Sustainable manufacturing process applied to produce magnesium oxide from sea water

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Abstract. Magnesium oxide is one of the most important materials that used to produce a basic refractory material which is applied for lining steel and iron furnaces as well as cement furnaces. In this research, magnesium oxide was produced from sea water that contain effective percentage of magnesium hydroxide instead of magnesium carbonate rock. The process has been done by adding additive materials which include high alumina, iron oxide, sodium phosphate and sodium silicate to reduce the sintering temperature to 1400 °C instead of 1750 °C. Moreover, kiln furnace was used instead of rotary furnace to do the sintering process. The results show that there is a possibility to produce magnesium oxide with purity of 56%. It is stable at temperature less than 1600 °C and resists the humidity and water. The process of producing magnesium oxide could be considered as a sustainable manufacturing process due to the applied lower sintering temperature which leads to reduce cost, energy and pollution.

Keywords: Magnesium, sea water, refractory, sintering, sustainability.

1. Introduction
Refractory material is defined as a heat-resistant material that designed to resist the decomposition by heat and pressure, withstand the chemical attack and high temperature. It is commonly consists of ceramic and mineral materials [1]. Moreover, they are defined according to ASTM C71 as non-metallic materials have chemical and physical properties that make them applicable for structures, or as components of systems that exposed to environments above 538 °C [2]. Refractory materials can be classified into acidic refractories such as alumina, silica, and fireclay, basic refractories materials like magnesite and dolomite and neutral refractories materials such as carbon, silicon carbide, chromite and zirconia. Refractory materials are used for lining hot surfaces for many industrial processes like furnaces, kilns and reactors etc.,. Today, 70% of all refractory material have been produced for iron and steel industry application and metal casting sectors. It must be chemically and physically stable at high temperature and resistant to thermal shock [3-5]. Magnesium oxide is the most important basic refractory materials which can be considered as industrial magnesium compound that used for steel and iron industry applications. Moreover, it is largely used in many other industrial sectors like food and animal feed industries. Magnesium oxide can be produced from both natural magnesium carbonate and synthetic magnesia as magnesium chloride from seawater and brines. The production process involves decomposition of the MgCO₃ to MgO and CO₂ as gas. However, sea water magnesite made by a chemical process of Mg (OH)₂. The whole refractory magnesia used in UK, USA and Japan comes from the sea water magnesite plants [6-7].
Refractory material is usually sintered in lamp form with different temperatures in the range of 600-2000 °C. The first type of magnesium oxide produced at temperatures in the range of 1500 – 2000 °C as dead burned magnesium oxide that extensively used in steel production serving as protective and replaceable linings for equipment used to handle molten steel. The second type of magnesium oxide produced at temperatures ranging of 1000 – 1500°C as hard-burned which is typically used in applications where slow degradation or chemical reactivity is required with animal feeds and fertilizers. The third grade of magnesium oxide is produced by calcination at temperatures ranging from 600 – 1000 °C as light-burn or caustic magnesia which is used in plastics, rubber, paper and pulp processing, steel boiler additives, adhesives, and acid neutralization. Different types of magnesium oxide are produced by using the dry process route, such as dead burned magnesia, caustic calcined magnesia and fused magnesia. Manufacture of magnesium oxide is high energy consuming because it is manufactured at very high temperatures which consumed (6 and 12) GJ/t of magnesium oxide [6-11].

Pilarska et al., had studied the effect of type and concentration of modifiers on the physicochemical and functional properties of magnesium hydroxide which is obtained by precipitation from magnesium sulphate and sodium dioxide that subjected to thermal decomposition at 450 °C with calcination magnesium oxide. The results show that the presence of a modifier did not change the crystalline structure of the products [12]. J. Chen and et al, had studied the effect of using preparation spherical magnesium hydroxide with a cured like could be successfully by magnesium sulfate, ammonia water and sodium hydroxide solution. The results show that the products obtained with smooth surface and the percentage of SO4 will decrease [13]. Z. Xing and et al, investigated the chemical kinetics model of the hydration reaction with different active magnesium oxide under an unforced and ultrasonic condition. The result indicated that the rate order of hydration was different in the hydration process under an unforced condition [14].

2. Experimental work

2.1 Materials
Mg(OH)2 that prepared from sea water has been used to produce magnesium oxide. It was mixed with sodium phosphate, iron oxide, sodium silicate, and aluminium oxide as an additive material to reduce the sintering temperature. Tables 1-6 show the main chemical and physical specifications of magnesium hydroxide and their additives.

Table 1. Specifications of magnesium hydroxide

| Chemical Symbol | Purity % | CaO % | Colour | Density (gm/cm³) | Shape          |
|-----------------|---------|-------|--------|------------------|----------------|
| Mg(OH)2         | 85      | 3     | White  | 0.9              | Fine powder    |

Table 2. Specifications of Tri Sodium Phosphate

| Chemical Symbol | Purity % | Colour | Water soluble % | PH % | Shape          |
|-----------------|---------|--------|-----------------|------|----------------|
| Na₃PO₄·H₂O      | 92      | White  | 42              | 11.8 | Fine powder    |

Table 3. Specifications of Iron Oxide

| Chemical Symbol | Purity % | Fe % | Colour | Shape          |
|-----------------|---------|------|--------|----------------|
| Fe₂O₃           | 100     | 68   | Red    | Fine powder    |

Table 4. Specifications of Hexa Meta Phosphate

| Chemical Symbol | P₂O₅ % | Fe % | Solubility % | Colour | PH | Density (gm/cm³) | Shape          |
|-----------------|--------|------|--------------|--------|----|------------------|----------------|
| Na₃(PO₄)₆       | 68     | 68   | 5            | Red    | 7.5| 1.4              | Fine powder    |
Table 5. Specifications of Sodium Silicate

| Chemical Symbol | SiO$_2$ % | Na$_2$O % | H$_2$O% | Density (gm/cm$^3$) | Shape |
|-----------------|-----------|-----------|---------|--------------------|-------|
| Na$_2$SiO$_3$   | 37.5      | 12.5      | 50      | 1.5                | Liquid |

Table 6. Specifications of Aluminium Oxide

| Chemical Symbol | Purity % | SiO$_2$ % | (CaO+Mgo) % | Fe$_2$O$_3$ % | Shape     |
|-----------------|----------|-----------|--------------|--------------|-----------|
| Al$_2$O$_3$     | 57       | 37        | 2            | 2.5          | Fine powder |

2.2 Production procedure

The procedure was started by mixing magnesium hydroxide with additive materials by using mechanical stirrer to get a good homogeneous mixture. The water was added to make good mixture for all materials. Table 7 present the main experimental work that done in the laboratory to prepare cylindrical specimens with diameter of 40 mm and length of 10 mm. The specimens were prepared by pressing the mixing materials in hydraulic press with pressure of 40 tons. Then, the specimens burnt in furnace with a temperature in the range of 1300 – 1500 °C. After that, the best mixing percentages were determined as shown in table 8 which are used to produce high quantity of magnesium oxide in the refractory plant. Moreover, the quantity of mixing materials that used in refractory plant shown in Table 9.

The blending materials that get after mixing with quantity of 1562 kg was burnt by kiln furnace with temperature up to 600 °C as first burnt. Then press by hydraulic press with pressure of 50 bars to form green block for easy handling and transportation. After that, the press blocks were burnt in the same kiln furnace with temperature up to 1400 °C for 72 hours and cooling gradually in the same furnace with decreasing rate of 25 °C per hour for 48 hours. Therefore, the total period of time that need for first burnt is 120 hours. The result quantity of this burnt is 893 kg with loss of ignition equal to 43%. The burnt quantity that get from the first burnt was crushing into fine powder and mixing again with 5% liquid sodium silicate, 5% of sodium phosphate and 5% of water to form as green block by pressing with pressure of 150 bars. The result blocks dried and burnt for 120 hours as in the first burnt procedure to get final products of magnesium oxide.

Table 8. The main experimental works in the laboratory to prepare magnesium oxide

| Experiment No. | Mg(OH)$_2$ % | Na$_2$HPO$_4$% or Na$_2$PO$_4$.H$_2$O % | Al$_2$O$_3$ % | Fe$_2$O$_3$ % | Na$_2$SiO$_3$ % | H$_2$O % | Temp. °C | Burnt Time (hr) |
|----------------|---------------|----------------------------------------|---------------|---------------|----------------|---------|----------|----------------|
| 1              | 90            | 10                                     | -             | -             | -              | -       | 1250     | 18             |
| 2              | 70            | 30                                     | -             | -             | -              | -       | 1250     | 18             |
| 3              | 50            | 50                                     | -             | -             | -              | -       | 1250     | 18             |
| 4              | 30            | 70                                     | -             | -             | -              | -       | 1250     | 18             |
| 5              | 85            | 15                                     | -             | -             | -              | -       | 1250     | 18             |
| 6              | 85            | 15                                     | -             | -             | -              | -       | 1250     | 18             |
| 7              | 77            | 13                                     | 5             | 5             | -              | -       | 1250     | 18             |
| 8              | 75            | 15                                     | -             | 10            | -              | -       | 1250     | 18             |
| 9              | 75            | 15                                     | -             | 10            | -              | -       | 1250     | 18             |
| 10             | 70            | 15                                     | 5             | 5             | 5              | 5       | 1250     | 18             |
| 11             | 70            | 15                                     | 10            | 5             | -              | 10      | 1250     | 240            |
Table 8. The best mixing percentages in the laboratory to prepare magnesium oxide

| Experiment No. | Mg(OH)₂ % | Na₃(PO₄)₆ or Na₃PO₄.H₂O % | Al₂O₃ % | Fe₂O₃ % | Na₂SiO₃ % | H₂O % | Temp. °C | Burnt Time (hr) |
|----------------|-----------|-----------------------------|---------|---------|-----------|-------|---------|-----------------|
| 1              | 70        | 15                          | 5       | 5       | 5         | 5     | 1250    | 18              |
| 2              | 70        | 15                          | 10      | 5       | -         | 10    | 1250    | 240             |

Table 9. The main experimental works in the laboratory to prepare magnesium oxide

| Materials  | Mg(OH)₂ Kg | Na₃PO₄.H₂O Kg | Al₂O₃ Kg | Fe₂O₃ Kg | Na₂SiO₃ Kg | H₂O % |
|------------|-------------|---------------|----------|----------|------------|-------|
| Quantity   | 1130        | 163           | 95       | 50       | 50         | 5     |

3. Results and discussion

3.1 Chemical composition

The chemical analysis of the final magnesium oxide produced in this work shown in table 10. It has been found that the percentage of magnesium oxide increased with increasing the number of burns. The percentage of magnesium oxide after the first burnt with temperature of 1400 °C for 120 hours is 43% and 56-58% after the second burnt at 1400 °C for 240 hours while calcium oxide is found to be less than 13%. Aluminium oxide, sodium phosphate and sodium silicate were used as bindery materials to get good adhesive between powders.

Table 10. Chemical composition of magnesium oxide produced in this research work

| No. of burnt | Burnt time (hr.) | MgO % | R₂O₃ % | SiO₂ % | CaO % | SO₃ % | Sum % |
|--------------|------------------|-------|--------|--------|-------|-------|-------|
| 1            | 120              | 43    | 19     | 2.56   | 9.53  | 1.54  | 99.42 |
| 2            | 240              | 56    | 23     | 4.45   | 12.79 | 1.83  | 99.091|
| 3            | 240              | 59    | 27     | 1.31   | 10.65 | 1.95  | 99.37 |

3.2 Loss of ignition

Magnesium oxides that produced at laboratory and factory were evaluated to determine their loss of ignition. The results show that, the loss of ignition for laboratory samples is equal to 38% with shrinkage of 13.5% in dimensions, while for factory samples are equal to 24% for the first burnt and 0.12% for the final burnt as shown in Table 11.

Table 11. Loss of ignition for magnesium oxide produced in this research work

| No. of burnt | Burnt time (hr.) | L. O. I % |
|--------------|------------------|-----------|
| 1            | 120              | 24        |
| 2            | 240              | 0.37      |
| 3            | 240              | 0.12      |

3.3 Sintering temperature

Additive materials were used to reduce the sintering temperature of magnesium hydroxide to be 1400 °C instead of 1750 °C by using kiln furnace instead of rotary furnace to reduce the waste of materials.
4. Conclusions

The main conclusions of this research work include the possibility to produce magnesium oxide with purity of 56% from seawater by using kiln furnace instead of rotary furnace in order to reduce the waste of materials and temperature of 1400 °C instead of 1750 °C to reduce energy and pollution. Moreover, the maximum time that required for producing dead burnt magnesite is 240 hours using two stages of burnt. In addition, additive materials help to reduce the sintering temperature to be 1400 °C instead of 1750 °C. Finally, magnesium oxide that produced in this work can be withstanding the high temperature up to 1600 °C and high humidity.

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