/tonne as illustrated in Table III. These of great environmental concern as these emissions contain toxic metal particles. The composition is bound to differ from time to time depending on the nature of scrap used as well as furnace additives. This is in contrast to other studies for instance; Fatta *et al.* (2004) developed guidelines in Cyprus recommending that total dust emissions should be less that 0.5 kg/tonne of molten metal produced. A study in India by Pal *et al.* (2008) found out that SPM, varied between 1,170-2,200 mg/Nm^3 (milligrams per normal cubic metre) against standard requirements of 150-450 mg/Nm^3.

Energy utilisation

Most of the energy is utilised in the furnaces. As can be seen from the Figure 4, the furnaces account for 45 per cent of the energy. Here, the electric furnace is being used.

Process	Aspect	Impacts
Pattern making	Saw dust and glue fumes	Air pollution, health hazard to employees
Mould making, core-making, shakeout, fettling	Carbon and sand dust Waste sand (contaminated) disposal	Air pollution, health hazard Land sterility
Melting in Cupolas furnace	Burning of fuel (coke) Ash	Air contamination by SOx, CO, CO_2, NO_x, smoke, heat, resource depletion, global warming Land and air pollution
Pouring	Metal spillages Slag disposal Binder fumes Cooling of melt during pouring, prompting reheating	Land contamination with rust Land sterility Toxic health hazard Excessive resource depletion (fuel)

Table I. Environmental aspects and impacts

Binding/ hardner system	Mixing	Moulding	Pouring/solidification	Shakeout	Reclamation
Acid-catalysed furan opr phenol resin	Formaldehyde furfuryl alcohol	Formaldehyde furfuryl alcohol	CO, SO_2, benzene, toluene, xylene, phenols, cresoler, furan	CO, SO_2, benzene, toluene, xylene, phenols, cresoler, furan	SO_2, hydrogen Sulphide
Amine-catalysed polyurethane resin	At sand temperature, over 35^o	As for mixing	CO, phenol, benzene, topulene, xylene, trimethyl benzene, napthalines, amines, piridines	CO, phenols, benzene, trimethyl benzene, naphthalenes	As for pouring and solidification
Shell sand	Undertaken by supplier	Phenol Ammoni	CO, phenol. ammonia, hezamine, formaldehyde,benzene, toluene,xylene, cresoler	CO, phenol, benzene, toulene	CO, phenols, amines, benzene, toulene

Table II.
Gasses developed during moulding processes with organic binding agents

Process	Emission (kg/tonne)	Emitted to work environment (kg/tonne)	Emitted to atmosphere (kg/tonne)
Scrap and charge handling, heating	0.3	0.25	0.1
Magnesium treatment	2.5	2.5	0.6
Inoculation	1.5-2.5	–	–
Pouring	2.5	5	1
Cooling	5	10	0.5
Shakeout	16	32	0.5
Cleaning-finishing	8.5	17	0.05
Sand handling, preparation	20	40	1.5
Core making, baking	0.6	1.1	0.6

Note: Emissions are expressed as weight of pollutant per weight of metal melted given in kilograms per tonne

Table III.
Emission factors for fugitive PMs

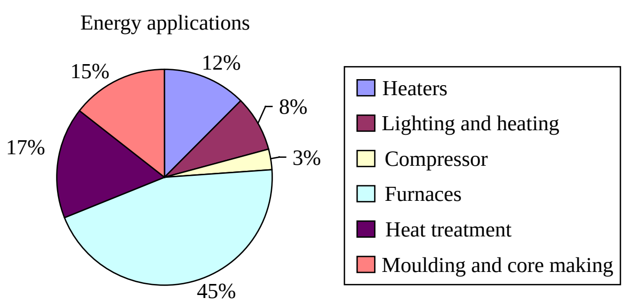

Figure 4.
Energy applications in a typical foundry

Others studies concur with this. Pal *et al.* (2008) points out that melting is the most energy intensive stage in the foundry. In his study, he was focussing on the cupola furnace and demonstrated that energy efficiency can be realised with regards to melting. Similarly, there are many opportunities for improving energy efficiency here. Some of these, such as optimising the efficiency of ancillary services can be achieved at minimal cost and make a valuable improvement to the bottom line. Reports from many foundries suggest that energy efficiency is one of the most significant CP options still to be addressed in the industry. Foundries should undertake an audit to establish the full cost of energy to the company and the major demands on energy in the process. This will help prioritise improvement strategies. Energy is a major cost for all foundries, typically accounting for around 10 per cent of the total operating costs (The Foundryman, 1997a, b).

Effluent discharge

One of the major concerns in environmental management is the use and management of water. Figure 5 shows the many uses of water at the company. As can be seen, most of the water is utilised in the cooling towers whilst domestic consumption takes up the other 28 per cent. The water from the cooling towers was observed to be discharged to the sewer system. Besides, the economic waste; there is also the environmental hazard presented by the water as it wishes some of the dumped sand into the river. Analysis of the effluent water stream is given in Table IV.

The effluent from the industry is illustrated above. The pH flacuates between alkaline and acidic and trace elements such as zinc and copper are discharged. This is in contrast to a research carried out in Cyprus by Fatta *et al.* (2004) that showed the values at almost half of the figures in Table IV. Thus, opportunity for improving environmental performance with regards to effluent exists. The physical properties of green sand

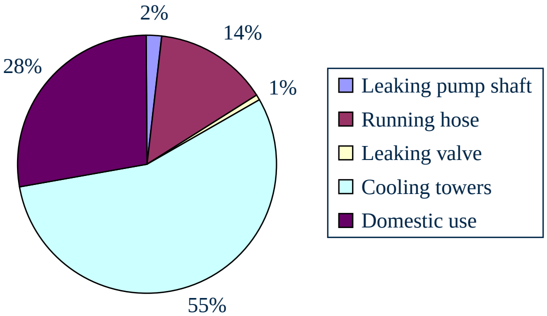

Figure 5.
Water applications

Parameter	Maximum value
pH	5-10
Oil and grease	20 mg/l
Copper	1 mg/l
Zinc	5 mg/l

Table IV.
Effluent analysis

residual are presented in Table V. Based on the Radar foundry data, temporal and process variability can be expected from a single foundry's waste stream. Thus, by reusing the sand; beside the economic gains; better environmental performance can be achieved.

Figure 6 shows that CO emissions generally increase with increasing carbon content of molten metal and in the presence a binder and heat energy. For the tests, the temperature of the cast material was 1,400 °C, and the type of sand used was quartz sand. The levels of CO emissions can be seen flactuating between 0 and 200 mg/kg. There is need to arrest these emissions so as to make them more consistent.

Recommendations

Air emissions

Dust emission control technologies include cyclones, scrubbers (with recirculating water), baghouses, and electrostatic precipitators. Scrubbers are also used to control mists, acidic gases and mines. Gas flame is used for incineration of gas from core manufacture. Target values for emissions passing through a fabric filter are normally around 10 mg/Nm^3 (dry). Emissions of PM from furnaces (including casting machines used for die casting) should not exceed 0.1-0.3 kg/tonne of molten metal, depending on the nature of the PM and the melting capacity of the plant. At small iron foundries, a somewhat higher emission factor may be acceptable, while in large heavy-metal foundries, efforts should be made to achieve a target value lower than 0.1 kg PM per metric ton. Using bioscrubbers may eliminate odours.

Table V.
Compositional makeup of residual sand

Component/property	Range
Sand (%)	70-80
Water (%)	2-4
Clay (%)	5-15
Additives (%)	2-5
Moisture (%)	0-4
Carbon loss on ignition (%)	0.2-8
PH	3-12
AFS-grain fineness no.	40-150
% Fines (passes 200 mesh sieve)	1-12
Density	1.0-1.6 g/cm^3

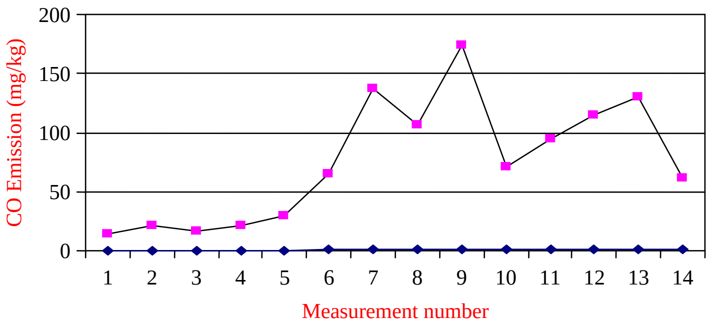

Figure 6.
CO emission (mg/kg)

Pollution prevention and control

The following pollution prevention measures should be considered:

- Replace the cold-box method for core manufacture, where feasible.
- Improve feed quality: use selected and clean scrap to reduce the release of pollutants to the environment.
- Preheat scrap, with afterburning of exhaust gases.
- Store scrap under cover to avoid contamination of storm water.
- Provide doghouse enclosures for induction furnaces.
- Use dry dust collection methods such as fabric filters instead of scrubbers.
- Use continuous casting for semi-finished and finished products wherever feasible.
- Store chemicals and other materials in such a way that spills, if any, can be collected.
- Control water consumption by recirculating cooling water after treatment.
- Use closed-loop systems in scrubbers where the latter are necessary.
- Reduce nitrogen oxide (NO_x) emissions by use of natural gas as fuel, use low-NO_x burners.
- Reclaim sand after removing binders.

Dust control

Use of pneumatic transport, enclosed conveyor belts or self-closing conveyor belts, as well as wind barriers to reduce the formation of fugitive dust is recommended. Reduction of dust emissions at furnaces can be achieved by covering iron runners when tapping the blast furnace and by using nitrogen blankets during tapping.

Cleaning room waste

Cleaning room waste that is ultimately disposed of in a landfill includes used grinding wheels, spent shot, floor sweepings and dust from the cleaning room dust collectors. This waste may be hazardous if it contains excessive levels of toxic heavy metals.

Dust collectors and scrubber waste

During the melting process, a small percentage of each charge is converted to dust or fumes collected by baghouses or wet scrubbers. This dust may contain varying amounts of zinc, lead, nickel, cadmium and chromium depending on the charge. Carbon-steel dust tends to be high in zinc and lead as a result of the use of galvanized scrap, while stainless steel dust is high in nickel and chromium.

Slag waste

Slag is a relatively inert, glassy mass with a complex chemical structure. It is composed of metal oxides from the melting process, melted refractories, sand and other materials. Slag may also be conditioned by fluxes to facilitate removal from the furnace. Hazardous slag may be produced in melting operations if the charge materials contain significant amounts of toxic metal such as lead, cadmium and chromium. To reduce the sulphur content of iron, some foundries use calcium carbide desulphurisation in the production of ductile iron. The calcium carbide desulphurisation slag generated by this process may be classified as a reactive waste.

Wastewaters
Cooling water (such as that lost from cooling of induction furnaces), is discharged without treatment. Water quenching baths, if employed, when purged or discarded, may require treatment depending on the nature of contaminants and regulations governing discharges. Storm water, if uncontaminated by contact with waste materials, such as SFS, usually can be discharged directly to municipal storm sewers.

Miscellaneous waste
Most foundries generate miscellaneous waste that varies greatly in composition, but makes up only a small percentage of the total waste. This waste includes welding materials, waste oil from forklifts and hydraulics, empty drums of binder and scrubber lime.

Table VI shows some waste management practices. Management initiative, commitment and involvement are key elements ensuring waste reduction. Other factors include:

- employee awareness and participation;
- improved operating procedures;
- employee training;
- improved scheduling of processes; and
- continuous application and Evaluation of CP.

Employee training, awareness and participation are critically important. Employees are often resistant to broadening their roles beyond the traditional concepts of quantity and quality of products produced. Total commitment and support from both management and employees are needed for waste minimization program to succeed. This includes the evaluation, implementation and maintenance of techniques and technologies to minimize waste. The use of good process control procedures often leads to increased process efficiency. Workers and management need to continually educate themselves to keep abreast of improved waste reducing, pollution-preventing technology. Information sources to help inform companies about such technology include trade associations and journals, chemical and equipment suppliers, equipment expositions, conferences and industry newsletters.

Waste and source	Waste management practice
Spent	Offsite re-use by concrete mix manufacturer
Moulding	Gulley reclamation
Green sand	Land fill
Spent core making sand	Recycle to green sand moulding and ultimately dispose as spend green sand
Baghouse dust	Recycle to original process
	Offsite reuse by concrete mix manufacturer
	Recycle metal values
Melting furnace slug	Onsite storage
Shot blast grit from cleaning	Offsite reuse by concrete mix manufacturer
Fettling area and other waste	Municipal land fill if uncontaminated by heavy metals

Table VI.
Waste management practices

The furnaces

The furnace used at the foundry company is an electric arc furnace. By sending an alternating electric current through the coil, a current is induced in the metallic charge placed in the crucible and this generates heat that melts and superheats the charge. Thus, most of the energy is used in the furnace for the melting of charge.

Refractory linings of the furnace

The refractory lining of the electric furnace suffer wear and tear. The refractory lining comprises of quartz, aluminium silicate and removal of lining is usually dusty. Owing to the high temperatures, some of the quartz undergoes transformation into cristobalite and finally tridymite. The furnace has to be constantly religned due to the wearing down. The burnt out refractory lining from the furnace and crucible also contributes to the waste

Lead vapour

Lead is an element that is not desired in cast iron in high quantities. The amount of lead expelled into the atmosphere is not documented in Zimbabwe. However, lead contained in the working environment affects the workers within the vicinity.

Other emissions

Theses usually contain gasses and dust that originate from dirt, oils, paint and rust on the scrap used in the charge. The amount of the emissions depends on the cleanliness of the scrap. There are also gasses and dust in the form of fine metal and metal oxide particles. The amount of these types of emissions depends on the manner in which charging takes place, the frequency of the furnace and nature of scrap used for charging.

Waste

Waste is mostly arises as a result of removal of slag and it consists of metal steel, iron silicates/oxides. The burnt out refractory lining from the furnace and crucible also contributes to the waste. Induction furnaces use circulating water loops to cool the induction coils and power panels. The water typically goes into a hotwell, then into a water-to-water heat exchanger that is looped with a dedicated cooling tower. This water flows into the council drainage system and collects dirt along the way such as oil and binding agents.

Limiting the load on the environment

The smoke generated from the electric furnace can be filtered through a bag filter. Extraction of this smoke is made difficult due to convection currents at the furnace and partly due to charging and emptying of the furnace when large amounts of smoke are generated.

Conclusion

It was generally discovered that there is lack of continuity in the implementation of CP. Over the passage of time, companies seem to view CP concepts with sceptism and there is need for a deliberate and systematic approach to the promotion of the concept. Local authorities and the government are generally slack in enforcing regulations and companies get away with environmentally damaging practices. There is, therefore, a need for all stakeholders to collectively drive towards the same goal of sustainable utilisation of resources. This is particularly the case for small to medium companies that are especially vulnerable to economic conditions. These companies are also limited to the amount of capital available to invest and many projects (including those externally imposed) affect the ability to implement CP projects regardless of the projected environmental and economic benefits. As such, there is still work to be done to remove some barriers. These include:

- Removing legislative and bureaucratic costs of beneficial reuse and environmental compliance; increasing opportunities for the foundries to work together to develop solutions for mutual problems where individual companies are too small to work alone.
- Adopting a supply chain management approach particularly in terms of working with major suppliers to develop better inputs and developing centralised recycling facilities; working to enhance the image of the foundry industry as an innovative, environmentally conscious and high-tech industry.
- Technologies (AMT) will go a long way in promoting SD.

Continuous research and development is necessary in order to inculcate a culture of environmentally conscious manufacturing. An integration of the CP concept with other philosophies such as total quality management, total productive maintenance, coupled with advanced manufacturing. The study highlighted some practical findings from the study company. The range of PM varied from 0.1 to 1.5 kg/tonne. These of great environmental concern as these emissions contain toxic metal particles. The composition is bound to differ from time to time depending on the nature of scrap used as well as furnace additives. This is in contrast to other studies for instance; Fatta *et al.* (2004) developed guidelines in Cyprus recommending that total dust emissions should be less that 0.5 kg/tonne of molten metal produced. A study in India by Pal *et al.* (2008) found out that SPM, varied between 1,170-2,200 mg/m^3 against standard requirements of 150-450 mg/m^3.

From the study, it can be concluded that if DCs are to achieve environmentally conscious manufacturing with regards to the foundry industry a lot of issues have to be taken into account. Waste prevention benefits can only be realised if management commitment is obtained; and this can only be done if potential benefits are perceived. It is also important to train employees in waste prevention techniques. By empowering workers, everyone becomes involved and proactive in the goal of achieving environmentally friendly manufacturing. Previous research has pointed out that there are numerous benefits associated with waste prevention and environmental conscious manufacturing as earlier pointed out in the introduction. The case study findings support this conclusion. As outlined, there are several options that can contribute to waste reduction in the foundry industry. These include sand reclamation. Used sand at the study company was just piling up and latter dumped. But this sand can be re-used and latter utilised in the manufacturing of low-strength materials.

Both beneficial reuse and internal reclamation are likely to significantly improve environmental performance and reduce costs to the industry over the next few years. As shown in this review, there are gains to be made throughout the foundry and these improvements do not necessarily have to come at a great price. While there are a number of barriers to implementing CP, the benefits are real. Several CP opportunities are available for the foundry industry and these differ from place to place and are affected by the socio-economic environment

This study also demonstrates that DCs face number of unique challenges which may inhibit the adoption of CP. For instance, they often lack the necessary technological sophistication. There is thus need to scan the horizon and identify the BATs for application within the plant. The plant was found to be using outdated equipment and some of the options required huge initial investments which were not available. Even where there was a demonstrated financial return from such investments, there is also the challenge of lack the resources and expertise to exploit such opportunities. This was consistent with Wijayatunga *et al.*'s (2006) postulations with regards to the hindrances faced in the implementation of environmentally conscious manufacturing.

Though there are many regulatory measures in place to curb environmental loads and deterioration. For instance, there is the Environmental Management Act of Zimbabwe. This act seeks to provide for the sustainable management of natural resources and protection of the environment; the prevention of pollution and environmental degradation; the preparation of a National Environmental Plan for the management and protection of the environment. Gases such as CO, CO_2, SO_2 were being emitted and were not being monitored and regulated. This is worsened by the absence of industry-specific emission limits. Thus, the pressure from stakeholder is not strong enough to encourage the adoption CP techniques. This underlines the fact that there is need to develop industry specific emission levels for regulatory purposes; this is key to facilitate monitoring.

From the study, there are many opportunities for improving energy efficiency. Some of these, such as optimising the efficiency of ancillary services can be achieved at minimal cost and make a valuable improvement to the bottom line. Reports from many foundries suggest that energy efficiency is one of the most significant CP options still to be addressed in the industry. There is need to regularly undertake audits to establish the full cost of energy to the company and the major demands on energy in the process. This will help prioritise improvement strategies. Energy is a major cost for all foundries, typically accounting for around 10 per cent of the total operating costs.

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