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The chemical reactor design configuration of CO_2 concrete green solution

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Abstract

The construction industry is known as one of the main harmful industries in terms of environmental impacts. Concrete as the mainstream construction material across the globe with the production volume above all of the other substances on earth. With the governments putting more emphasis on decreasing the greenhouse gas emissions by imposing restraints on CO_2 emission, the construction companies specially those who have a sort of contribution to concrete production are urged to minimize their carbon footprint. One of the successful examples of these policies are carbon tax which is evaluated by using the life cycle assessment softwares. Nevertheless, it is predictable that the industry soon will be out fashioning the companies those who are not considering environmental effects. In this study, a new type of concrete chemical admixture had been proposed in order to let the construction industry wear a green dress on. The admixture is incorporating the chemical reaction of CO_2 gas in the mix. The chemical reactor had been designed and manufactured and the details synthesis process had been disclosed.

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Keywords

Chemical Admixture; Built Environment; Concrete technology

Introduction

Carbon Dioxide (Co2) is a naturally occurring gas which occurs in the environment through decomposition of plants/animals, volcanic eruptions and as a waste product through respiration. Carbon Dioxide has always been present in the environment however since the industry revolution in 1760 the amount of Co2 in the atmosphere has increased by approximately 40%(BBC). Since the industrial revolution over 200 years ago the amount of carbon dioxide in the atmosphere has increased dramatically due to the discovery that us humans can use naturally occurring elements such as fossil fuels (coal, oil and natural gas) and hydrocarbon fuels (methane, butane, propane, and hexane) as a fuel source to power machines and vehicles, as a source of electricity, to heat homes and in the power and manufacturing industries. At first the use of fossil and hydrocarbon fuels as a power source was well regarded however as time when on and technology has advanced it is now known that the high carbon emissions are having a severe impact on our environment and is believed to be the main driving force towards climate change. As shown in the chart below in Australia since the 1960's there have been a few times where the temperature was just above average however as you look further down the chart you can see that since the 1980's the temperature in Australia has been above average and the closer you get to the present time the amount over the average temperature also increases; in the 1960's the temperature was less than half a degree over the mean temperature, in the 1980's the temperature was getting closer to 1 degree above average and now in 2019 the temperature is roughly 1.5 degrees above the average. Because it is widely believed that carbon emissions are a driving force behind climate change there have been several calls for large companies to monitor and limit their carbon emissions; However, the carbon emissions can only be limited so far, this is why carbon capturing technology has started to be implemented across the world. Other than that, human curiosity towards extra-terrestrial exploration such as Mars missions, is highlighting the viability of CO_2 capturing techniques in CO_2 rich Martian atmosphere [1].

Carbon can be taken from power plants in 3 different ways; Post Combustion, Pre-Combustion and Oxy-Fuel combustion and if implemented correctly carbon capture technology has the potential to capture between 80-90% of a plants carbon emission before it even enters the atmosphere.

ISO 14040.2016 : Environmental management defines Life Cycle Assessment (LCA) as a technique for assessing the potential environment aspects and potential aspects associated with a product or service. In relation to this report the Life Cycle Assessment of fossil fuel power plants and cement plants will be assessed. There are several driving forces behind the implementation of the life cycle assessment; Firstly, several governments are beginning to impose "Life Cycle Accountability"; A term which is used to hold manufacturers accountable for production impacts and environmental impacts associated with product use, transport and disposal. Another driving force is the implementation of the ISO standards and care programs which businesses are beginning to abide by, by following standards such as the ISO businesses are able to improve their environmental management systems.

Within a Life Cycle Assessment there are 4 main components which if used correctly can be used to provide an accurate in-depth evaluation of the environmental impacts associated with a product/services use. These four components are: Goal definition and scoping; which refers to the purpose and products of the study while also identifying the boundaries of the study and assumptions based on the goal. The second component of an LCA is the life cycle inventory, Where the energy and material inputs are quantified and the environmental releases that occur in each stage of production. Impact analysis is the third component of an LCA which involves measuring the impacts of the energy and material inputs have on both human health and the environment. The final component is the improvement analysis where the company is able to assess the results found through the above process and offer solutions which can reduce energy consumption, material inputs and the overall environmental impact in each stage of production. It has been found that when carbon capturing technology is implemented in power plants it leads to a life cycle greenhouse gas emission reduction of between 68-92% in relation to fossil power generation and 39-78% regarding cement production.

There are several different ways captured carbon can be stored or disposed; The most common being depositing the captured carbon underground. A common problem with captured carbon dioxide is the transportation process from the captured site to the storage location. Carbon Dioxide is transported in all 3 states of matter: Liquid, Gas and solids, with a different transportation process for each. The captured carbon is generally liquified or solidified in an attempt to reduce the overall volume which needs to be transported. The most common transport technique for either liquid or gas carbon dioxide are tanks, ships and pipelines.

Geological storage of carbon dioxide was first introduced in the 1970's in the USA as part of various enhanced oil recovery projects; During this time the effects of geological storage of carbon dioxide were unknown as there wasn't much research conducted in the field until the 1990's. However once in-depth research surrounding the topic was conducted the idea went from a concept of limited design to an important mitigation system. There are several underground locations which are suitable for carbon injection such as: basins, oil fields, depleted gas fields, deep coal seams and saline formations as shown in the figure below.

Even though underground storage is a good idea there are several risks which are associated with this form of storage which must be addressed such as: How long can the captured carbon be stored for and how secure the storage is. In order to ensure the storage site, remain safe for long periods of time they must be designed in a way which possible leakage pathways can be identified and ways in which the carbon can be monitored and measured.

Technological aspects

There is a vast collection of trapping systems for the CO_2 capturing mechanism that does a sufficient job of entrapping a projected 90% of carbon dioxide emission for power conservation that is then diverted to industrial sites, factories or chemical deposit plants. The technology is not cheap – up to 40% of a power station's energy could end up being used to run the CCS (carbon capture and storage scrubbing and transport systems and experts estimate the average cost of retro-fitting Australia's aged power stations at about $1bn each. The oldest power stations may end up being uneconomical to refit. Capturing CO_2 is most effective at point sources, such as large fossil fuel or biomass energy facilities, industries with major CO_2 emissions, natural gas processing, synthetic fuel plants and fossil fuel-based hydrogen production plants. Extracting CO_2 from air is also possible, although the far lower concentration of CO_2 in air compared to combustion sources presents significant engineering challenges. The research is to achieve the most inexpensive an efficient CO_2 capture method in the benefit that the future of the construction delivery process cannot be overly involved in the degradation of high carbon emissions.

There are three main technological layouts of CO_2 capturing techniques all of them highly effective: post combustion, pre combustion and oxyfuel.

Post-combustion capture

Within this method CO_2 is separated from the flue gas of the power station by over exertion of the gas through an absorber column packed with liquid solvents (such as ammonia) that preferentially take out the CO_2. In the most commonly-used techniques, once the chemicals in the absorber column become saturated, a stream of superheated steam at around 120°C is passed through it. This releases the trapped CO_2, which can then be transported for storage elsewhere. More experimental techniques to scrub CO_2 from flue gas without the need of a two-step process include using seawater to absorb the gas and then returning the mixture back to the ocean for long-term storage. But, so far, these methods have proved less efficient and reliable. The technology is well understood and is currently used in other industrial applications, although not at the same scale as might be required in a commercial scale power station. Post combustion capture is most popular in research because existing fossil fuel power plants can be retrofitted to include CCS technology in this configuration. CO_2 can be captured from the exhaust of a combustion process by absorbing it in a suitable solvent. This is called post-combustion capture. The absorbed CO_2 is liberated from the solvent and is compressed for transportation and storage. Other methods for separating CO_2 include high pressure membrane filtration, adsorption/desorption processes and cryogenic separation [2-5].

Pre-combustion capture

When coal, oil or natural gas is burned in normal air, the amount of CO_2 produced is between 3-15% of the waste gases, this is dependent on various conditions. Separating the greenhouse gas out after combustion requires energy so an alternative CCS method is to burn the fossil fuel in an atmosphere of pure oxygen. In this environment, virtually all the waste gas will be composed CO_2 and water vapour. Then can be condensed out while the former can be piped or transported directly to a storage facility. Pre-combustion is basically the removal of CO_2 from the already existing fossil fuels before the combustion is completed. For example, in gasification processes a feedstock (such as coal) is partially oxidized in steam and oxygen/air under high temperature and pressure to form synthesis gas. This synthesis gas, or syngas, is a mixture of hydrogen, carbon monoxide, CO_2, and smaller amounts of other gaseous components, such as methane. The syngas can then undergo the water-gas shift reaction to convert CO_2 and water (H_2O) to H_2 and CO_2, producing a H_2 and CO_2-rich gas mixture. The concentration of CO_2 in this mixture can range from 15-50%. The CO_2 can then be captured and separated, transported, and ultimately sequestered, and the H_2-rich fuel combusted [6].

Oxy-fuel combustion capture

This method is normally applied to coal-gasification combined cycle power plants. The coal is gasified to produce a synthetic gas made from carbon monoxide and hydrogen. The former is reacted with water to produce CO_2, which is captured, and more hydrogen. The hydrogen can be diverted to a turbine where it can be burned to produce electricity. Alternatively, some of this gas can be bled off to feed hydrogen fuel cells for cars. One disadvantage of the pre-combustion method is that it cannot be retro-fitted to the older crushed coal power plants that make up much of the world's installed base of fossil fuel power. It could perhaps be used in natural gas stations, where a synthetic gas is first produced by triggering the methane with steam to produce carbon dioxide and hydrogen. But the economic advantage of this method over post-combustion is yet to be proven. A certain fraction of the CO_2 generated during combustion will inevitably end up in the condensed water. To warrant the label "zero emission" the water would thus have to be treated or disposed of appropriately. It is highly important to evaluate rising threats such as the rise of Carbon emissions, greenhouse gasses, global warming and rising of CO_2. All these concerns can drastically change the ever-growing construction industry and its project delivery methods. With the added solution of advanced technological capturing methods, we can see safer, greener and decreased carbon emissions in the world. This safely protects the future development and more the populous [2, 6-15].

Political Aspects

Following reports conducted in 2009 which made it evident that climate change is a global challenge, the Clean Energy Act 2011, a carbon pricing scheme, was introduced. Ultimately, the goal of this policy was to achieve a reduction of the amount of carbon emissions. This was accomplished by demanding a payment of the full social cost, per tonne, of carbon released. According to the Centre for Public Impact the law was intended to transform the Australian economy and provide support to low and middle income households. The Clean Energy Act 2011 mainly reflects the true cost of burning carbon.

The introduction of the tax initiative, the Clean Energy Act 2011 reduced Australia's greenhouse gas emissions by a significant 14 per cent. In theory, by increasing fees, it encourages people to find alternative resources such as catching public transportation or replacing incandescent bulbs with compact fluorescent lamps. With more overheads involved, companies are prompted to find efficient ways to manufacture and maintain their services.

Whilst successfully claiming the largest recorded decrease in the past decade, disadvantages such as factory closures and loss of jobs, proved to be experienced frequently due to a 10% cost increase to electricity. By increasing the expense of fossil fuels it imposes a burden on lower income earners. Much like any challenge, to be successful, the tax initiative must be used in conjunction with other incentives which aim at lowering the carbon footprint.

Revenue accumulated from tax payers is reinvested in to advancing technologies such as low emission fossil fuel technologies:

- Carbon capture utilisation and storage (CCUS) with associated transport, injection and monitoring.

- High efficiency low emission (HEKE) electricity program
- Fugitive emission abatement technologies

Environment legislation has contrasting levels of support from leading political parties. The Greens are the most engaged stakeholders in the policy. Between the years 2007 to 2013 commitment towards the carbon tax scheme was given from the Labour government however Liberal opposed, expressing concerns regarding its political sustainability due to the impact linked to goods and services. Compensation commitments and transition initiatives for trade exposed industries and households meant an increase in public confidence in favour of the Clean Energy Act 2011.

According to The Australian Greens Party 'urgent and sustained local, notational and global action is required to avoid catastrophe and ensure a safe climate'. By not planning for the future and relying on fossil fuels The Greens state:

- An increased cost of adaption
- Increased risk of extreme weather events and bushfires; and
- Risks to water resources, agriculture and food security
- Ultimately the Australian Greens Party are in favour:
- Increasing the cost of electricity to reflect their true costs
- Developing and expanding robust distribution networks to sustainable alternatives

Australian Government invests in policies which removes its association with the extraction and consumption of fossil fuels.

Previously the introduction of a carbon tax by Twenty Seventh Prime Minister, Julia Gillard, of the Australian Labor Party, was ruled out a carbon tax as an interim measure. According to ABC TV's Lateline Julia states "the pricing of carbon I think is best done through a market-based mechanism that is the carbon reduction scheme". The tax incentive passed the Senate in 2011, which saw the carbon price starting at $23.00 per tonne.

The ongoing challenges faced with justifying the implementation of the tax incentive and the collapse of the carbon prices in Europe eventually resulted in a repeal of the carbon tax. In 2013, Tony Abbott of the Liberal Party announced the abolishment of the tax incentive ultimately saving household $550.00 per year.

1st April 2019, Bill Shorten, of the Labor Party Australia, announced the pursuit of 'Plan B'. The objective of this is to encourage an advancement on the use of renewables. In conjunction to this, an initiative to reduce the industrial pollution rate by imposing a pollution baseline on companies is expected to see a reduction of 45% of levels by 2030. In lieu of this, according to an article by The Guardian, Scott Morrison, of the Liberal Party Australia declared that the implementation of these policies may see similar results as previously attempted whilst imposing major costs on Australians. Scott suggests considering the implications of the latest policy sector by sector prior to its execution.

The Australian Liberal Party predicts that Australia will meet its global emissions target of approximately 26% below recorded levels in the year 2005 by 2030. It is suggested this can be achieved by alternatives to a tax incentive such as:

- Climate Solution Fund: to aid farmers, low earning businesses and indigenous communities to lower energy costs and improve the natural environment.
- Construction of 'Snowy 2.0': a pumped hydro renewable power station capable of providing power to approximately 500,000 homes.
- National Electric Vehicle Strategy: to assist in the transition of upcoming technologies.
- Environment Restoration Fund: to support practical action on waste and recycling by working with the packaging industry to ensure 100% of Australian packaging is recyclable, compostable or reusable by 2025.

Ultimately without the consistent support and ensured reliability of incentives they will not fester into a successful proposal. With the various schemes at offer they ultimately amount to a single objective, decreasing the release of excess carbon emissions and increasing sustainable resources.

Leaning towards reducing the effect of greenhouse gases on climate change, scientist across the globe had put emphasise on CO_2 capturing methods to be implemented on cement factories and other sectors of construction industry subject to high CO_2 emission. It is known that production of 1 ton of cement is equivalent to the emission of 1 ton of CO_2 gas in the atmosphere. Added to the harmful effects of construction on environment, the rapid population growth and its consequent increase in the number of housing being built, boosts up the generation of construction and demolition wastes. Although construction and demolition waste recycling had gain a popular attention since decades ago, but the implementation of such recycling techniques is still facing serious barriers. Nevertheless, the recycled aggregate had shown promising performance once it is used as road base material and also for paving blocks. Report from the global trend in CDW recycling in 14 major countries with the highest GDP and/or largest population across the globe including Australia, Canada, EU, USA, Brazil, Russia, China, Japan, Pakistan, India, Bangladesh, Indonesia, Mexico and Nigeria indicates that only three of these major countries had yield a higher recycling rate than CDW generation with certain level of concrete proportion. They are Australia, Canada and Japan followed by EU and the US with a closer recycling rate to the concrete proportion [16].

Many technologies had been adopted since awareness had been arisen in regards to the reduction of carbon footprint in concrete productions; CO_2 capturing technologies to be only one of the few. Other popular approaches in that context is the utilization of robotics in construction and solidification of CO_2 gas into carbon nanoparticles [17-21]. Most of which, however, are either deploying physical interlock of CO_2 gas inside the concrete mix or with a low absorption rate. It can be claimed that such techniques compromise as low absorption rate which does not satisfy the business entities to invest in these technologies due to the low efficiency rate. Nevertheless, experimental studies on the concrete samples subject to physical injection of CO_2 gas had shown a few improved properties such as lower water adsorption and increased strength.

One of the methods proposed by Butera [22], as an example, was the injection of carbon dioxide in recycled aggregate under controlled pressurized condition in a carbonation chamber. Zhan et al. [23] had investigated flow-through CO_2 curing method under ambient pressure. Although the schematics presented in the article published by Zhan shows mechanisms for absorption of surplus CO_2 at the outlet, Tam et al. [16] believe that this is solution for permanently absorb the CO_2 gas. Kou et al. [24] had almost conducted the same CO_2 curing procedure as Butera but with a few variations in the mechanism. Kou's method compromises the presence of silica gel at the bottom of curing chamber to avoid the so-called adverse effect of humidity on carbonation.

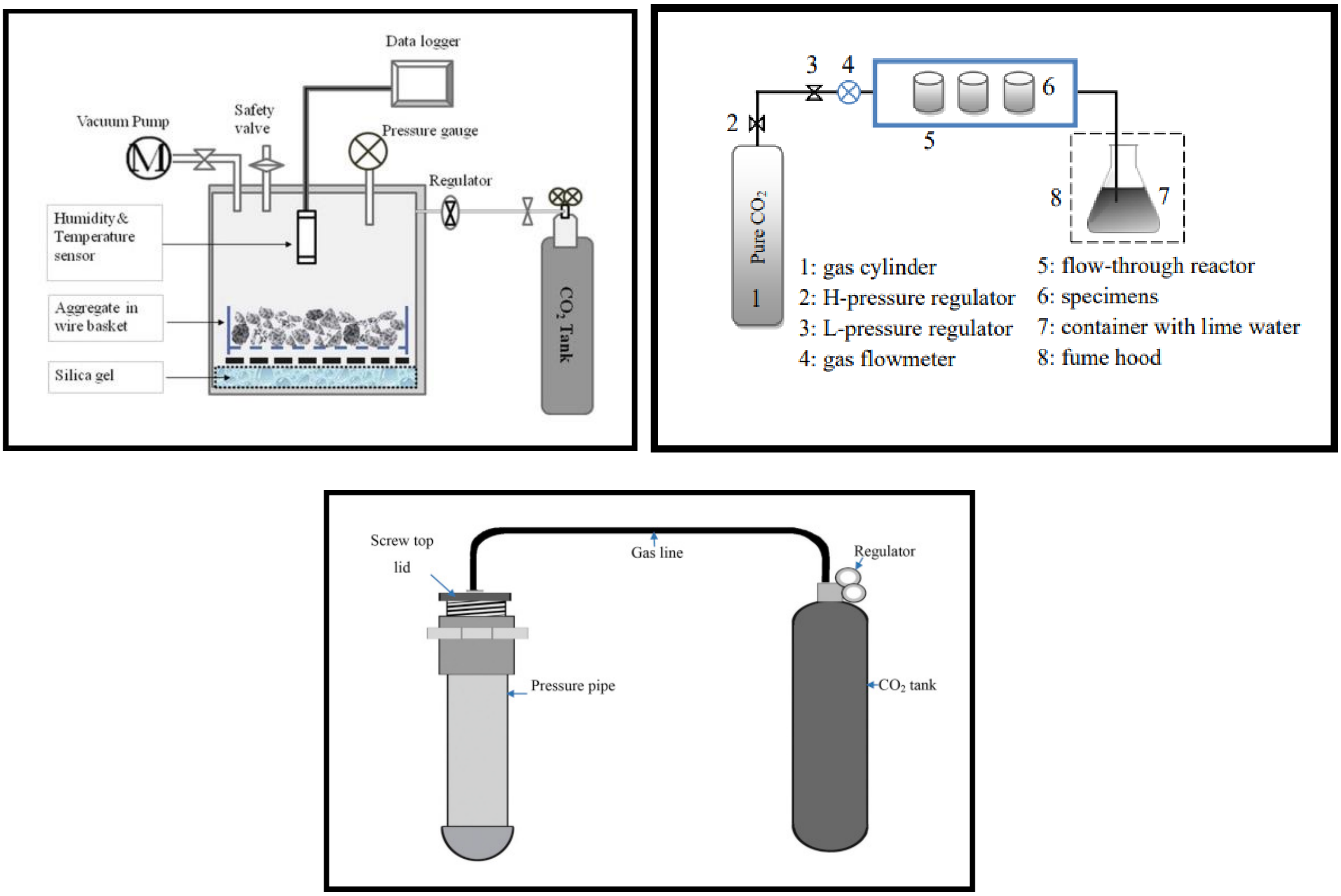

Figure 1 Top Left: Carbonation procedure proposed by Kou[24]. **Top right:** Zhan's proposal for concrete carbonation[23]. **Bottom:** Butera's model of carbonation [22].

The absorption efficiency of all of the current techniques available at the moment for CO_2 sequestration in concrete product is low, based on the fact that a large portion of the injected CO_2 is always remain as surplus. If the claim to have a high absorption meant to be accepted as a true fact for the current methods, there must be a loss of pressure constantly being observed as the CO_2 gas being converted into a crystalline format throughout the experiments. None of the previous studies had reported loss of pressure in the chamber before. This is can be explained using basic chemical interpretations. The bond length of O=C=O is measured as 1.164 Angstroms which require a total of 492.63 kJ/mol to break the molecule into sub atoms ready for being involved in crystallization.

In order to address the issue brought up just above, it is better to propose a chemical approach for a higher efficiency yield of CO_2 absorption i.e. putting the focus on liquid chemical admixtures used in concrete rather than focusing on the reaction between CO_2 and the recycled aggregate. The recent studies conducted at Institute of Construction Materials, Western Sydney University reveals a successful implementation of chemically activating CO_2 gas in a liquid solution with extraordinary absorption rate. This new type of environmental concrete chemical admixture is made from the mixture of polycarboxylic superplasticizer, Monoethanolamine and the injected CO_2 gas. Previous studies had shown satisfactory results on both fresh and hardened state of concrete made with recycled aggregate. The slump flow was enhanced to a state where it could be compared to the rheological performance of SCC (Self-compacting concrete). A high 7 day compressive strength of 36 MPa had also been recorded in previous studies [25]. However, the previous studies in this field lack in the measurement of factors affecting the quality of the proposed new chemical admixture. In order to being able to quantitatively assess the properties of this liquid phase CO_2 admixture a proper calibrated reactor is needed. Thus, in this study, the design process of a chemical reactor had been described. The final design is now manufactured and assembled which is ready to function the purposed of the upcoming research practices.

Chemical reactor design process

Since the main idea is to reduce the environmental impact of construction activities, all of the steps involved in the proposal of a new approach need to comply with the main objective which is to reduce the carbon footprint. This also expands to the design and manufacturing process of the chemical reactor as well. In coherence with the development of a new product design, there are 12 widely accepted principles of green engineering those were realised upon this study [26, 27].

- Principle 1: Designers must ensure that all of the inputs and outputs including materials and energy are inherently nonhazardous as possible.
- Principle 2: Rule of thumb indicates that prevention is always better than treatment. Thus, the design process needs to be pre-evaluated before the manufacturing process starts.
- Principle 3: Separation and purification operations should be designed to minimise energy consumption and material use.

- **Principle 4:** Products, processes and systems should be designed to maximise mass, energy, space and time efficiency.
- **Principle 5:** Products, processes and systems should be 'output pulled' rather than 'input pushed' by using energy and materials.
- **Principle 6:** Embedded entropy and complexity must be viewed as investments when making design choices on recycle, reuse or beneficial disposition.
- **Principle 7:** Targeted durability, not immortality, should be a design goal.
- **Principle 8:** Design for unnecessary capacity or capability (e.g., 'one size fits all solutions should be considered a design flaw.
- **Principle 9:** Material diversity in multicomponent products should be minimised to promote disassembly and value retention.
- **Principle 10:** Design of products, processes and systems must include integration and interconnectivity with available energy and material flows.
- **Principle 11:** Products, processes and systems should be designed for performance in a commercial 'afterlife'.
- **Principle 12:** Material and energy inputs should be renewable rather than depleting.

Based on the principles above a semi-commercial sealed chemical reactor had been designed similar to the schematics shown in Figure 2 with the capacity of 15 litres.

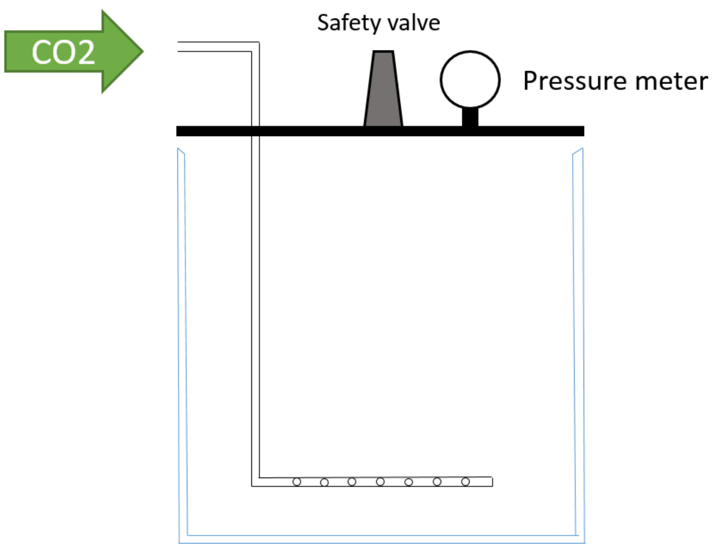

Figure 2 Schematic graph of the chemical reactor.

Experimental test design

The aim to this series of laboratory tests were to evaluate the absorption rate of the so-called concrete solution based on the chamber internal pressure. An initial CO_2 pressure of 100 KPa had been injected in the reactor first. The CO_2 inlet then had been closed and the readings from the pressure gauge were recorded in the time spans of every 15 minutes. The rationale behind this particular test design is to observe whether the reactor's internal pressure drops upon the development of the chemical reaction. If so, then it can be said that the CO_2 gas had been absorbed chemically and turned into a phase rather than gas. The following steps had been undertaken in order to produce the data:

1. Liquids are poured in the reactor
2. CO_2 capsule is attached.
3. The reactor's cap is then closed and sealed.
4. The outlet pressure gauge on the CO_2 capsule had been set to 100 KPa
5. Once the pressure meter on the cap had shown 100 KPa, the pressure regulator on the capsule had been closed to keep the CO_2 mass constant inside the reactor.
6. The records of the pressure gauge on the cap was read then.

References

[1] F. Sartipi, K. Palaskar, A. Ergin, and U. Rajakaruna, "Viable construction technology for habitation on Mars: Fused Deposition Modelling," *Journal of Construction Materials,* vol. 1, no. 2, 2020, doi: https://doi.org/10.36756/JCM.v1.2.2. Institute of Construction Materials.

[2] A. Henni, A. V. Rayer, K. Z. Sumon, T. Sema, R. Idem, and P. Tontiwachwuthikul, "Solubility of CO2 in reactive solvents for post-combustion CO2 capture," Future Medicine, 2013.

[3] K. Li *et al.*, "Reaction Enthalpy Conversion in Amine Based Post-Combustion CO 2 Capture," *Chemical Engineering Transactions,* vol. 69, pp. 139-144, 2018.

[4] Z. H. Liang *et al.*, "Recent progress and new developments in post-combustion carbon-capture technology with amine based solvents," *International Journal of Greenhouse Gas Control,* vol. 40, pp. 26-54, 2015.

[5] T. C. Merkel, H. Lin, X. Wei, and R. Baker, "Power plant post-combustion carbon dioxide capture: An opportunity for membranes," *Journal of membrane science,* vol. 359, no. 1-2, pp. 126-139, 2010.

[6] S. García, M. Gil, C. Martín, J. Pis, F. Rubiera, and C. Pevida, "Breakthrough adsorption study of a commercial activated carbon for pre-combustion CO2 capture," *Chemical Engineering Journal,* vol. 171, no. 2, pp. 549-556, 2011.

[7] D. Barker, S. Turner, P. Napier-Moore, M. Clark, and J. Davison, "CO2 capture in the cement industry," *Energy procedia,* vol. 1, no. 1, pp. 87-94, 2009.

[8] A. Bosoaga, O. Masek, and J. E. Oakey, "CO2 capture technologies for cement industry," *Energy procedia,* vol. 1, no. 1, pp. 133-140, 2009.

[9] T. C. Drage, J. M. Blackman, C. Pevida, and C. E. Snape, "Evaluation of activated carbon adsorbents for CO2 capture in gasification," *Energy & Fuels,* vol. 23, no. 5, pp. 2790-2796, 2009.

[10] O. Falk-Pedersen, M. S. Grønvold, P. Nøkleby, F. Bjerve, and H. F. Svendsen, "CO2 capture with membrane contactors," *International journal of green energy,* vol. 2, no. 2, pp. 157-165, 2005.

[11] J. D. Figueroa, T. Fout, S. Plasynski, H. McIlvried, and R. D. Srivastava, "Advances in CO2 capture technology—the US Department of Energy's Carbon Sequestration Program," *International journal of greenhouse gas control,* vol. 2, no. 1, pp. 9-20, 2008.

[12] M. T. Ho, G. W. Allinson, and D. E. Wiley, "Comparison of MEA capture cost for low CO2 emissions sources in Australia," *International Journal of Greenhouse Gas Control,* vol. 5, no. 1, pp. 49-60, 2011.

[13] C. Lu, H. Bai, B. Wu, F. Su, and J. F. Hwang, "Comparative study of CO2 capture by carbon nanotubes, activated carbons, and zeolites," *Energy & Fuels,* vol. 22, no. 5, pp. 3050-3056, 2008.

[14] P. Luis, "Use of monoethanolamine (MEA) for CO2 capture in a global scenario: Consequences and alternatives," *Desalination,* vol. 380, pp. 93-99, 2016.

[15] K. Vatopoulos and E. Tzimas, "Assessment of CO2 capture technologies in cement manufacturing process," *Journal of cleaner production,* vol. 32, pp. 251-261, 2012.
[16] N. Zhang, H. Duan, T. R. Miller, V. W. Tam, G. Liu, and J. Zuo, "Mitigation of carbon dioxide by accelerated sequestration in concrete debris," *Renewable and Sustainable Energy Reviews,* vol. 117, p. 109495, 2020.
[17] A. Todhunter, M. Crowley, M. Gholamisheverini, and F. Sartipi, "Advanced technological implementation of construction and demolition waste recycling," *Journal of Construction Materials,* vol. 1, no. 1, 2019, doi: https://doi.org/10.36756/JCM.v1.1.3.
[18] A. Todhunter, M. Crowley, and F. Sartipi, "Construction productivity indices in socialism compared with capitalism," *Journal of Construction Materials,* vol. 1, no. 1, 2019, doi: https://doi.org/10.36756/JCM.v1.1.2.
[19] F. Sartipi and A. Sartipi, "Recycling of coal mining slurry in concrete mortar," *Journal of Construction Materials,* vol. 1, no. 2, 2019, doi: https://doi.org/10.36756/JCM.v1.1.6.
[20] M. Gamil, A. Gharizadeh, and F. Sartipi, "A review on graphene reinforced cement composite: technical approach for ecofriendly construction," *Journal of Construction Materials,* vol. 1, no. 1, 2019, doi: https://doi.org/10.36756/JCM.v1.1.4. Institute of Construction Materials.
[21] F. Sartipi, A. Gharizadeh, and M. Gamil, "Electrical resistance of graphene reinforced cement paste," *Journal of Construction Materials,* vol. 1, no. 1, 2019, doi: https://doi.org/10.36756/JCM.v1.1.5. Institute of Construction Materials.
[22] V. W. Y. Tam, A. Butera, and K. N. Le, "Carbon-conditioned recycled aggregates in concrete production," *Journal of cleaner Production,* 2016.
[23] Z. B. Jian, P. C. Sun, and S. C. Jun, "Properties of Cement-based Construction Materials Prepared with Construction Waste and CO2 Curing."
[24] S.-C. Kou, B.-j. Zhan, and C.-S. Poon, "Use of a CO2 curing step to improve the properties of concrete prepared with recycled aggregates," *Cement and Concrete Composites,* vol. 45, pp. 22-28, 2014.
[25] A. Todhunter, M. Crowley, F. Sartipi, and K. Jegendran, "Use of the by-products of post-combustion carbon capture in concrete production: Australian case study," *Journal of Construction Materials,* vol. 1, no. 1, pp. 1-1, 2019, doi: https://doi.org/10.36756/JCM.v1.1.
[26] S. Y. Tang, R. A. Bourne, R. L. Smith, and M. Poliakoff, "The 24 principles of green engineering and green chemistry:“IMPROVEMENTS PRODUCTIVELY”," *Green Chemistry,* vol. 10, no. 3, pp. 268-269, 2008.
[27] D. Carro-López, B. González-Fonteboa, J. d. Brito, F. Martínez-Abella, I. González-Taboada, and P. Silva, "Study of the rheology of self-compacting concrete with fine recycled concrete aggregates," *construction and Buidling materials,* vol. 96, 2015.