CARBONDIOXIDE CAPTURE BY GREEN CONCRETE SLAB WITH MICROALGAE

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Abstract:

This paper presents a study on CO_2 capture by porous green concrete slab. CO_2imprint has been steadily increasing in the world we live in especially due to industrial sector. Among the varied CO_2 capture techniques, microalgae employment shows a better progress. This paper details about a construction-based CO_2 sequestration technique, where a green lightweight slab with microalgae can be employed as a prefabricated compound wall to sequester CO_2 from the atmosphere. It was found that porous geopolymer lightweight slab with microalgae had absorbed 30g of $CO_2$for 20 sq.m than the slab without microalgae. It was also proved that about 27g of algal biomass has been imbibed on the porous slab with microalgae and 14 g on non-porous slab. Microalgae employed as green wall gives a luscious bright green aesthetic look. It is one of the most promising strategies for reducing the carbon dioxide footprint in the atmosphere using microalgae. Thus, using this technique, CO_2sequestered can be a good way to reduce the global warming, thus illustrating the need for this study.

Keywords: lightweight geopolymer, microalgae, porous slab, aluminum powder, CO_2 sequestration

1. INTRODUCTION

As even the population keeps expanding and livelihoods rise, theworld's pollution also is constantly rising significantly. Since fossil fuels dominate the global energy landscape, CO_2 is responsible for more than half of all greenhouse gases' (GHGs') warming potential. Industrial sector majorly contributes to the CO_2 emissions. The idea of using microalgae for CO_2 sequestration will be an easier method. The photosynthesis technique that powers larger plants is used by microbes called microalgae to flourish in a liquid matrix [1]. Across every manner, it performs better than higher plants and marine algae. Land-based plants contribute 52% of the total CO_2 absorbed by the earth's biosphere, while ocean-based algae contributed 45% to 50% of that, which means that despite their small size, algae can absorb carbon-dioxide efficiently. They are also the chosen microorganisms because of their capacity for tolerating high CO_2 levels, poor lighting, ecological sustainability, and co-production of quality products. For the past couple of years, extensive research have demonstrated the necessity to determine whether microalgae growth techniques are feasible in order to reduce CO_2 footprint[2] [3] [4]. According to estimates, microalgae contribute over 50% of the oxygen in the atmosphere and use CO_2 to grow photo autotrophically [5]. Microalgae are the best option for CO_2 removal since they have significantly quicker levels of growth and CO_2 fixation than normal plants, farms, and organisms [11]. These microorganisms can absorb CO_2 with a 10 times greater efficiency than terrestrial ecosystems that use energy from the sun because of their energy-saving architecture. The two environments thought to be the most usual for growing phototrophic microalgae were open ponds and photo bioreactors [12]. This paper aims to provide a real-time application of the current state of micro algal CO_2 fixation, encompassing culture, and handling.

2. OBJECTIVE OF THE STUDY

- To identify the microalgae species that sequesters the CO_2.
- To develop a smart concrete matrix for microalgae growth on screed concrete for exposed areas of the building.
- To calculate the CO_2 absorption and effectiveness of the microalgae selected.
- To measure the amount of microalgae growth on the matrix.
- To compare the amount of growth on porous slab seeded with microalgae vs. non-porous slab.

3. RESEARCH SIGNIFICANCE

Industries contribute the most in CO_2 emissions. Cement is the second-most-consumed product globally after potable water. It is also a major contributor to global warming. Thus, we aimed to create a substrate medium for the microalgae to grow. A lightweight geopolymer porous concrete omitting the use of cement and aggregate was made. Previous studies have proved that microalgae’s role in carbon sequestration is commendable. Employing microalgae over the porous slab proves to be a good way to sequester CO_2 from the atmosphere. They can be deployed in an existing building or can be newly built using trained labour.

4. SCIENTIFIC IMPORTANCE

The amount of pollution in a country is influenced by CO_2 emissions. India is ranking third in terms of its contribution to the huge global CO_2 emissions in 2022 with 2,597.36 metric tons of CO_2 emissions. The use of microalgae in biomass conversion in PBRs is one of the strategies for CO_2 reduction that is widely studied.CO_2 sequestration is the need of the hour to minimize CO_2 footprint to a considerable scale, thereby contributing to a sustainable living environment.

5. METHODOLOGY

The proposed project was basically rooted on developing a smart concrete matrix of porous ability to accommodate maximum microalgae on it, aiding maximum CO_2 absorption. It in turn is an important tool to reduce global warming to a greater extent. Fig 1 explains the methodology of the work [8].

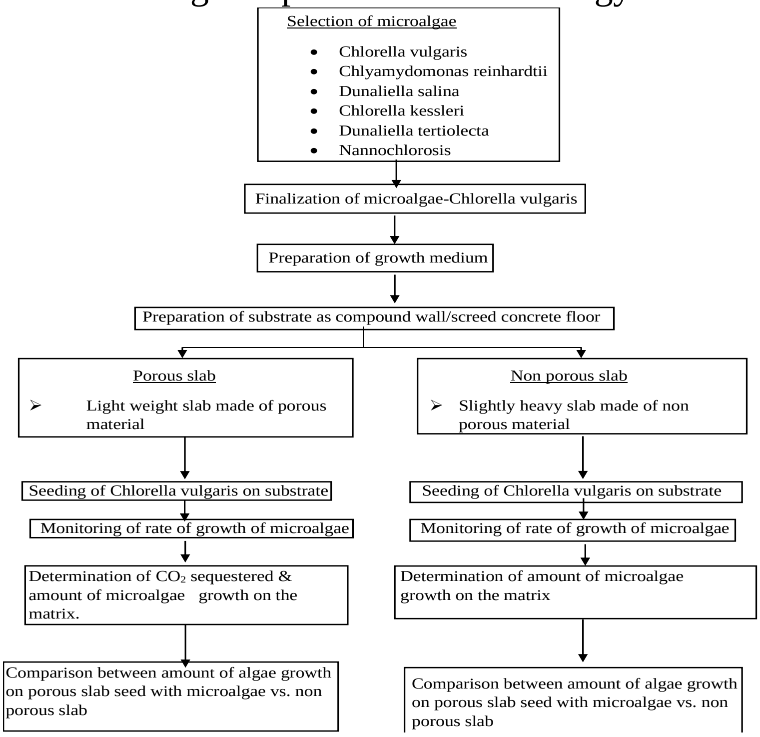


Fig 1. Methodology flowchart

6. METHOD

a. Selection and finalization of microalgae:

Six types of microalgae were identified by reviewing different literature. Based on their employability, optimized growth rates, etc, among the 6 microalgae identified and Chorella vulgar is was chosen to be a suitable micro alga for our project.

b. Preparation of growth medium:

Microalgae Chlorella vulgaris was identified in sewage treatment plant (STP), behind SRM Ramapuram campus, Chennai.

c. Preparation of substrate:

In geopolymerisation, alkaline solution plays an important role. Sodium hydroxide pellets were dissolved in distilled water to achieve the concentration of 8M. Alkali activator was prepared by mixing NaOH and Na_2SiO_3 solution at ratio of 2.5 as shown in figs2 and 3.

Fig 2: Na_2SiO_3 solution Fig 3: NaOH solution Fig 4: Al powder

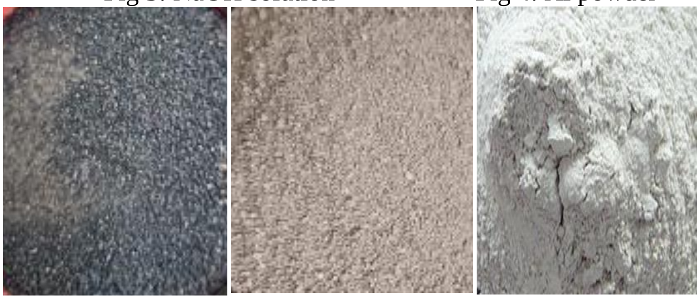


Fig 5: Dry mix materials (Copper Slag , Fly ash , GGBS)

In this study, fly ash produced from Ennore Power Plant, Tamil Nadu, India was used.Class F has been chosen as a base material to synthesize geopolymer in order to better utilize this industrial waste by-product material.The alkaline activator solution (AAS) and fly ash were mixed well together at ratio of 0.35. Distilled water was used for mixing. Copper slag was bought from Sterlite industries. We have used it as a replacement for fine aggregate. Ratio of fly ash to copper slag was 1:1.5. Aluminium powder is used to introduce voids in the geopolymer mix. The aluminium powder quickly reacts with the activator solution and releases hydrogen gas (bubbles) which is trapped in the slurry. A lightweight concrete is achieved. The aluminium powder is dissolved in distilled water as shown in fig 4.Ground granulated blast-furnace slag (GGBS) Makes the slab durable and strong. Equal parts of lime and GGBS are taken as shown in fig 5. Soap oil stabilizes the gas bubbles. Superplasticizers are used to attain higher workability and required flow ability of the fresh concrete, superplasticizer and a specified amount of water was used. Conptlast SP 430 was used. Table 1 depicts the mix design for the porous geopolymer concrete.

Table 1. Mix Design:

Flyash	1155 kg/m^3
Copper slag	840 kg/m^3
Flyash/copper slag ratio	1: 1.5
Na_2SiO_3/NaOH ratio [AAS]	2.5
Mass of alkaline liquid	405 kg/m^3
Mass of NaOH	115 kg/m^3
Mass of Na_2SiO_3	290 kg/m^3
AAS/flyash ratio	0.35
Distilled water	246.95g

d. Testing of geopolymer brick:

Testing of geopolymer light weight bricks were done for easy feasibility and confirming to IS Code 6441.Brick size of 200×100×100 mm was cast and tested. The same mix mortar will be used as a slab which can be used as a prefabricated compound wall sequestering CO_2 from the atmosphere.

Table 2.Bulk density, water absorption, and compressive strength test results

S.No	Weight of Brick (kg)	Weight of Wet brick (kg)	Moisture content	Bulk Density of Brick (kg/m^3)	Max.Load (kN)	Comp.Strength (kN/m^2) as per IS 6441 Part V
1	2.16	2.96	37.06	1091	67.40	3.96
2	1.89	2.42	15.79	960	87.50	4.38
3	1.78	2.36	31.84	927	66.70	3.92

RESULT: From the values obtained as shown in Table 2, the maximum compressive strength obtained is $4.38kN/m^2$, the maximum bulk density of the brick is 1091 kg/m^3 and the water absorption test showed the maximum value of 37.06.

e. Casting of specimen (Porous slab):

Slab mould of size 300×300×40mm was made. The concrete mixture was poured into the mould as shown in fig 6.After some time, the concrete rises up due to high porosity and subsides. The aluminium powder reacts to form air bubbles. It produces a very lightweight concrete.

Fig 6: Partial setting of concrete

After complete setting, the slab demoulded is kept for 3 days inside the oven at temperature at 100°C. Then the slab was transferred to a hot water bath at 100°C. The slab was kept for 3 days.

f. Casting of specimen (Non-porous slab):

Slab mould of size 300×300×40mm was made. The same mortar mix excluding the aluminium powder was made and was poured into be mould. Same curing process was followed and thereby the non-porous geopolymer slab was achieved as shown in fig 7.

Fig 7: Non-porous geopolymer slab

g. Seeding of Chlorella vulgaris on substrate:

i. Porous slab

Slab was cut into 9 cubes each of size 10×10×4 cm. Each cube was transferred into the tray and the microalgae were poured on top of the slab. STP water immersing the entire slab was ensured. In between days, the tray was refilled with STP final water, as shown in fig 8, ensuring that the slab was always covered. After 1 week, it was noted that the microalgae had covered the entire slab.

Fig 8: Seeding of microalgae on porous slab

ii. Non-Porous slab

Slab of size 300×300×40 mm was cast. Slab was transferred into the tray and the microalgae were poured on top of the slab. STP final water immersing the entire slab was ensured. In between days, the tray was refilled with STP final water, ensuring that the slab was always covered. After 1 week, it was noted that the microalgae had covered the entire slab as shown in fig 9.

Fig 9: Seeding of microalgae on non-porous slab

h. Monitoring of rate of growth of microalgae

i. Porous slab: Daily growth of microalgae on the cubes was inspected as shown in figs 10a–10d.

Fig 10a: Seeded day Fig 10b: Day 8 Fig 10c: Day 13 Fig 10d: Day 17

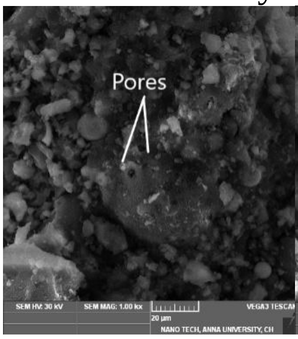
ii. **Non-Porous slab:** Comparatively slower growth of Chlorella vulgaris on the non-porous slab was noted. Day-wise pictures were recorded on visual inspection as shown in figs 11a–11d.

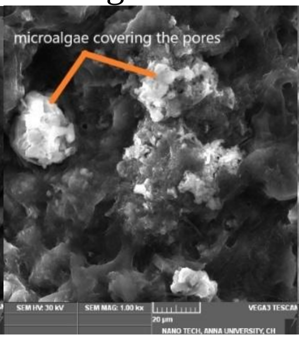



Fig 11a: Day 1 Fig 11b: Day 3 Fig 11c: Day 11 Fig 11d: Day 25

7. EXPERIMENTAL TESTINGS:

a. **Scanning Electron Microscope (SEM) Analysis of geopolymer slab without microalgae:** The microstructure of the concrete is analysed using SEM.





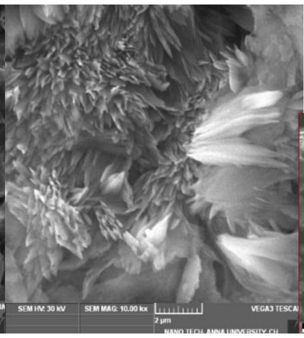
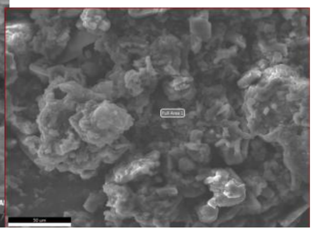



Fig 12a Fig 12b Fig 12c Fig 12d

The micro level analysis was studied on the samples using the instrumentVEGA3 TESCAN, which is equipped with both SEM and Energy Dispersive X-ray(EDX). To carry out a micro level analysis (SEM and EDX), the sample was collected by grounding the slab into fine crystals. Fig 12a describes the surface morphologies of the geopolymer concrete consisting of majorly of fly ash and copper slag. The aluminium powder has played an important role in creating pores inside the slab. The fly ash particles incross-section reveals a typical spherical morphology. The copper slag's SEM image (Fig. 12a) clearly demonstrates that the majority of its particles are 20 µm or smaller, and that under alkaline conditions, these particles are effectively involved in the geopolymerization process. The round-shaped particles denote ideal fly ash for concretein terms of workability [9]. Visible pores can be identified in fig 12a indicating the porosity of the geopolymer concrete slab.

b. **SEM EDX Analysis of geopolymer slab with microalgae:**

SEM and EDX analysis (as shown in figs12b and 12c) were performed to examine the microstructure and chemical composition of elements in slab with microalgae. In fig 12c, the flower petal shape components indicate massive growth of microalgae on the porous slab. Fig 12b indicated that microalgae have adhered well to the porous thereby revealing commendable growth of microalgae inside the porous slab.EDX is a method allowing elemental analysis of the sample. The quantity of O, C, Na were 50.44, 17.19 and 23.01 respectively. EDX spectra values measures in atomic and weight % as detailed in Table 3. As shown in figs12d and 12e, chromium and oxygen composition is evident by the peaks at 0.5 and 0.6 KeV. Amounts of sodium and carbon can also be noted at peak rise at 0.9 and 0.1 KeV respectively.

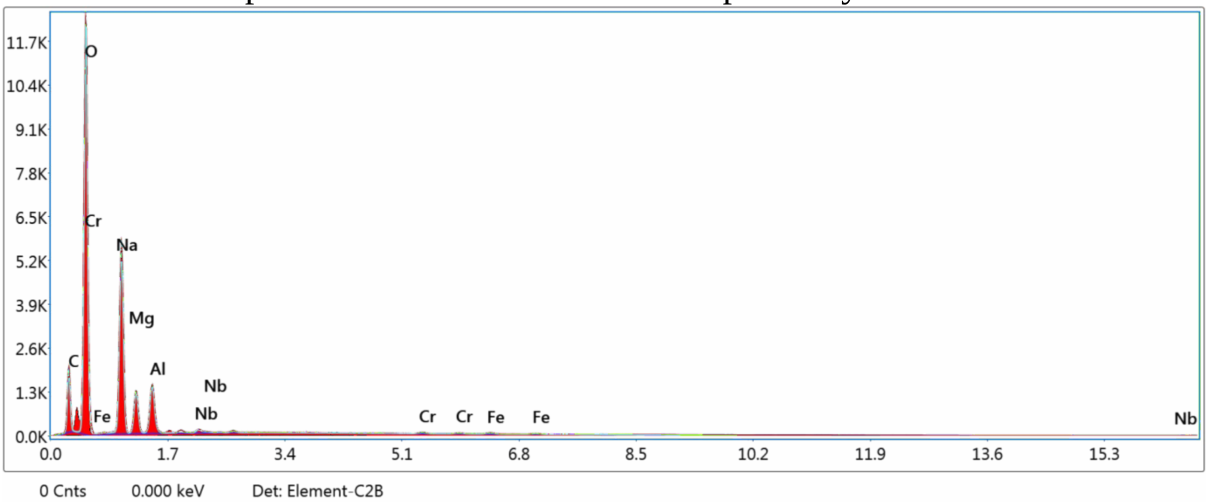


Fig 12e

Table 3: Smart Quant Results

Element	Weight%	Atomic %	Net Int.	Error %
C K	17.19	24.13	100.14	9.37
O K	50.44	53.16	775.90	7.95
NaK	23.01	16.88	395.85	8.23
MgK	4.47	3.10	94.78	9.55
AlK	4.05	2.53	113.76	8.45
NbL	0.44	0.08	9.57	15.02
CrK	0.17	0.06	5.43	24.31
FeK	0.23	0.07	6.23	25.36

c. Fourier transform infrared spectroscopy (FTIR)

FTIR analysis uses infrared radiation (IR) to adhere to samplings and examines the sample's absorbency of infrared light at different wavelengths to ascertain the molecular geometry and properties of the material. They identify the functional group of the materials. There are two regions (4000–2200 cm^{-1} and 2200–500 cm^{-1}) for the samples as shown in fig 13. In the region of 2200–400 cm^{-1}, well-resolved sharper bands were observed. The absorption peak at 3400 cm^{-1} shows a presence of water content in the porous geopolymer slab. The band between 900 and 1200 cm^{-1} is attributed to the asymmetric stretching vibration of Si-O-T bonds (T=Si or Al).The peak at 1013 cm^{-1} is assigned to the Al-O-H bending. The sharp absorption peak at 1565cm^{-1} confirms the carbonate group of vibrations in the slab. The observed twin peaks at 3092 cm^{-1} and 3144 cm^{-1} indicates the presence of C-H stretching mode of vibration. Vibration of O–H groups, and those between 1600 cm^{-1} and1650 cm^{-1} are associated with O–H bending. The band 1452 cm^{-1} was identified in the fly ash and GGBS is assigned to the symmetric stretching mode of O-C-O bonds of carbonate group subjected to superficial weathering of fly ash and GGBS during storage [6]. After alkali activation by NaOH solution [7], asymmetric stretching vibration of Si-O-T bonds (T=Si or Al) shift to lower frequencies (997 cm^{-1}).

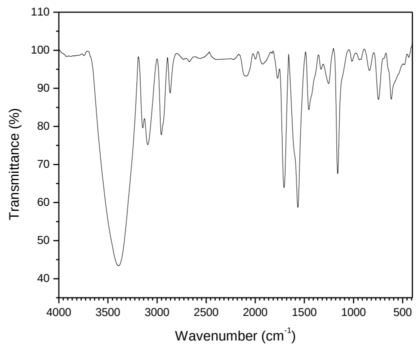


Fig 13:FTIR spectra of porous slab with microalgae

d. THERMOGRAVIMETRY/DIFFERENTIAL THERMAL ANALYSIS (TG/DTA):

The thermal behaviour of the porous geopolymer slab with microalgae is obtained. It can be seen from the fig 14 that TG1 = 125 °C and TG2 = 150°C. Main transactions occur in these two regions only. Heating the pan with 6.218g of the sample, water molecules are removed and major weight loss of 15% occurs at TG1. One of the components evaporates and when the temperature is further increased, after attainingTG2, weight loss becomes very less and material moves to a crystalline state.

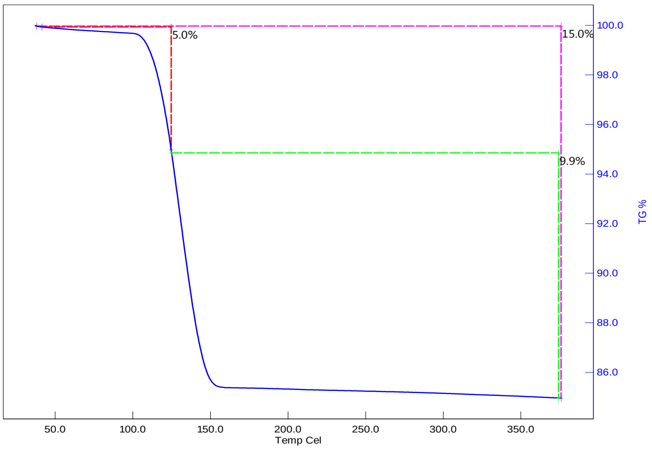


Fig 14.TGA curves of the specimen

e. DRY WEIGHT OF BIOMASS

Fig 15a. Porous slab

Fig 15b. Microalgae from non-porous slab

Under this test, the amount of algae growth on the slab is determined. In fig 15a, the microalgae grown on porous slab are scrapped using a brush as shown. Then it is kept in a dish, weighed and kept inside the oven for 1 hour. The dish with microalgae is then weighed. The same procedure was undertaken for non-porous slab as well depicted in fig 15b. Table 4 indicates the results obtained.

Table 4: Comparison between amount of microalgae on porous slab seeded with microalgae vs. non-porous slab

Porous slab		
Sl. No	Description	Weight (g)
1.	Weight of empty dish	40
2.	Weight to dish + microalgae	80
3.	Weight of dish + microalgae after oven curing	67
Non-porous slab		
1.	Weight of empty dish	40
2.	Weight to dish + microalgae	66
3.	Weight of dish + microalgae after oven curing	54

RESULT: It is found that porous geopolymer slab consists of more algal mass and more water removal than the non-porous slab. About 27g of algal biomass has been grown on the porous slab with microalgae and 14 g on non-porous slab.

f. CO_2 ABSORPTION TEST

Fig 16. Experimental setup

Fig 17a: Before carbonation

Fig 17b:After carbonation

CO_2 absorption test is undertaken using a chamber attached with CO_2 cylinder and pump as shown in fig 16. The goal of this test is to identify the amount of CO_2 absorbed by porous geopolymer slab with and without microalgae. Figs 17a and 17b show the slab after and before carbonation and Table 5 shows the results of weights. Comparison between amount of CO_2 absorbed by porous slab seeded with microalgae vs. porous slab without microalgae is done and the graph is plotted as shown in fig 18.Pressure absorption at varied time intervals in CO_2 chamber is depicted in Table 6.

Table 5: Indication of weight of slabs after and before carbonation

Sl.No	Description	Weight before carbonation (g)	Weight after carbonation (g)
1.	Weight of slab without microalgae	270 (wetted)	260
2.	Weight of slab with microalgae	300	330

Table 6: Pressure absorption at varied time intervals in CO_2 chamber

SL.NO	**Time (Hr.min)**	**Pressure absorbed (kg/cm^2)**
1.	9.45	3
2.	10.10	2.7
3.	10.20	2.5
4.	10.30	2
5.	10.45	1.9
6.	11.00	1.5

7.	11.30	1.3
8.	11.45	1
9.	12.15	0.9
10.	12.30	0.9
11.	12.45	0.8
12.	1.00	0.6
13.	1.30	0.4
14.	1.45	0
15.	2.00	0

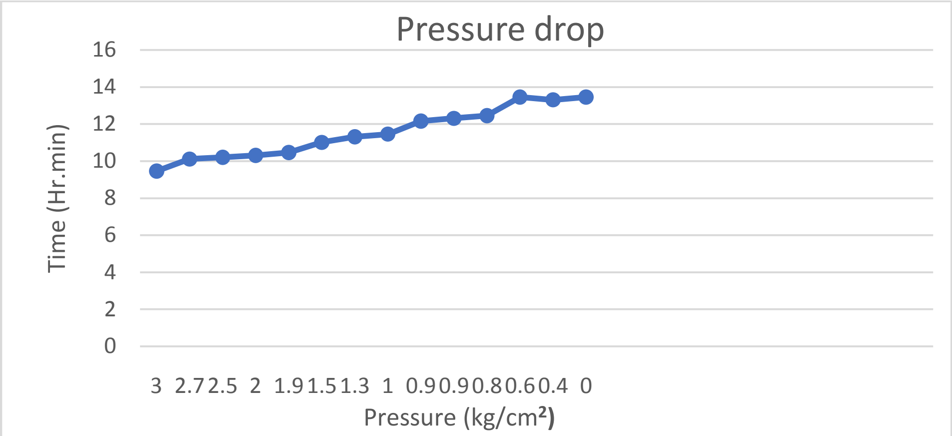


Fig 18. CO_2 absorption curve

RESULT: It is concluded that porous geopolymer slab with microalgae had absorbed 30g of CO_2 than the slab without microalgaeTherefore, about 21.21% CO_2 is absorbed by the slab with microalgae. This thereby confirms that microalgae are best in CO_2 sequestration.

8. DISCUSSION

From our study, it was found that after seeding of microalgae on the slab, there was commendable growth in the 1^{st} week. Progressing to 2.5 weeks, there was full growth of microalgae covering the entire slab. After achieving maximum growth/over growth condition, the microalgae can be scrapped from the surface and growth happens again in the next week. They have anearthy, musty, and potent smelling. According to a study, 4000 m^3 microalgae in open ponds may absorb up to 2.2 k tonnes of CO_2 annually when exposed to natural sunlight [3].It was also stated in another study that 4047 sq.mof algae can remove up to 2.7 tons per day of CO_2.It was found that porous geopolymer lightweight slab with microalgae had absorbed 180g per day of CO_2 for 20 sq.m. The geopolymer lightweight porous slab with microalgae can sequester approx. 6570 kg/cm^2 of CO_2 per year. Carbon capture is a successful method for removing CO_2 from the air, decarbonizing industries, and facilitating the creation of sustainable fossil fuels. These days, carbon sequestration is essential to solve the climate change challenge. It is now a successful strategy for reducing climate catastrophe and/or global warming. This has also evolved into a sustainable technology.

CONCLUSION

- Biological CO_2 capture through fast-growing microalgae from point sources is one of the critical aspects that can ultimately help sequester CO_2 and, hence, ameliorate global warming.
- Our study found that sewage/STP water is very effective for the fast growth of microalgae.
- CO_2absorption improves the environmental footprint and reduces CO_2 emission in industrial buildings, industrial processes, and large urban infrastructures.
- Our goal of achieving microalgal growth inside the pores of the geopolymer slab was achieved.
- Microalgae Chlorella vulgaris was finalized for enhanced growth over the substrate.
- SEM analysis proved that the microalgae were embedded inside the porous of the slab which will aid better CO_2 sequestration.
- Comparison between amount of microalgae on porous slab seeded with microalgae vs. non-porous slab proved that porous slab contains comparatively more algal mass than the non-porous slab due to better integration.
- In future, the porous geopolymer slab can be integrated as a prefabricated compound wall where $CO_2$from the atmosphere is sequestrated, thereby providing a healthy and safe environment and reducing the harmful GHG.
- There is a strong potential for future development of algae-integrated buildings, predominantly reducing a large amount of CO_2 emissions, thereby potentially improving the performance of buildings and also the environment we live in.

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