Carbon Dioxide (CO_2) Sequestration In Bio-Concrete, An Overview

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Abstract. The emission of CO_2 into atmosphere which has increased rapidly in the last years has led to global warming. Therefore, in order to overcome the negative impacts on human and environment, the researchers focused mainly on the reduction and stabilization of CO_2which represent the main contributor in the increasing global warming. The natural capturing and conversion of CO_2 from atmosphere is taken place by biological, chemical and physical processes. However, these processes need long time to cause a significant reduction in CO_2. Recently, scientists shifted to use green technologies that aimed to produce concrete with high potential to adsorb CO_2 in order to accelerate the reduction of CO_2. In the present review the potential of bio-concrete to sequestrate CO_2 based on carbonation process and as a function of carbonic anhydrase (CA) is highlighted. The factors affecting CO_2 sequestration in concrete and bacterial species are discussed. It is evident from the literatures, that the new trends to use bio-concrete might contribute in the reduction of CO_2 and enhance the strength of non-reinforced concrete.

1 Introduction

Concentration of Carbon dioxide and other gasses in the atmosphereare increasing due to anthropogenic activities. The increase of CO_2 had caused intensive phenomena such as; climatic changes, global warming and change in rainfall and rise of sea level [1]. CO_2 emissions in atmosphere come from different sources, mainly from the combustion of fossil fuels used in power generation, transportation, industrial processes and residential and commercial buildings. In precisely, industrial process such as cement manufacturing is considered as the major source of CO_2 in atmosphere. Whereas, cement manufacturing is responsible for 88% of the anthropogenic CO_2 emissions while land-use change, primarily deforestation, is accountable for the remaining 12% [2]. The above discussion pointed out that, there is a need to reduce the atmospheric concentration of CO_2 to be below of the current levelin future [3].

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In recent years, there are many researches [1-4], with different technologies interest on reducing of atmospheric CO_2 concentration and limiting the emission of CO_2 from differencegenerated sources. based on previous studies, sequestration of CO_2 can be done using different technologies such as; chemical absorption, physical separation, membrane separation and biological fixation [5-7]. Biological sequestration of CO_2 can naturally convert CO_2 to biominerals including carbonate minerals such as calcium carbonate ($CaCO_3$) and magnesium carbonate through bio-mineralization process [8]. In this case, bacterial carbon anhydrate (CA) used as bio-mimetically for CO_2 capture and conversion. CA has the ability to accelerate hydration of CO_2 to HCO_3^-, which can be precipitate in the form of carbonate as $CaCO_3$ [4,9,10]. On the other hand, CO_2 penetrates and sequestrates into concrete by reacting with Portland cement in the presence of moisture to form $CaCO_3$. The rate of carbonation process in concrete depend on several factors whereas, concentration of CO_2 considered as the most factor affect carbonation process as illustrated in section 3 in this manuscript [11-12].

Nowadays, concrete technology used different types of bacteria such as *Ureolytic, Bacillus sphaericus, Shewanella and Bacillus pasteurii, pseudomonas aeruginosa* as natural additive material to concrete in producing new type of concrete namely bio-concrete. This type of concrete has the ability to accelerate the precipitation process of $CaCO_3$ in concrete pores [13-16]. Bio-concrete incorporating ureolytic bacteria such as *Bacillus sphaericus*proved that, theused of urease helps in mineralization of $CaCO_3$and hydrolyzing urea that present in the environment. In line with that, $CO_2$is released from urea and combines with calcium ions resulting in deposition of $CaCO_3$ in the form of calcite[17]. The objective of this paper is to highlight the potential of bio-concrete to sequestration CO_2. This paper will provide understanding on the use of bacteria as CO2 sequestration.

2 Carbon dioxide sequestration in concrete

Sequestration and capture of $CO_2$are considered as a new technology that can reduce and eliminate of CO_2 emissions. Most of previous studies focused on sequestration of CO_2 using geological sequestration conducted by injecting CO_2 into deep underground rock formation, or capture CO_2 by using power plants and biological sequestration [18-19].

Nowadays, many studies in concrete technology were conducted to reduce CO_2 emission by reducing the amount of cement used in concrete mix and replaced it by other materials such as fly ash, silica fume and waste ash of palm oil, which produced different types of green concrete can be used in construction rather than conventional concrete [20-23].

On the other hand, sequestration of CO_2 from atmosphere in concrete and lime can be achieved via carbonation process. Carbonation occurred on the surface of concrete though CO_2 penetration into the pores inside concrete. CO_2 penetration into concrete pores depend on different factors such as; CO_2 concentration and relative humidity, the availability of $Ca(OH)_2$ and water, the additional materials that replace cement [24]. Carbonation is famed as a neutralizing process, which occurred as a results of the chemical reaction of $Ca(OH)_2$ and calcium-silicate-hydrate (C-S-H) with CO_2 to form calcium carbonate$CaCO_3$ and H_2O [25].

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

Pade & Guimaraes[26] mentioned that, carbon dioxide production can be re-capture in concrete by chemical reaction to calcination in the form of carbonation. Furthermore, carbonation can improve the surface hardness strength and durability of concrete by pore refinement of the cement paste matrix. However, carbonation is useful in non-reinforced concrete. It can lead to steel corrosion in reinforced concrete by reduced pH of carbonated cement paste due to carbonation [26].

Previous study by Pade & Guimaraes [26] approved that, carbonation process in concrete is generally very slow especially in normal concrete. Therefore, there is an interest in accelerating carbonation processespecially in non-reinforcement concretealong primary life applications and long term life of concrete in order to make the life cycle of concrete more carbon neutral with respect to the calcination reaction. In order to achieve the purpose, factors affecting carbonation process in concrete must be studied, if there is an interesting in accelerating carbonation in the concrete [24].

3 Factors affecting carbonation process in concrete

There are many factors that affect the acceleration process of carbonation into concrete such as; concentration of CO_2, concrete porosity, types of material, water cement ratio, relative humidity and degree of hydration of concrete materials.

Yoon et al [27] approve that, CO_2 concentration plays an important role on the carbonation depth of concrete. At the same time, the different of water cement ratio(W/C) and microclimatic conditioncontributed affectively of carbonation of concrete structures. The results show that, the carbonation in concrete increased with increased of CO_2 concentration and with high W/Ccompared to low W/C.

According to the study by Chang & Chan [28], three distinct regions of carbonated zone in concrete were identified; fully carbonated, partly carbonated and noncarbonated zones. Concrete with the fully carbonated zone is identified with the degree of carbonation greater than 50% and pH< 9.0. Furthermore, the degree of carbonation in the partly carbonated zone lies between 0% and 50% when pH is between 9.0 and 11.5. The non-carbonated zone is where the test specimen shows no sign of carbonation. The change of pH and concentration of CO_2 play an important role on penetration of carbonation into concrete. Therefore, carbonation of the concrete is considered as deterioration mechanism, because it help to decrease the pH of the concrete. Concrete with the lower pH causes the reinforcement steel to lose its electrochemical protection, so that corrosion may initiate and progress. For this reason, carbonation is not good for reinforced concrete. However, carbonation can be helpful for non-reinforced concrete [29]. Many of researches mentioned that, the relative humidity with surrounding environment around 50% to 70% can help to increase carbonation of concrete [11,12,29]. Furthermore, concrete with high internal moisture content shows a low rate of carbonation because the diffusion of CO_2 becomes difficult when the pores in concrete is saturated by water. Carbonation rate also decreases at lower internal moisture level due to insufficient water in pores [4].

4 Bacteria in concrete

The used of bacteria as additional material in concrete produce new type of concrete namely bio-concrete. The most popularbacteria used in concrete are presented in Table 1. Bacteria can play an important role in concrete by microbial mineral precipitation due to metabolic activities of some specific microorganisms in concrete. Whereas, metabolic activities of some microorganisms improve the overall behavior of concrete specially, compressive strength and concrete penetration which in role reduce the environmental factors that affect concrete which may lead to concrete deterioration. These improvements were due to the precipitation of calcium carbonate due to presence of bacteria in bio-concrete. In addition, bacteria plays an important role in bio-concrete to improve the deterioration of pores materials and enhance the durability of building materials especially sand, also healing of porosity and cracks in the concrete [15,30].

Table 1. Types of bacteria used in bio-concrete for different applications.

Researcher	Application	Types of bacteria
Bang et al. [13]	Microbial concrete as crack healer	*Bacillus Pasteurii* *Pseudomonas Aeruginosa*
Ghosh et al. [14]	To increase strength in concrete mixture	*Shewanella*
Achal et al. [37]	Enhanced urease and calcite production	*S. pasteurii*
Al-Thawadi. [16]	Strength enhancement of sand	*Ureolytic, Bacillus*
Wiktor & Jonkers. [15]	Self-healing concrete	*Bacillus alkalinitrilicus*
Pacheco-Torgal & Labrincha.[38]	Microbial concrete as surface treatment	*Bacillus Sphaericus*
Nosouhian et al. [39]	Enhancement of concrete properties	*B. subtilis*

There are some factors affecting the growth of bacteria such as growth medium, temperature, high pH value and anaerobic conditions [31]. The factors restricting the growth of bacteria in bio-concrete were extreme pH and anaerobic conditions.
According toTittelboom et al [17],when bacteria are used to heal pores in concrete, the major hindering factor is the highly alkaline pH of the concrete which restricting the growth of bacteria. Therefore, bacteria cells immobilized in silica gel to protect them from the high pH in concrete. Other authors had already suggested the use of polymer encapsulation [13].

The study by Wiktor & Jonkers [15] found that anaerobic condition restricting the growth of bacteria. However, the denitrification is the biological reduction of nitrogenous oxides to gaseous products during anaerobic (no oxygen) bacterial growth.
Al-Thawadi[16] approved that, ureolytic bacteria (*Bacillus)* have the ability to precipitate calcium carbonation which used in many application such as removing contaminates and surface coating of monumental estuaries to improve the mechanical properties of the concrete especially sandy material.Furthermore, *Bacillus* bacteria has a great innovation to hydrolyzed urea to generate adenosine triphosphate (ATP) using the efflux of ammonium ions through ATP-synthase which in role produce carbonate. Whereas, the presence of calcium ions with excess amount, conformed that calcium carbonate will precipitate. Availability of calcium carbonate is known as bio-grout or bio-cementation used as superior to the chemical cemented sandy material in terms of reduced penetration and insignificant decrease in porosity, also used for the purpose of strength formation and resistance of weathering factors.

Tittelboom et al [17] mentioned that, urease can be used to catalyzes the hydrolysis of urea ($CO(NH_2)_2$) into ammonium (NH_4^+) and carbonate (CO_3^{2-}). Whereas, urea is hydrolyzed intracellular in carbonate and ammonia (Eq.2). Carbonate spontaneously hydrolyses to form ammonia and carbonic acid (Eq.3).These products from bicarbonate and ammonium and hydroxide ions (Eqs.4-5). Which in role caused increase in pH, which can shifts the bicarbonate equilibrium, resulting in the formation of carbonate ions (Eq. 6).

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3 \quad (2)$$
$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3 \quad (3)$$
$$H_2CO_3 \leftrightarrow HCO_3^- + H^+ \quad (4)$$
$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \quad (5)$$
$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2O \quad (6)$$

When bacteria cell wall charged negatively, the bacteria draw cations from the environment, including Ca^{2+}, to deposit on their cell surface. The Ca^{2+} -ions react with CO_3^{2-} -ions, which in role lead to precipitation process of $CaCO_3$ at the cell surface (Eqs.7-8).

$$Ca^{2+} + Cell \rightarrow Cell\text{-}Ca^{2+} \quad (7)$$
$$Cell\text{-}Ca^{2+} + CO_3^{2-} \rightarrow Cell\text{-}CaCO_3\downarrow \quad (8)$$

5 Influence of bacterial carbonic anhydrase on accelerate bio-sequestration of CO_2

In the global effort to eliminate CO_2 emission, several technologies are being deliberated. Bio-sequestration of CO_2 is one of the most important technology applied to accelerate sequestration process.

In order to accelerate the process of biological sequestration of CO_2 under a conducive environment, which progressesthrough the hydration of CO_2, an enzyme known namely carbonic anhydrase (CA) is employed [32,33]. CA is a metallo-enzyme containing zinc (Zn^{+2}) metal ion in its active site, encoded by almost all organisms including eukaryotes and prokaryotes, and catalyzes the reversible hydration of carbon dioxide (CO_2) into bicarbonate ions (HCO_3^-) which in role has the ability to promote $CaCO_3$ [32]. CA can be extracted from different bacteria such as; *Ureolytic bacteria, Bovine CA, Bacillus cereus and Citrobacter freundii* for sequestration purpose of CO_2 [4,10,34-35].

Chen et al [34] & Ramanan et al [35] mentioned that, the precipitation process of carbonate minerals is naturally very slow. Therefore, the used of CA can play an important role to accelerate the reaction and the formation of carbonate under a conducive environment as presented in Eqs 9-13. $CO_{2\,(g)}$ diffuse through the solution, producing $CO_{2(aq)}$, $HCO_3^-{}_{(aq)}$and $CO_3^{2-}{}_{(aq)}$, which could be used for precipitation reaction. While, the reaction started by releasing of bicarbonate ion into the reaction medium by hydration of CO_2[13,35]. At the end of this reactions solid calcium carbonate ($CaCO_3$) is produced in the presence of calcium ion.

$$CO_{2\,(g)} \Leftrightarrow CO_{2\,(aq)} \quad (9)$$
$$CO_{2\,(aq)} + H_2O \Leftrightarrow HCO_3^- + H^+ \quad (10)$$
$$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-} \quad (11)$$
$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3\downarrow \quad (12)$$
$$Cell\text{-}Ca^{2+} + CO_3^{2-} \rightarrow Cell\text{-}\ CaCO_3\downarrow \quad (13)$$

According to reaction series for the precipitation process of $CaCO_3$ (Reaction 10-12), the hydration of CO_2 to form carbonate ion and proton (Reaction 10) forwards with an extremely slow pace and pace is the rate limiting step. When the biocatalyst CA is employed to catalyze the hydration of CO_2 (Reaction 10), resulting dramatically increases in the rate of hydration which in role make the reaction much faster. It can be seen clearly that, the CA enzyme play vital role in making the reaction much faster, which can help in accelerate the process of CO_2 sequestration [36].

6 Concluding remarks

$CO_2$is considered as one of the main factors affecting environmental and global warming challenges. Many researches were conducted to minimize emissions of CO_2 and to capture CO_2 in the atmosphere. Carbonation of concrete can be considered as one of CO_2 sequestration process but it is very slow. Furthermore, concrete carbonation caused steel corrosion in structural reinforced concrete. Therefore, carbonation can be conducted in non-reinforced concrete to avoid steel corrosion. Accelerating of carbonation process in non-reinforced concrete tobe one of the vital attribution in CO_2sequestration. the used of bacteria in concrete can help in precipitation of $CaCO_3$ process which used bacteria enzyme and atoms of CO_2 during the chemical reaction. Previous studies had pointed out that many bacteria had showed possibility in improving concrete properties and self-healing. Therefore, it is very important to study the role of bacteria enzyme in carbonation process and the ability to accelerate the sequestration process of CO_2 into bio-concrete.

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