



## Preparation of nano-structured strontium carbonate from Dasht-e kavir celestite ore via mechanochemical method

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### ABSTRACT

In the present investigation, nano-structured strontium carbonate was synthesized by mechano-chemical reaction of raw mineral celestite ore ( $\text{SrSO}_4$ ) collected from Dasht-e kavir, Iran, without initial acid leaching and chemical beneficiation, and sodium carbonate during high energy mechanical milling. X-Ray diffraction (XRD), X-ray fluorescence spectrometer (XRF), atomic absorption spectroscopy (AAS) and scanning electron microscope (SEM) were used to characterize the obtained samples. XRD results showed that at a  $\text{Na}_2\text{CO}_3:\text{SrSO}_4$  molar ratio of 1.05:1, mechano-chemical reaction started after 1 hour of milling. Although the longer milling times gives a more conversion of  $\text{SrSO}_4$  to  $\text{SrCO}_3$  but it has not been completed even after 16 hours of milling. However, by increasing the molar ratio of  $\text{Na}_2\text{CO}_3:\text{SrSO}_4$  to 1.25:1, the  $\text{SrCO}_3$  formation was completed after 2 hours. The results also showed that the mean crystallites sizes of produced nano-powder were approximately 32 nm. XRF result indicated that the final product was obtained with a purity of 95 wt.%. AAS results specified that the recovery rate for production of  $\text{SrCO}_3$  from celestite concentrate was about 97%. SEM studies confirmed the formation of  $\text{SrCO}_3$  nano-powder with a mean particle size of 80 nm.

**Keywords:** Strontium carbonate; Celestite ore; Nano-structured; Mechanochemical.

### 1. Introduction

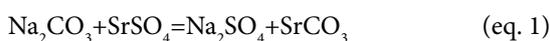
Strontium carbonate ( $\text{SrCO}_3$ ) is one of the most important strontium compounds that have been used in a variety of technological and industrial applications. It is particularly used as an additive in the fabrication of glass cathode-ray tubes for TV and computer monitors (more than 65% of total production) and as a constituent of magnetic ferrites (more than 20% of total production). Other applications are in the manufacturing of special glasses, in pyrotechnics, paints, medicine and photocatalysts such as strontium titanate and zirconate for aqueous degradation of organic pollutants and advanced ceramic materials. Although  $\text{SrCO}_3$  occurs naturally as mineral

strontianite, most of it that is available has been produced from celestite ore ( $\text{SrSO}_4$ ) that is the only commercially exploited strontium mineral [1-3].

There are two commercial processes to manufacture  $\text{SrCO}_3$  from celestite; the black ash and the double decomposition (direct conversion) processes. In the black ash process,  $\text{SrSO}_4$  is reduced with coke (or coal) at temperatures generally over than 1000 °C to produce water soluble SrS. The sulfide is then leached in hot water and strontium carbonate is precipitated using soda ash, ammonium bicarbonate and/or  $\text{CO}_2$  [4-7]. In the second process, finely powdered celestite is reacted with hot sodium carbonate solution (>90 °C) to obtain  $\text{SrCO}_3$  and by-product sodium

sulfate by a double decomposition reaction. Although the black ash method produces a higher purity  $\text{SrCO}_3$  product, it is more energy intensive than the double decomposition process [8-11]. Beside the two above commercial methods, there are several reports of the conversion of celestite to  $\text{SrCO}_3$  by other methods including the high temperature and high-pressure reaction between celestite and either sodium or potassium carbonate and direct leaching of celestite with  $\text{Na}_2\text{S}$  to produce  $\text{SrCO}_3$  [12].

During the last few years, application of mechanical milling to induce solid-state reactions, reduction of metal oxide to metallic materials, synthesis of nanoparticles and composite materials have been widely studied. Erdemoglu [13] studied on the kinetics of the conversion of celestite to  $\text{SrCO}_3$  by mechano-chemical processing under wet milling conditions by varying the amount of sodium carbonate with respect to the stoichiometric amount required for the conversion reaction. The celestite reacts with sodium carbonate giving solid strontium carbonate and soluble sodium sulfate, according to the following reaction (eq. 1).



Zhang and Saito [14] prepared  $\text{SrCO}_3$  indirectly by carbonation of  $\text{Sr}(\text{OH})_2$  which was produced by dry high-energy milling of celestite and  $\text{NaOH}$  in a planetary ball mill. Obut et al. [15] prepared  $\text{SrCO}_3$  from celestite concentrate using both solid and aqueous sodium carbonate in a planetary ball mill and showed that 93% conversion of  $\text{SrCO}_3$  could be obtained after 40 min milling. Further experiments showed that the best conversion of celestite to strontianite occurs during dry milling. These results are very interesting since they demonstrated a direct solid-state conversion of  $\text{SrSO}_4$  to  $\text{SrCO}_3$  and a further examination of dry milling is warranted.

The aim of this work is to evaluate the influence of the  $\text{Na}_2\text{CO}_3:\text{SrSO}_4$  molar ratio and milling time

on the synthesis of  $\text{SrCO}_3$  nano-particles from celestite natural ore by mechanical milling in a systematic manner. To the best of our knowledge, there is no work that has been reported on the production of the strontium carbonate with a good purity from the low cost celestite mineral obtained from Dasht-e kavir mine. Specially, starting material of celestite ore without initial acid leaching and chemical beneficiation will make the process more economical to produce strontium carbonate with a good purity as compared to the use of high purity starting materials. Also a detailed understanding of the preparation process is crucial in order to control the morphology and structure of the produced nano-powder for the desired applications.

## 2. Materials and methods

celestite concentrate with a particle size range of 100–500  $\mu\text{m}$  beneficiated by shaking table supplied from Dasht-e kavir mine, Iran (96%  $\text{SrSO}_4$ , 2%  $\text{CaCO}_3$ , 1%  $\text{BaSO}_4$  and 1% other impurities) and  $\text{Na}_2\text{CO}_3$  (98% purity) were used as the starting materials. The milling experiments were performed for different durations of time up to 16 hours and various  $\text{Na}_2\text{CO}_3:\text{SrSO}_4$  molar ratios of 1.05:1, 1.15:1 and 1.25:1 in a high-energy planetary ball mill (PM2400 model) with hardened steel chamber and balls 15 mm in diameter, under air atmosphere. The rotational speed and ball to powder weight ratio were 300 rpm and 30, respectively. The milled samples were washed with water to remove the produced  $\text{Na}_2\text{SO}_4$  phase during reaction to obtain a pure  $\text{SrCO}_3$  nano-powder.  $\text{Na}_2\text{SO}_4$  leached by neutral water with the pH of 7 (solid/liquid ratio=1:30 g/mL, ambient temperature  $\sim 20^\circ\text{C}$ , time=30 minutes, stirring speed=300 r/min). Then, the solid and the liquid phases were separated, and the solid product was dried at  $110^\circ\text{C}$ . The flowchart of the experimental work is shown in Fig. 1.

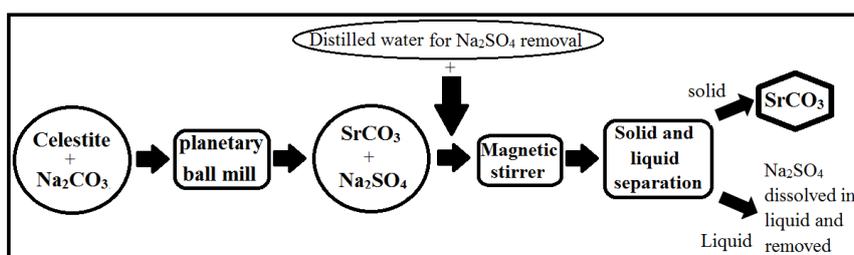


Fig. 1- Flowchart of the experimental procedure.

Philips PW-1730 X-ray diffractometer (XRD) using Cu K<sub>α</sub> radiation (λ= 1.5405 Å) in the range of 20° ≤ 2θ ≤ 70° and step size of 0.02 was used for the structural characterization. The Oxford ED2000 model X-ray fluorescence spectrometer (XRF) and an atomic absorption spectrometer (AA spectrometer, UNICAM939) were employed for chemical analysis and evaluation of final purity of the product. The morphology of powders was examined by scanning electron microscope (SEM, TESCAN). The mean crystallite size of the samples was calculated from full-width at half maximum (FWHM) peak by the Williamson-Hall equation (eq. 2) [16]:

$$B \cos \theta = \frac{0.9\lambda}{D} + 4 \varepsilon \sin \theta \quad (\text{eq. 2})$$

Where D is the crystallite size, λ is the X-radiation wavelength, θ is the diffraction angle, β is the full width at half maximum and ε is the internal strain.

### 3. Results and discussion

Fig. 2 depicts the XRD patterns of the mixture before and after different milling times at the constant Na<sub>2</sub>CO<sub>3</sub>:SrSO<sub>4</sub> molar ratio of 1.05:1. The as-received celestite concentrate started to be converted into strontium carbonate after 1 hour of milling. As indicated in the figure, the celestite peaks intensities decreased with increasing milling

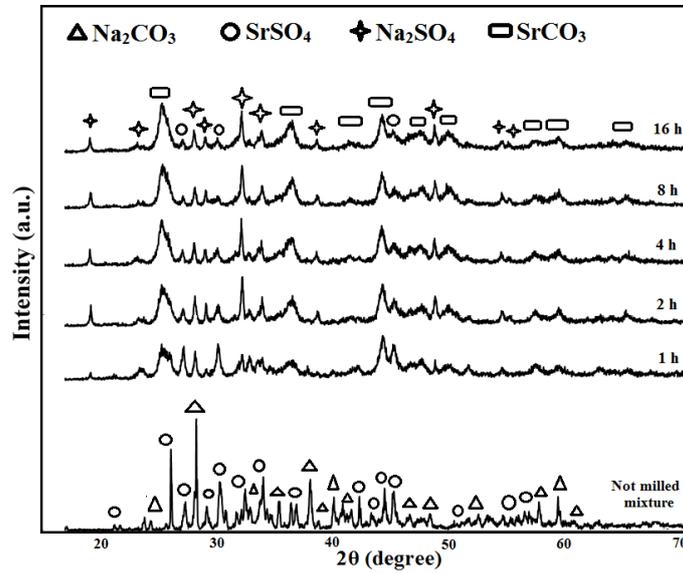


Fig. 2- XRD patterns of the milled sample for different times at constant Na<sub>2</sub>CO<sub>3</sub>:SrSO<sub>4</sub> molar ratio of 1.05:1.

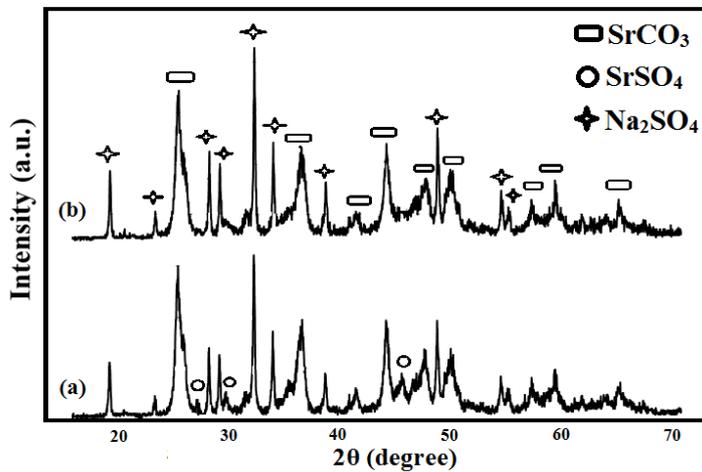


Fig. 3- XRD patterns of (a) milled sample for 16 hours in a molar ratio of 1.15:1 (b) milled sample for 2 hours in a molar ratio of 1.25:1.

time, but the peaks did not disappear completely after 16 hours. Therefore, the conversion of  $\text{SrSO}_4$  to  $\text{SrCO}_3$  has not been completed.

The X-ray diffraction patterns of the samples synthesized with a  $\text{Na}_2\text{CO}_3:\text{SrSO}_4$  molar ratios of 1.15:1 and 1.25:1 are shown in Fig. 3. Analysis of

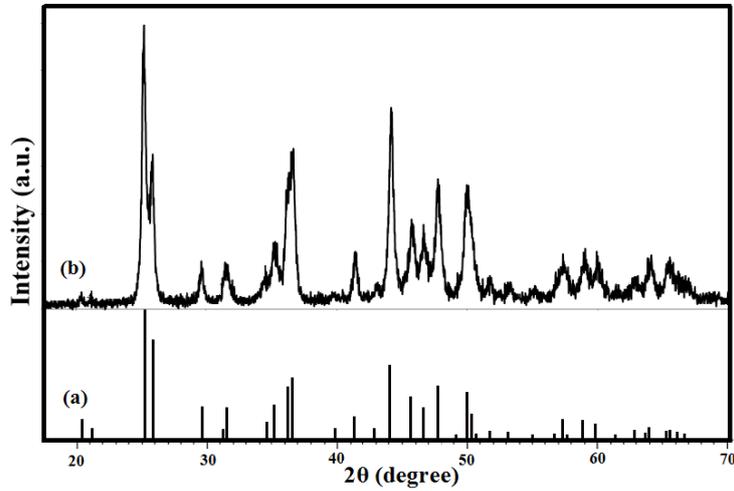


Fig. 4- (a)  $\text{SrCO}_3$  reference pattern (JCPDS: 00-005-0418). (b) XRD pattern of 2 hours milled mixture after  $\text{Na}_2\text{SO}_4$  removal.

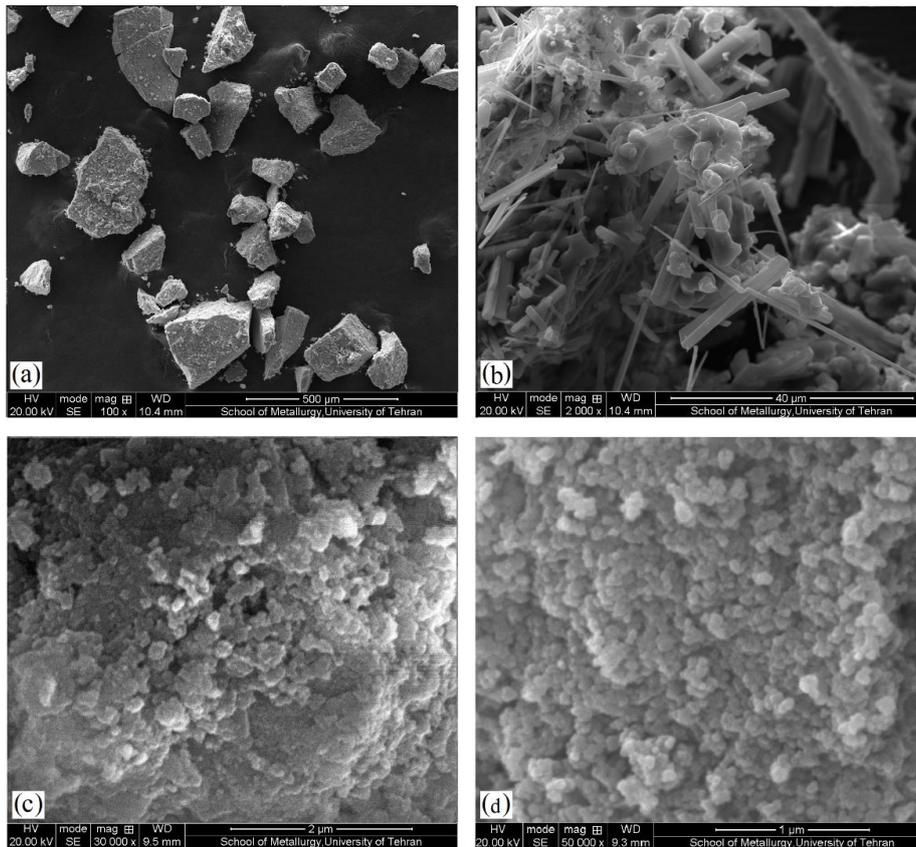


Fig. 5- The SEM micrographs: (a) celestite, (b) sodium carbonate (c) celestite and sodium carbonate mixture after 2 hours milling in 1.25:1 molar ratio, (d) Final product ( $\text{SrCO}_3$ ) removed from  $\text{Na}_2\text{SO}_4$ .

the XRD patterns revealed that increasing the ratio from 1.05:1 to 1.15:1 and 1.25:1, gave an increase in the extent of reaction. At a molar ratio of 1.15:1, the  $\text{Na}_2\text{CO}_3$  peaks are disappeared during reaction and the celestite peaks intensities decrease on increasing the milling time but do not disappeared completely even after milling for 16 hours. It is verified that the amount of  $\text{Na}_2\text{CO}_3$  in this molar ratio is not enough for completion of reaction. Finally, by increasing of the molar ratio to 1.25:1, the celestite peaks are disappeared completely. The excess  $\text{Na}_2\text{CO}_3$  provides the maximum contact area between the reacting particles during milling. It is shown that the conversion has been completed in 2 hours of milling.

Fig. 4 shows the XRD pattern of milled sample for 2 hours in a molar ratio of 1.25:1 after washing by water for  $\text{Na}_2\text{SO}_4$  removal. It is verified that  $\text{Na}_2\text{SO}_4$  is removed from the mixture and single-phase strontium carbonate obtained. The mean crystallites size calculated by Williamson-Hall equation was approximately 32 nm.

The XRF results showed that the final product contained mainly 66.7% SrO, 1.4% CaO, 0.9% BaO and 0.5%  $\text{SO}_3$  by weight. Since the XRF spectrometer cannot detect carbon, in accordance with XRD results which reveals the presence of  $\text{SrCO}_3$  phase (the only Sr-containing phase), the content of SrO in XRF results is related to the  $\text{SrCO}_3$  phase with a purity of approximately 95 wt.%. AAS results indicated that the strontium content of the feed material and the final product was 58 and 56.3%, respectively. Therefore, the recovery rate for production of  $\text{SrCO}_3$  from celestite concentrate was about 97%.

The SEM images of processed samples are shown in Fig. 5a–d. Fig. 5a shows the celestite concentrate that contains angular particles and facet surfaces with the particle size of 100–500  $\mu\text{m}$ . It should be noted that the initial powder particle size is not very critical in mechanical alloying process, except that it should be smaller than the grinding ball size. This is because the powder particle size decreases exponentially with time and reaches a small value of a few microns only after a few minutes of milling [17]. Therefore, this wide range of celestite concentrate particle size has no considerable effect on reaction progress. The needle-like particles of  $\text{Na}_2\text{CO}_3$  are shown in Fig. 5b. As indicated in Fig. 5c, the reaction products after milling for 2 hours significantly affected by the milling and consist of spherical particles with narrow range of particle

size. It is shown in Fig. 5d that the final product ( $\text{SrCO}_3$ ) contains nanoparticles with the mean size of 80 nm.

#### 4. Conclusions

In the present investigation, mechanochemical reaction of  $\text{SrSO}_4$  with  $\text{Na}_2\text{CO}_3$  and preparation of nano-structured  $\text{SrCO}_3$  has been studied as a function of the milling time and  $\text{Na}_2\text{CO}_3$ : $\text{SrSO}_4$  molar ratio. The as-received celestite concentrate started to be converted into strontium carbonate in all molar ratios. In 1.05:1 and 1.15:1 molar ratios, the reaction was not completed even in extended milling time and celestite peaks remained. By increasing the molar ratio to 1.25:1, the mechanochemical reaction completed after 2 hours of milling. The  $\text{Na}_2\text{SO}_4$  easily washed out from milled mixture by water and  $\text{SrCO}_3$  with a purity of 95 wt.% was obtained from low-cost raw mineral celestite in an economical process. The final product consists of spherical  $\text{SrCO}_3$  nano-particles with the mean size of 80 nm.

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#### References

1. Bingöl D, Aydoğan S, Bozbaş SK. Production of  $\text{SrCO}_3$  and  $(\text{NH}_4)_2\text{SO}_4$  by the dry mechanochemical processing of celestite. *Journal of Industrial and Engineering Chemistry*. 2012;18(2):834-8.
2. Martínez AL, Uribe AS. Interfacial properties of celestite and strontianite in aqueous solutions. *Minerals Engineering*. 1995;8(9):1009-22.
3. Griffiths J. Celestite: New production and processing developments. *IND. MINER. Ind. Miner*. 1985(218):21.
4. Chen W, Zhu Y. Preparation of strontium carbonate from celestite. *Mineral Processing and Extractive Metallurgy*. 2000;109(1):1-5.
5. Sonawane RS, Apte SK, Kale BB, Dongare MK. Effect of a catalyst on the kinetics of reduction of celestite ( $\text{SrSO}_4$ ) by active charcoal. *Metallurgical and Materials Transactions B*. 2000;31(1):35-41.
6. Erdemoğlu M, Canbazoğlu M. The leaching of SrS with water and the precipitation of  $\text{SrCO}_3$  from leach solution by different carbonating agents. *Hydrometallurgy*. 1998;49(1-2):135-50.
7. Owusu G, Litz JE. Water leaching of SrS and precipitation of  $\text{SrCO}_3$  using carbon dioxide as the precipitating agent. *Hydrometallurgy*. 2000;57(1):23-9.
8. Beg M, Arshad A, Khan SA, Hasan N. Production of strontium carbonate from celestite. *Pakistan J. Sci. Ind. Res*. 1986;29:217-21.
9. Iwai M, Toguri JM. The leaching of celestite in sodium carbonate solution. *Hydrometallurgy*. 1989;22(1-2):87-100.
10. Castillejos AHE, de la Cruz del FPB, Uribe AS. The direct conversion of celestite to strontium carbonate in sodium carbonate aqueous media. *Hydrometallurgy*. 1996;40(1-2):207-

- 22.
11. Bingol D, Aydoğan S, Gultekin SS. Neural model for the leaching of celestite in sodium carbonate solution. *Chemical Engineering Journal*. 2010;165(2):617-24.
12. Setoudeh N, Welham NJ, Azami SM. Dry mechanochemical conversion of SrSO<sub>4</sub> to SrCO<sub>3</sub>. *Journal of Alloys and Compounds*. 2010;492(1-2):389-91.
13. Erdemoğlu M, Aydoğan S, Canbazoğlu M. A kinetic study on the conversion of celestite (SrSO<sub>4</sub>) to SrCO<sub>3</sub> by mechanochemical processing. *Hydrometallurgy*. 2007;86(1-2):1-5.
14. Zhang Q, Saito F. Mechanochemical processing of celestine. *Chemical Engineering Journal*. 1997;66(1):79-82.
15. Obut A, Baláz P, Girgin İ. Direct mechanochemical conversion of celestite to SrCO<sub>3</sub>. *Minerals Engineering*. 2006;19(11):1185-90.
16. Venkateswarlu K, Chandra Bose A, Rameshbabu N. X-ray peak broadening studies of nanocrystalline hydroxyapatite by Williamson–Hall analysis. *Physica B: Condensed Matter*. 2010;405(20):4256-61.
17. Suryanarayana C. Mechanical alloying and milling. *Progress in Materials Science*. 2001;46(1-2):1-184.