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Study and Measurements of Waste Heat Recovery of Slag in Melting Furnaces in SME's Foundry Industry

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Abstract

The Indian foundry produces around 6 million ton of castings annually. The slag generated annually is around 1.8 million ton. The slag produced in an ore refining or smelting process of a blast furnace, is almost 30 % of metal produce, and at a temperature @ 1150^{0}C. The heat energy is carried away by slag is proportional to its temperature and quantity.

The study is carried out to evaluate slag heat content and if utilized in recovery to save energy in terms of coke consumption as slag heat content has never been used before to recover the energy contained in it. Special technique to measure specific heat, which is function of temperature, is developed and used to verify the standard values and used for theoretical analysis.

Paper further reveals the various experimental studies that have been set forth for evaluation of energy conservation and are tested, the results of which (for sample foundry) are for reference. The waste heat potential of sample foundry is 609120 KJ/day, increase in efficiency is 16.06%, increased metal production is 1.602 ton/day, and increase in metal melting rate is 216 Kg/hr. This data is further used to re-estimation of energy conservation.

***Keywords**: Analysis, Cupola, Pre-heated air, Slag, etc.*

Nomenclatures

Cp_{slag}=Specific heat of slag (KJ/KgK)

Cp_{w}= Specific heat of water (KJ/KgK)

Cp_{air}= Specific heat of air (KJ/KgK)

Cp_{iron}= Specific heat of iron (KJ/KgK)

M_{slag}=Mass of slag in Kg

$M_{w=}$Mass of water in Kg

$T_{w\ i/p}$= Input temperature of water in ^{0}C

$T_{w\ o/p}$= Output temperature of water in ^{0}C

$T_{slag\ i/p}$= Input slag temperature in ^{0}C

$T_{slag\ o/p}$= Output slag temperature in ^{0}C

1) Introduction

The Indian foundry produces around 6 million ton of castings annually. The slag generated annually is around 1.8 million ton. It is well known that slag produced in an ore refining or smelting process as, for example, in a blast furnace, is of a great quantity(30% of metal produce) and it's at high temperature around 1150^{0}C. The heat energy is carried away by slag is of tremendous quantity. However this slag is ordinarily allowed to flow into melt dumping yard to cool naturally or by sprinkling with water and according to present practice, there is no whatsoever use of this tremendous heat energy, which is therefore wasted.

2) Problem Definition

It's said that quantity of slag produced in a blast furnace is ordinarily of the order of 0.28 to 0.35 parts per one part of pig iron. From a blast furnace of 10000 metric ton daily production, the slag output is approximately 3000 Metric tons per day. On the assumption that slag temperature is 1500 ^{0}C and that Specific heat of slag is 0.24 KJ/Kg^{0}C, the heat loss is approximately $1.08X10^9$ KJ per day or $45X10^6$KJ per hour converted into terms of oil, this rate is 4500Kg/hr, which is a considerable quantity. This huge amount of heat otherwise wasted should be conserved through appropriate mechanism. The project is therefore undertaken to exactly evaluate the waste heat and its recovery for better energy conservation in foundry sector.

3) Methodology

It includes the study of following objectives set and meeting them step by step approach to reach the solution towards defined problem.

1) The survey of various foundry industries in Foundry cluster, Maharashtra, India

2) Study of furnaces and slag in various industries

3) Trial readings for the purpose of determining the test set up establishment for slag heat contents.

4) The study of slag temperature and other parameters

5) To finalize data acquisition techniques for selected foundries

6) Determination of actual slag specific heat i.e. C_p of Specific foundry calculation of heat content for finding waste heat potentials.

7) Analysis of the waste heat content

8) Estimates of potentials and applications

9) Energy conservation estimates

It is with respect to functioning of Cupola and it's frequency of melt, tonnage capacity, instruments available for measurement like digital thermometer indicator, ladle available for collecting slag, etc. The report of Kolhapur foundry sector is studied and decided the visit plan of sample foundry, Kolhapur, India. To achieve the objectives 1 to 5 mentioned above, the survey is done in sample foundry.

4) Measurements

Data Collected at sample foundry

1) Melting Rate=2000Kg/hr,
2) Blower capacity=1900 m^3/hr
3) Metal produced per day=5000 Kg/hr
4) Slag produced per day=1500 Kg/hr

4.1) Charge Composition

Sr no	RR Kg	Scrap Kg	Pig Iron Kg	MS Kg	Coke Kg
1	40	90	70	16	15

Table I shows Charge Composition for sample foundry

4.2) Observation Table for sample foundry

Sr No.	M_{slag} Kg	$T_{slag\ i/p}$ ^0C	$T_{slag\ Output}$ ^0C	M_{water} Kg	T i/p^{0}C	$T_{w\ Output}$ ^0C	Cpw KJ/Kg
1	0.4	1152	39	4	27	39	4.187
2	0.6	1152	44	4	32	44	4.187
3	0.9	1152	60	4	40	60	4.187

4	1.1	1152	69	4	47	69	4.187
5	0.9	1152	48	4	26	48	4.187
6	0.4	1152	39	4	27	39	4.187

Table II shows Observation Table for sample foundry

4.3) Formulae

In order to determine the specific heat and heat content of slag, the formulae's given below are used.

$(MXCpXdT)_{slag} = (MXCpXdT)_{water}$

Slag heat content= $(MXCpXdT)_{slag}$

4.4) Calculated Table for sample foundry

Sr no.	**Cp_{slag} KJ/KgK**	**Heat content of slag KJ/KgK**
1	0.46	200.976
2	0.32	200.97
3	0.35	335
4	0.31	368.5
5	0.37	368.5
6	0.46	200.976

Table III shows Calculated Table for sample foundry

5) Calculations for for calculating efficiency of Cupola

From thermodynamic point of view, a higher temperature in the air blast is beneficial, because this means higher inlet energy without increasing the amount of coal coke rate.

$$C_p m \Delta T = q m_c \quad (1)$$

Where C_p is the Specific heat of air blast at constant pressure (1.29 KJ/Nm^3 °C), m the air mass, ΔT the temperature increase, q the combustion heat of carbon (27,044 KJ/Kg of C, m_c the carbon mass

1. Metal production per heat=5 ton/day
2. Slag production per heat= 1.5 ton/day
3. Heat content in slag = mXCpXdT

   = 101520 KJ/hr
4. $(mCpdT)_{air}$ = Slag heat content per hr

$T=233^0C$

5. Output blast air temperature= 233^0C

Charge composition of sample foundry

Sr no	RR Kg	Scrap Kg	Pig Iron Kg	MS Kg	Coke Kg
1	150	150	120	90	60

Table IV shows Charge composition of sample foundry

6. To produce 5000Kg metal,

No. of charging= (total metal production/metal in single charge)

=10

Carbon % in material used in sample foundry

Sr No.	Material	C%	Total Carbon in Kg
1	Pig Iron C%	3.9	54.6
2	Steel C%	0.1	0.90
3	Scrap C%	3.6	46.8
4	Runner and riser C%	3.5	52.50
			154.8 Kg

Table V shows carbon % in material used in sample foundry

Total carbon Mass in charge=154.8 Kg

7. Heat loss in oxidation = Mass of carbon X heat of combustion of carbon in KJ/Kg
   =4191820 KJ
8. Heat of combustion of coke = (total coke utilised)X(heat content of coke) =(bedcoke+ no.of chargingsXcoke in single charge)X(heat content of coke)
   =9713840 KJ
9. Efficiency of Cupola= (Heat utilised in melting)/(heat of combustion of coke+ heat loss in oxidation)
   =38.50%

   $(mCpdT)_{air}=(MXq)_{Carbon}$ [from equation 1]

   Where,

   M= Mass of carbon in charge in Kg/hr

q = heat of combustion of carbon in KJ/Kg=27044 KJ/Kg

m= Mass of air in Nm^3/hr

Cp= Specific heat of air in KJ/ Nm^3 ^{0}C

dT= temperature difference in ^{0}C1 Nm^3/hr = 0.94 m^3/hr

10. M =4.41 Kg/hr

For fixed carbon Mass of 0.3464 in coke,

M=13 Kg/hr

For 6 hours of operation of Cupola,

Total carbon Mass saved=6X13=78 Kg/day

Total carbon in use=502 Kg

For an increase of 200°C in air temperature leads to an increase in melting rate and production capacity.

Production capacity

$$C_p m \Delta T \eta = C_{Fe} T M \qquad (2)$$

Where C_p is the Specific heat of air, m the air volume, ΔT the temperature increase, η the Cupola efficiency, C_{Fe} the mean Specific heat of iron, T the iron temperature, M the iron production increase.

To calculate increased amount of iron,

$(MXCp_{iron}XdT)_{iron}=(mXcpXdT)_{air}$ X Efficiency of Cupola [From equation 2]

Where, M= Mass of increased amount of iron in Kg

Cp_{iron} = mean Specific heat of iron=0.75 KJ/Kg

T= molten metal temperature in ^{0}C

m= Mass of air in Nm^3/hr

Cp= Specific heat of air in KJ/ Nm^3 ^{0}C

dT= temperature difference in ^{0}C

11. M=109.22 Kg/hr

For 6 hours of operation of , total increased amount of iron= 655.36 Kg/day

Total amount of iron produced in a day= 5000+655.36= 5655 Kg/day

12. Improved Cupola efficiency= (Improved heat utilized in melting)/(improved heat of combustion of coke+ improved heat loss in oxidation+ heat content of blast air)

13. Improved heat utilised in melting = 6056505 KJ

    Heat loss in oxidation = Mass of carbon X heat of combustion of carbon in KJ/Kg = 2082388 KJ

14. Heat of combustion of coke = (total coke utilised)X(heat content of coke)

    =(bedcoke+ no.of chargingsXcoke in single charge-carbon saved)X(heat content of coke)

    = 8407496 KJ

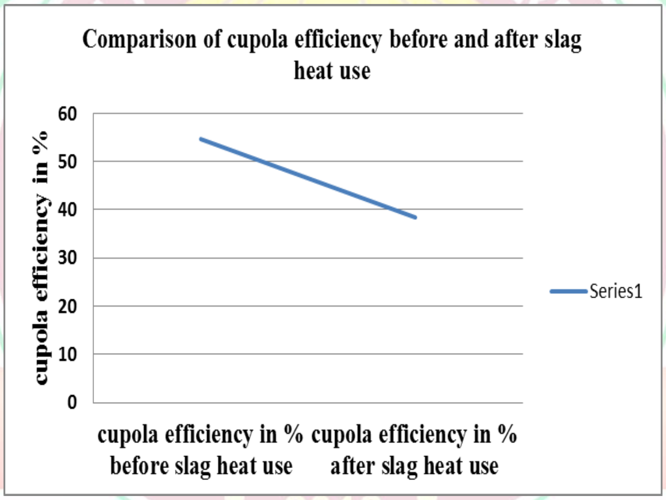
15. Improved Cupola efficiency= 54.56%

    Increase in Cupola efficiency =54.56-38.50=16.06%

6. Analysis of calculated data of Cupola efficiency and other parameters

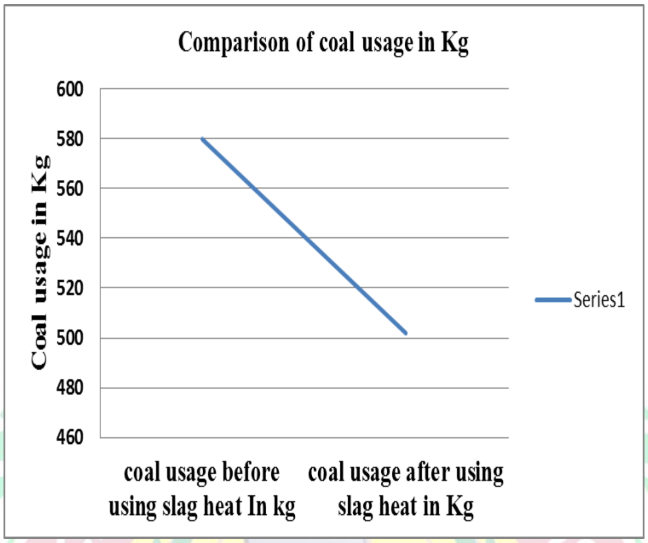
On basis of data calculated above, the analysis is done by plotting following graphs.

Graph I below shows improved efficiency of Cupola after using slag heat.



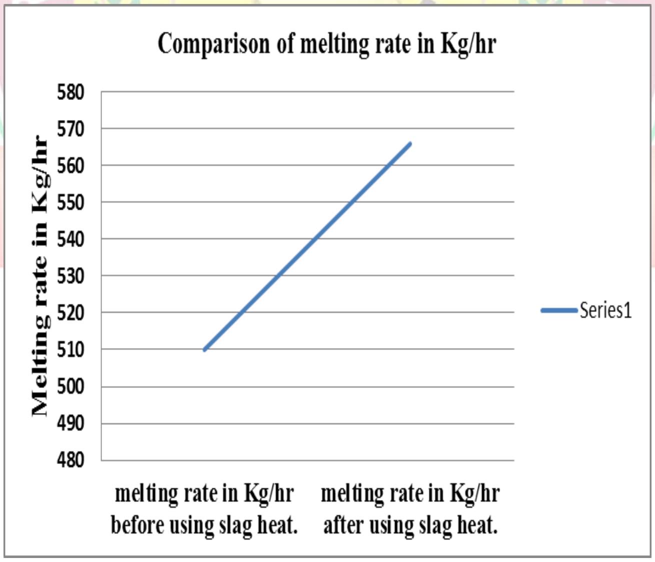
The efficiency of Cupolaafter use of slag heat increases due to reduction in heat of combustion, heat content of coal, and rise in air blast heat content. The lesser heat loss due to combustion is because of carbon saving and so emissions reduction, effective coal combustion due to use of preheated air and improved metal to coke ratio. The rise in blast heat content is due to reusing water immersed slag heat through heat exchanger to blast air. Thus the preheated air improves the effective combustion of coal in Cupola. Thus it minimizes the required coal as well, thereby minimizing heat content of coal required for actual melting and burnt coal emissions.

Graph II below shows reduced coal usage after using slag heat.



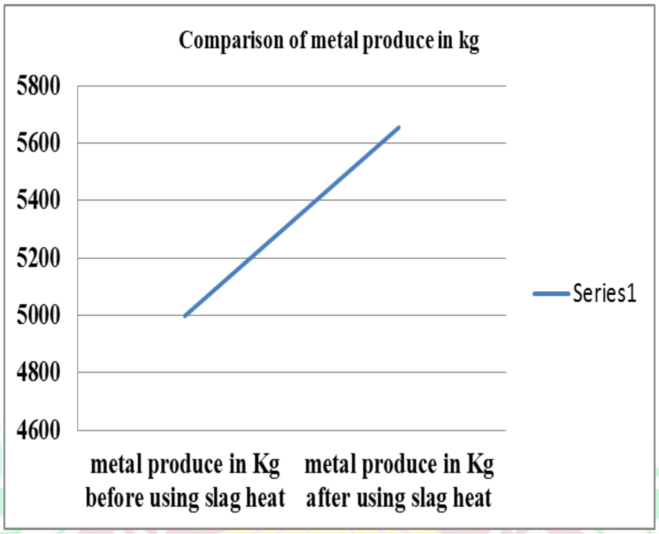
The coal usage reduces as metal to coke ratio improves after using slag heat content in Cupola. Slag heat utilization reduces the need of coal heat content. So coal requirement also minimizes.

Graph III below shows increased melting rate in Kg/hr after using slag heat.



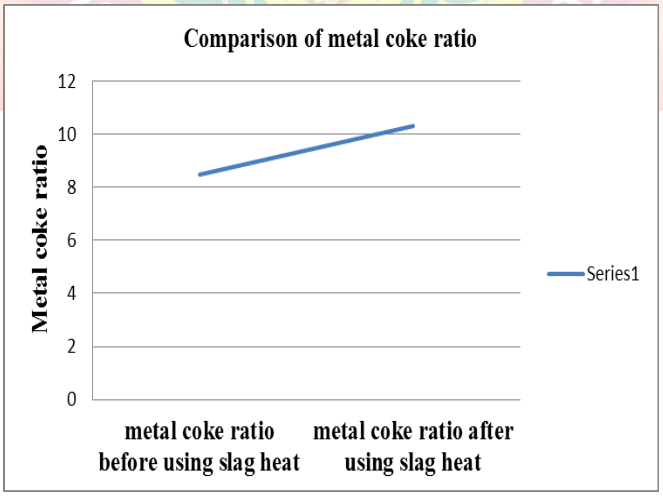
The melting rate enhances as metal to coke ratio improves after use of slag heat content. The melting rate depends upon metal to coke ratio and blast rate. The slag heat reuse reduces coal heat requirement and thus minimizes coal usage. At the same time, slag heat given to blast air, increases the blast air heat content. Thus the preheated air raises effective coal combustion. Thus metal to coke ratio is improved. Thus both improved metal to coke ratio and blast rate raises melting rate.

Graph IV below shows increased metal produce in Kg after using slag heat.



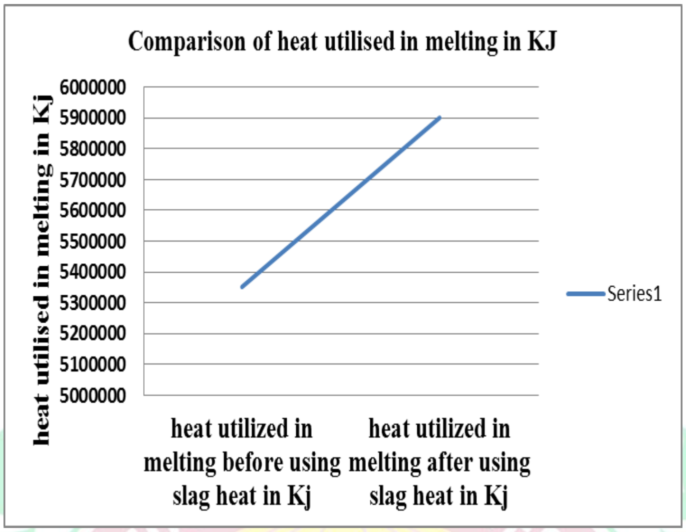
The improved metal to coke ratio, melting rate enhances metal production per day. Slag heat reuse minimizes the coke required. Effective coal combustion happens due to use of preheated air and improved metal to coke ratio. The rise in blast heat content is due to reusing water immersed slag heat through heat exchanger to blast air. Thus the preheated air improves the effective combustion of coal in Cupola. Thus there is improved metal to coke ratio and so rise in melting rate. Thus it raises metal production.

Graph V below shows increased metal coke ratio after using slag heat.



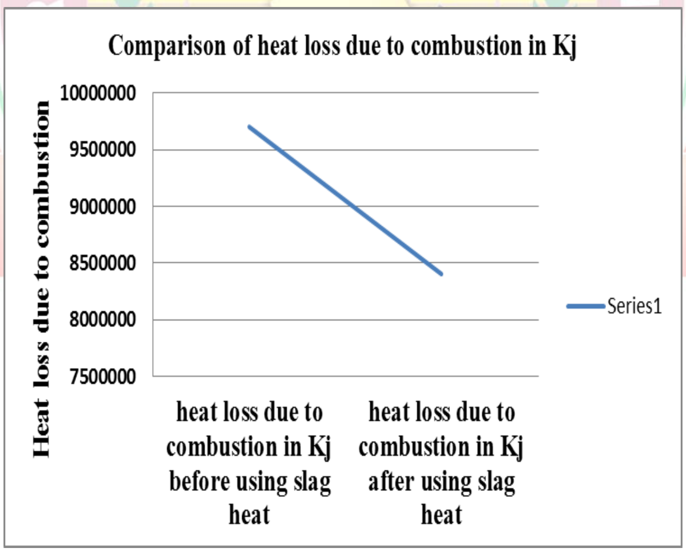
The slag heat reuse minimizes required coal heat content before. Thus coke required is minimized. Due to slag heat reuse, there is improvement in metal to coke ratio.

Graph VI below shows increased heat utilized in melting after using slag heat.



The heat from slag is used and so coal usage reduces, thus it improves the metal to coke ratio. Also there is increase in melting rate and so rise in production. Thus increased production requires higher heat for melting.

Graph VII below shows reduced heat loss due to combustion after using slag heat.



The lesser heat loss due to combustion is because of carbon saving and so emissions reduction, effective coal combustion due to use of preheated air and improved metal to coke ratio.

7. Conclusion

The paper work concludes that by recovering waste heat, Cupola efficiency can be improved thereby saving heat energy. In SME's, Cupola and induction furnaces are used with duplex operations. Energy losses are due to Cupola operations and are investigated for energy conservation. Various experimental studies have been set forth for evaluation of energy conservation and are tested, the results of which are (for sample foundry) for reference. The waste heat potential is 609120 KJ/day, increase in efficiency is 16.06%, increased metal production is 1.602 ton/day, and increase in metal melting rate is 216 Kg/hr.

There is around 238 million ton as estimated slag production in India, which contain slag enthalpy of 1.6 GJ/ton, its heat value of 1.5 TWh/year. Such large amount of slag heat can be recycled and reused in furnace itself, thereby increasing the efficiency of furnace. Total slag produced leads to waste heat recovery of 2070,000 million KJ, $5671x10^6$KJ per hour, converted into terms of oil; this rate is 5.671x $x10^6$kg/hr. So that for energy conservation, the slag heat recovery is essential in Indian foundry sector. Thus there is large potential of energy conservation with slag heat reuse. The energy conserved is energy produced.

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