

EXPERIMENTAL INVESTIGATIONS OF PHYSICAL ADSORPTION OF CARBON DIOXIDE BY ACTIVATED CARBON AS ADSORBENTS- A REVIEW

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Abstract

This paper reviews different types of carbonaceous adsorbents used for CO₂ capture by physical adsorption. Adsorption is a preferable method due to less energy penalty than absorption process. Paper mainly focuses on carbonaceous adsorbents which include activated carbon (AC), activated carbon fiber's (ACFs) and graphene adsorbent materials. Operating parameters were discussed and experimental investigations for high CO₂ capture capabilities were stated. Performance parameters such as CO₂ uptake, adsorbent surface modification methods, adsorption/regeneration kinetics were discussed. A comprehensive study on carbonaceous adsorbents have been made to update progress in area of CO₂ capture. Future research to maximize CO₂ capturing using carbonaceous adsorbents is suggested.

Keywords: CO₂ capture; carbonaceous; physical adsorption; activated carbon;

Nomenclature

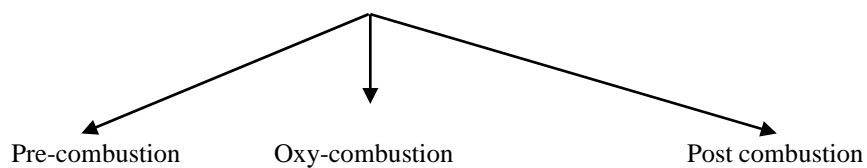
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|--------------------|--|-----------------|------------------------------|
| $T_{g\text{feed}}$ | Flue gas feed temperature | acronyms | |
| $P_{f\text{feed}}$ | flue gas feed temperature | AC | Activated carbon |
| C_{out} | CO ₂ concentration at outlet | BET | Brunauer-Emmett-Teller |
| C_{feed} | CO ₂ concentration in feed stream | NaOH | Sodium hydroxide |
| mmole | millimole | PSA | Pressure swing adsorption |
| g | grams | TSA | Temperature swing adsorption |
| KJ/mole | kilojoule per mole | ACFs | Activated carbon fibers |
| mg | milligram | CNT | Carbon nano tube |
| lpm | liters per minute | GO | Graphene oxide |

1. Introduction

Global warming is the result of increasing greenhouse gases, CO₂ is the major contributor, level in the environment making it a very serious issue for the environmentalist [1][2] (Mondal, Balsora et al. 2012, Lee and Park 2015). Usage of fossil fuels is the influencing source to satisfy energy demand all over the world. Fossil fuel used for energy generation contributes

approximately 40% of CO₂ emissions [3] (Yang, Xu et al. 2008). Use of fossil fuels may go for several coming years more even if several other ecofriendly energy producing technologies are emerging. This scenario has created necessity to develop technologies which will be efficient and economical to capture CO₂ gas from the environment [4] (Rubin and De Coninck 2005). CO₂ is the major contributor, about 64%, to enhance greenhouse effect [5] (Change 1990). Due to concern of greenhouse effect it is need of an hour to develop technologies for reducing level of CO₂ in environment for which carbon capture and storage (CCS) is the main technology to reduce CO₂ level. This paper briefly reviews the experimental investigations for CO₂ capture using carbonaceous materials used as adsorbents and focuses on providing a current understanding of the experimental work done so far with the use of carbonaceous adsorbent materials. CO₂ capture technology mainly includes physical and chemical absorption, adsorption, cryogenic and membrane process [1] (Mondal, Balsora et al. 2012).

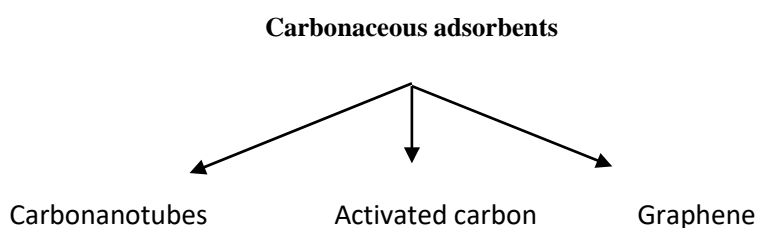
Classification of carbon capture technologies [6] (Herzog 2009)



2. Carbonaceous adsorbents

Using carbonaceous adsorbents has various benefits like high chemical and physical stability, good heat transfer, physical strength and bio-affinities [7][8][9] (Pinto, Goncalves et al. 2013, Rondeau-Gagné and Morin 2014, Zhang, Aboagye et al. 2014). These adsorbents are very effective for adsorbing gases, they are light weight as well as have more specific surface area and porosity [10][11] (Lee and Park 2010, Gupta and Saleh 2013). Carbonaceous adsorbents have varieties like activated carbon having good porosity, molecular carbon sieve, carbon nano tubes and graphene. They are very economical to procure and can be made available from natural resources [12] (Abd, Naji et al. 2020).

3. Physical adsorption by using carbonaceous materials

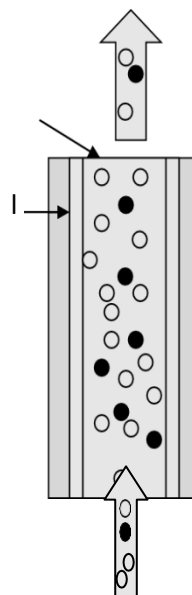


From several reviews on CO₂ capture by adsorption indicates that amount of CO₂ may be reduced from source like flue gases by using carbonaceous adsorbents such as activated carbon, carbon nanotubes, grapheme [13][12](Songolzadeh, Ravanchi et al. 2012, Abd, Naji et al. 2020). Physical adsorption is advantageous as it is easy for regeneration /desorption of adsorbent material by pressure swing adsorption(PSA) or temperature swing adsorption(TSA)[13](Songolzadeh, Ravanchi et al. 2012), making it an economical process due reduced energy requirement for post combustion carbon capture due to absence of bonding between the sorbate and sorbent[14][13](Ben-Mansour, Habibetal. 2016)(Songolzadeh, Ravanchi et al. 2012). On the other side some adsorbents like activated carbon have low carbon dioxide(CO₂) and nitrogen (N₂) selectivity[15](Li, Ma et al. 2011). In most of the experiments carried out for CO₂ capture selective separation of CO₂ molecules on gas solid influence is involved[16](Balsamo, Budinova et al. 2013). Development of suitable adsorbent material with high affinity towards CO₂ molecules is a very important in investigating the better results on CO₂ adsorption[14](Ben-Mansour, Habib et al. 2016).

Various laboratory scale experiments conducted on physical adsorption by researchers by using a stream of feed gases (mostly mixture of CO₂ and N₂). As a result of intermolecular attraction between feed gases and adsorbents physical adsorption takes place. This physical adsorption depends upon various influencing operating parameters such as temperature, partial pressure, porosity of adsorbing material[17](Meisen and Shuai 1997).

During laboratory scale experiments, column is filled with adsorbents and a mixture of gases (comprising mostly CO₂ and N₂) is passed through this column. Due to affinity towards CO₂ molecules, it gets adhere on surface of adsorbing material till surface area of adsorbents gets saturated i.e no surface area is available for deposition of CO₂ gas molecules. Further regeneration process of adsorbent has to be carried out for further cycles of experiment. Fig 1 shows adsorption mechanism.

1. Fig 1-Schematics of adsorption carbon capture process in a cylindrical bed[14](Ben-Mansour, Habib et al. 2016)



4. Carbonaceous materials for physical adsorption

Overview: Due to easy availability, cheap in cost and good thermal stability it is established that carbonaceous materials are preferred over available adsorbents for CO₂ adsorption. These are carbon based material having better properties like affinity towards carbon dioxide molecules, chemical and thermal stability, heat conduction and strength[18][19](Lozano-Castelló, Cazorla-Amorós et al.2002, Bilalis, Katsigiannopoulos et al. 2014). Various forms of carbonaceous adsorbents are available cheaply like porous activated carbon, charcoal coal, molecular carbon sieve, carbon nano tubes and graphene having high specific surface area, high porosity and light weight. Due to its low cost, high

surface area, wide availability, easy surface fictionalization and easy surface desorption process these carbonaceous material can be used as CO₂ adsorbents[20](Younas, Sohail et al. 2016). Activated carbon and charcoal, due to its high porosity, is capable of capturing CO₂ up to 10 to 15% by weight. Therefore it is suitable in the case when CO₂ purity is below 90% because of low selectivity towards CO₂/N₂[21][22](Radosz, Hu et al. 2008, Levesque and Lamari2009).

Physical adsorption and chemical adsorption are the main CO₂ adsorption processes. Physical adsorption is the common phenomenon and due to weak vander waals forces, binding force between adsorbent and adsorbate can be broken by thermal means[23](Su, Lu et al. 2009). Rise in temperature above 50⁰C decreases CO₂ adsorption capacity significantly. Therefore ambient temperature is more suitable for adsorption [24](de Andrés, Orjales et al. 2013). Adsorption capacity is important parameter in determining quantity of adsorbent material required and deciding dimensions of adsorption column of experimental set up. Better efficiency of adsorption results in reduced adsorbent requirement and compact experimental set up. Process of adsorption is considered as best technology, when adsorption attains a CO₂ loading within range of 3-4mmol/g of adsorbing material[25](Gray, Champagne et al. 2008). Selectivity and adsorption/desorption kinetics are also important factors responsible for achieving more efficiency of adsorption by adsorbents. CO₂ adsorption kinetics mass transfer through the surface of adsorbent depends upon porosity of adsorbent as well as functional group on the surface of adsorbent material[12](Abd, Naji et al.2020). Another important and necessary criterion for cheap operational cost is the regeneration/desorption capacity of adsorbent for which heat of adsorption for energy requirement calculation is required. In case of physical adsorption heat of adsorption ranges from -25 to -50 kJ/mol and in chemical adsorption it is -60 to -90 kJ/mol[26](Samanta, Zhao et al. 2012).

5.Experimental investigations on activated carbon (AC) as adsorbent material-

Activated carbon (AC) is suitable because of its capability of giving desired performance at atmospheric pressure and ambient temperature. Due to activated carbon (AC) particles characteristics like large specific surface area and small low- volume pores it has been widely accepted as potential adsorbent. Activated carbon (AC) is hydrophobic in nature due to which moisture removal process can be avoided before lab scale experimentation on adsorption. Activated carbon (AC) has great affinity towards CO₂ molecules and ease in regeneration of adsorbent at a temperature lower than 373 K. Activated carbon (AC) has high resistivity to acidic and alkali conditions, high porosity, enhance adsorption process and gas diffusion as well. Activated carbon (AC) are easy to modify in its surface chemistry and physiochemical characteristics through modification methods[27](Mukherjee, Okolie et al. 2019). Some

reviewed experimental work by using activated carbon is tabulated in table 1.

(Raganati, Ammendola et al. 2014) conducted CO₂ adsorption experiments with sound assisted fluidized bed using activated carbon (AC) as adsorbent material. An activated carbon DARGO FGD (NORIT) has been investigated at ambient pressure and temperature. Operating conditions of the adsorption experiment like fluidization velocity (0.1, 0.25, 0.5, 0.75, 1, 1.5, 2 cm/s), CO₂ inlet concentration (5, 10, 15 % vol in N₂), sound pressure level (120, 125, 135, 140 dB) and frequency (20, 50, 80, 120, 300 Hz) were varied to test adsorption capacity. Pressure drops and bed expansion curves were analyzed with application of sound and without sound conditions along with optimum range of frequency for high fluidization.

Absorption test were performed with and without sound assistance to evaluate effect of sound pressure level adsorption capacity for CO₂. Comparative analysis is done in terms of breakthrough curves, moles of CO₂ adsorbed (n_{ads}), breakthrough time (t_b), the fraction of bed utilized at breakpoint (W) [28].

(Raganati, Chirone et al. 2020) in further research work tested activated (AC) carbon as CO₂ adsorbent, with and without sound assistance fluidization. Study on sound assisted fluidized bed temperature swing adsorption cycle by modifying through heating and purging strategy were carried out. Adsorption/desorption temperature (25⁰-150⁰C) and CO₂ partial pressure (0.05-0.2 atm) were experimented and its effects was evaluated. It was observed that by application of heating and purging strategy to a fluidization by sound assistance results in recovery of CO₂ up to 80%. This research work concluded that working capacity of CO₂ during temperature swing adsorption processes is affected by operating temperature and partial pressure of CO₂ [29].

(Huang, Cheng et al. 2015) prepared a high-quality activated carbon (AC) from coconut shell. Experimental investigations were done by varying parameters like activation temperature and time to study basic characteristics of activated carbon such as charcoal yielding, ash, Brunauer-Emmett-Teller specific surface area, pore volume. Increase in activation temperature and time increases the ash content and reduced ash content respectively. Activation done at 100⁰C for 120 minutes gains highest BET specific surface area (824 m²/g) and total pore volume (0.502 ml/g). Analysis shows that coconut shell activated carbon has more adsorption capacity in comparison to commercial activated carbon [30].

(Karbalaie Mohammad, Ghaemi et al. 2020) in his research work make use of activated carbon modified by using hydroxide solution (concentration range of 10-40%) for CO₂ adsorption. For experimentation temperature range of 20⁰- 80⁰C and pressure range between 2 bars -10 bars were kept for investigating kinetics, isotherms and CO₂ adsorption thermodynamics involved. To see the optimal results of CO₂ pressure and temperature on CO₂ adsorption capacity, response surface methodology technique is applied. Optimum results on adsorption capacity (104.32 mg/g) were obtained for 30% NaOH concentration at 20⁰ temperature and 6 bars. The Sips model for CO₂ adsorption isotherms is found to be best. Kinetic study shows that pseudo-second-order model best fitted for experimental data. Thermodynamic parameters indicates that CO₂ adsorption process is exothermic in nature [31].

(Al Mesfer, Danish et al.) experimented CO₂ adsorption process by using activated carbon as adsorbent material ranging from 0.4 cm to 0.8 cm in size. Best results were obtained at on a set feed rate of $6.67 \times 10^{-5} \text{ m}^3/\text{sec}$ and with a carbon dioxide concentration of 0.05 (wt.fraction). Finding observed that breakthrough times depends upon temperature and feed rate. Maximal breakthrough time and saturation times of 870sec and 1050 sec were observed. Results were compared with silica gel as adsorbent material. Breakthrough time and saturation times have been compared between activated carbon and silica gel. With increased feed rates ($8.33 \times 10^{-5} \text{ m}^3/\text{sec}$), maximum capacity of 39.14 g CO₂/kg were achieved. It was found that due to greater sorption capacity and better characteristics parameters activated carbon is more economical option for CO₂/N₂ gases mixture [32].

(Das, Behera et al. 2019) developed four stage counters current multistage fluidized bed adsorber to capture CO₂ from flue gas. Monoethanoamine impregnated activated carbon (coconut shell based) used as adsorbent and optimum operating parameters were described which are responsible for CO₂ removal efficiency. Optimization using response surface methodology along with central composite design (CCD) is used to find out relation between three operating variables (CO₂ inlet concentration ranging from 3000ppm to 20000ppm, impregnation ratio ranging from 0.2 to 0.6 and weir/bed height in range 20mm to 60mm) with four stages of fluidized bed column (0.21 m height per stage and 0.095m internal diameter) were fixed together with flange joint. Regression model equation is developed through design expert software. Results after optimization found to be for CO₂ concentration (7312ppm), impregnation ratio (0.31), weir/bed height of 48.65mm and CO₂ removal efficiency of 95.17%. With same operating condition experimental CO₂ removal efficiency was found to be 95.97%, thus found to be in agreement with predicted operating conditions [33].

(Al-Ghurabi, Ajbar et al. 2018) conducted experiment considering four cases of mixing in different proportions of external group B particles in fluidized bed containing activated carbon (500g). The amount of external group B particles added were in proportion of free weight basis 0, 5, 10 and 30% weight. Results of fluidization hydrodynamics due to addition of external particles were studied and shows better quality of fluidization, thus better CO₂ removal efficiency. 10% by weight showed better results over 5% and 30% by weight mixing. On the other hand, poor quality of fluidization was observed with 5% by weight sand mixing [34].

(Dantas, Amorim et al. 2009) used commercial activated carbon and nitrogen enriched activated carbon by mixing 10g of activated carbon in 500mL of 10^{-1} M 3-chloropropylamine hydrochloride solution as adsorbent material. Some chemical and physical factors were identified that influence CO₂ adsorption capacity. His work concluded that nitrogen enrichment blocked some pores of activated carbon due to which only the large pores is filled by CO₂ resulting in decreased CO₂ adsorption and increased adsorption rate [35].

(Casas, Schell et al. 2012) performed experimentation in a fixed bed packed with adsorbent (commercial activated carbon) with mixture of CO₂/H₂ gas as feed mixture. Different temperature (25°C, 45°C, 65°C and 100°C) and pressures (1bar, 5 bar, 10 bar, 15 bar, 20 bar, 25 bar, 35 bar) were set for conducting experiments. Adsorption phenomenon of CO₂/H₂ mixture

were analyzed focusing on number of important features having impact on capacity of adsorption in continuous process (PSA or TSA) for separating CO₂ and H₂. Mathematical model has been developed for checking accuracy level depending on operating conditions. Research work done consider it as better, as such no adjustment was done on the adsorption isotherms after measuring them in an independent manner in a gravimetric set-up [36].

(Rashidi, Yusup et al. 2014) developed economical and efficient activated carbon (coconut based) with single stage activation process making it porous. Due to predominantly micro porosity activated carbon help in CO₂ gas adsorption. Experiment was carried out at temperatures (25^oC, 50^oC, 100^oC) using adsorbate purified carbon dioxide and mixture of binary gases. Experimental result shows that due to less surface area and micro pore volume, lower CO₂ adsorption capacity on optimized activated carbon occurs. Lower adsorption capacity attributes to reduced CO₂ partial pressure in case of mixture of gases. Kinetic studies were carried out for purified CO₂ adsorption by activated carbon and it results in dominant physisorption mechanism indicating the magnitude of activation energy lesser than 25 kJ mol⁻¹. Further concluded that gas adsorptive behavior gets reduced at high temperatures [37].

(Danish, Parthasarthy et al. 2021) carried adsorption test using silica gel and date pits-based activated carbon synthesized using tubular furnace by physical activation. Rise in temperature is kept at 10^oC/min carbonization of biomass and N₂ flow is monitored continuously for 2h around 600^oC. Important parameters like dependence of temperature, feed flow and initial CO₂ level on the breakthrough and exhaustion periods were varied with operating parameters. Comparison between carbon produced from date and silica gel clearly shows that exhaustion and breakthrough spans were longer for carbon produced from dates. Maximal CO₂ adsorption of 73.1 mg/g was achieved at 5 lpm of feed gas at temperature of 298 K and CO₂ proportion of 5% in feed gases. [38]

(Ibrahim and Al-Meshragi 2019) conducted CO₂ adsorption test on activated carbon produced from olive trees in fixed bed apparatus. In order to investigate kinetic and thermodynamic parameters, adsorption and breakthrough curves were determined at various temperatures (30^oC, 50^oC, 70^oC and 90^oC). Experimental result shows that the CO₂ adsorption on olive tree activated carbon depicts physisorption behavior and adsorption capacity decreases as temperature increases. Maximum CO₂ sorption capacity on activated carbon ranged from 109.5 mg CO₂ /g to 35.46 mg CO₂ /g and from 129.65 mg CO₂ /g to 35.55 mg CO₂ /g. of activated carbon for initial concentrations of 10% and 13.725 % vol respectively. [39]

(Al-Janabi, Vakili et al. 2018) conducted combined experimental and numerical study of CO₂/N₂ adsorption in fixed bed with three different adsorbents one of which is bulk activated carbon. Effect of adsorbable gas (CO₂) inlet concentration on CO₂ breakthrough curves were studied by varying N₂ flow rate based on a constant CO₂ flow rate of 5 cm³/min to avoid fast saturation of adsorption bed by CO₂. Experiment with different adsorbents was conducted at constant temperature of 50^oC. His work further concluded that percentage shift in breakthrough curve is practically independent of adsorbent used or total flow rate. His work is helpful in predicting the performance of materials under flow conditions. [40]

(Zulkurnai, Ali et al. 2017) prepared activated carbon using sea mango functionalized with

deep eutectic solvent DES which is a compose of choline and glycerol. Impregnation with DES ratio for preparation of activated carbon was kept at 1:2 precursor -to- activate ratio. The results show optimum CO₂ adsorption capacity of the activated carbon by using CO₂ gas treatment method (9.851 mgCO₂/gsol), followed by the absence of gases (9.685 mgCO₂/gsol), steam (9.636 mgCO₂/gsol), and N₂ (9.536 mgCO₂/gsol). Experimental investigation reveals about higher CO₂ adsorption capacity of DES- functionalized activated carbon than non-functionalized activated carbon despite reduction in surface area of functionalized activated carbon about 50% than non- functionalized activated carbon. Elemental N on the surface of the activated carbon plays a significant role in CO₂ adsorption.[41]

(Boonpoke, Chiarakorn et al. 2012) synthesizes collected sugar bagasse, washed to remove dust and oven dried (378K for 24 h) to make activated carbon. Activated carbon was activated by ZnCl₂ maintaining weight ratio of bagasse to ZnCl₂ of 1:1 at ambient temperature for 1h. Surface modification was done on a bagasse based activated carbon by three different amines: Polyethylenimine (PEI), monoethylenimine (MEI) and aniline (ANL) with loading ratio of 5%, 25% and 50% of weight. Desirable characteristics like high carbon content, high surface area and porosity were obtained on this synthesized activated carbon. High CO₂ adsorption efficiency was observed decreasing with rise in temperature but keeping temperature above 323K and a concentration of CO₂ lower than 30% v/v., bagasse based activated carbon modified with PEI at 5 and 25% weight results in higher adsorption capacity.[42]

(Dantas, Luna et al. 2011) conducted study on fixed bed adsorption of carbon dioxide with CO₂/N₂ mixture on activated carbon (NORIT R2030). Experimentation was done at various temperatures and adsorption dynamics were analyzed for different effect caused by N₂ adsorption and desorption. Breakthrough curves were obtained at these temperature (301K-306K, 323K, 373K and 423K) with CO₂/N₂ mixtures. Study of adsorption kinetics of CO₂ and N₂ were carried out by fitting linear driving force (LDF) based model taking into account energy and momentum balance.[43]

| Source of activated carbon | Surface area (m ² /g) | Pore volume (cm ³ /g) | Pore diameter | | Gas composition | Temperature | Ref |
|--|--|-----------------------------------|---|--|--|------------------------------|-----|
| DARGO FGD (NORIT) | 1060 | - | <2nm | 0.31(mmol/g) ordinary condition 0.37(mmol/g) (sound assisted) | 5% CO ₂ in N ₂ 10% CO ₂ in N ₂ 15% CO ₂ in N ₂ | Ambient | 28 |
| Activated carbon (coconut shell) | 824 | 0.502 | 30 mesh | 14.40 mg/L | 100% CO ₂ | Ambient | 30 |
| Activated carbon modified by sodium hydroxide solution | 483.91 | 0.2744 | 2.2678nm | 104.319 mg/g | 100% CO ₂ | 20°C -80°C | 31 |
| Commercial activated carbon | 858 | 0.425 | 0.4 -0.8 cm | 39.14 g CO ₂ /Kg sorbent | 0.05 (vol. %) | 298K | 32 |
| Amine impregnated activated carbon | 572.27 | 0.259 | 100 mesh | - | 3000 ppm to 20,000 ppm | Ambient | 33 |
| Activated carbon with mixed external particle of Geldart group B classification | 941.51 | 0.22973 | 1.7–300.0 nm | Better with mixed external particle of Geldart group B classification | 0–2 SLPM for N ₂ 0–200 CCPM for CO ₂ | Ambient | 34 |
| Nitrogen-Enriched Activated Carbon | 1053.0 | 0.0972 | 0.0038 m | | 10% and 20% CO ₂ in helium | 301K,323 K, 373 K, and 423K. | 35 |
| Commercial activated carbon | 8.5 × 10 ⁸ [m ² /m ³] Specific surface area | - | 0.003m | higher with lowering temperature | CO ₂ /H ₂ mixtures (25%/75%, 50%/50% and 75%/25%) | 25 °C, 45 °C, 65 °C and 100 | 36 |
| Activated carbon(agriculture residue) | 370.71(optimized) 717.22 (commercial) | 0.15 optimized 0.29 commercial | 1.63nm (optimized) 1.64nm (commercial) | 1.79 mmol /g (optimized) | 20 % CO ₂ and 80 % nitrogen (N ₂) | 25 °C, 50 °C, 100 °C | 37 |
| Activated carbon (date pits based) | 848.3 | 0.45 | 2.26nm | 73.1 mg/g | CO ₂ /N ₂ | 20 °C, 25 °C, 40 °C | 38 |
| Activated carbon(from olive trees) | 602 | 0.61 | 5mm | 109.5 to 35.46 and from 129.65 to 35.55 mg CO ₂ /g | 10 and 13.725% vol., | 30°C, 50°C, 70°C, and 90°C | 39 |
| Bulk Activated carbon(sigma Aldrich) | - | - | 0.15mm | 0.242mmol/g | 15–25% CO ₂ in CO ₂ /N ₂ mixtures | 50°C | 40 |
| Activated carbon(sea mango based) | 882.71 | 0.4696 | - | by using CO ₂ gas treatment method (9.851 mgCO ₂ /gsol), | 15% CO ₂ in N ₂ | ambient | 41 |

| | | | | | | | |
|--|------------------------|--------|----------|-------------|---|-----------------------------|----|
| Bagasse-based activated carbon | 923.39 | 0.5330 | 2.01nm | 0.20 mmol/g | <30% CO ₂ v/v | 323K | 42 |
| Commercial activated carbon (NORIT R2030) | 1053 m ² /g | - | 0.0038 m | - | 10% CO ₂ /N ₂ v/v | 301–306, 323, 373 and 423 K | 43 |

Table 1- Reviewed physically and chemically activated carbon dioxide adsorption

6. Conclusion

Physical adsorption of carbon dioxide using carbonaceous adsorbent is efficient due to less energy requirement for desorption process as compared to other capturing technologies. This paper concludes about state of knowledge about physical adsorption by carbonaceous adsorbents for CO₂ capture. Modification by functionalization of adsorbent material enhances CO₂ adsorption process. Other activated carbon materials like activated carbon fibres and graphene due to high porosity are promising for CO₂ capture. Properties like high thermal stability, mechanical strength, high CO₂ selectivity, low preparation cost of adsorbent material and high resistance to moisture are the main criteria for comparison with other adsorbent materials. Compared with other materials carbonaceous material possess high stability and are cheaper. Influential operating parameters like temperature and pressure has greater effect on physical adsorption. With the rise in temperature, adsorption capacity gets reduced. To overcome this difficulty efforts are required towards modification of carbonaceous material by suitable activation of adsorbent material. Research regarding preparation of low cost, sustainable and easy to regenerate/recycle carbonaceous material should be carried out. Eco friendly raw material for producing adsorbent should be focused. There is scope of research for CO₂ capture by using ACF and graphene.

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