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Research article

CLEANER PRODUCTION OPTIONS IN SAND CASTING FOUNDRIES.

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ABSTRACT

The purpose of this paper was to assist foundries in pollution prevention by devising clean technologies which maintain or improve the quality of the ambient surrounding. The paper used Cleaner Production and its opportunities to minimize material consumption, optimize production yield and to prevent polluting the air, water and land. The reseachers reviewed how sand casting foundries can implement Cleaner Production and benefit from the created conducive environment as well as saved financial capital. The review gave an overview of the environmental aspects and impacts of foundry operations. It also outlined best practices to improve the energy, material, and environmental efficiency, and the product output of the operation. The current environmental status and performance of foundry companies in Zimbabwe was determined from the initial environmental review, energy and environmental audits. Once the environmental status was established, Cleaner Production options were then modelled. The feasibility of the options were also analysed, and life cycle analysis of casted products was carried out. The researchers concluded that raw materials, water, and energy were to be saved if foundry companies implemented Cleaner Production options. **Copyright © IJSEE, all right reserved.**

Key Words: Cleaner Technologies, Sand Casting, Environmental Impact Assessment

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1.0 Introduction

Globalisation impacts and its associated demands in competitive environment have created a need to take decisive actions responsive to environmental changes, and implement strategies that continually improve quality, capability and process efficiency.

This paper provides information about Cleaner Production opportunities within the foundry industry, to point the way towards greater profitability and improved environmental performance.

This was achieved through:

- Determining the current environmental status and environmental performance.
- Exploring Cleaner Production opportunities through identifying, assessing and evaluating environmental aspects and impacts and ascertain the benefits of implementing Cleaner Production.
- Carrying out feasibility studies of Cleaner Production opportunities at foundry companies.
- Improving on life cycle resource management.

The paper highlighted environmental aspects and impacts associated with industrial processes in sand casting foundries. Approaches that organizations can take to avoid or minimize these impacts were also outlined and their feasibility studied and analysed.
The researchers endeavoured to answer the following questions:

1) Where is waste generated in the company?
2) How can waste and emissions be minimized in the company?
3) Which production process produces the highest amount of waste and what are the figures?
4) How does the company view recycling, reuse and reclaiming of waste?
5) What has been done by other industries to overcome the problem of waste?
6) Does environmental consciousness have any impact on organizational performance?
7) Are there any environmentally friendly materials, which can be substituted for the existing ones?

1.1 Research Scope and Justification

- There is an increase in pollution and disposal of waste in the manufacturing sector in Zimbabwe hence the study provided empirical evidence of the impact of the company’s environmental activity, and found ways of reducing negative environmental impacts of casted products.

- As the nations of the world industrialise, the growth rate in production and consumption has increased the challenge of sustainability and ecological balance thus there is need to efficiently use the available resources.
- The researchers focused on modelling some CP options for the sand casting foundries in Zimbabwe which will enable the effective use of resources (energy and raw materials).
- The project was confined to Life cycle analysis of products, Energy management, Waste management

2.0 Cleaner Production Concept

Cleaner Production (CP) is used in conjunction with other elements of environmental management; it is a practical method for protecting human and environmental health, and for supporting the goal of sustainable development, Yacoub et al (2006). CP can reduce environmental risks and liabilities and lead to greater competitiveness. By demonstrating a commitment to Cleaner Production, companies can also improve their public image and gain the confidence of consumers. It aims at avoiding the generation of waste and emissions, by making more efficient use of materials and energy, through modifications in the production processes, input materials, operating practices and/or products and services. As a rough guide, 20-30% reductions in pollution can be achieved with no capital investment required, and a further 20% or more reduction can be obtained with investments, which have a payback time of only months. (Habil, Stanikis, Stasiskiene and Arbaciauskas, 2001). Cleaner Production requires changing attitudes, responsible environmental management, creating conducive National Policy and evaluating technology options. (Global Environment Centre Foundation, 2008)

2.1 Means of Cleaner Production

a. *PRODUCTION PROCESSES:* Conserving raw materials, water and energy, eliminating toxic and dangerous raw materials, reducing the quantity and toxicity of all emissions and wastes at source during the production process.
b. *PRODUCTS:* Reducing the environmental, health and safety impacts of products over their entire life cycle, from raw materials extraction, throughout manufacturing and use to the ultimate disposal of the product.
c. *SERVICES:* using a preventive approach involves design issues, housekeeping improvement, and the better selection of material inputs (in the form of products).

2.2 Cleaner Production procedural tools

Tools for conducting cleaner production which are implemented in the research include

a) Life Cycle Analysis (LCA)
b) Environmental accounting
c) Eco efficiency
d) Energy management

e) Waste management

2.2.1 ECO Efficiency

Eco-Efficiency involves increasing production while reducing the environmental pressure per unit produced (Lovins, L. et al (2008)). It is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution. The publication allays that eco-efficiency is achieved through the delivery of "competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity.

WBCSD (2000) highlight the critical aspects of eco-efficiency as:

- A reduction in the material intensity of goods or services;
- A reduction in the energy intensity of goods or services;
- Reduced dispersion of toxic materials;
- Improved recyclability;
- Maximum use of renewable resources;
- Greater durability of products;
- Increased service intensity of goods and services.

(WBCSD) describes eco-efficiency as a management strategy of doing more with less. Case studies of companies that have adopted eco-efficient technologies and practices demonstrate that eco-efficiency stimulates productivity and innovation, increases competitiveness and improves environmental performance.

2.2.2 Waste management

Waste management is the collection, transportation, processing (waste treatment), recycling or disposal of waste materials, usually ones produced by human activity, in an effort to reduce their effect on human health or local aesthetics or amenity (The Wikipedia, 2010). The following foundry waste streams were defined:

a. Solid waste

Solid waste makes up a large portion of the pollution from foundries. On-quarter to one ton of solid waste per one ton of castings is expected (Shah, 1995). The waste comes from sand, slag; emissions control dust and spent refractories. Sand waste from foundries using sand molds has been identified as the most pressing waste

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problem in foundries (Twarog, 1992). Molding and core sand make up 66-88% of the total waste from ferrous foundries (USEPA, 1992).

b. Sand waste

Green foundry sand is routinely reused. After the sand is removed from the metal piece, it can easily be remolded. However, sand fines develop with reuse. These particles are too small to be effective in molds and have to be removed and often landfilled, McKinley M (1994). Sand that is chemically bound to make cores or shell molds is more difficult to reuse effectively and may be landfilled after a single use. Sand wastes from brass and bronze foundries pose further waste problems as they are often hazardous. Lead, copper, nickel, and zinc may be found in the sand in sufficient levels to require further treatment before disposal

c. Cleaning room waste

Trombly J (1995) explains that finished metal pieces are often cleaned in abrasion cleaning systems. He goes on to say that the abrasive cleaners and the sand they remove from the metal pieces contribute to solid waste. Grinding wheels and floor sweepings also add solid waste. These wastes are collected and usually landfilled,

d. Slag wastes

McKinley et al (1994) allays that slag waste is often very complex chemically and contains a variety of contaminants from the scrap metals. Common components include metal oxides, melted refractories, sand, and coke ash (if coke is used). They further on say that fluxes may also be added to help remove the slag from the furnace. Slag may be hazardous if it contains lead, cadmium, or chromium from steel or nonferrous metals melting. Iron foundry slag may be highly reactive if calcium carbide is used to desulfurize the iron. Special handling is required for highly reactive waste.

2.3 Life Cycle Analysis

A Life Cycle Analysis, (LCA, also known as life cycle analysis, ecobalance, and cradle-to-grave analysis) is the investigation and evaluation of the environmental impacts of a given product or service caused or necessitated by its existence. Porteous (2000),define LCA as a tool to evaluate the environmental performance of products which focuses on the entire life cycle of a product, from the extraction of resources and processing of raw material through manufacture, distribution and use to the final processing of the disposed product.

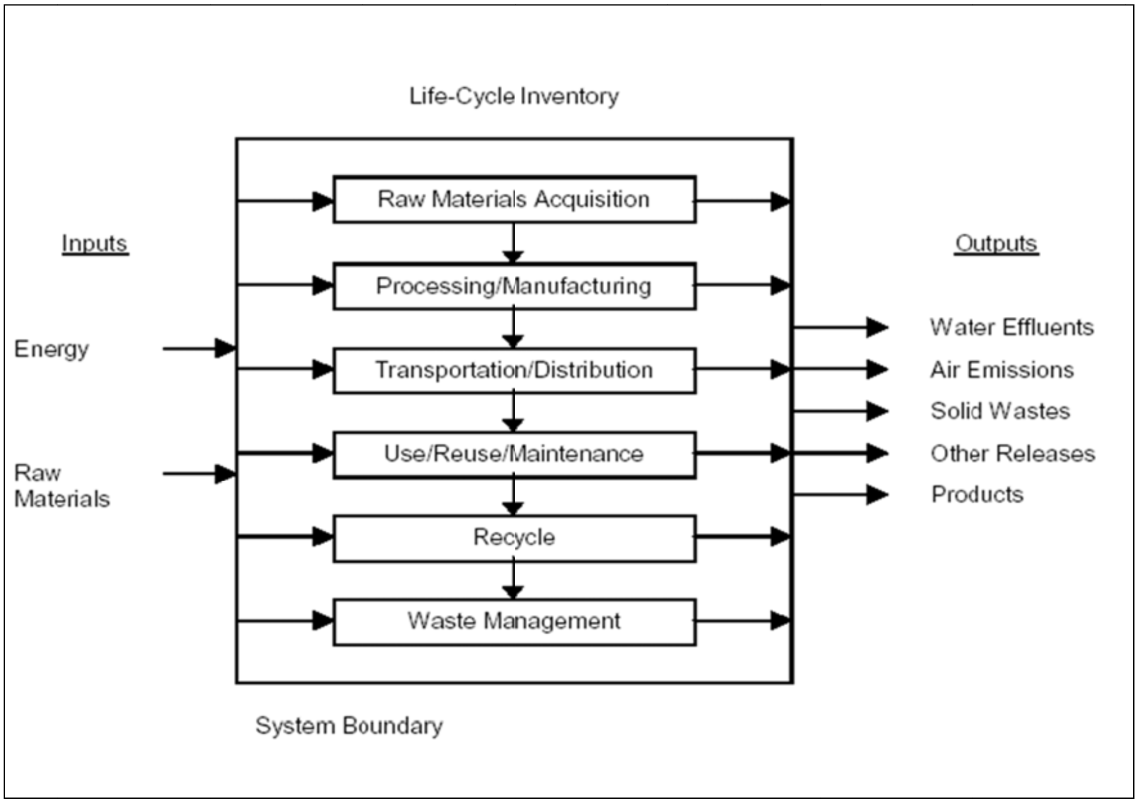

Fig2.1 Stages in the Life Cycle of a Product (Adapted from Krozer 1998)

2.4 Energy management

Energy management is the process of monitoring, controlling, and conserving energy in a building or organization. Clark, W (2004) list the steps involved in energy management as;

1. Metering your energy consumption and collecting the data.
2. Finding opportunities to save energy, and estimating how much energy each opportunity could save. You would typically analyze your meter data to find and quantify routine energy waste, and you might also investigate the energy savings that you could make by replacing equipment (e.g. lighting) or by upgrading your building's insulation.
3. Taking action to target the opportunities to save energy (i.e. tackling the routine waste and replacing or upgrading the inefficient equipment). Typically you'd start with the best opportunities first.
4. Tracking your progress by analyzing your meter data to see how well your energy-saving efforts have worked.

Five steps to effective energy management according to Clark (2004) are commitment, understand (establish the facts), plan and organize, act and control, monitor and review.

2.5 Environmental Protocols and laws in Zimbabwe

The Ministry of Environment and Tourism, administers most of the environmental acts that deal with the environment directly. Some of the environmental acts which are legalised in Zimbabwe are, Natural Resources Act (1941), Hazardous Substances and Articles Act (1977), Atmospheric Pollution Prevention Act (1971), Solid waste disposal act, Clean Water Act (1976), Environmental Management Act, Environmental protection act and Clean air act (1993). Zimbabwe is also a signatory of some environmental agreements which include Basel Convention, Kyoto protocol, Montred protocol, Commission of sustainable development, Agenda 21, International declaration on CP by UNEP 1998.

3.0 Methodology

3.1 Research Based on Case study

The case study company (anonymous) deals with the casting of ferrous components and spares. The casting of these products is done to customers' specifications (jobbing production) hence enabling the company to cast across various sectors including mining, automotive, agriculture, construction, plumbing and general engineering. The manufactured products include slurry pumps, water pump, brake discs and drums, impellers, casings, delivery heads and mill balls. Equipment at the company includes two induction furnaces, a heat treatment furnace, an overhead crane, lathe machine, milling machine, grinding machine, pyrometer and a sand mixer.

The company release solid and gaseous waste. The generated waste has some negative environmental impacts and results in problems of pollution. Sand moulding process constitutes over fifty five percent of the generated waste. Currently the solid waste is disposed at Pomona barracks. Although the company is able to reclaim approximately 45% of green sands, there is need to adopt CP techniques so that resources are efficiently used and waste is reduced.

3.2 Data Collection

- Work orders were used to get production data
- Interviews were done with stakeholders
- Questionnaires were distributed to operators
- Walk through inspection was done to understand operation
- Process flow diagrams studied
- Inputs and outputs were identified

4.0 Data Presentation and analysis

4.1 Sand casting process flowchart

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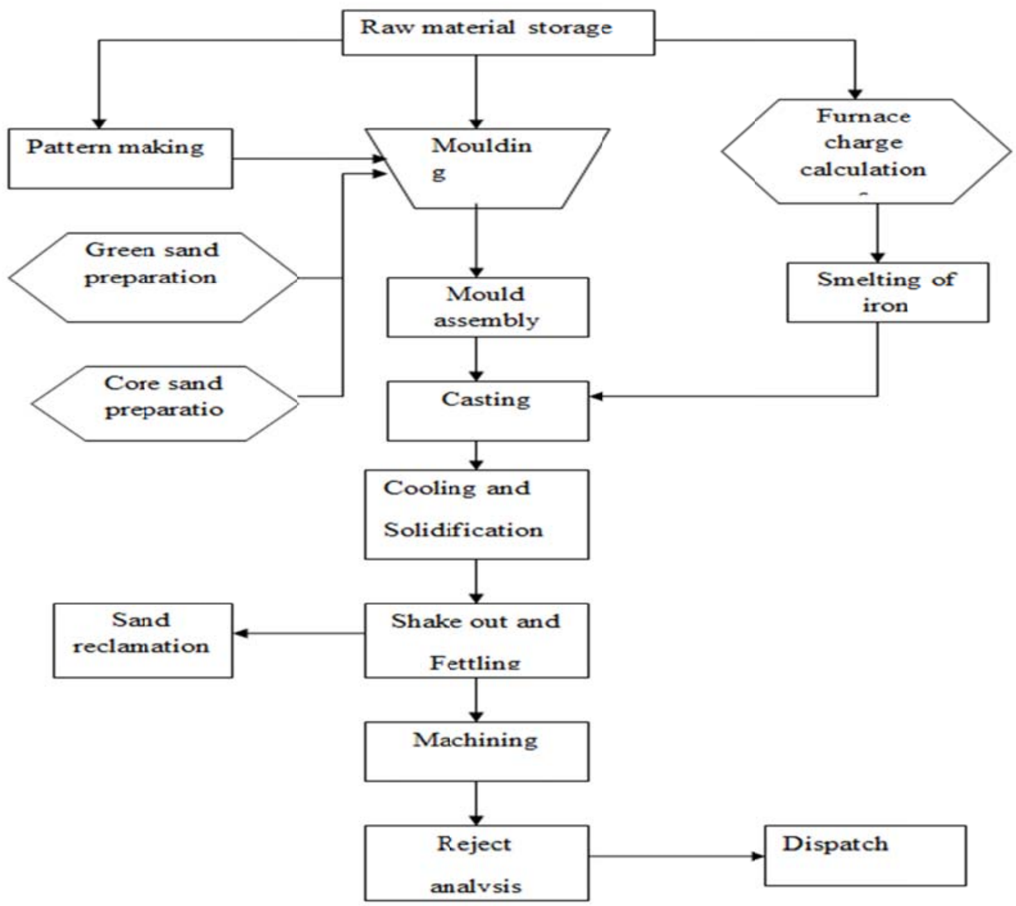

Fig4.1 Sand casting process flow chart

4.2 Material balance for sand casting process

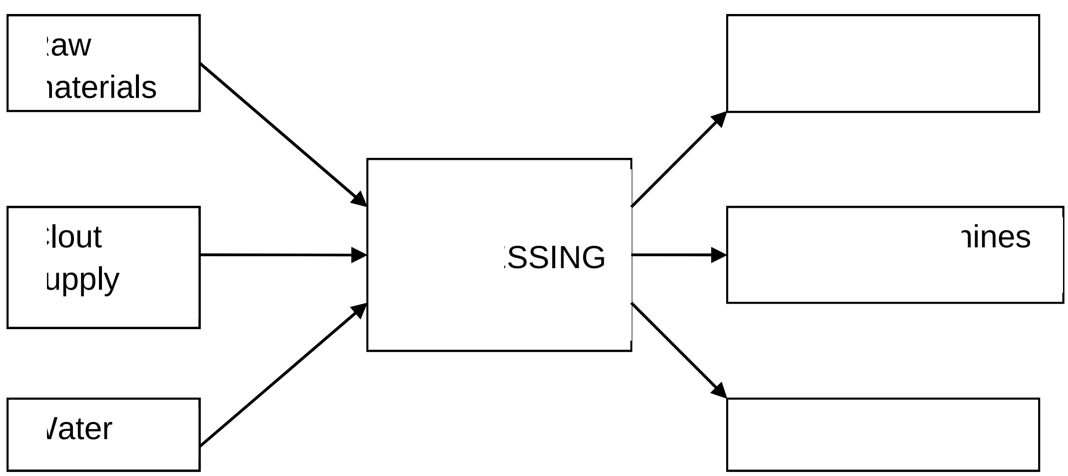

Fig4.2 Material balance for the entire process

4.3 Pattern making process flow chart

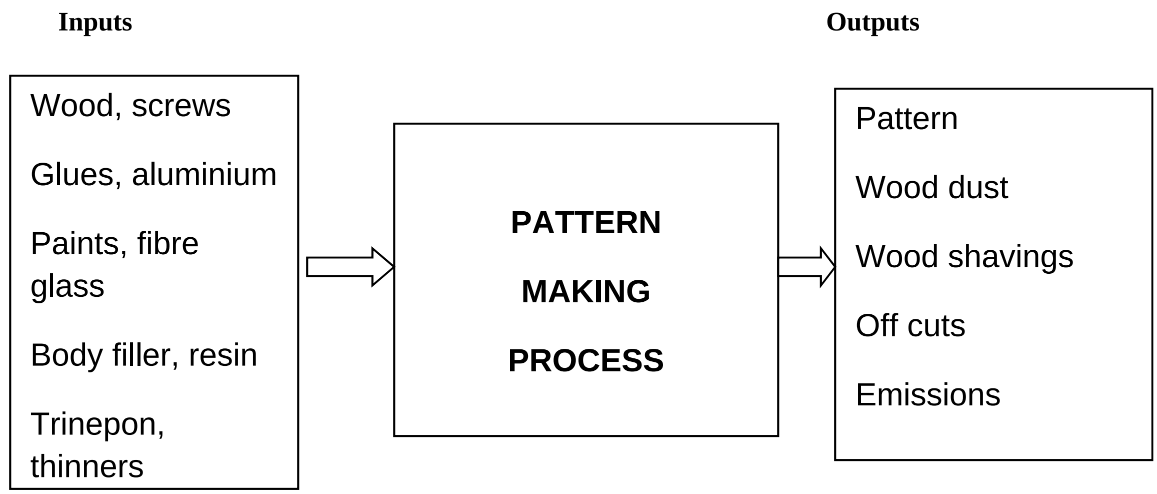

Fig 4.3 Pattern making process flow chart

Aspect and impact register

ENVIRONMENTAL ASPECTS	ENVIRONMENTAL IMPACTS
Use of paints, glues	Emissions, gaseous waste
Off cuts, wood shavings	Land pollution
Use of wood, fibre glass, resin	Resource depletion
Wood dust	Health hazard

Table 4.0 Aspect and impact register for pattern making

Impact assessment

AFFECTED ELEMENT IN	IMPACT OR EFFECT	SIGNIFICANCE RATING (1 –
Air	Pollution from wood dust	2
Land	Pollution from shavings, off cuts	2
Natural resource	Depletion of natural resources, wood, resin and fibre glass	2
Humans	Health hazards from dusts and emissions	3

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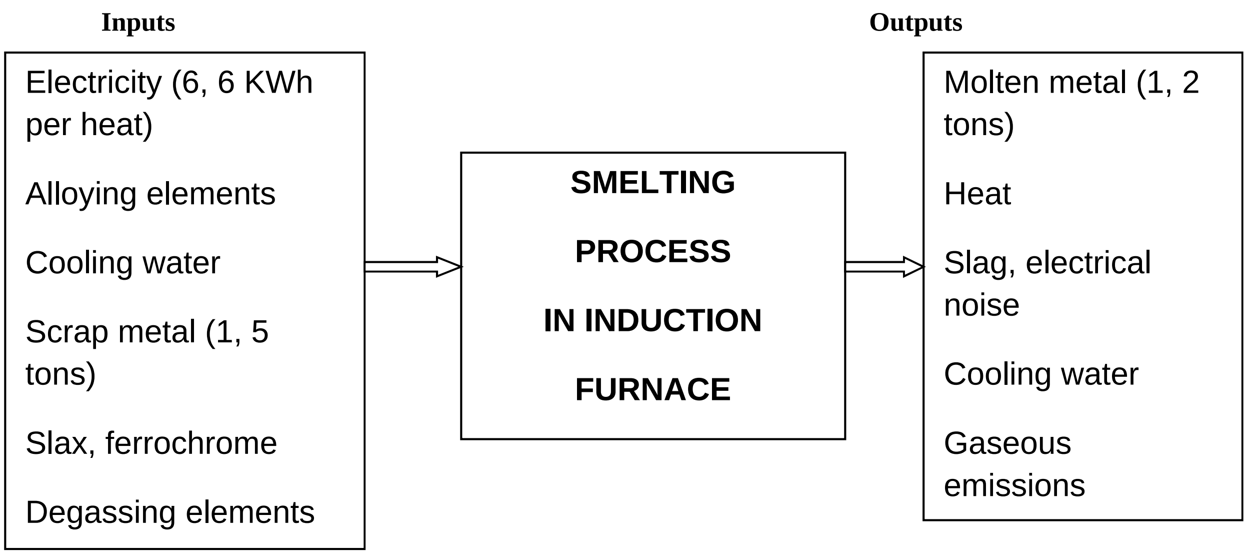
Table 4.1 Impact assessment for pattern making smelting process

4.4 Smelting process flow chart



Aspect and impact register

ENVIRONMENTAL ASPECT	ENVIRONMENTAL IMPACT
Use of chemicals	Health hazard
Use of metals (scrap and alloys)	Resource depletion
Use of electricity	Resource depletion
Smelting of ferrous metals in induction furnace	Odours, emissions and potential accidents
Scorification and tapping	Potential accidents
Skimming of slag	Land pollution
Smelting additives	Health hazard (exposure to irritant dusts)
Handling of high temperature materials	Potential accidents e.g. splashing and spills

Table 4.2 Aspect and impact register for smelting process

Impact assessment

AFFECTED ELEMENT IN	IMPACT OR EFFECT	SIGNIFICANCE RATING (1-
Air	Pollution from gas emissions	1
Land	Pollution from skimmed slag	2
Natural resource		2

Humans	Health hazard from gaseous emissions, potential accidents from spills during skimming and handling of molten metal	2

Table 4.3 Impact assessment for smelting process

4.5 Induction furnace process flow chart

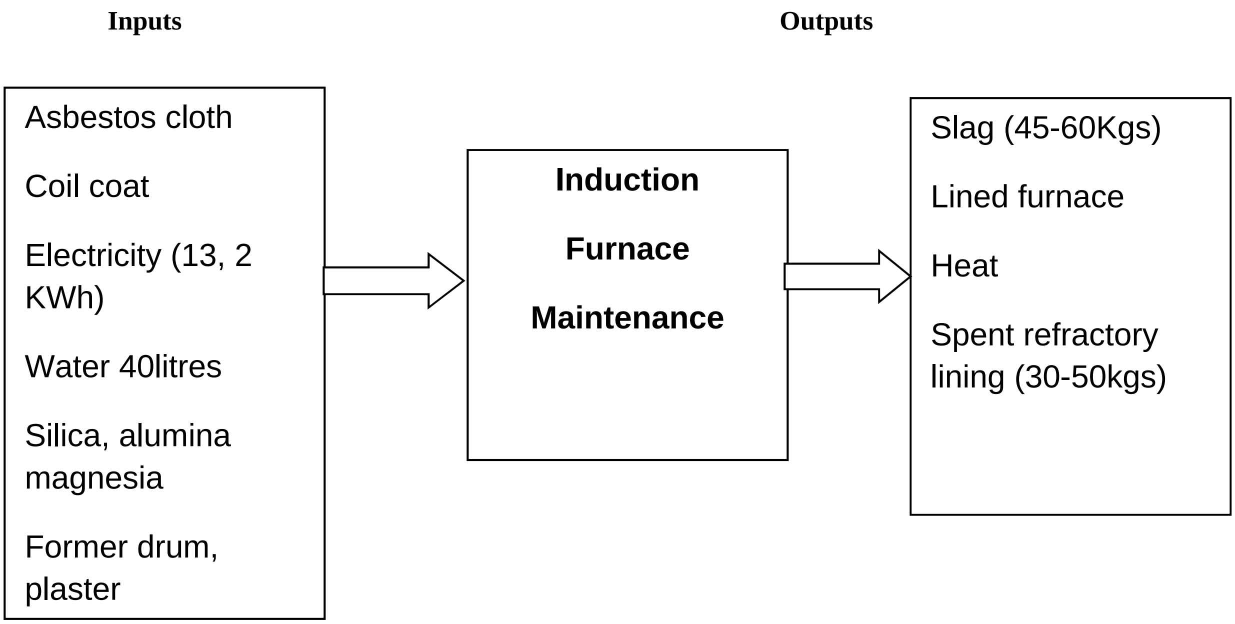


Fig 4.5 Process flow chart for induction furnace maintenance

Aspects and impacts register

Environmental Aspect	Environmental Impact
Use of lining materials	Resource depletion
Use of chemicals	Health hazard
Mixing of chemicals	Dust emissions
Use of hand held tools	Potential accidents
Spent refractory lining	Land pollution

Table 4.4 Aspect and impact register for furnace maintenance

Impact assessment

AFFECTED ELEMENT IN	IMPACT OR EFFECT	SIGNIFICANCE RATING
Air	Pollution from mixing chemicals, health hazard, respiratory diseases from dusts	2
Water		1
Land	Pollution from spent refractory lining	2
Natural resource	Depletion of lining materials	2
Humans	Health hazard from dusts	2

Table 4.5 Impact assessment for furnace maintenance

4.6 Material and energy balance of sand moulding per annum.

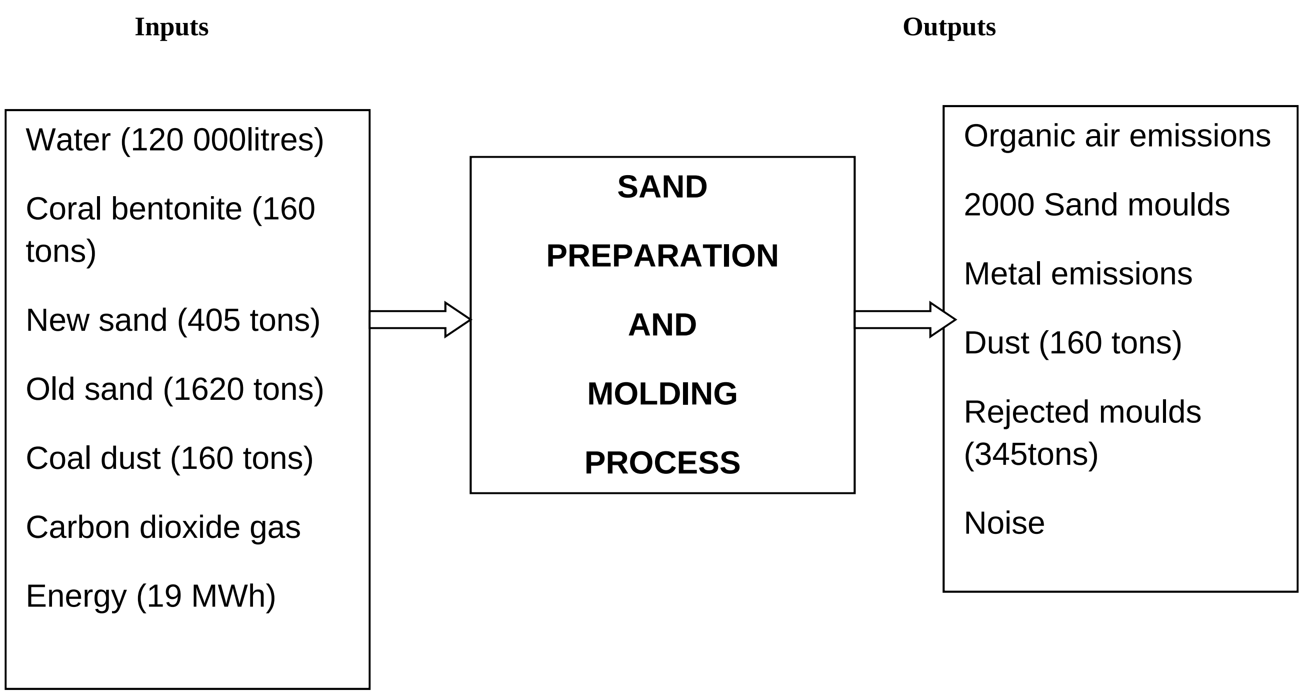


Fig 4.6 Process flow chart of sand casting process

Aspect and impact register

ENVIRONMENTAL ASPECT	ENVIRONMENTAL IMPACT
Sand preparation	Exposure to dust
Use of carbon dioxide gas	Resource depletion

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Use of sand mixer	Potential accidents, noise
Use of chemicals	Health hazard
Spent sand	Land pollution
Use of oils or lubricants	Odour , resource depletion
Use of water	Resource depletion

Table 4.6 Aspects and impact register for sand moulding

Impact assessment

AFFECTED ELEMENT IN	IMPACT OR EFFECT	SIGNIFICANCE RATING
Air	Pollution from dusts	1
Water	Resource depletion	1
Land	Pollution from spent sand	3
Natural resource	Depletion of sands	3
Humans	Health hazards from dusts,	3

Table 4.7 Impact assessment for the sand moulding

4.7 Maintenance process flow chart

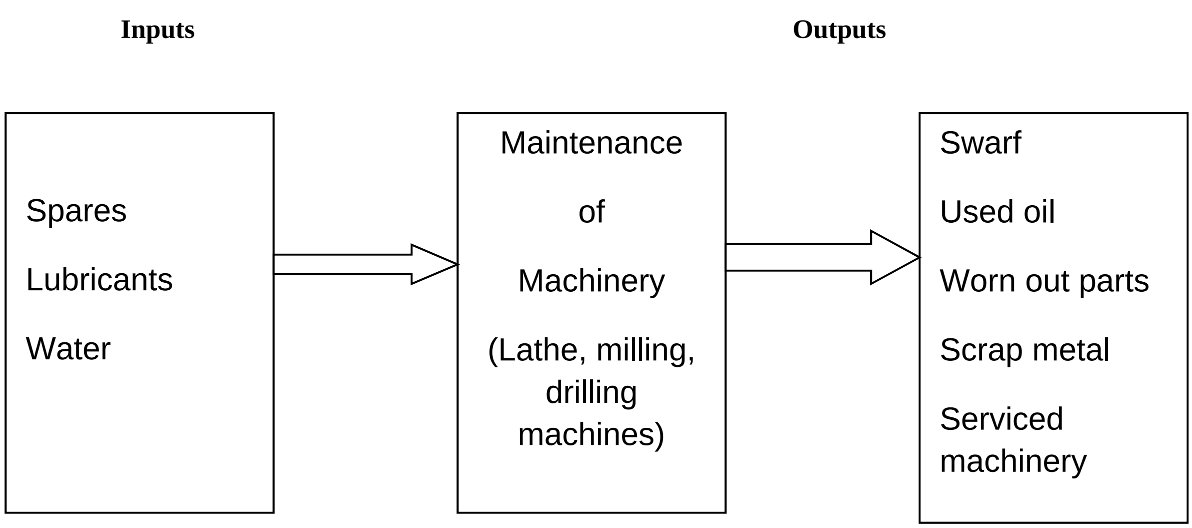

Fig 4.7 Process flow chart of machinery maintenance

Aspects and impacts register

ASPECT	**IMPACT**
Use of lubricants	Resource depletion

Swarf, worn parts	Land pollution

Table 4.8 Aspect and impact register for machinery maintenance

5.0 Results

5.1 Impacts evaluation of casting processes

Calculations using environmental impact matrix

C = S (L+I)

If C≥ 9then the aspect is significant

S = Seriousness of the impact if allowed to continue without control (consider the above ratings and pick the highest score)

L = Likelihood of the effect "escaping" or going undetected. This is inversely proportional to the amount and effectiveness of the control or abatement technique.

- If there is **NO** control or **above the limits** or **NO** means of monitoring then **L=3**
- If there is some control but not reliable **L=2**
- If there is **Complete** control and can be monitored then **L=1**

I=Impact of the effect (size of the danger)

- If the risk is fatal or leads to a penalty **I=3,**
- If the risk is presented in the long term then **I=1,**
- If the risk is presented in the short term then **I=2**

5.2 Environmental Impact Matrix calculations

5.2.1 Pattern making

ASPECT/IMPACT	S	L	I	C
Air pollution	2	2	3	10
Land pollution	2	2	1	6
Resource depletion	2	2	1	6
AVERAGE	2	2	1,666	7,333

Table 4.1 Impact evaluation of pattern making

5.2.2 Smelting in furnace

ASPECT/IMPACT	S	L	I	C
Air pollution	1	2	2	4
Land pollution	2	2	2	8
Resource depletion	3	2	1	9
Potential accidents	3	2	3	15
AVERAGE	2,25	2	2	9

Table 4.2 impact evaluation of smelting process

5.2.3 Furnace maintenance

ASPECT/IMPACT	S	L	I	C
Air pollution	2	2	3	10
Land pollution	2	2	3	10
Resource depletion	2	2	1	4
Health hazard	2	3	2	10
AVERAGE	2	2,25	2.25	8,5

Table 4.3 impact evaluation of furnace maintenance

5.2.4 Sand Moudling

ASPECT/IMPACT	S	L	I	C
Air pollution	2	3	3	12
Land pollution	2	2	2	8
Resource depletion	3	2	2	12
AVERAGE	2,33	2,33	2,33	10,66

Table 4.4 Impact evaluation of sand moulding

5.2.5 Pouring and Solidification

ASPECT/IMPACT	S	L	I	C
Air pollution	1	2	1	3
Land pollution	1	2	1	3
Resource depletion	1	2	1	3
Potential accidents	2	3	2	10
AVERAGE	1,25	2,25	1,25	4,75

Table 4.5 Impact evaluation of pouring and solidification

5.2.6 Shake out, Fettling and Machining

ASPECT/IMPACT	S	L	I	C
Air pollution	3	3	3	18

Land pollution	3	2	2	12
Resource depletion	2	2	1	4
Health hazard	3	3	3	18
AVERAGE	2,75	2,5	2,25	13

Table 4.6 Impact evaluation of shakeout and fettling

5.2.7 Machinery maintenance

ASPECT/IMPACT	**S**	**L**	**I**	**C**
Air pollution	1	1	1	2
Land pollution	2	2	1	6
Resource depletion	2	2	1	6
Potential accidents	2	2	2	8
AVERAGE	1,75	1,75	1,25	5,5

Table 4.7 Impact evaluation of machinery maintenance

5.2.8 Overall impact assessment of processes

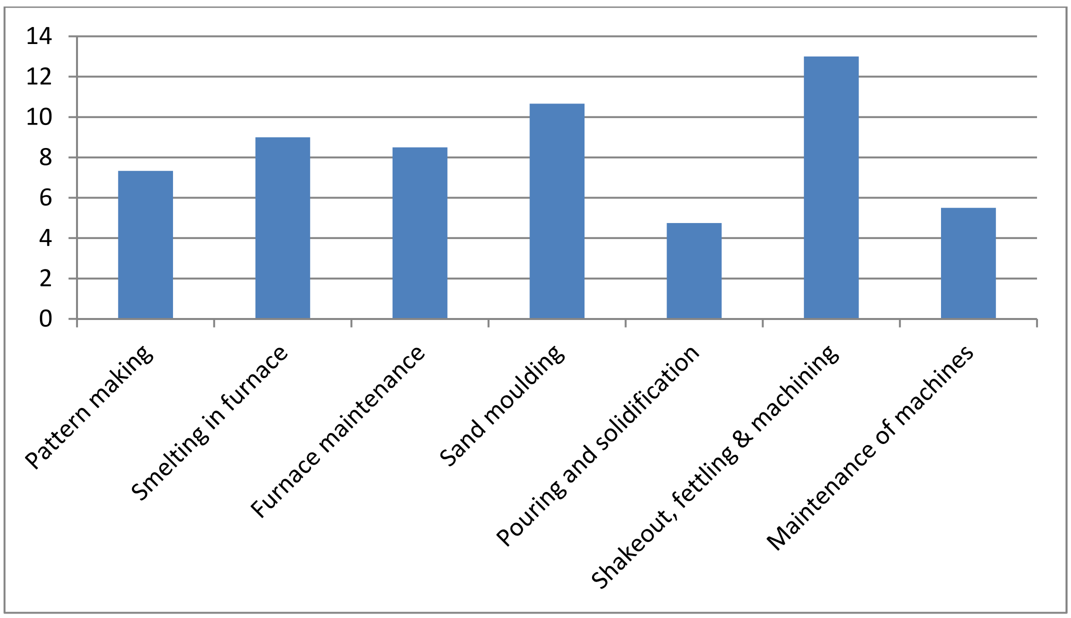

Fig 4.1 Overall impact assessment

5.2.9 Energy Audit

The audit quantified the energy consumption at the case study company. The major energy consumers are the induction furnace, heat treatment furnace, and the machines in the machine shop.

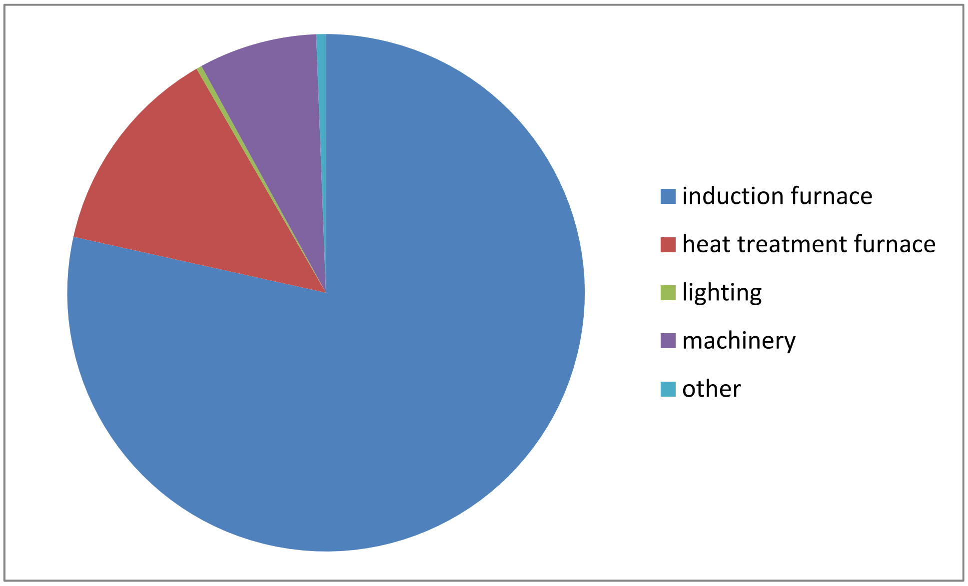

Fig5.2 Energy consumption

5.2.10 Reject Analysis

An analysis of the casting defects in 100 cast products was done from the company documents. The results highlight that the defects are mainly caused by run out therefore the quantities of molten metal should be correctly calculated so that run out is avoided.

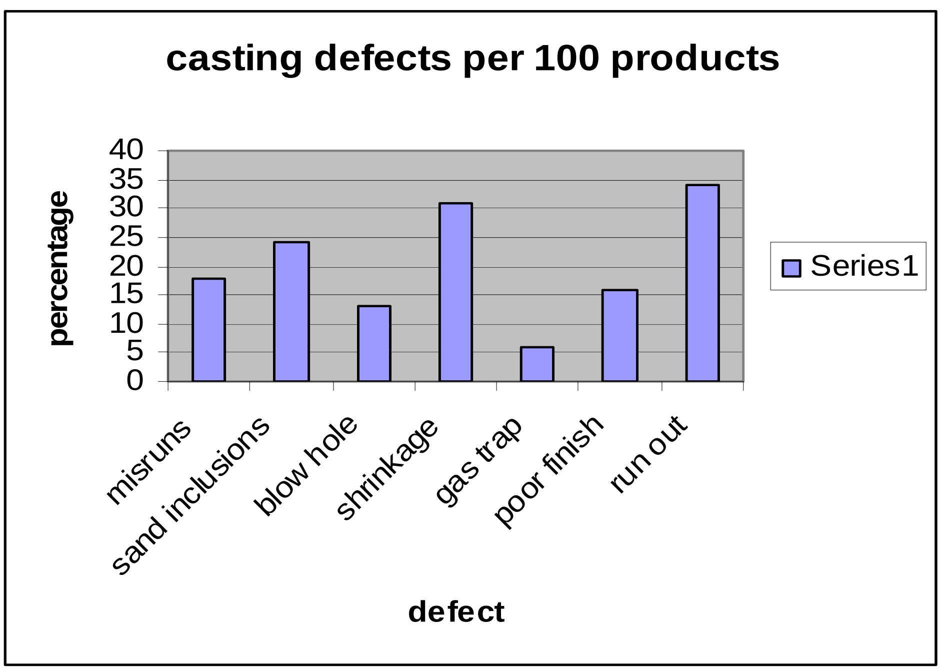

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Fig5.3 Reject analysis

Comments

Smelting, sand moulding and shakeout have an average of c ≥9 implying that the environmental impacts of the processes are significant. Shake out, fettling and machining has the highest significance rating meaning that the process require the most environmental attention. Dust emissions are the major aspects, the impact being a health hazard to employees. From the results, management should give more attention to the shakeout process and implement ways of reducing dust emissions into the atmosphere as well as solid waste (used sand).

6.0 Discussion

6.1 CP Opportunities

6.1.1 Pattern making

ENVIRONMENTAL ASPECT/IMPACT	CP OPTIONS
Wood dust	• Install an efficient dust removal and ventilation system
Pollution from shavings and off cuts	• Apply industrial ecology, use as fuel

6.1.2 Furnace maintenance

ENVIRONMENTAL ASPECT/IMPACT	CP OPTIONS
Spent refractory lining	• Apply industrial ecology as an aggregate in road construction.

6.1.3 Smelting in the Induction furnace

ENVIRONMENTAL ASPECT/IMPACT	CP OPTION
Process consumes a lot of energy	• Proper furnace charge calculation. • Avoid over heating of metals. • Proper furnace maintenance.
Pollution from slag	• Cleaning scrap before use.

	• Applying industrial ecology (selling slag to quarries).
Gaseous and metallic emissions	• Proper ventilation.

6.1.4 Sand moulding

ENVIRONMENTAL ASPECT	CLENER PRODUCTION OPTION
Sand mixer noise and accidents	• Segregating the machine in a sound-dampening enclosure. • Substitution of old jolt-squeeze machines with newer automatic hydraulic or pneumatic ones also result in a noise reduction. • Use of IPDs -Individual Protection Devices, such as ear protection.
Handling of oils	• IPDs (face mask, protective gloves and apron).
Pungent odours	• Use of appropriate ventilation.
Dust emissions	• Powdered additives and mixtures should be handled in a sludge form. (Mixed with water). • Manual handling of additives and mixtures not in the sludge form shall require the use of IPDs (dust-proof face mask, protective gloves and apron). • The whole facility and more specifically the sand mixers and load stations shall be enclosed and fitted with an exhaust and ventilation system.

6.1.5 Pouring and Solidification

ENVIRONMENTAL ASPECT/IMPACT	CP OPTIONS
Potential accidents from spillages	• Redesigning the plant to minimise transportation distances.
Energy losses in the molten metal	• Insulating the furnace and covering ladles.

	• Reheating the ladles before metal is tapped.

6.1.6 Shake out, Fettling and Machining

ENVIRONMENTAL ASPECT/ IMPACT	CP OPTIONS
Dust emissions	• Invest in dust extraction equipment.
Pollution from spent sand	• Invest in effective sand reclamation equipment (rotary screen and shot blasting reclaimers).
Pollution from foundry returns and rejects	• Invest in gating system design software for proper gating.

6.1.7 Maintenance of machinery

ENVIRONMENTAL ASPECT/IMPACT	CP OPTIONS
Machine consuming a lot of energy	• Implement an effective routine preventative maintenance strategy.

6.2 Environmental analysis

CP OPTION	ENVIRONMENTAL BENEFIT
Sand reclamation	Sand waste savings, reduced raw material costs and reduced disposal costs Better house keeping
Dust collection	Health hazard eliminated Better working environment for workers Elimination of regulation penalties and fines
Furnace insulation	Energy consumption
Process optimization	Efficient use of resources Improved productivity Better product quality, no reworking on products

6.3 Implementation plan

The initial environmental review highlighted existing environmental aspects and impacts in the production process, the ranking of the significance of the impacts should be used when selecting the projects to implement, shouting or serious impacts e.g. dust emissions require immediate attention hence options to minimise dust should be implemented first. Some

CP options can require capital investment whilst others do not need capital injection thus management should give priority to those options which do not require capital investments for example housekeeping.

7.0 Conclusion and Recommendations

CP has proven in practice to be a very valuable concept for abating industrial wastes and emissions. Economic benefits can be achieved from preventing waste and emissions in the first place, as raw materials, energy and water are saved and waste disposal costs are minimized. The aim of the project was to model CP options which enable the efficient use of resources and improve the environmental performance of foundry companies. Options were modelled and their feasibility was analysed, the analysis reviewed how raw materials, water and energy were to be saved once the options were implemented. The environmental performance would also improve since wastes and emissions would be reduced.

The environmental status and performance of the case study company was determined and opportunities of reducing waste and increasing resource efficiency were modelled. Feasibility study on the modelled options was conducted therefore the earlier stated objectives were achieved. The benefits of implementing CP at foundry companies were ascertained, these include;

a) Reducing waste through efficient use of energy and raw materials.

b) Enhancing productivity and increasing product yield through greater efficiency.

c) Increasing profitability and quality of products.

d) Reducing the risks of environmental accidents and avoiding regulatory compliance costs leading to insurance saving.

The researchers put forward recommendations to the case study company management so that they can implement them for decision making purposes. Sand casting foundries can benefit from CP if they implement the recommendations listed below;

a) Incorporate supply chain personnel in the organogram so that better raw materials are received from suppliers.

b) Developing and compiling of standard operation procedure for every process as well as documenting the procedures.

c) Training of personnel to upgrade skills of operations, training on use of the new technology and sand technology to minimise sand related defects. Training involving environmental awareness and issues should be a priority in manufacturing organisations, so that everyone gets involved in finding ways for reducing waste.

d) Management should communicate with employees so that they are aware of environmental issues.

e) Development of a management model, a description on how the production and logistics are organised and managed, showing material flow as well as distribution of responsibilities to the total production work.

f) Development of a computer based tool to simulate the casting process and optimise production methods.

g) Incorporating a research and development department in the company structure so that the company stays up to date with the latest technology.

h) Improve the sand reclamation process through investing in more efficient equipment e.g. rotary and shot blasting reclaimers.

The researchers recommend manufacturing companies to frequently review their environmental performance so that resources can be conserved and the working place is made a better and safer place.

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