

Article

CO₂ Capture Performance on Wall Paint Modified by K₂CO₃ and CA(OH)₂ for Added-Value CO₂ Capture Paint Development

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Abstract. “Smart paint” is an application that can adsorb CO₂ contributed by transportation in urban areas. This research investigated the adsorbent and their effect which can enhance the CO₂ adsorption in paint. CO₂ capture was tested after drying coated paint. The apparatus was designed as a layered box under open indoor system for investigating the effect of modified paints. The paints were modified by adding K₂CO₃ or Ca(OH)₂. In order to carry out the experiment, 100 g of modified paint were applied to the board inside the CO₂ adsorption unit while the gas flow rate and moisture were controlled at the ambient temperature. The results showed that the increase in solid adsorbent loading in the modified paint with K₂CO₃ could raise the adsorption capacity of the paint. However, the adsorption capacity was limited by some properties in the paint, such as glossy. The adsorbent loading influenced the long-term stability of the paint. On the other hand, the modified paint with Ca(OH)₂ could adsorb CO₂ with higher capacity and maintain better long-term stability than that with K₂CO₃. Also, the effect of gas flow rate and humidity showed that the increase in either flow rate or humidity could also enhance CO₂ adsorption capacity. The best case of modified paint with Ca(OH)₂ in this study could adsorb CO₂ at 9.61 mg-CO₂/g-paint, which is equivalent to 4.58 g-CO₂/m² while the conventional paint (non-modified paint) could adsorb CO₂ of approximately 0.06 g-CO₂/m². Finally, this study demonstrates that modified paint with K₂CO₃ and Ca(OH)₂ can be a new feature to add value to the paint industry.

Keywords: Carbon capture and storage, CO₂ adsorption, CO₂ capture paint, smart paint, solid adsorbent.

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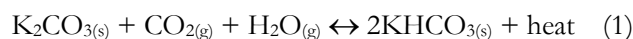
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1. Introduction

An increase in air pollution (e.g., carbon dioxide (CO₂), methane (CH₄), carbon monoxide (CO), and sulfur dioxide (SO₂)) is recently considered an important global environmental problem [1, 2]. To mitigate its negative impact, UN Climate Change Conference COP26 in 2021 has urged the governments to keep the global mean temperature rise below 2°C while pursuing efforts to limit an increase of 1.5°C relative to the pre-industrial level [3]. CO₂ emission is the main cause of global warming and climate change. Carbon Capture Storage and Utilization (CCSU) technology is applied to reduce CO₂ emissions to the atmosphere. Several techniques can be implemented to mitigate industrial emissions, contributing to about half of the annual global emissions [4]. As commonly acknowledged, trees and forests function as substantial CO₂ capture and storage systems, however, the ongoing proliferation of construction and accommodation infrastructures poses the potential for the displacement of these pivotal ecological resources. Consequently, the emission from mobile sources, such as transportation, remains a considerable challenge since it keeps increasing [5]. To address this challenge, painted areas of buildings could serve as a CO₂ storage solution akin to trees. Nevertheless, there are limited research studies on direct air capture compared to industrial capture.

In 2010, Armstrong et al. [6] introduced "smart paint" that could react with CO₂ in the atmosphere to produce calcium carbonate (CaCO₃) using dissolving salts and esters in oil droplets. Obtaining limestone as a product was a merit of this CO₂ fixation because it could heal micro-cracks on the concrete surface for a couple of years. Graphenstone company [7] studied in the laboratory demonstrated the CO₂ absorption of paint by using Graphenstone, lime-based products and claimed that three 15L buckets of Graphenstone could absorb more than 14.7 kg of CO₂ for Ecosphere Premium paint. This study was tested by coating paint in the vessel as a closed system. The CO₂ was absorbed during the drying paint process, and it could reduce CO₂ concentration from 512 ppm to 374 ppm as a 27% reduction. Photopoulos J. [8] reported that a thermo-regulating paint was developed. It could absorb and release heat inside a building to keep rooms warm whenever necessary by using excess energy. This paint added some additives (e.g. phase-change materials (PCMs)) to enhance its properties. Salt hydrates were also used due to their low cost and high volumetric energy storage. However, smart paints are on top of the paint tier based on their prices. Therefore, the availability of this innovation is very limited, only being used in Europe.

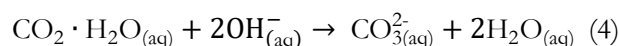
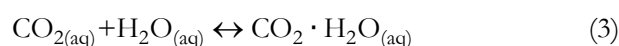
Carbonate salts are well-known adsorbents for CO₂ capture due to their high reaction rate, high CO₂ adsorption capacity, and inexpensiveness [9]. Potassium carbonate (K₂CO₃) is one of the prominent solid adsorbents which can capture CO₂ in several conditions. The reaction is shown in Eq. (1),



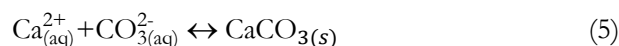
Iruetagoiena et al. [10] compared the CO₂ adsorption capacity of alkali metals I (e.g., Na, K, and Cs). They reported that potassium showed the highest CO₂ adsorption capacity because of its suitable basicity and surface distribution. Rodriguez et al. [11] and Guo et al. [12] investigated CO₂ adsorption performance at low temperatures (20 – 60°C) and low CO₂ concentration (~1% by volume) using K₂CO₃. It was found that K₂CO₃ could adsorb CO₂ at low temperatures.

Furthermore, alkaline earth metal oxides have been reported as good adsorbents for CO₂ capture at ambient temperature. Ridha et al. [13] and Erans et al. [14] studied the performance of carbonation of lime base materials at ambient conditions. It was found that it could be a solution for Direct Air Capture (DAC) due to the potential to obtain capture performance at a low cost. Li et al. [15] conducted a CaO regeneration study and found that the regeneration temperature was over 930°C. Regarding its very high regeneration temperature, the use of CaO can be considered as a possible carbon fixation in the paint.

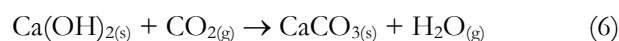
Shih et al. [16] showed that significant carbonation of Ca(OH)₂ at temperatures between 60°C and 90°C occurred once the humidity was higher than a critical value of less than 10%RH while the reaction rate increased with increasing RH above the critical value. The carbonation of hydrated lime occurred in several steps. Firstly, Ca(OH)₂ is partially dissolved and dissociated in the adsorbed water layers then Ca²⁺ and OH⁻ were released,



Finally, the reaction between Ca²⁺ and CO₃²⁻ leads to the formation of CaCO₃,



The overall reaction can be



Pontiga et al. [17] studied the capture of CO₂ by powder beds of Ca(OH)₂ and nanosilica/Ca(OH)₂ fluidized by a dry gas at ambient temperature and low CO₂ pressure. The results indicated that the chemisorption of CO₂ on Ca(OH)₂ took place at ambient temperature even in dry atmospheric conditions. Also, there is the rise of vapor water at the end of the fast carbonation phase. Using additives as nanosilica could increase the gas-solids

contact efficiency, hence, enhancing CO₂ chemisorption on Ca(OH)₂ particles.

Hence, calcium hydroxide (Ca(OH)₂) presents itself as a viable option as a CO₂ adsorbent in paint due to its capacity to react with CO₂ and undergo a conversion into CaCO₃ [13, 16], which is one of the conventional components in paint as shown in Eq. (6).

In the context of these literature reviews, this study aims to investigate the potential of modified paint compositions containing K₂CO₃ and Ca(OH)₂ as solid adsorbents, with a particular focus on understanding the variables that impact their capacity for atmospheric CO₂ adsorption post-application. In case all the building surfaces were coated with modified paint, there are several concerns: type of paint, the component in paint, paint shelf life, wind direction, temperature, and more. Consequently, this experimental design was crafted to simulate a practical scenario, resembling an open indoor system, for assessing CO₂ adsorption within the paint coatings. Following the drying of the modified paint, the study examined the effect of CO₂ adsorption capacity with a focus on key variables, including (i) the proportion of solid adsorbent in the paint, (ii) the type of paint and adsorbent, and (iii) gas flow rate. This experiment was conducted under room temperature (~30°C) and pressure of 1 atm. As such, the results of this study serve as fundamental knowledge for the advancement of smart paint technologies in the future, offering a potential avenue for CO₂ Capture and Storage (CCS) within the atmosphere.

2. Experimental

2.1. Paint Sample

Wall paint generally consists of 4 main ingredients, i.e., pigments, binders, solvents, and additives. First, the pigment in paint significantly impacts color and appearance since it provides whiteness as well as adds bulk to paint. TiO₂ and CaCO₃ are general pigments that affect the property of paint in that CaCO₃ gives extra weight to the paint while TiO₂ is the prime pigment that provides whiteness to the paint [18]. Second, the binder in a mixture of paint is responsible for supplying adhesion and giving the paint resistance properties to make the finished coating tough and durable, but the presence of pigment will detract from this quality. Third, the solvent is to deliver the binder and pigment to the substrate surface. The type of solvent depends on the component in the paint. Fourth, the additive is provided to be manipulated or enhance the paint properties to facilitate application [19].

This study considered modifying the pigment, TiO₂ and CaCO₃, in paint since the pigment is a powder similar to the solid adsorbents, K₂CO₃ and Ca(OH)₂. Moreover, the finished paint's characteristic needs to be formed as a liquid. Therefore, the other ingredients (i.e., binders,

solvents, and additives) should be carefully adjusted accordingly. It is to maintain the physical characteristics and lifespan of the paint. The major characteristics focused in the research are smooth surface, no cracking on drying, and long lifespan. The particle size of the adsorbents was not over 60 μm (≤60 μm). The paint was generated into three types: matte, semi-gloss, and gloss paints with pigment modified by adding two solid adsorbents of K₂CO₃ and Ca(OH)₂, to study their CO₂ capture performances. These types of paint represent the three sheen levels of the paint, from the highest sheen of gloss paint to the very little or no sheen of matte paint. Table 1 and

Table 2 show the approximate percentage of the components in modified paints with K₂CO₃ and Ca(OH)₂, respectively, and the conventional paint. Firstly, the paint in Table 1 was used to study the effect of the amount of adsorbent and type of paint on the CO₂ adsorption capacity in modified paint. The modified paint with K₂CO₃ was limited to 1%wt due to the paint's physical instability which could not form and coat on board as liquid phase. Hence, the modified paint with K₂CO₃ in this study would not be higher than 1%wt. Then, all results (e.g., the effect of type of paint) would be the information to select the type of paint and new adsorbent to test CO₂ adsorption in paint. The paint in

Table 2 was used to study the effect of gas flow rate and humidity on CO₂ adsorption in modified paint. All the components were mixed under the paint expert's suggestion to obtain the liquid paint that could be coated on the board.

The 25 g of paint was coated on the two sides of each board, which has a dimension of 149 mm in width, 210 mm in length, and 1.6 mm in thickness, and dried at ambient temperature for 24 hours before testing its CO₂ capture capability. Therefore, four boards with 100 g of paint were used for one experiment.

2.2. Apparatus

Regarding the purpose of this study, CO₂ capture performance in the paint should be tested as finished paint on the wall due to a realistic situation. The CO₂ adsorption was investigated in a laboratory-scale apparatus, as shown in Fig. 1. CO₂ concentration, temperature, flow rate, humidity, and pressure sensors were installed at the inlet and outlet of the CO₂ adsorption unit. Also, the CO₂ adsorption unit was designed as a layered box for enhancing the contact time of the open gas flow system. The gas flow rate was manipulated using a rotameter with a flow rate sensor. Before entering the CO₂ adsorption unit, the water vapor was added to the mixed gas by a gas bubbler. A heater and heating tape were used to control the gas temperature. The boards were put inside the apparatus to test the CO₂ adsorption. The CO₂ concentration sensor detected the outlet gas from the CO₂ adsorption unit. During the adsorption process, the

sensors were recorded every 10 s to track the CO₂ concentration and gas temperature. Real-time outputs of the sensors were collected by LabVIEW system design software which was specifically written for this CO₂ adsorption of paint, and the breakthrough curve was plotted.

Table 1. Percentage of the components in conventional paints and modified paints with K₂CO₃.

No.	Type	Components in wall paint (% by weight)		
		CaCO ₃	TiO ₂	K ₂ CO ₃
M-1	Matte			-
M-2		15 - 20	10 - 15	0.2
M-3				0.5
M-4				1
S-1	Semi-gloss			-
S-2		10 - 15	15 - 20	0.2
S-3				0.5
S-4				1
G-1	Gloss			-
G-2		-	15 - 20	0.2
G-3				0.5
G-4				1

Table 2. Percentage of the component in modified paint with Ca(OH)₂ and the conventional paint.

No.	Type	Components in wall paint (% by weight)		
		CaCO ₃	TiO ₂	Ca(OH) ₂
Ca-1	Matte	40 - 45	-	9 - 12
Ca-2		15 - 20	>10	-

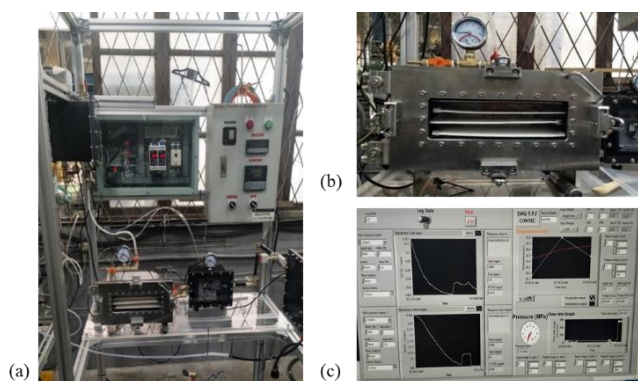


Fig. 1. The apparatus in this research (a) CO₂ adsorption system and its instrument, (b) CO₂ adsorption unit, and (c) LABVIEW panel for recording the data.

2.3. CO₂ Adsorption in Paint Methodology

This experiment consisted of 3 parts: paint preparation, as seen in section 2.1, system preparation, and testing.

For system preparation, the experimental conditions were related to indoor air quality. The humidity of air is 40 - 50% RH for human living conditions, and the average temperature is 30°C based on the ambient condition range of Thailand [20]. The gas flow rate, based on calm wind speed (< 0.3 m/s), was used [21]. Due to the low gas flow rate and the large volume of an adsorption unit, half of the concentration from flue gas [22] with 6% CO₂ by volume balanced by N₂ was used to reduce the time for investigation. The system was necessary to remove all contaminants inside the system by purging an inert gas (99.99% N₂) before starting the operation. The CO₂ concentration sensors were used to check the released gas until CO₂ could no longer be detected. Then, gas with 6% CO₂ by volume balanced by N₂ was fed to the apparatus. The feed gas in the experiment could be dry gas (not passing through the water reservoir) or humid gas (passing through the water reservoir). The gas temperature was controlled at 30°C. The concentration of CO₂, gas temperature, and humidity in the feed were measured at two positions: immediately after the heater (sensor box no.5) and before the CO₂ testing unit (sensor box no.7) as shown in Fig. 2. Once the inlet CO₂ concentration remained unchanged, the inlet valve at CO₂ adsorption unit was switched on for feeding gas into the unit.

Before testing the developed paint, the calibration of the CO₂ sensors was carried out throughout the experimental set. Then, the board, coated with various concentrations of solid adsorbent, was placed in the CO₂ adsorption unit to determine the CO₂ capability to the proportion of solid adsorbent. The limitation of the lab-scale apparatus led to using flow rates 100 times lower than calm wind speed (< around 50,000 mL/min). Hence, these experiments studied the effect of gas flow rate on the adsorption capacity at 100, 200, 400, and 600 mL/min with humid gas (40 - 50%RH) at 30°C. The influence of water vapor on CO₂ adsorption capacity in paint was carried out by bubbling through the water reservoir at a constant temperature. It was divided into two cases: passing the gas through the water reservoir to prepare humid gas (40 - 50%RH) and not passing gas through the water reservoir to prepare dry gas (10 - 20%RH). Due to the open system, dry gas preparation could accept the humidity outside not over 20%RH. To start the process of adsorption, the condition of inlet gas would be 6%v/v CO₂ concentration with temperature, flow rate, and humidity as set for the experiment before entering the system. The process would stop once the paint could not adsorb CO₂, which was detected when the outlet CO₂ concentration had the same concentration as the inlet

condition (6%v/v). After the end of each operation, inert gas was also used to clean the system's contaminants before starting the next operation. In this study, the CO₂ adsorption time of 160 mins was performed.

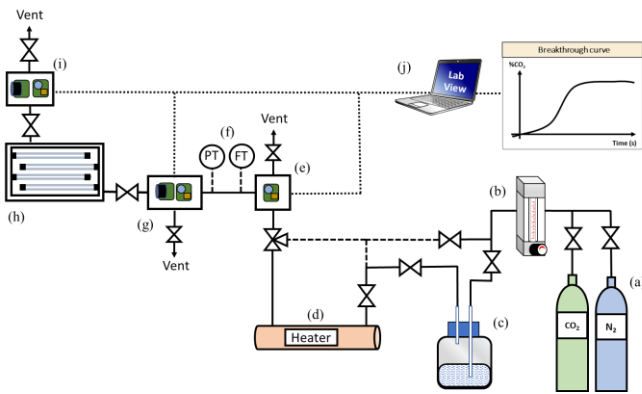


Fig. 2. Schematic diagram of the CO₂ adsorption in paint system (a) Gas 6 %vol CO₂/N₂, (b) Rotameter, (c) Water bottle, (d) Heater, (e,g,i) Sensor box (CO₂/ % RH/ Temperature), (f) Pressure sensor and flow sensor, (h) CO₂ adsorption unit, and (j) Computer.

3. Results and Discussion

3.1. CO₂ Adsorption Capacity in Paint

This research study started by testing the CO₂ adsorption capacity of 100 g paint without adding solid adsorbents so-called conventional paint which was coated on both sides of a board.

Fig. 3 shows the three types of conventional paint on the board after drying for 24 hours. Sample M-1 represented the matte paint which was smooth and not sheen, as shown in Fig. 3(a). Sample S-1 was the semi-gloss paint that reflected the light and provided a bright sheen lower than Sample G-1, a gloss paint, as shown in Fig. 3(b) and 3(c), respectively.

Table 3 presents the CO₂ adsorption capacity of conventional paint on different types of paint. The 100 mL/min inlet gas was passed through the water to perform humid gas at 30 – 40%RH and temperature at 30°C before being imposed through the sample in the CO₂ adsorption unit. The experimental result showed that the conventional paint could adsorb CO₂ at low capacity (<0.5 mg-CO₂/g-paint). Sample S-1 (Semi-gloss) had the highest CO₂ adsorption capacity, followed by samples M-1 (Matte) and G-1 (Gloss), respectively. This is because of the chemisorption and physisorption of CO₂ on the coated board. The chemisorption occurred when the CaCO₃ reacted with water vapor and CO₂ gas to form calcium bicarbonate (Ca(HCO₃)) [23, 24]. There was no CaCO₃ in sample G-1, and the higher glossiness prevents contact between gas and a porous surface, hence, the gloss paint is the lowest adsorption capacity. Even though sample M-1 contained no glossiness (as shown in Table 1), the adsorption capacity of sample S-1 was greater than that of sample M-1 (as given in Table 3). The reason is that

there is not only CO₂ chemisorption but also physisorption at this operating condition [25]. Sample S-1 loaded with more TiO₂ than sample M-1. Regarding a much larger surface area of TiO₂ [26-28], sample S-1 possessed a higher adsorption capacity than sample M-1.

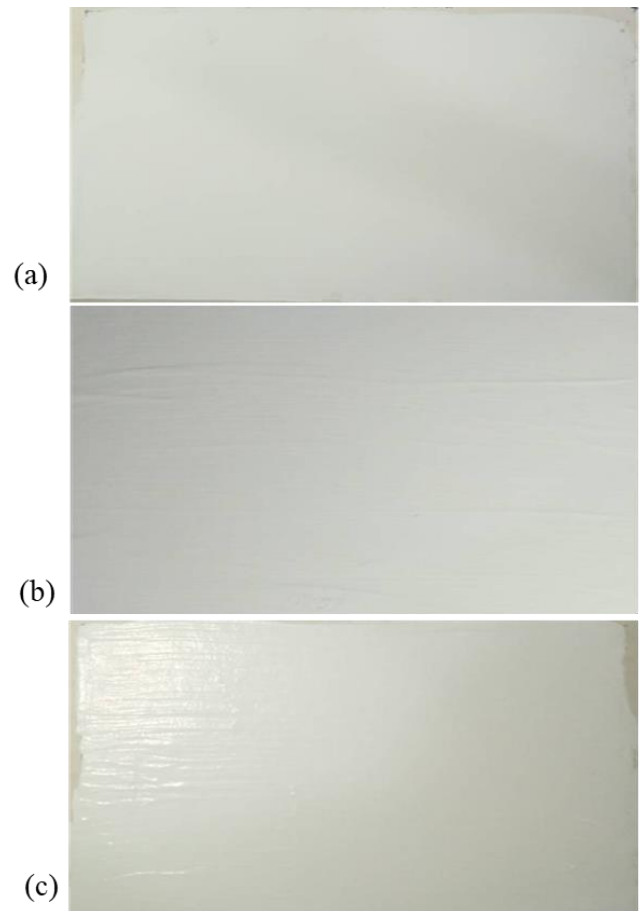


Fig. 3. Three types of conventional paint coated on board after drying for 24 hours (a) Matte paint, (b) Semi-gloss paint, and (c) Gloss paint.

Table 3. CO₂ adsorption capacity of the paints without solid adsorbent.

Type of Sample	CO ₂ adsorption capacity (mg-CO ₂ /g-paint)
M-1	0.414
S-1	0.436
G-1	0.284

Note: M-1 = Matte paint of 0% solid adsorbent, S-1 = Semi-gloss paint of 0% solid adsorbent, and G-1 = Gloss paint of 0% solid adsorbent.

3.2. CO₂ Adsorption Capacity of K₂CO₃ Adsorbent in Paint

Fig. 4 presents the adsorption capacity of modified paint with different amounts of K₂CO₃ and conventional paint on three types of paint. The 100 mL/min inlet gas was passed through the water to perform humid gas at 30 – 40% RH and temperature at 30°C before being imposed through the sample in the CO₂ adsorption unit. The CO₂ adsorption capacity of paint with various K₂CO₃ loading reported that an increasing amount of the solid adsorbent enhanced the CO₂ adsorption capacity for each type of paint. This is due to the chemical reaction of K₂CO₃, H₂O, and CO₂ to form potassium bicarbonate (KHCO₃) as shown in Eq. (7) [12]:

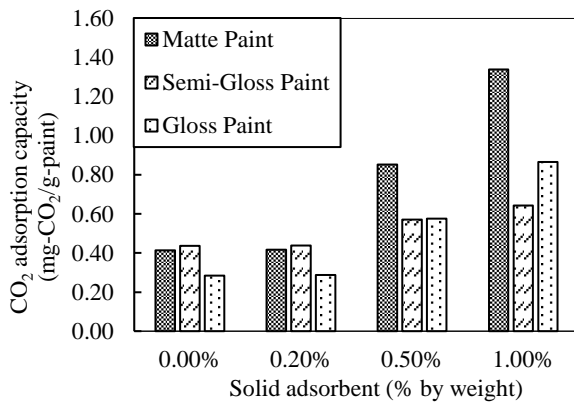
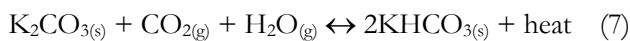


Fig. 4. CO₂ adsorption capacities of conventional paint and modified paints with various amounts of K₂CO₃ on three types of paint: Matte paint, Semi-gloss paint, and Gloss paint.

It can also be seen that the addition of 1% by weight K₂CO₃ resulted in the highest adsorption capacity of each type. However, the addition of K₂CO₃ was limited to 1% by weight because of instability and a gel formation of the paint at greater K₂CO₃ concentration. Moreover, the comparison of CO₂ adsorption on the paint type at 1% by weight K₂CO₃ could be seen in the figure. The matte paint gave the highest CO₂ adsorption capacity at 1.4 mg-CO₂/g-paint, followed by the gloss paint at 0.9 mg-CO₂/g-paint and the semi-gloss at 0.6 mg-CO₂/g-paint, respectively. This is because the adsorption capacity depends on not only the solid adsorbent but also the physical property of the paint. The gloss paint showed a higher glossy surface than the matte paint, as seen in

Fig. 5(a) and (c). The glossiness of the paint decreases the chance to contact between gas and solid sorbents in the paint. Therefore, the adsorption capacity of the gloss paint was lower than the matte paint.

However, the adsorption capacity of the semi-gloss paint was found to be lower than the matte and glossy

paint, as seen by increasing the amount of K₂CO₃ above 0.5% by weight. That was because the semi-gloss paint formed gel after the addition of 0.75% and 1.0% by weight of K₂CO₃, in other words, the paint lost its stability. After the gelation, the semi-gloss paint was coated on the board for CO₂ adsorption measurement. As a result, non-uniform paint was observed on the board surface as shown in

Fig. 5(b). In addition to CO₂ adsorption capacity, the modified paints were tested for their long-term stability by keeping them in a heated condition at 60°C for 2 weeks. The result showed that the quality of the paint with K₂CO₃ adsorbent could not maintain the paint stability at the test. For instance, the modified paint did not have a smooth surface after long-term stability testing. Based on this criterion, even though the addition of K₂CO₃ can successfully enhance the CO₂ adsorption capacity of the modified paint in short-term, it leads to a failure of the long-term stability of the paint.

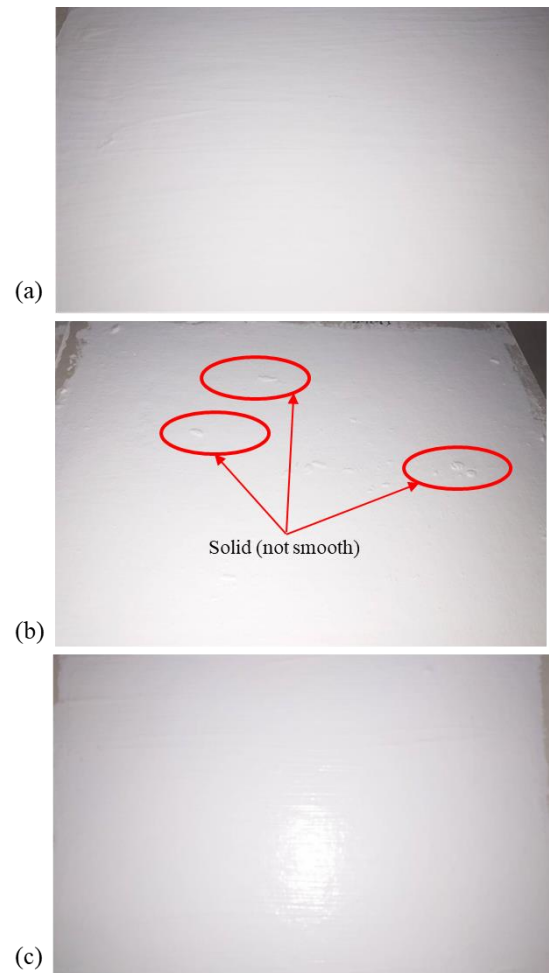


Fig. 5. Paint finishes of modified paint with 1% by weight K₂CO₃ adsorbent on 3 types of paint: (a) Matte paint, (b) Semi-gloss paint, and (3) Gloss paint after drying 24 hours.

3.3. CO₂ Adsorption Capacity of Ca(OH)₂ Adsorbent in Paint

Regarding the result in section 3.2, the instability and gel formation of the modified paint with K_2CO_3 caused unacceptable results. Thus, $Ca(OH)_2$ as an alternative solid adsorbent (regarding equation (2)) was considered. As can be seen the products of CO_2 adsorption on $Ca(OH)_2$ are $CaCO_3$ and H_2O (which are the typical ingredients of the paint), it is therefore believed that the addition of $Ca(OH)_2$ will not affect the long-term stability of the paint and might enhance the CO_2 adsorption capability.

Approximately 9 – 12% by weight of $Ca(OH)_2$ was added into the paint as sample Ca-1 and compared with sample Ca-2 (without $Ca(OH)_2$). As presented in

Table 2, the main components of sample Ca-1 were $Ca(OH)_2$ and $CaCO_3$ without TiO_2 as brightness pigment, while those of sample Ca-2 were TiO_2 and $CaCO_3$. Hence, sample Ca-1 tended to be gray while sample Ca-2 showed more whiteness, as illustrated in Fig. 6. To compare the effect of the type of solid adsorbent on CO_2 adsorption capacity, the modified paints with and without $Ca(OH)_2$ were tested under similar conditions. The 100 mL/min of inlet humid gas (30 – 40%RH) was fed into the CO_2 adsorption unit at 30°C. Table 4 showed that the CO_2 adsorption capacity of sample Ca-1 was 5.40 mg- CO_2 /g-paint, which was much higher than that of sample Ca-2 (0.06 mg- CO_2 /g-paint) because of the addition of $Ca(OH)_2$ in sample Ca-1. Its CO_2 adsorption capacity was also much higher than the addition of K_2CO_3 . Moreover, the modified paint with $Ca(OH)_2$ was tested for stability in long-term keeping. The satisfying results were observed.

Table 4. CO_2 adsorption capacity of modified paint with and without $Ca(OH)_2$ adsorbent.

Type	CO_2 adsorption capacity in paint (mg- CO_2 /g-paint)
Ca-1 (Matte paint with adsorbent)	5.40
Ca-2 (Matte paint without adsorbent)	0.06



Fig. 6. The color of the paint finishes after drying 24 hours: (a) gray for sample Ca-1 (with $Ca(OH)_2$) and (b) white for sample Ca-2 (without $Ca(OH)_2$).

3.4. Comparison of CO_2 Adsorption Capacity with the Literature

Table 5 compares the results of each highest case in this study with the literature in terms of the CO_2 adsorption capacity in paint. The CO_2 adsorption capacity in modified paint obtained from this research was lower than that reported in the literature due to different experimental methods and components in paint. Moreover, the CO_2 adsorption capacity from modified paint with $Ca(OH)_2$ was greater than that with K_2CO_3 . As stated above, the modified paint with $Ca(OH)_2$ adsorbent could satisfy long-term stability testing. Therefore, this paint was selected to study the effect of parameters on CO_2 capture capacity in the next section.

Table 5. Comparison of the obtained CO_2 adsorption capacity of paint in this study with the literature.

Data	Graphenstone Company [7]	Conventional paint	Paint with K_2CO_3 adsorbent	Paint with $Ca(OH)_2$ adsorbent
Type of paint	- Note 1	Matte	Matte	Matte
CO_2 adsorption capability (mg- CO_2 /g-paint)	233.29 Note 2	0.06 - 0.43	1.34	5.40
CO_2 adsorption rate (mg- CO_2 /(g-paint.min))	- Note 1	$3.75 \times 10^{-4} - 2.69 \times 10^{-3}$	8.38×10^{-3}	3.38×10^{-2}
CO_2 adsorption System	Closed system	Open system	Open system	Open system
Equipment	Vessel	Layered box	Layered box	Layered box
Adsorption time (min)	- Note 1	160	160	160
Testing paint method	Testing during the drying paint process	Testing after drying 24 hrs.	Testing after drying 24 hrs.	Testing after drying 24 hrs.
Adsorbent	$Ca(OH)_2$	-	K_2CO_3	$Ca(OH)_2$
CO_2 concentration	0.05%v	6.00%v	6.00%v	6.00%v
Gas flow rate (mL/min)	- Note 1	100	100	100
Testing the stability of paint (i.e., shelf life).	Yes (Pass)	Yes (Pass)	Yes (Fail)	Yes (Pass)

Note 1: No information.

Note 2: CO_2 adsorption capacity of Ecosphere Premium paint converts from 4.9 kg CO_2 /15L.

3.5. Effect of Inlet Gas Flow Rate

Inlet gas flow rate could be a critical factor affecting the CO₂ adsorption capability of modified paint. To evaluate the effect of inlet gas flow rate, the experiments were carried out at different flow rates of 100, 200, 400, and 600 mL/min to measure the CO₂ adsorption of modified paint with Ca(OH)₂. The gas was at 30°C and 6%CO₂ + H₂O (30 – 50% RH). The results are illustrated in Fig. 7. The amount of CO₂ adsorption in the modified paint was 5.40, 9.27, 9.61, and 8.46 mg-CO₂/g-paint as the flow rate increased from 100 to 600 mL/min. It was noticed that the CO₂ adsorption capability increased when the inlet gas flow rate increased due to increasing the reactant (CO₂) in the system. However, as the flow rate increased to a certain point, the CO₂ adsorption capability dropped. This is due to a shortened contact time between gas and solid adsorbent [12]. The highest adsorption capability in paint was observed at an inlet gas flow rate of 400 mL/min.

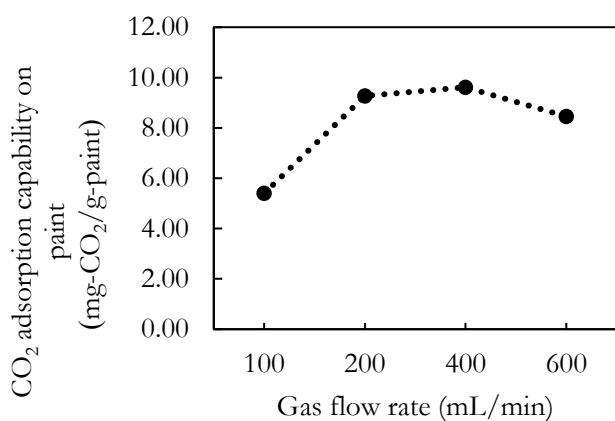


Fig. 7. The effect of inlet gas flow rate on CO₂ adsorption capability of modified paint (Ca(OH)₂).

3.6. Effect of Humidity

This research studied further to see the effect of humidity on CO₂ adsorption in modified paint. It was tested by using modified paint with Ca(OH)₂ as solid adsorbent at two conditions of (i) dry gas flow of 10 – 20%RH and (ii) humid gas flow of 40 – 50%RH at 30°C and 400 mL/min. The adsorption capacity of the humid flow (9.61 mg-CO₂/g-paint) was higher than that of the dry flow (4.18 mg-CO₂/g-paint). In other words, the humid flow showed 2.3 times greater adsorption capacity than the dry flow. It indicated that the effect of H₂O on CO₂ adsorption was significant due to its role as chemisorbed water of the Ca(OH)₂ adsorption process. Generally, the carbonation of Ca(OH)₂ consists of several steps as shown in equations (2) to (6) [16]. The carbonation reaction on the modified paint was affected by the presence of water in the system. Therefore, the modified paint could adsorb more carbon dioxide in the environment with higher humidity.

4. Conclusion And Recommendations

In this study, the CO₂ capture capacity in modified paint was studied by adding K₂CO₃ and Ca(OH)₂ as a constituent of paints and tested at ambient temperature (~30°C) and atmospheric pressure using 6%vol CO₂ as the inlet gas balanced by nitrogen. The necessary testing apparatus was constructed as a layered box for investigating the performance of coating paint at conditions in its application. Generally, conventional paint exhibits limited CO₂ adsorption capacity. Upon the modification with K₂CO₃, a notable enhancement in adsorption capacity was observed. However, the improvement in CO₂ adsorption capacity linked to the increased K₂CO₃ content was found to be constrained by the long-term stability of the paint. Besides, it was found that the glossiness of the paint negatively affected the adsorption capacity. This is because the paint ingredients that create the glossiness cover the paint-coated surface resulting in a decrease in surface area between CO₂ and sorbent. In addition, the semi-gloss paint formed a gel after the addition of K₂CO₃. Thus, the semi-gloss paint possessed a much lower adsorption capacity than the matte and gloss paints. Under the same operating condition, the modified paint with Ca(OH)₂ showed a higher adsorption capacity than that with K₂CO₃ and could satisfy long-term stability testing, while the modified paint with K₂CO₃ failed. Furthermore, gas flow rate and humidity significantly affected CO₂ adsorption on the paint. An increase in gas flow rate resulted in a higher influx of CO₂, leading to greater levels of adsorption within the paint. The highest amount was found at 9.61 mg-CO₂/g-paint of modified paint with Ca(OH)₂ at 400mL/min. However, it was observed that the CO₂ adsorption capability decreased as the gas flow rate exceeded 400 mL/min due to the shortened contact time between gas and adsorbent. Additionally, an increase in system humidity was found to enhance the CO₂ adsorption capacity of paint, as the presence of a water vapor layer facilitated the Ca(OH)₂ adsorption process. This level of adsorption is equivalent to an approximate reduction of CO₂ in the atmosphere by 4.58 g-CO₂/m², a significantly higher capacity compared to conventional paint, which captures CO₂ at approximately 0.06 g-CO₂/m². This study introduces a novel approach to Carbon Capture and Storage application, combining highly effective adsorbents with paint. The impacts and potential of CO₂ capture in the modified paint are being evaluated in this preliminary investigation. Results imply that the modified wall paint can adsorb CO₂. The further experiments included CO₂ concentrations that should be close to those in the atmosphere (400ppm), the fluctuating environmental temperatures between day and night as well as the use of oxygen (O₂) as an additional interesting variable that would be considered in further research. Moreover, the utilization of this modified paint represents a compelling solution for CO₂ capture, characterized by low investment costs and the absence of equipment installation requirements which can be further investigated

to enhance the potential benefits of direct air capture technology.

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References

- [1] P. Spezzano, "Mapping the susceptibility of UNESCO World Cultural Heritage sites in Europe to ambient (outdoor) air pollution," *Science of The Total Environment*, vol. 754, p. 142345, 2021.
- [2] R. Lindsey. "Climate Change: Atmospheric Carbon Dioxide. ClimateWatch 2020." Accessed: 24 June 2021. [Online]. Available: <https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>
- [3] J. Rogelj *et al.*, "Paris Agreement climate proposals need a boost to keep warming well below 2 °C," *Nature*, vol. 534, no. 7609, pp. 631–639, 2016.
- [4] A. Samanta, A. Zhao, G. K. H. Shimizu, P. Sarkar, and R. Gupta, "Post-Combustion CO₂ Capture Using Solid Sorbents: A Review," *Industrial & Engineering Chemistry Research*, vol. 51, no. 4, pp. 1438–1463, Feb. 2012.
- [5] Union of Concerned Scientists. "The 20 countries that emitted the most carbon dioxide in 2018." [Online]. Available: <https://www.ucsusa.org/resources/each-countrys-share-co2-emissions>
- [6] R. Armstrong, "Smart paint makes buildings carbon," *New Scientist*, vol. 205, no. 2742, p. 7, 2010.
- [7] Graphenstone. "Manufacturer Declaration." [Online]. Available: www.graphenstone.com.
- [8] J. Photopoulos. "The paint that eat pollutants and heat home." [Online]. Available: <https://ec.europa.eu/research-and-innovation/en/horizon-magazine/paints-eat-pollutants-and-heat-homes>
- [9] S. Boonprasop, B. Chalermisinsuwan, and P. Piumsomboon, "Effect of the operating parameters on the CO₂ capture capacity of potassium carbonate supported on gamma alumina (K₂CO₃/γ-Al₂O₃) using conventional heat regeneration," *Journal of the Taiwan Institute of Chemical Engineers*, vol. 78, pp. 282–289, 2017.
- [10] D. Iruretagoyena, X. Huang, M. Shaffer, and D. Chadwick, "Influence of alkali metals (Na, K and Cs) on CO₂ adsorption by layered double oxides supported on graphene oxide," *Industrial & Engineering Chemistry Research*, vol. 54, no. 46, pp. 11610–11618, Oct. 2015.
- [11] R. Rodríguez-Mosqueda, E. A. Bramer, T. Roestenberg, and G. Brem, "Parametrical study on CO₂ capture from ambient air using hydrated K₂CO₃ supported on an activated carbon honeycomb," *Industrial & Engineering Chemistry Research*, vol. 57, no. 10, pp. 3628–3638, Mar. 2018.
- [12] Y. Guo, C. Zhao, C. Li, and Y. Wu, "CO₂ sorption and reaction kinetic performance of K₂CO₃/AC in low temperature and CO₂ concentration," *Chemical Engineering Journal*, vol. 260, pp. 596–604, 2015.
- [13] F. N. Ridha, V. Manovic, A. Macchi, and E. J. Anthony, "CO₂ capture at ambient temperature in a fixed bed with CaO-based sorbents," *Applied Energy*, vol. 140, pp. 297–303, 2015.
- [14] M. Erans, S. A. Nabavi, and V. Manović, "Carbonation of lime-based materials under ambient conditions for direct air capture," *Journal of Cleaner Production*, vol. 242, p. 118330, 2020.
- [15] Z.-H. Li, Y. Wang, K. Xu, J.-Z. Yang, S.-B. Niu, and H. Yao, "Effect of steam on CaO regeneration, carbonation and hydration reactions for CO₂ capture," *Fuel Processing Technology*, vol. 151, pp. 101–106, 2016.
- [16] S.-M. Shih, C.-S. Ho, Y.-S. Song, and J.-P. Lin, "Kinetics of the reaction of Ca(OH)₂ with CO₂ at low temperature," *Industrial & Engineering Chemistry Research*, vol. 38, no. 4, pp. 1316–1322, Apr. 1999.
- [17] F. Pontiga, J. M. Valverde, H. Moreno, and F. J. Duran-Olivencia, "Dry gas–solid carbonation in fluidized beds of Ca(OH)₂ and nanosilica/Ca(OH)₂ at ambient temperature and low CO₂ pressure," *Chemical Engineering Journal*, vol. 222, pp. 546–552, 2013.
- [18] San Nopco. "Industry.02 Paint and Coating." Accessed: 17 June 2021. [Online]. Available: <https://www.sannopco.co.jp/eng/products/industry/industry2.php>
- [19] Thomas. "General Industrial Paint Components." [Online]. Available: <https://www.thomasnet.com/articles/chemicals/paint-components-general-industrial/>
- [20] Thai Meteorological Department. "Weather Summary." [Online]. Available: <https://www.tmd.go.th/en/index.php>
- [21] National Weather Service. "Estimating Wind Speed." [Online]. Available: <https://www.weather.gov/pqr/wind>
- [22] H. J. Herzog, "What future for carbon capture and sequestration?," *Environmental Science & Technology*, vol. 35, no. 7, pp. 148 A - 153 A, Apr. 2001.
- [23] T. Tenno, E. Rikmann, I. Zekker, L. Daija, and A. Mashirin, "Modelling equilibrium distribution of carbonaceous ions and molecules in a heterogeneous system of CaCO₃–water–gas," *Proceedings of the Estonian Academy of Sciences*, vol. 65, p. 68, Jan. 2016.
- [24] T. Tenno, K. Uiga, A. Mashirin, I. Zekker, and E. Rikmann, "Modeling Closed Equilibrium Systems of H₂O–Dissolved CO₂–Solid CaCO₃," *The Journal of*

- Physical Chemistry A*, vol. 121, no. 16, pp. 3094–3100, Apr. 2017.
- [25] J. Kapica-Kozar *et al.*, “Adsorption of carbon dioxide on TEPA-modified TiO₂/titanate composite nanorods,” *New Journal of Chemistry*, vol. 41, no. 16, pp. 7870–7885, 2017.
- [26] R. Drunka, J. Grabis, and A. Krumina, “Microwave assisted synthesis, modification with platinum and photocatalytical properties of TiO₂ nanofibers,” *Materials Science*, vol. 22, no. 1, pp. 138-141, Feb. 2016.
- [27] M. Kosmulski, *Surface Charging and Points of Zero Charge*. CRC Press, 2009.
- [28] J.-H. Yang, S.-M. Shih, C.-I. Wu, and C. Y.-D. Tai, “Preparation of high surface area CaCO₃ for SO₂ removal by absorption of CO₂ in aqueous suspensions of Ca(OH)₂,” *Powder Technology*, vol. 202, no. 1, pp. 101–110, 2010.



Waranya Khantiudom, photograph and biography not available at the time of publication.

Teerawat Sema, photograph and biography not available at the time of publication.

Benjapon Chalermssinsuwan, photograph and biography not available at the time of publication.

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