CHAPTER 4

EXPERIMENTAL WORK
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4.1. INTRODUCTION

Thermo-pneumatic unit for reclamation of CO₂ / sodium silicate was fabricated consisting of a fluidized bed and a scrubber. Sodium Silicate / CO₂ sand reclamation was carried out by combination of thermal and pneumatic reclamation processes by making use of this unit. The characteristics of the reclaimed sand thus obtained were evaluated by reusing the reclaimed sand in the sodium silicate / CO₂ sand moulding. Test castings namely, step cone piece and SFSA test block were produced by casting in the CO₂ moulding prepared by reclaimed sand. Surface finish test was performed on these test castings. Cost calculation and analysis were also carried out.

The procedure for the CO₂ reclamation starts from collecting sodium silicate bonded sand from the steel foundry. Collected sand was crushed, magnetically separated and sieved.

Fabricated pneumatic scrubber and fluidized bed were used for this research work. Various operating parameters were optimized to get the best sand from reclamation. The reclaimed sand was tested for the different properties and reused with sodium silicate for the production of SFSA block as well as step cone test castings. These castings were evaluated to check the performance of suitability of the reclaimed sand under actual conditions. Cost analysis was also carried out.

The scheme of experimental work on CO₂ / silicate sand reclamation is shown in Fig.4.1.
Reclamation of CO₂/Sodium Silicate Sand in Foundry

Experimental Work

Fig. 4.1. - Reclamation of Sodium Silicate Sand and its Evaluation

4.2

KNOCK OUT SAND
after crossing Drier,
Magnetic separator, Lump reducer,
Coarse-Fine separator

FLUIDIZATION

FINES COLLECTOR

PNEUMATIC SCRUBBER

BLOWER

RECLAIMED SAND
TO REUSE

DUST TO DUMP

TESTS FOR
CHARACTERISATION
OF SAND
Shape of grains, pH, AFS, ADV,
Na₂O, Clay Content,
Permeability, Water absorption,
Compactability, Mould Hardness,
L.O.I., Compressive strength

COMPARISON
with concerned properties of
new sand and used sand

REUSE OF SAND IN CO₂
MOULD FOR TEST
CASTINGS

CASTING EVALUATION

COST EVALUATION

Fig. 4.1. - Reclamation of Sodium Silicate Sand and its Evaluation
4.2. KEY TERMS

4.2.1. Combination Method of Reclamation

Various thermal reclamation methods had been described in different years in the past, similar to the periodical mention of the pneumatic reclamation of unused disposable sand from foundry. The combination of both is named as combination method of reclamation. Thermo-pneumatic reclamation method for CO$_2$ / Sodium Silicate bonded sand is its other name.

4.2.2. Fluidization

Fluidization is the operation by which fine solids are maintained into a fluid like state through contact with a gas or liquid.

4.2.3. Fluidized Bed

If a fluid is passed upward through a bed of solids with a velocity high enough for the particles to separate from one another and become freely supported in the fluid, the bed is said to be fluidized. Then the total fluid frictional force on the particles is equal to the effective weight of the bed. Fluidized beds are used in the chemical industry because of the intimate contact between solid and gas, the high rates of heat transfer and the uniformity in temperature within the bed, and the high heat transfer coefficients from the beds to the walls of the containing vessel.

4.2.4. Gassing

Hardening of silicate mould is due to the chemical reaction where CO$_2$ converts the sodium silicate into silica gel. Gassing is to supply CO$_2$ gas to all parts of the mould at the
same time and at a rate sufficient for the reaction (Gas supplied at much faster rate fulfills no useful purpose; it simply escapes to the atmosphere).

4.2.5. **New Sand (Fresh Sand)**

Sand purchased for moulding purpose in foundry is called as “New Sand”.

4.2.6. **Reclamation**

Treatment of the used sand to restore the sand grains to a physical state so as to enable the production of casting whose quality equals to that produced by new sand is called reclamation.

4.2.7. **Recovery**

Recovery is defined as the ratio of weight of sand after reclamation, to the weight of sand before reclamation. It is expressed as the percentage of sand before reclamation.

4.2.8. **Regeneration Cycle**

Regeneration cycle is the number of repeated cycles undergone by a particular mass of sand in the reclamation unit.

4.2.9. **Scrubbing**

The equipment which is capable of subjecting sand grains to repeated impact or abrasion at a target is named as scrubber and the process is termed as scrubbing.

4.2.10. **System Sand**

Old sand is cleaned and reused by adding additives and binders, and it is called system sand.
4.2.11. Used Sand

Sand obtained from the moulding flasks after the metal pouring operation in the foundry is called "Used Sand". Before subsequent reuse of the same for moulding, the lump is crushed and sieved.

4.3. RECLAMATION OF CO$_2$/SODIUM SILICATE SAND

Sodium silicate sand reclamation was carried out by combination method viz. thermo-pneumatic method using the fluidized bed (thermal) and a scrubber (pneumatic).

4.3.1. Fluidized Bed

A "Fluidized bed" of $\phi$200mm x 1000mm is placed immediate ahead of the "Air-Scrubber". A fluidized bed in construction is very similar to that of muffler furnace. The fluidized bed is a long mild steel cylinder of thickness up to a maximum of 8mm. A perforated sheet called as distribution plate, is a 10mm thick S.S. plate and kept in the bottom part of the cylinder. Holes of diameter 2mm are uniformly distributed over the S.S. plate. A mesh of size 200 microns overlaps the perforated sheet. The perforated sheet is either welded or fastened to the flange. An air gap of 60 to 70mm below the perforated sheet enables even distribution of air. The fluidized bed is placed centrally inside the heating chamber such that an air gap of 50 – 60mm is provided circumferentially between former and latter. The heat transfer takes place by radiation. The heating coils are made of nichrome material. The coil grade is SWG 14. The heating coil in the heating chamber is in the shape of spiral, accommodated in the groove provided in the bricks. The heating coil grade and the coil material depend on the maximum temperature required. Refractory insulating bricks are used to prevent the heat radiating to
the surroundings. The outer casing enclosing the bricks is M.S. sheet of thickness 2mm. A thick layer of ceramic wool placed in between the outer casing and the refractory bricks prevents heat loss to the atmosphere. The lid of the fluidized bed material is made of mild steel. The screened sand is introduced into the fluidized bed.

Compressed air is introduced from the bottom of the fluidized bed as shown in the Fig.4.2. An Aluminium-oxide layer with coarse and fine grains forms the bottommost layer in the fluidized bed, above which the screened sand is poured. Height of Aluminium-oxide grains is approximately 150mm. Aluminium-oxide aids in the better conduction of heat.

The used sodium silicate sand gets suspended in the fluidized bed and behaves like a fluid due to the forced entry of air inside the fluidized bed. The sand inside the fluidized bed is heated to a certain temperature using heaters surrounding the fluidized bed. Heating of the sand continues till the sodium silicate coating gets brittle.
Reclamation of CO₂/Sodium Silicate Sand in Foundry Experimental Work

Fig. 4.2. - Fluidized Bed

Fig. 4.2 - Fluidized Bed
Fig. 4.3 - View of Perforated Sheet of Fluidized Bed

Fig. 4.4 - Fabricated Fluidized Bed
Fig. 4.5. - Fluidized Bed being enclosed in the Refractory Container
Fig. 4.6. – Final Assembly of Fluidized Bed
4.3.2. Scrubber

The scrubber of ø350mm x 1100mm is a cylindrical cell. A center pipe called regenerating tube and a conical target are enclosed in this cell. Conical target as well as the center pipe both are supported by means of the ribs welded to the body of the scrubber (Fig.4.7.). Air from blower or compressor is introduced into the scrubber from the bottom of the sand scrubbing cell via a nozzle. The hot sand when it is brittle in the fluidized bed is transferred to the scrubber through a hopper.

Essentially it consists of a containing shell, an air nozzle, a bottom flared center pipe, a conical target, an expansion chamber, and an exhaust duct. The drawing shows the normal height of sand charged into the unit. Its peculiar shape is better understood when one considers the manner in which it functions.

In operation, the unit is charged with a batch of used sand. Air from a positive-pressure type blower is introduced through the high-velocity nozzle.

The elongated portion which has been termed as the “well” of the containing shell surrounding the center-pipe is so designed for a purpose. By concentrating the weight of the charged sand on a small horizontal area, sufficient vertical “sand-pressure” is developed to overcome the static pressure of the air stream after it leaves the nozzle and before it enters the center-pipe. This “sand-pressure” confines the airstream from passing upward through the center-pipe, and prevents “below-backs” along the exterior of the center-pipe and upward through the “well”. The sand-pressure also forces sand into the high-velocity air stream, and ensures a consistent loading of the stream at a maximum rate.
Reclamation of CO₂/ Sodium Silicate Sand in Foundry Experimental Work

4.12

**Fig. 4.7. - Scrubber**
Fig. 4.9. - Fabricated Scrubbing Cell
4.3.3. **Carbon-dioxide Sand Reclamation Unit**

The hot brittle sand from the fluidized bed is instantaneously transferred to the sand scrubbing cell via the hopper of the sand scrubber as shown in the Fig. 4.10. The sand from the hopper drains down and settles at the bottom portion of the sand scrubber. The compressed air is introduced to the scrubber via a heating chamber to maintain the temperature of the sand inside the scrubber. It is important to note that the temperature of the air introduced into the scrubber should be equal to the temperature of the sand at the exit of fluidized bed. Due to the high pressure of the air entering the scrubber, the sand is hurled upward through the center pipe with a considerable velocity and is forced to collide with the conical target. Due to the forced impact of the sand onto the conical target, the brittle sodium silicate coating of the sand gets peeled off. The sand after colliding with the target returns to the main mass and soon finds itself forced to repeat the cycle. The main mass collected in the “well” is the reclaimed sand to be removed for reuse.
Fig. 4.10. - Carbon-dioxide Sand Reclamation Unit
Fig. 4.11. - Thermo Pneumatic Reclamation Unit of CO$_2$/Sodium Silicate Sand - Fluidized Bed being at elevated position than the Scrubbing Cell
Fig. 4.12. - Thermo Pneumatic Reclamation Unit of CO₂ / Silicate Sand – Side View
4.3.4. Effluents

The products removed from the sand during “scrubbing” are disposed off though dust collectors and an exhaust blower. A cyclonic type of collector should be used to trap heavier fines and a collector (wet / dry) for lighter fines. Recycling of the sand in the scrubber is done as many times as possible until the last traces of coating of sodium silicate are removed from the sand so as to secure the best sand.

In view of the cost considerations, the air to the scrubber is drawn from the exhaust of the fluidized bed. The temperature of the air drawn is sufficient to warm up the main inlet air proceeding to the scrubber.

4.4. EXPERIMENTAL ITEMS

The fabrication of fluidized bed and scrubber had been carried out. The required following accessories, materials, connections and substances were made available:

1. Air connection
2. Aluminium Oxide – Coarse
3. Aluminium Oxide – Fine
4. Asbestos rope
5. Chutes
6. Crushed and sieved disposable CO₂ / Silicate Sand
7. Digital Temperature Controller
8. Electrical connection
9. Heater for Fluidized Bed (in-built)
10. Hoses
11. Nozzles
12. Pressure gauge
13. Steel platform for fluidized bed
14. Sub passage for waste hot air to the scrubber from fluidized bed.
15. Thermo couple (in-built)
16. Valves
17. Water filter (Moisture Filter)

4.5. TEST PROCEDURES FOR CHARACTERIZATION OF SAND

Procedures for conducting different tests for evaluation of sand characteristics are explained in this subdivision and through Fig.4.13 and Fig.4.14.
4.13. - Experimental Sequence – Sand Characteristics
Fig. 4.14. - Sand Characterization Test Procedures
4.5.1. Shape of Sand Grains

The shape of sand grains is studied using a stereo-microscope in order to evaluate the efficiency of reclamation and to compare the roundness or angularity of reclaimed sands with new sand.

4.5.2. pH

pH is the measure of alkalinity or acidity in sand. It indicates the amount of sodium oxide present in sand.

Method:

50 ml of distilled water is added to 10 gms of the sand sample and stirred well. By immersing the pH meter in the mixture, the pH value is measured directly in the meter.

4.5.3. AFS Number

AFS number indicates the size of the sand grains, as determined in the reclaimed and fresh sand.

Method:

100 gms of dried sand sample is introduced to the top-most sieve of assembled sieve set which is covered with the lid. A pan is the bottom-most in the sieve series. The whole assembly of sieve series is subjected to vibration for 10 minutes. Later, the weight of sand in each sieve was recorded as shown in the table. Percentage of various size in different sieves are multiplied by the given multiplying factor.

AFS grains fineness number is the total of products divided by total of grain percentage retained in the pan and each sieve.
Table 4.1. - Sample Calculation for Fineness Number

<table>
<thead>
<tr>
<th>Sieve Size (micron)</th>
<th>Sieve Size (micron)</th>
<th>% Retained (c)</th>
<th>Factor (d)</th>
<th>Product (e = c x d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700</td>
<td>0.05</td>
<td>0.0544</td>
<td>5</td>
<td>0.272</td>
</tr>
<tr>
<td>850</td>
<td>1.73</td>
<td>1.7455</td>
<td>10</td>
<td>17.455</td>
</tr>
<tr>
<td>600</td>
<td>5.79</td>
<td>5.8419</td>
<td>20</td>
<td>116.838</td>
</tr>
<tr>
<td>425</td>
<td>23.14</td>
<td>23.3477</td>
<td>30</td>
<td>700.431</td>
</tr>
<tr>
<td>300</td>
<td>24.49</td>
<td>24.7099</td>
<td>40</td>
<td>988.396</td>
</tr>
<tr>
<td>212</td>
<td>26.14</td>
<td>26.3747</td>
<td>50</td>
<td>1318.735</td>
</tr>
<tr>
<td>150</td>
<td>6.41</td>
<td>6.4675</td>
<td>70</td>
<td>452.725</td>
</tr>
<tr>
<td>106</td>
<td>5.9</td>
<td>5.9529</td>
<td>100</td>
<td>595.29</td>
</tr>
<tr>
<td>75</td>
<td>3.01</td>
<td>3.037</td>
<td>140</td>
<td>425.18</td>
</tr>
<tr>
<td>53</td>
<td>1.97</td>
<td>1.9876</td>
<td>200</td>
<td>397.52</td>
</tr>
<tr>
<td>Pan</td>
<td>0.48</td>
<td>0.4843</td>
<td>300</td>
<td>145.29</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99.11</strong></td>
<td><strong>100.01</strong></td>
<td></td>
<td><strong>5158.132</strong></td>
</tr>
</tbody>
</table>

\[AFS \text{ Number} = \frac{5158.132}{100.01} = 51.57 \approx 52\]

4.5.4. ADV

Chemical balance of the sand system is represented by Acid Demand Value (ADV). ADV is a measure of alkaline matter in the sand.

Method:

To 50 gms of dry sample sand is added 50 ml of 1N Sodium Hydroxide (NaOH) and 50 ml of distilled water by means of pipette. The solution is stirred well in the beaker and is allowed to settle for 2 hours. Further titration is carried out using 1N sulphuric acid
to a pH value of 7 which is determined by pH meter. Back titrate value is determined by adopting the above procedure without reclaimed sand.

ADV is expressed as the amount in ml of normal NaOH required to neutralize 100 gms of sand.

Sample calculation for ADV:

Back Titrate for old sand = 17 ml
Burette value - New sand = 6 ml
ADV ml/100 gms(50 gms x 2) = [Back Titrate - Sample Titrate (ml)] x 2
= (17 - 6) x 2 = 22 ml / 100 gms

4.5.5. Na2O Content

This determines the extent of required binder. Na2O (alkali) is neutralized by known normality HCl by volumetric analysis.

\[ \text{Na}_2\text{O} + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} \]

2 gm molecular weight of HCl is neutralized by 1 gm molecular weight of Na2O.

On Weight Basis: 2 (1 + 35.45) HCl = 1 (23 + 23 + 16) Na2O

On Volume Basis

20,000 ml of 0.1N HCl Solution = 62 gms of Na2O
i.e. 1 ml of 0.1N HCl Solution = 0.0031 gms of Na2O

\[ \text{Na}_2\text{O \%} = \frac{\text{ml of HCl} \times 0.0031}{\text{wt. of sample}} \times 100 \]

Method:

10 gms of sand is added to 50 ml of distilled water in a beaker. The solution is heated for about half an hour and the beaker is removed just before boiling and allowed to
cool. Aqueous extract of the above solution is obtained by filtering it. This solution is taken in a 250 ml flask and water is added upto the mark.

50 ml of this solution is transferred to conical flask by means of pipette. Four drops of methyl orange indicator is mixed and shaken thoroughly when the colour of the solution changes to yellow.

This yellow solution is titrated against 0.1N HCl contained in the burette. Reading is noted when the solution in the conical flask just turns to pink from yellow. The procedure is repeated to get consistent readings.

**Table 4.2. - Sample Calculation for Na₂O Content**

<table>
<thead>
<tr>
<th>Volume of Na₂O (in ml)</th>
<th>Volume of HCl (in ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>4.2</td>
</tr>
<tr>
<td>50</td>
<td>4.2</td>
</tr>
<tr>
<td>50</td>
<td>4.1</td>
</tr>
</tbody>
</table>

For 10 gms of sand the required 0.1N HCl solution = \(5 \times 4.2 = 1 \text{ ml}\)

\[
\text{Na}_2\text{O Percentage} = \frac{\text{ml of HCl} \times 0.0031}{\text{wt. of sample}} \times 100
\]

\[
= \frac{21 \times 0.0031}{10} \times 100
= 0.651
\]

**4.5.6. Total Clay Content**

Total clay content represents the mineral particles in moulding sand. The size of the grain is equal to or less than 0.02 mm.
Method:
To 50 gms of dried sand sample is added 475 ml of distilled water and 25 ml of caustic soda solution (25 gms / litre). Stirring is done in the agitator for 10 minutes, diluted to the height of 150 mm with water. Water is allowed to settle for 10 minutes. 125 mm of muddy liquid is decanted and again upto 150 mm height it is diluted and again allowed to settle down. This is repeated number of times till the water is clear. Sand retained in the beaker is dried and weighed.

\[ \text{Total Clay Content} = 2 \times \text{loss in Weight} \]

4.5.7. Permeability
Permeability and strength are two of the most essential properties of sand.

Method:
Permeability meter would allow a controlled amount of air to be taken in a sand sample. The time taken for all the air to pass through the sand sample is measured.

\[ \text{Permeability Number} = \frac{Vh}{p \cdot a \cdot t} \]

Where
\[ V = \text{Volume of air in cc} \]
\[ h = \text{height of sample in cm} \]
\[ p = \text{The Pressure of air in gm / cm}^2 \]
\[ a = \text{Cross-sectional area of sample in cm}^2 \]
\[ t = \text{Time in minutes} \]

4.5.8. Water Absorption
This represents the retained water content in water soaked sand grains.
Method:
Thoroughly stirred 200 gms of sand with water contained in a beaker is filtered using a filter paper. 100 gms of sand from filter paper is dried rapidly in oven and weighed. Drying and weighing is repeated till the weight remains constant.

Water absorption is expressed in percentage of the weight difference between dry sand and wet sand.

4.5.9. Compactability
Compactability test measures the percentage decrease in height from the original constant level of loose sands with fixed compacting force. When moisture increases, the compactability increases.

Method:
Specimen tube is loosely filled with the sand and it is rammed three times with the sand rammer. Percentage decrease in height from the original level gives the compactability of the sand.

4.5.10. Mould Hardness
This gives the uniformity of degree of compactness. Mould hardness is measured using an instrument resembling a dial gauge and having a plunger protruding from a flat base. The plunger gets pressed and forced into the sand when the tester is on the mould surface. The reading is indicated on the dial.
4.5.11. L.O.I.

Loss on Ignition (L.O.I.) indicates organic combustible matter present as impurity leading to gas evolution. This results in a reduction of the refractoriness of the sand.

Method:

10 gms of sand is taken out of the 25 gms of dried sand from the oven and kept in the furnace at 875°C in a crucible for one hour. The crucible is transferred to a desiccator from the furnace. The crucible is weighed and loss in weight after ignition is expressed in percentage of original weight. This gives the L.O.I. value.

4.5.12. Compressive Strength

This measures the stress at which failure occurs under a constant rate of loading.

Method:

The sand sample as prepared by a standard sand rammer is placed in the holder of the universal strength machine (Pendulum type) and squeezed mechanically until it breaks. The force applied in squeezing is shown in the indicator. The force registered at the breaking point is the compressive strength of the sand.

4.5.13. Test Castings

This test was conducted to verify the performance of the reclaimed sand. The three different moulds for this purposes were prepared by the new sand, used sand and reclaimed sand and the tests on castings had been carried out.
4.5.13.1. Step Cone Casting

This is developed to evaluate the possible occurrence of veining defect and finning defect. (Fig.4.15.).

4.5.13.2. SFSA Test Block

This standard block of Steel Foundries Society of America (SFSA) was casted to evaluate the erosion, penetration and burn on conditions of the moulding sand (Fig.4.16.).
Fig. 4.15. - Step Cone Casting
4.16. - SFSA Test Block
4.5.14. **Casting Process**

4.5.14.1. **Moulding**

Each type of sand viz. new sand, reclaimed sand and used sand is mixed with 4% sodium silicate, 0.4% dextrin and 0.5% of collapsible agent. The mixing operation was carried out in a muller. The sand mixtures thus prepared were used for preparation of three different moulds. The sand mixture being the same, step cone pattern is used followed by SFSA test block pattern. The sand used for moulding was also utilized for preparing the cores.

4.5.14.2. **Pouring**

Molten metal with carbon equivalent of 4.2% and proprietary inoculant 0.3% at a temperature of 1430°C was poured into the moulds.

4.5.14.3. **Knock out and Shot Blast**

After cooling for sufficient time, the casting was knocked out from the flasks and shot blasted. Castings were then inspected for surface quality.

4.6. **RECLAMATION TRIALS**

The following are the experimental sequence for CO₂ / silicate sand reclamation trials as diagramed in Fig.4.17.

i. The first series of experiments was conducted by separately varying the inlet pressure to the fluidized bed and scrubber.

ii. The second series of experiment was conducted by varying the temperature of sand inside the fluidized bed keeping the pressure 2.5 Bar and the airflow inlet constant.
iii. The third series of experiments was conducted by varying the time of passing the CO$_2$ gas while preparing the mould.

iv. The fourth series of experiments was conducted by varying the percentage of binder added in moulding sand from 3 to 5%.

v. The fifth series of experiments was conducted by direct scrubbing without the involvement of the fluidization process, keeping the scrubber pressure at 4 Bar.

vi. The sixth series of experiments was conducted by varying the time of retention of sand in the fluidized bed.

vii. The seventh series of experiments was conducted by varying the pressure of CO$_2$ gas during the moulding.

viii. The eighth series of experiments was conducted varying the sand retention time in the scrubber with the 2.5 Bar fluidized pressure, 4 Bar scrubber pressure, 15 minutes fluidized time and 675°C temperature.

ix. The ninth series of experiments was conducted for reclamation of sodium silicate / CO$_2$ sand before the pouring as well as after the casting is poured.

x. The tenth series of experiments was conducted for evaluating the shape / profile of sand using microscope for various samples used for different tests.
4.17. – Experimental Sequence
Reclamation Trials

4.35