Thai Geoscience Journal 3(4), 2022, p. 5-11

ISSN-2730-2695; DOI-XXXXXXXXXX

Mitigation of carbide lime waste and CO_2 gas emission from acetylene gas industry: feasible technique of high-grade PCC production

Emee Marina Salleh[1*], Rohaya Othman[1], Siti Noorzidah Mohd Sabri[1]

[1]Mineral Research Centre, Department of Mineral and Geoscience Malaysia, Jalan Sultan Azlan Shah, 31400 Ipoh, Perak, Malaysia

Corresponding author: emeemarina@jmg.gov.my

Received 17 March 2021; Accepted 1 December 2021.

Abstract

The global acetylene gas market is currently witnessing stable growth. Owing to its high flame-temperature properties, acetylene gas is extensively used for numerous metalworking applications including oxy-acetylene cutting, heat treating, soldering, brazing and welding. Acetylene gas is a colourless combustible gas that is produced through the combination of calcium carbonate ($CaCO_3$) and water. However, the gas manufacturing results in a production of carbide lime as a by-product that is classified as a scheduled waste in Malaysia under Environmental Quality Act: EQA 1974 (SW 427). In addition to the abundant carbide lime waste, the acetylene manufacturing also causes an increase in carbon dioxide (CO_2) gas emission that trap heat in the atmosphere. This phenomenon has become a crucial environmental concern as the rise of CO_2 gas emission leads to global warming. In mitigating the accumulative wastes, this current work was performed by revolutionising the carbide lime waste that is rich in calcium hydroxide ($Ca(OH)_2$) of 25 to 30% and CO_2 gas waste as a main precursor of carbonate (CO_3^{2-}) ions in producing high-grade precipitated calcium carbonate (PCC). The high-grade PCC was produced using these industrial wastes as primary starting materials via a feasible carbonation technique. In increasing the PCC yield, the production of PCC was initiated via forming an ionic solution by extracting Ca^{2+} ions from carbide lime waste using a promoter agent. The current outcome signified that ~20 g of high-grade PCC with a purity of 98% was produced for every 1 litre of ionic solution. Interestingly, miscellaneous functional morphologies namely rhombohedral and spherical structures of PCC were formed, attributable to various processing parameters. Effectively, the PCC production was completed within less than 10 minutes per litre of ionic solution which significantly offered a fast-rate process. The conducted feasible carbonation technique provides high potential in converting the harmful industrial wastes to profitable products. Via this technique, the production of high-grade PCC as a main product with zero waste, not only reduces the waste management cost but also increases the industrial profits. Remarkably, the recycling of abundant carbide lime waste and CO_2 gas usage in producing high-grade-high-profit PCC results in zero waste production, and thus may help in preserving environmental sustainability.

Keywords: carbide lime waste, feasible carbonation, Precipitated calcium carbonate, waste mitigation

1. Introduction

In the fabrication industry, acetylene gas is needed for applications that involve metal including welding, cutting, and heat treating. Owing to its properties, acetylene forms an important part of numerous crucial processes in industries that make it an extremely useful gas (Han et al., 2006). However, the production of acetylene results in a formation of massive carbide lime as by-product. In Malaysia, the carbide lime waste is classified as a scheduled waste under the Environmental Quality Act; EQA 1974 (SW 427). The carbide lime waste is environmentally hazardous which is attributable to its high alkalinity with a pH of ~12.5, unpleasant odour and it can cause irritation to skin and throat (Salleh et al., 2021). In 2018, almost 20,000 tonnes of carbide lime has been produced from the Malaysian

acetylene gas industry and this statistic keeps increasing year by year. This condition makes the carbide lime an avoided by-product where the industry has to pay a high cost for water treatment in disposing of the scheduled waste. Consequently, vast amounts of carbide lime waste require urgent utilisation to avert handling and disposal difficulties. **Fig. 1** shows a dumping site of carbide lime waste from Malaysian acetylene gas manufacturing.

Fig. 1: Abundant carbide lime waste at Malaysian acetylene gas manufacturing

In addition to the production of carbide lime waste, the manufacturing of acetylene gas has also caused an increase in carbon dioxide (CO_2) gas emission. Currently, the emission of CO_2 gas into the atmosphere has increased to over 400 parts per million (ppm) due to human activities and industries causing a climate change phenomenon. The climate change encompasses not only the rising average temperatures that is referred to as global warming but also extreme weather events, shifting wildlife populations and habitats, rising seas, and a range of other impacts (Rattapong et al., 2019). Globally, the output of greenhouse gases is a source of severe concern. According to this scenario in the acetylene industry, this innovation is introduced by recycling the CO_2 gas in order to minimize its emission into the atmosphere.

In mitigating the accumulative wastes, the carbide lime waste that is rich in calcium hydroxide ($Ca(OH)_2$) up to 25% to 30% and CO_2 gas were targeted to be the main precursor in producing a more profitable product, i.e. precipitated calcium carbonate (PCC). By utilising those wastes as the main precursors, it not only enhances the production of a profitable product via a feasible technique but it can significantly revolutionise its usage.

Consequently, this approach can offer a promisingly high return to industry especially the acetylene gas manufacturers (due to the relatively high amount of the waste) and can preserve the environmental sustainability by converting the industrial waste to wealth.

PCC is the most extensively used mineral filler in numerous commercial applications which is due to its large range of properties, thus makes it highly applicable in fulfilling various needs. There are a number of uses of PCC as a mineral filler in wide-range industrial applications including papermaking, paint, rubber and plastic, sealants, pharmaceutical and skincare products (Han et al., 2007; Ana et al., 2010; Ligia et al., 2017). There are several approaches in synthesizing PCC and commercially, the carbonation process is the most commonly used technique (Hadiko et al., 2005; Catagay et al., 2018). Carbonation is a complex process and involves simultaneous dissolution of calcium hydroxide ($Ca(OH)_2$) and carbon dioxide (CO_2) as well as the crystallization of calcium carbonate ($CaCO_3$) (Yong et al., 2005, Othman et al., 2015). The carbonation reaction is generally performed in a series of reactors under closely controlled operating conditions to produce the PCC with

required morphology and particle size distribution (Santos et al., 2012; Onimisi et al., 2016). Since the reaction between Ca^{2+} and CO_3^{2-} ions is the main approach to synthesize PCC, the generation of CO_3^{2-}dominates the reaction during the process (Shirsath et al., 2015; Sun et al., 2017). It is well known that CO_2 gas can be used as raw material to provide CO_3^{2-} and then react with Ca^{2+} obtaining PCC (Walsh and Mann, 1995; Hadiko et al., 2005). Hence, this current work was mainly focused on producing high-grade precipitated calcium carbonate (PCC) by recycling industrial wastes from acetylene gas industries i.e. carbide lime and CO_2 gas. Inclusively, this research methodology in utilising industrial waste as a promising industrial raw material will lead to green environment as well as will generate more utilisation of mineral resources efficiently.

2. Research Methodology

2.1 Materials

Carbide lime waste was acquired from an acetylene gas manufacturer (MCB Industries, Sdn. Bhd., Taiping, Perak). Quicklime which also used as a controlled starting material was obtainedfrom Simpang Pulai quarry in Malaysia. Sucrose that acts as a promoter agent was purchased from a local company and compact CO_2 gas of 99% purity was supplied by Linde Malaysia Sdn. Bhd.

2.2 PCC Production via Continuous Carbonation Technique

Ionic solution containing calcium ions (Ca^{2+}) was prepared using carbide lime waste (or quicklime) as starting materials with the addition of 10 wt.% of the promoter agent. 1 litre of Ca-rich ionic solution was continuously supplied and simultaneously, CO_2 gas was introduced in order to provide an effective carbonation process. Prior to the PCC production using carbide lime waste, high-purity quicklime was utilised in order to ensure the capability of the studied technique using ionic solution. The presence of both Ca-rich ionic solution as liquid droplets and CO_2 gas under high pressure in the carbonation reactor might enhance the precipitation mechanism of PCC.

In order to investigate an effect of CO_2 gas flow on the PCC formation, an atomizing air pressure was varied at 10, 20, 30, 40 and 50 psi. In addition, liquid air pressure and cylinder air pressure were kept constant at 30 psi and 45 psi, respectively. 1 litre of PCC slurry was collected from the carbonation process. The synthesized PCC was then filtered and washed using warm water to remove the excess promoter agent. The filtrate was dried in an oven at 60 °C for 24 hours. The time taken for the carbonation process and weight of the PCC yield was measured. **Fig. 2** shows a research flow of producing high-grade PCC from calcium-based mineral.

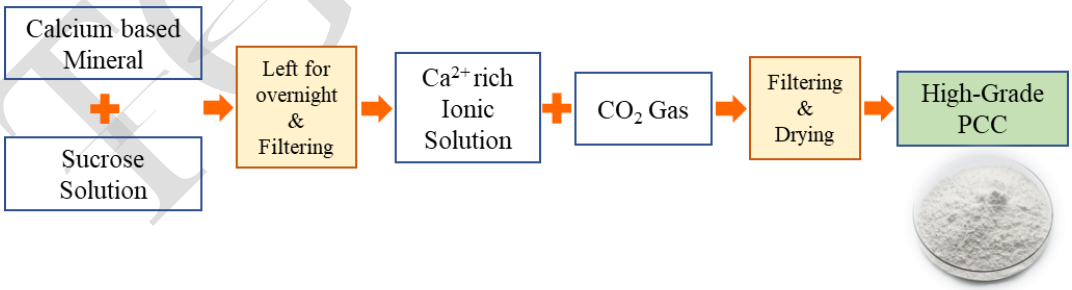

Fig. 2: A research flow of producing high-grade PCC from calcium-based mineral

2.3 Characterization of Produced PCC

The morphology of the synthesized PCC was evaluated using Field Emission Scanning Electron Microscope (FESEM) *Supra 40V Zeiss, Germany*. The particle size distribution of the PCC was measured using Laser Particle Size Analyzer.

3. Results and Discussion

Fig. 3 shows the effect of atomizing air pressure on carbonation time and the weight of produced PCC. The carbonation time gradually increased which as a function of atomizing air pressure. This phenomenon was attributed to the longer time was required in order to achieve a complete precipitation reaction at higher CO_2 gas feeding (Catagay et al., 2018). In addition to the increasing carbonation time, the PCC yield was also increased with increasing atomizing air pressure up to 40 psi. However, above that pressure, the PCC yield was slightly reduced. This situation suggested that the applied atomizing air pressure provided different effect on the both carbonation time and PCC yield.

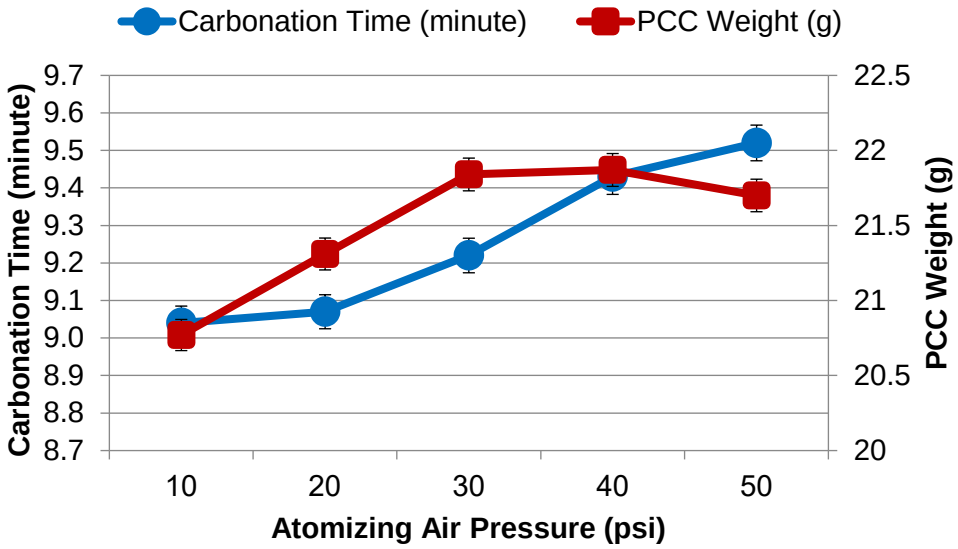

Fig. 3: Carbonation time and weight of PCC yield at various atomizing air pressure

Fig. 4 displays the size distribution of PCC particle at various atomizing air pressures. The PCC particle sizes were between 11 µm to 18 µm. As can be seen, the coarsest PCC particles (17.938 µm) were obtained at 30 psi which might be due to the particle intergrowth phenomenon that occurred during the carbonation reaction (Sun et al., 2017). The fluctuating particle size distribution of the produced PCC suggested the particle growth occurred differently under various CO_2 feeding pressure.

Fig. 5 illustrates the morphologies of PCC particles at different atomizing air pressures. At 30 psi, the PCC particles existed in a form of rhombohedral structure. According to the micrograph, there was a formation of inter-growth particles which resulted in enlargement of particles size as reported previously. Interestingly, at higher atomizing air pressure of 50 psi, the PCC particles were dominantly spherical. This current finding signified that various morphologies of produced PCC might be acquired by varying the atomizing air pressure (which was denoted to CO_2 gas feeding) during the precipitation process.

In ensuring the capability of this currently used technique, the research work was performed by recycling carbide lime waste from the acetylene gas industry as a primary starting material. **Table 1** shows a comparative study on PCC production from high-grade quicklime and low-grade carbide lime waste. According to the findings, the carbonation time for producing PCC using carbide lime waste (6 to 18 minutes) was slightly longer than the time taken by utilising quicklime (about 9 minutes) as a main source of Ca^{2+} ions. In addition, the PCC yield produced from carbide lime waste was between 9 to 12 g at different atomizing air pressure. The attained yield was considerably lower than the quicklime based PCC which was about 21g. This phenomenon was attributed to the lower calcium content in the carbide lime waste which was only 25% to 30% of calcium hydroxide as compared to the purely quicklime (99.9 purity) (Han et al., 2006).

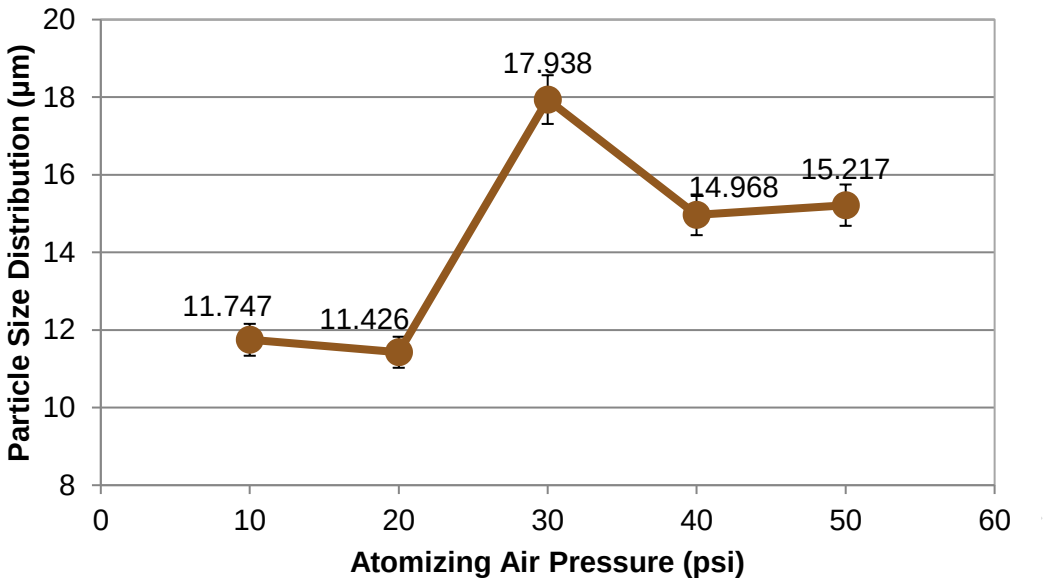

Fig. 4: Particle size distribution of produced PCC at various atomizing air pressure

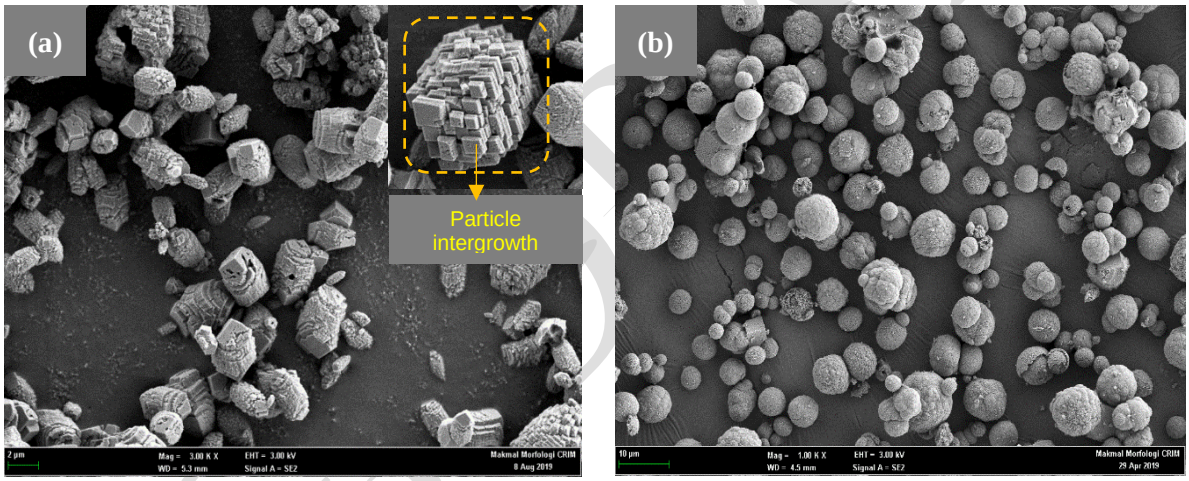

Fig. 5: Micrograph of PCC particles at (a) 30 psi and (b) 50 psi

Interestingly, via this currently used technique, the produced PCC from carbide lime waste showed markedly high purity of about 98% that represented the high-grade PCC. This finding might help industrial players in converting the massive waste into more profitable product i.e. high-grade PCC.

4. Conclusions

According to the findings, the currently used technique showed high potential in converting the harmful carbide lime waste to profitable products of PCC. The carbonation time gradually increased as a function of atomizing air pressure and the weight of PCC also increased with increasing atomizing air pressure up to 40 psi. The size distribution of PCC particles were between 11 µm to 18 µm. According to morphological study, various structures of PCC particles were formed at different atomizing air pressures. At low pressure of 30 psi, there was intergrowth of rhombohedral PCC particles. Meanwhile at higher pressure of 50 psi, the PCC particles formed in more spherical structures. Effec--tively, the utilisation of ionic solution as a feed stock showed high potential in extracting Ca^{2+} ions even from the industrial waste for producing high-grade PCC. By employing this technique, the produced PCC from carbide lime

Table 1: Carbonation time and weight of produced PCC from different starting materials at various

Starting Materials	Atomizing Air Pressure (psi)	Carbonation Time (minutes)	PCC Yield (g)
Carbide Lime Waste	10	14.53	12.2
	20	18.21	10.5
	30	6.18	9.3
Quicklime	10	9.04	20.8
	20	9.07	21.3
	30	9.22	21.9

waste showed markedly high purity of about 98% that represented the high-grade PCC. Profitably, CO_2 gas was used as main source of CO_3^{2-} ions, thus can mitigate its excessive emission into the atmosphere. Consequently, the recycling of abundant carbide lime waste and CO_2 gas from acetylene gas industry might not only reduce the waste management cost but might also increase the industrial profit and importantly, this scenario might help to sustain the natural resources and preserve the environmental sustainability.

Acknowledgement

This work was supported by the Ministry of Energy and Mineral Resources and MCB Industries Sdn. Bhd. The authors would like to thank the Mineral Research Centre, Department of Mineral and Geoscience Malaysia and the Rock Based Technology Section for technical support.

References

Ana M.L.P., Roberta P., Carlos G.G, Lourdes F.V., & C. Domingo.(2010). A breakthrough technique for the preparation of high-yield precipitated calcium carbonate. *The Journal of Supercritical Fluids*, *52*, 298-305.

Cagatay M.O., & Batur E. (2018). Influence of pH on morphology, size and polymorph of room temperature synthesized calcium carbonate particles, *Powder Technology*, *339*, 781-788.

Hadiko G., Han Y., Fuji M., & Takahashi M. (2005). Synthesis of hollow calcium carbonate particles by the bubble templating method, *Materials Letters*, *59*, 2519-2522.

Han J.T., Xu X., & Cho K. (2007). Sequential formation of calcium carbonate superstructure: From solid/ hollow spheres to sponge-like/solid films. *Journal of Crystal Growth*, *308*, 110–116.

Han Y.S., Hadiko G., Fuji M., & Takahashi M. (2006). Influence of initial $CaCl_2$ concentration on the phase and morphology of $CaCO_3$ prepared by carbonation, *Journal of Materials Science*, *41*, 4663–4667.

Ligia M.M.C., Gabriel M.O., & Rafael S. (2017). Precipitated calcium carbonate nano-microparticles: applications in drug delivery. *Advances in Tissue Engineering & Regenerative Medicine Open Access*, *3*, 336–340.

Onimisi J.A., Roniza I., Kamar S.A., Norlia B., & Hashim H. (2016). A novel rapid mist spray technique for synthesis of single phase precipitated calcium carbonate using solid-liquid-gas process. *Korean Journal of Chemical Engineering*, *34*, 1-5.

Othman A., Isa N., & Othman R. (2015). Preparation of precipitated calcium carbonate using additive and without additive. *Jurnal Teknologi*, *77*, 49-53.

Rattapong T., Ratchanon P., Pornpote P., and Benjapon C. (2019). Computational fluid dynamics of sulfur dioxide and carbon dioxide capture using mixed feeding of calcium carbonate/calcium oxide in an industrial scale circulating fluidized bed boiler. *Applied Energy*, *250*, 493-502.

Salleh E.M., Othman R., Mahim Z., & Mohd Sabri SN. (2021). Effect of Liquid Feeding Rate on Carbonation of Precipitated Calcium Carbonate via Continuous Method. *Journal of Physics: Conference Series*, 2080 012017

Santos R.M., Pieter C., & Tom V.G. (2012). Synthesis of pure aragonite by sonochemical mineral carbonation. *Chemical Engineering Research and Design*, *90*, 715-725.

Shirsath S.R., Sonawane S.H., Saini D.R., and Pandit A.B. (2015). Continuous precipitation of calcium carbonate using sonochemical reactor. *Ultrasonics Sonochemistry*, *24*, 132-139.

Sun J., Wang L., & Zhao D. (2017). Polymorph and morphology of CaCO3 in relation to precipitation conditions in a bubbling system, *Chinese Journal of Chemical Engineering*, *25*(9) 1335-1342.

Walsh D., & Mann S. (1995). Fabrication of hollow porous shells of calcium carbonate from self-organizing media. *Nature*, *377*, 320-323.

Yong S.H., Hadiko G., Fuji M., and Takahashi M. (2005). A Novel Approach to Synthesize Hollow Calcium Carbonate Particles. *Chemistry Letters*, *34*, 152-153.