



Cerium impregnated palm shell activated carbon (Ce/PSAC) sorbent for simultaneous removal of SO₂ and NO—Process study

S. Sumathi, S. Bhatia, K.T. Lee, A.R. Mohamed*

School of Chemical Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia

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ABSTRACT

The simultaneous removal of SO₂ and NO from simulated flue gas by cerium oxide supported over palm shell activated carbon (Ce/PSAC) was studied in a fixed bed adsorber. The effects of adsorber temperature, presence of humidity, feed gas concentration and space velocity were studied as the process parameter. The results were illustrated as sorption breakthrough curves. From the experimental results, it was found that at higher space velocity, the SO₂ and NO sorption capacity was reduced. Humidity enhanced the SO₂ sorption capacity but deterred the NO sorption at percentage more than 15%. Temperature played an important role in the simultaneous removal of SO₂ and NO by cerium supported over PSAC. The maximum simultaneous sorption capacity of SO₂ and NO was achieved at temperature 150 °C with 121.7 and 3.5 mg/g, respectively. This study shows that cheap biomass based activated carbon can be a potential sorbent for simultaneous removal of SO₂ and NO from flue gas.

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1. Introduction

The acidification of land and water through air pollution has received extra attention in recent years due to its growing threat to human health and nature. One of the prominent contributors of air pollution is fuel combustion process with stationary and mobile sources. The most widespread and dangerous outputs of this process are oxides of nitrogen (NO_x) and oxides of sulfur (SO_x) [1]. There are a number of technologies available to remove these gaseous pollutants. The literatures show that calcium based flue gas desulfurization, selective catalytic reduction (SCR) by NH₃ and CuO/Al₂O₃-based catalysts are the most effective technologies for SO₂ or NO removal [2–5]. However in order to lower the capital cost of equipment and operating cost, it is desirable to remove SO₂ and NO simultaneously in a single unit with a cheap sorbent. One of the good choices is via activated carbon (AC).

There are many types of AC prepared from various carbonaceous materials and impregnated with a variety of additives. Some of these AC have been used to remove NO_x and SO_x simultaneously. Researchers reported that metal oxides supported over AC have drawn interest because it could do the job simultaneously in a single step process. Many types of metal oxides have been studied, including Fe, Mn, Ca, V, Cu and Cr oxides in comparison to AC alone but so far none have reported on cerium (Ce) [6–13].

Currently interests are growing in the use of low-cost and abundantly available lignocellulosic material as the precursor for the preparation of AC. One alike is palm shell activated carbon (PSAC) made from oil palm fruit waste, *i.e.* palm shell which is abundantly available from the palm oil processing mills in Malaysia [14]. Palm shell based AC with and without impregnation have been used to remove SO₂ [15–18], however none have reported on NO removal or simultaneous removal of NO and SO₂.

In the present work, the potential of PSAC as a modified (impregnated with cerium oxide) sorbent was tested for its possibility in sorbing both SO₂ and NO gas simultaneously from a simulated flue gas at different process operating conditions.

2. Experimental

2.1. Preparation of sorbent

The PSAC was first prepared by thermal charring of the palm shell. Then it is followed by a physical activation using CO₂ gas at temperature 1100 °C. Details of the preparation method are reported elsewhere [17]. Prior to the impregnation process, PSAC was sieved to a size of 1 mm. The PSAC was subjected to pore volume impregnation by cerium nitrate. First, the PSAC was impregnated with cerium nitrate (Ce(NO₃)₃·6H₂O) of an appropriate concentration to obtain around 10 wt% of metal content per gram of PSAC (10 ml of 10 wt% metal solution/gram of PSAC). In this study cerium nitrate from Fluka was used as the metal precursor. During the impregnation, the solution of metal nitrate was continuously mixed with PSAC for 5 h. Then the samples were heated

* Corresponding author. Tel.: +60 45996410; fax: +60 45941013.

E-mail addresses: chrahman@eng.usm.my, sumesethu@yahoo.com (A.R. Mohamed).

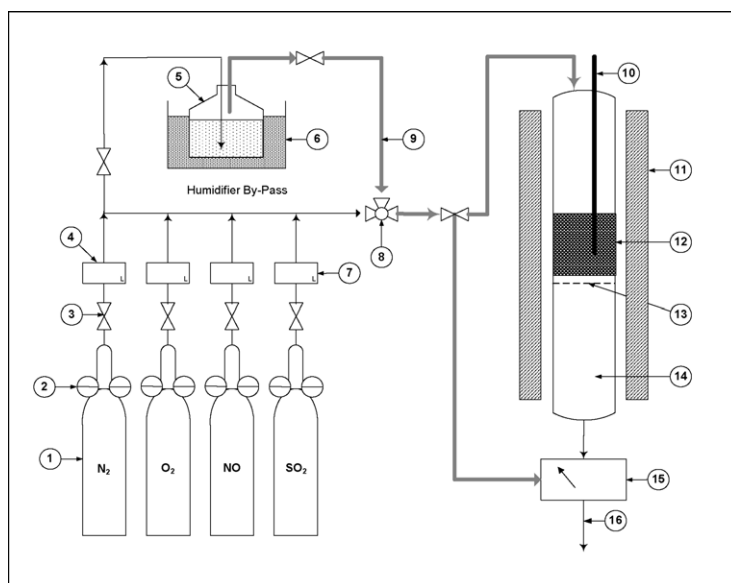


Fig. 1. Schematic diagram of the experimental setup for SO₂ and NO simultaneous sorption study: (1) gas cylinder, (2) pressure regulator, (3) pinch valve, (4) mass flow controller (Aalborg AFC), (5) humidifier, (6) water bath, (7) mass flow controller (Brooks Instrument), (8) three-way valve, (9) insulated pipeline, (10) thermocouple, (11) vertical tubular furnace, (12) sorbent sample, (13) glass wool, (14) stainless steel adsorber, (15) flue gas analyzer and (16) vent.

to 70 °C while being constantly stirred until the liquid was totally evaporated. After that the samples were dried in an oven at 110 °C for a period of 12 h. Finally, the prepared samples were heat-treated at 400 °C for 4 h in the presence of argon to form the reduced sorbents in oxide form. The selection of 10 wt% concentration of cerium was based on our preliminary study reported elsewhere [19]. Ce/PSAC denotes a sample impregnated with 10 wt% of cerium nitrate which has been calcined.

2.2. Activity test

The simultaneous removal activity of the prepared sorbent was carried out in a fixed bed adsorber. The schematic diagram is shown in Fig. 1. The prepared Ce/PSAC sorbent (1.0 g) was placed on borosilicate glass wool (0.05 g) in the center of the adsorber. A stream of gaseous mixture representing the simulated flue gas, containing SO₂ (2000 ppm) (50%), NO (500 ppm) (11%), O₂ (10%), and N₂ (29%) as the balance, was passed through the prepared sorbents. Water will added into the system as relative humidity to study the effect of humidity in the system. The feed flow through the adsorber was controlled at 150 ml/min. The inlet and outlet concentrations of SO₂ and NO were measured using a wall-mounted flue gas analyzer (IMR5000/400) before and after the sorption activity. Concentrations of SO₂ and NO were recorded continuously for every minute until the breakthrough point was achieved.

The activity of the sorbent towards SO₂ and NO was expressed by SO₂ and NO sorption capacity, which is defined by the breakthrough curves (C/C_0 versus t). C/C_0 is a dimensionless factor, where C is the outlet concentration of SO₂ and NO (ppm) from the adsorber, C_0 is the initial concentration of SO₂ and NO (ppm) and t is the sorption time (min). Each and every experimental run was repeated at least three times to increase the precision of the results, and only the average value was reported throughout this study. The repeatability was found to be sufficiently high with relative error less than 5%.

The effects of various process operating conditions on the simultaneous removal of SO₂ and NO were studied by varying the following parameters:

(i) relative humidity (RH) from 0% to 60%,

- (ii) feed concentration of SO₂ from 500 to 2500 ppm,
- (iii) feed concentration of NO from 100 to 700 ppm,
- (iv) gas hourly space velocity (GHSV) from 14,000 to 36,000 h⁻¹ and
- (v) adsorber temperature ranging from 100 to 300 °C.

3. Results and discussion

From the preliminary study which was reported earlier in the literature [17], it was concluded that without the addition of metal oxide onto PSAC, PSAC could only sorb SO₂ successfully. PSAC could not remove NO or SO₂ and NO simultaneously. Impregnation with different types of metal oxides over PSAC was proven able to remove SO₂ and NO simultaneously [18]. It was found that PSAC impregnated with 10 wt% of CeO₂ gave the best simultaneous removal of SO₂ and NO [19]. Hence, in this study to further understand the simultaneous removal of SO₂ and NO over Ce/PSAC, an assessment was done by varying the various process operating conditions.

3.1. Effect of relative humidity (RH)

Water vapor is an inevitable component in the industrial flue gas. Furthermore it was reported that water vapor plays a major role in the sorption of sorbents with SO₂ or NO. The effect of water vapor onto the removal of SO₂ and NO was investigated in term of relative humidity (RH). The experiments were carried out using four different percentages of RH, i.e. 15%, 30%, 45% and 60%. The other operating conditions were kept unchanged, i.e. an adsorber temperature of 100 °C and feed gas containing 2000 ppm SO₂, 500 ppm NO, 10% O₂ and balance N₂ with total gas flow rate of 150 ml/min and the GHSV was 14,116 h⁻¹.

Figs. 2 and 3 show the effect of RH on simultaneous removal of SO₂ and NO over Ce/PSAC in the form of breakthrough curves. Fig. 4 shows the sorption capacity of SO₂ and NO based on different percentage of RH. From these figures, it was observed that the sorption of SO₂ increased when low percentage of water vapor was added into the simulated flue gas, i.e. from 15% to 30%. For NO it was noticed that at 15% of RH, the removal was almost similar to the dry condition and at higher percentage of RH the removal was deterred. It can be seen that when the sorption was carried out

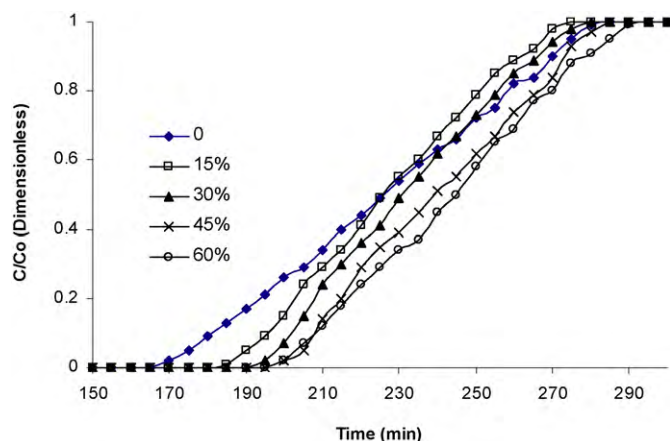


Fig. 2. Effect of relative humidity (RH) on SO₂ sorption breakthrough.

under dry condition (0% RH), the 100% removal time for SO₂ and NO was 165 and 115 min, respectively. Whereas when 15% of RH was added to the process, the 100% removal time for SO₂ and NO was 185 and 120 min, respectively.

When water vapor was added from 0% to 30%, 100% removal time of the sorbent increased significantly from 165 to 190 min for SO₂. The sorption capacity also increased with increasing RH from 115.8 mg/g to 131.5 mg/g. A similar report was presented by

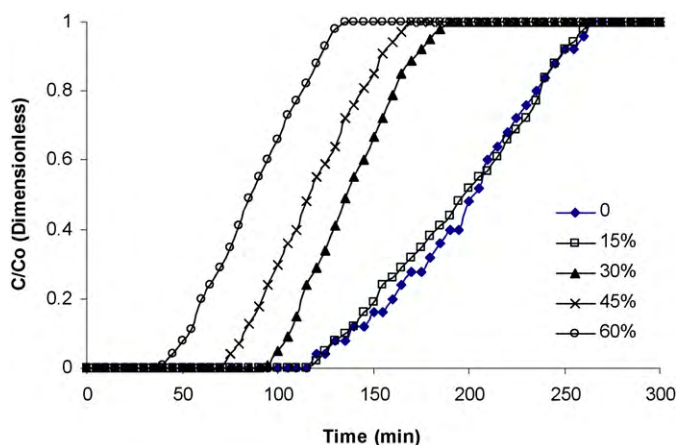


Fig. 3. Effect of relative humidity (RH) on NO sorption breakthrough.

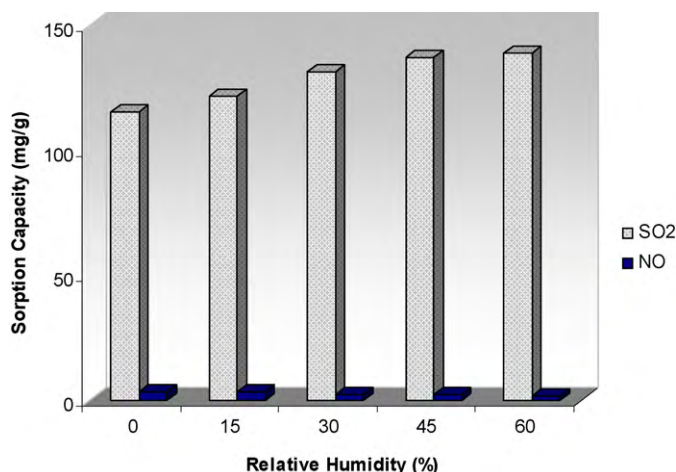
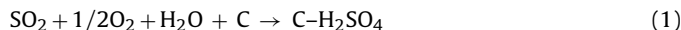


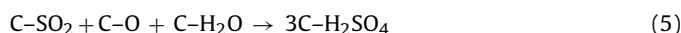
Fig. 4. Effect of relative humidity (RH) on SO₂ and NO sorption capacity.

[20,21] over calcium based adsorbent, with SO₂ sorption increased with the addition of water vapor into the simulated flue gas [20,21]. Moreover water accumulating on the surface and interior pore of sorbent forms a liquid film which could make the reaction gas (SO₂), more easily absorbed by the sorbent rather than gas-solid reaction [22].

It is known that AC has a great potential of adsorbing O₂, SO₂ and H₂O onto its carbon surface [23]. SO₂ molecules adsorbed onto the sorbent surface will combine with the water vapor to form SO₂·H₂O. This SO₂·H₂O may then dissociate to H⁺, HSO₃⁻, and SO₃²⁻, and these ions subsequently react with O₂ to form H₂SO₄. Normally the adsorbed O₂ is used to oxidize the adsorbed SO₂ to SO₃ and in the presence of water molecules the SO₃ gas easily forms H₂SO₄. The overall reaction is presented as



Most studies are sought to maximize the SO₂ removal capabilities of a carbon only, and assume a mechanism for SO₂ adsorption and conversion to H₂SO₄. In the literature, it is concluded that the following reaction sequence occurs before any SO₂ removal by carbon begins [23]:



It implies that SO₂, O₂, and H₂O are all adsorbed on the surface of carbon in close enough proximity and in the proper steric configuration to react and form H₂SO₄. A pH test was done on the samples after sorption of SO₂ and NO and it was found the sample was highly acidic with pH ranging from 3.5 to 4.0. The original PSAC sample gave a pH reading of from 6.0 to 6.5 and Ce/PSAC samples from 5.7 to 6.3. It was observed that further increase in RH from 45% to 60% did not show significant increase as shown in 15–30% for SO₂. This could be due to the accumulation of water vapor as well as the by-product (H₂SO₄) into the pores of Ce/PSAC. This occurrence inhibits additional adsorption of SO₂.

On the other hand, unlike SO₂ sorption it was observed in Fig. 3, the addition of water vapor into the simulated flue gas hindered the sorption of NO. It was observed that when RH was present more than 15% in the simulated flue gas, the breakthrough time maintaining 100% NO removal reduced from 120 min at 15% RH to 90 min at 30% RH. Fig. 4 shows that at RH 60%, 100% removal time was only about 35 min and the recorded sorption capacity was 1.7 mg/g compared to 0% RH, which were about 115 min and 3.2 mg/g correspondingly. In other words, NO sorption capacity becomes lower as more water vapor was introduced into the process. One of the key reasons for this observation is because NO has a low solubility molecule in water. A similar finding was reported for AC impregnated with V₂O₅ [24], whereby in this work it was suggested that pore blockage was due to the by-products produced (ammonium-sulfate salts) during the reaction and the main reason for the unfavorable removal of NO at higher percentage of RH. Another similar finding reported a trend for NO removal with calcium based sorbent, and found the possible reason as surface-catalyzed [20]. Therefore it can be concluded that when more water than necessary was on the sorbent surface, the water will foul the surface reaction.

At RH of 15% and less, the sorption of NO would still occur due to the role played by O₂ gas in the simulated flue gas. A related article reported the same observation for RH less than 20% [20]. Furthermore, O₂ gas enables the necessary two-step process before NO was converted to acid [25]. On a system of H₂O–O₂–NO–C, adsorption, reduction and catalytic oxidation of NO happened simultaneously,

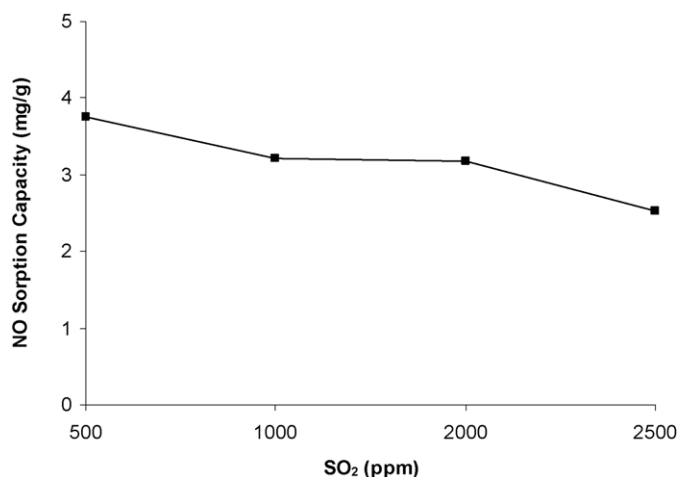
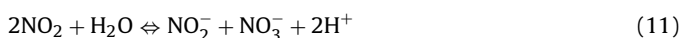
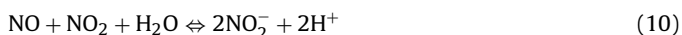
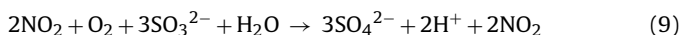
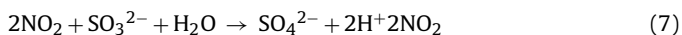
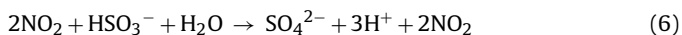


Fig. 5. Effect of SO₂ feed concentration on NO sorption capacity.

which explained why NO removal was still satisfying at low percentage of RH [26]. When both O₂ and NO are present in the gas phase, the tendency of approach to the equilibrium of the O₂/NO/NO₂ system raises the concentration of NO₂ in the gas phase to a higher value. As NO₂ is a much stronger oxidant and more soluble in water than NO and O₂, there are more NO₂ molecules present in the water layer, and oxidation of HSO₃⁻ and SO₃²⁻ to SO₄²⁻ is enhanced, which induces more SO₂ molecules to be captured into the humid layer [21]. The reactions that take place in the humid layer involving NO₂ can be represented by the following equations:



15% of RH was used in the simulated flue gas system for further experiments. This was chosen based on the results obtained. With the presence of 15% RH, the overall SO₂ removal was enhanced without disturbing the simultaneous removal of NO.

3.2. Effect of SO₂ and NO feed concentration

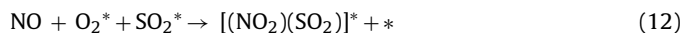
In order to investigate the effect of interactions between NO and SO₂ during the simultaneous removal, a particular experiment was conducted, whereby one gas (NO/SO₂) concentration was fixed and the other gas (NO/SO₂) concentration was varied in the feed stream. Experiments were conducted in which the SO₂ was fixed at 2000 ppm and the NO concentration was varied from 100 to 700 ppm. Then NO was fixed at 500 ppm and the SO₂ concentration was varied from 500 to 2500 ppm. The other conditions of the experiments were fixed as, 10% O₂, 15% RH, balance N₂ operating temperature of 100 °C and a total flow rate of 150 ml/min.

Figs. 5 and 6 show the results for the effect of feed concentration of NO and SO₂ over Ce/PSAC. It is indicated in Fig. 6 that small amount of NO in the feed could improve the Ce/PSAC capacity for SO₂. The same phenomenon was observed for NO when a small amount of SO₂ was introduced into the feed and vice versa, Fig. 5. By reducing SO₂ feed in the system, NO will have a larger active surface site on Ce/PSAC to reduce and oxidize. Furthermore by reducing the NO feed in the system SO₂ will have more space to adsorb onto the active sites of Ce/PSAC. At higher amounts of SO₂ or NO, i.e. 2500

and 700 ppm, respectively, the sorbent capacity for SO₂ or NO was definitely reduced. These results proved that there was a competitive sorption between NO and SO₂ over the active sites of Ce/PSAC. According to the traditional adsorption theory, SO₂ would be more easily adsorbed by the activated carbon than would NO because the boiling point of SO₂ is higher than that of NO [27]. Furthermore it is known for the previous study that PSAC could easily adsorb SO₂ without the help of metal oxide [17]. Consequently, the physically adsorbed NO could be replaced and desorbed by SO₂, and there would be no effect on SO₂ adsorption.

Higher feed concentration of NO, strongly decreases the removal capacity of Ce/PSAC for SO₂ as shown in Fig. 6. From the previous study, it was found that cerium oxide could oxidize NO to NO₂ and reduce NO to N₂ [28]. Hence for NO, cerium oxide is the core material which helped NO removal in the simultaneous removal of SO₂ and NO by Ce/PSAC. Higher concentrations of NO compared to SO₂ in the feed means that NO will be more favored catalytically bonded on the Ce/PSAC active sites. As a result, it reduces the active sites for SO₂ removal catalytically. The mechanism of adsorption of NO and on the Ce/PSAC active sites is quite complicated, which is still under investigation.

A comparable research was reported using AC modified with KOH and NaOH [27]. In their report, the mechanism took place on the active site during the adsorption is written as



An asterisk is equally to the active sites of Ce/PSAC. Gas molecules with asterisk stands for adsorbed molecules on the active sites. This mechanism indicated that SO₂ and NO themselves exist in interaction during the adsorption process, which could enhance each others adsorption ability. Eq. (12) presents this reaction. This was precisely consistent with the present experimental results, whereby when low concentration of NO was used, it enhanced the SO₂ adsorption and vice versa. The reason of why more amounts of SO₂ in the feed could decrease the adsorption ability of NO by Ce/PSAC can be explained by Eq. (13), whereby increasing SO₂ onto the active sites of Ce/PSAC, it would strongly desorb the NO from the active sites and restrain NO sorption from the active sites of Ce/PSAC. This phenomenon could happen easily because the adsorber temperature was low, i.e. 100 °C. If the temperature was higher, then the active sites of Ce/PSAC might have behaved differently for both SO₂ and NO.

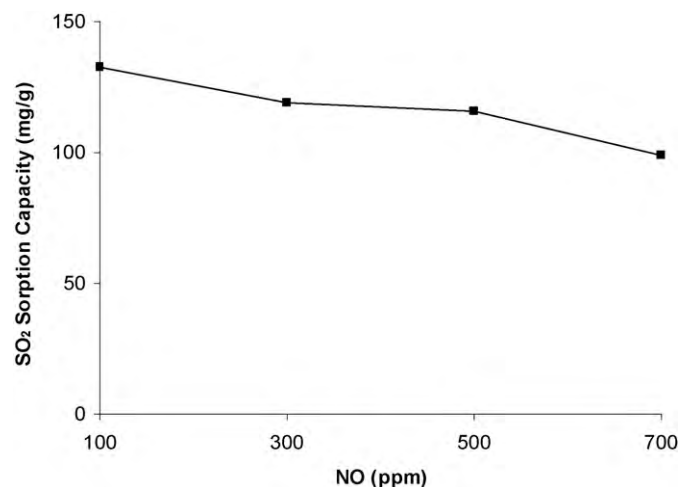


Fig. 6. Effect of NO feed concentration on SO₂ sorption capacity.

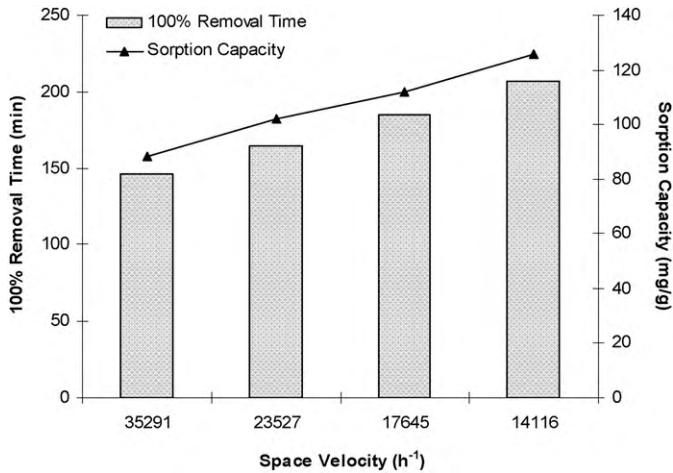


Fig. 7. Effect of gas hourly space velocity (GHSV) on SO_2 sorption capacity and breakthrough time.

3.3. Effect of gas hourly space velocity (GHSV)

The contact time between sorbent and flue gas is an important factor in determining the overall sorption capacity of the sorbent. This study was helpful to avoid any plugging during the sorption process and also to accommodate high flow rates. The amount of reference sorbent was changed from 0.5 to 1.25 g before it was subjected to simulated flue gas under the fixed conditions of 2000 ppm SO_2 , 500 ppm NO, 10% O_2 , 15% RH, balance N_2 and with a total flow rate of 150 ml/min at a temperature of 100 °C. The corresponding GHSV was calculated approximately from 14,116 to 35,291 h^{-1} .

Figs. 7 and 8 show the results of breakthrough curves for both SO_2 and NO sorptions at different GHSV over Ce/PSAC. It was observed that with increasing GHSV over the reference sorbent, the breakthrough time of sorbent to sorb 100% of SO_2 and NO decreased. For SO_2 sorption, the breakthrough time decreased from 200 to 150 min as the GHSV increased from 14,116 to 35,291 h^{-1} . A similar trend was also observed for NO whereby the breakthrough time decreased from 130 to 80 min as the GHSV increased from 14,116 to 35,291 h^{-1} .

Both Figs. 7 and 8 show that sorption capacities is inter-related with breakthrough time. As the GHSV increased, the sorption capacity of Ce/PSAC towards SO_2 and NO was decreased. At higher GHSV, the decrease in sorption capacity is due to inadequate contact time or space between the simulated flue gas and the sorbent.

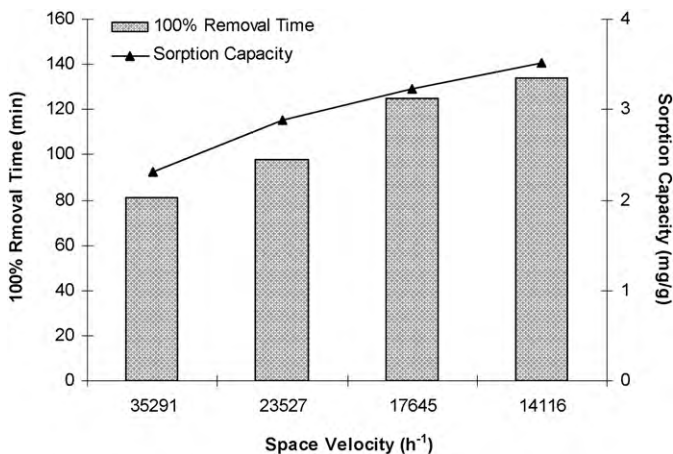


Fig. 8. Effect of gas hourly space velocity (GHSV) on NO sorption capacity and breakthrough time.

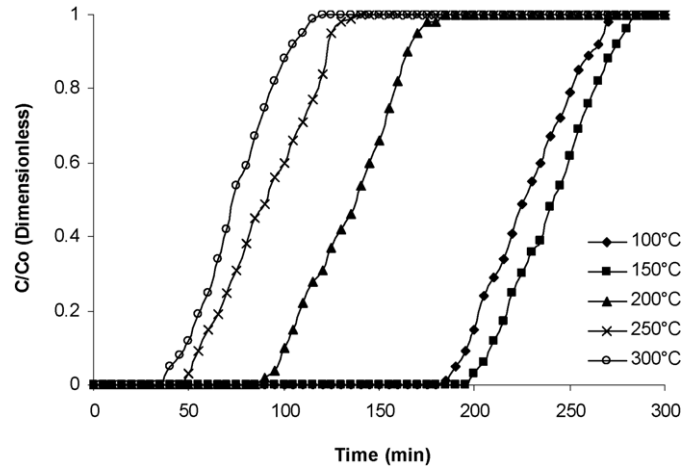


Fig. 9. SO_2 removal at different operating temperature.

High GHSV will create a state with insufficient amount of active sites to accommodate the high flux of simulated flue gas. This phenomena is generally reported by a number of researchers [12,27] and considered to be correct and common.

3.4. Effect of adsorber temperature

Temperature has a significant role on the overall simultaneous removal of SO_2 and NO processes. In this study the operating temperature of the simulated flue gas system was aimed to be in the range of 100–300 °C. This is because the temperature of flue gaseous in the industrial stack burners varies from 120 to 250 °C. All this while throughout the study a temperature of 100 °C was employed and proved to be sufficient for simultaneous removal of both gases. To further determine the effect of operating temperature on SO_2 and NO removal sorption capacities, experiments were carried out by varying the adsorber temperature from 100 to 300 °C while maintaining the simulated flue gases at fixed conditions of 2000 ppm SO_2 , 500 ppm NO, 10% O_2 , 15% RH, balance N_2 and with a total flow rate of 150 ml/min.

Figs. 9 and 10 illustrate the experimental breakthrough curves obtained under different temperatures over Ce/PSAC. It was observed from Fig. 9 for SO_2 adsorption, as the operating temperature increased from 100 to 150 °C, the breakthrough time of SO_2 was slightly increased from 180 to 195 min. Increment in operating temperature could enhance the chemical reaction rate and ionic

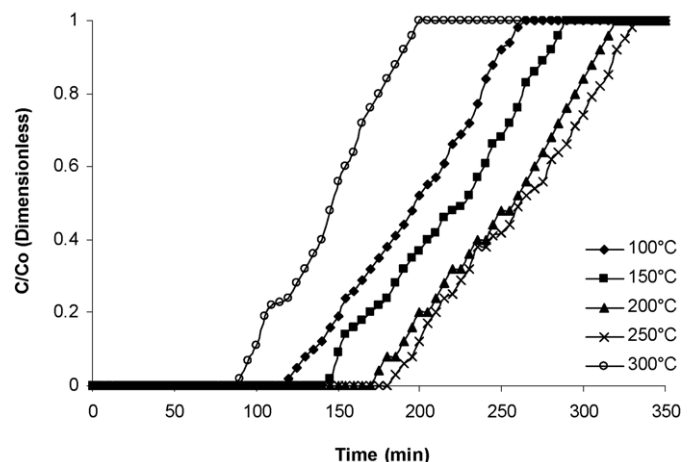


Fig. 10. NO removal at different operating temperature.

Table 1
Sorption capacity of SO₂ and NO by PSAC-Ce at different temperature.

Temp (°C)	100% Removal time (min)		Breakthrough time (min)		Sorption capacity (mg pollutant/g PSAC-Ce)	
	SO ₂	NO	SO ₂	NO	SO ₂	NO
100	180	115	285	275	115.83	3.17
150	195	140	295	300	121.72	3.46
200	85	170	195	330	76.56	3.81
250	45	180	160	345	62.82	3.98
300	35	85	130	210	51.04	2.42

diffusion rate of SO₂ [20]. Hence in this case at temperature 150 °C, SO₂ had higher ionic diffusion rate into the pores of Ce/PSAC. At higher temperature, cerium possessed high oxygen mobility [29], thus at 150 °C, SO₂ could be easily oxidized to SO₃ and this indirectly gave a higher breakthrough time.

However when the temperature was further increased from 200 to 300 °C, the SO₂ sorption was decreased. The reported breakthrough time at 300 °C was only 35 min. This could be due to kinetic energy of SO₂. It is known that at higher temperature SO₂ molecules lose their kinetic energies, thus making the adsorption an exothermic process [16]. This condition indirectly lessens the amount of SO₂ adsorbed into the pores of Ce/PSAC. Furthermore higher temperature would reduce the water accumulation and gas dissolution on the sorbent surface. Hence the SO₂ sorption due to water molecules was reduced at temperature above 200 °C.

On the contrary, in the case of NO as shown in Fig. 10, the sorption of NO was very favorable at higher temperature compared to the lower one. At temperature above 150–250 °C, the NO breakthrough time significantly increased from 140 to 180 min. It was found that at lower temperature (150–250 °C) metal doped carbons showed high catalytic activity due to the disassociation of NO chemisorption, accompanied by N₂O and N₂ evolution and oxygen accumulation on the catalyst surface [30].

Besides that when the temperatures were low (<150 °C) the impregnated cerium oxide was most likely in a less active state whereby lower temperature, the capability of CeO₂ to store and release O₂ via the redox shift between Ce⁴⁺ and Ce³⁺ under oxidizing and reduction conditions, respectively was lesser [4], thus giving only a moderate removal of NO from the simulated flue gas.

Higher temperature shows a better removal of NO comparatively because Ce/PSAC would be in a more active state to oxidize and reduce NO. Cerium oxide has high oxidation activity at high temperature conditions [31,32]. Moreover it is reported that at higher temperature AC itself could decompose NO and reduce it to N₂ [33,34]. In a literature it is indicated that a catalytic reaction and chemisorption of NO on active centers must occur at temperature of more than 200 °C [35]. This is well proven by the reported analysis data in Fig. 10, whereby higher temperature shows elevated removal of NO. Moreover higher temperature (>200 °C) means less water accumulation on the sorbent surface and thus allowing the cerium oxide (CeO₂) to become more active. A similar result was reported using honeycomb AC impregnated with vanadium oxide (V₂O₅/ACH) [13]. In this study, it was found that SO₂ sorption decreased with increase in temperature and a stable sorption of NO at temperatures between 230 and 250 °C. Ce/PSAC played a catalytic role at higher temperature by oxidizing and reducing NO to NO₂ and N₂.

However at temperature 300 °C, it was detected that the removal of both SO₂ and NO started deterring. This is owing to the oxygen-containing group formed on the surface of Ce/PSAC, which was attached to the carbon group of Ce/PSAC to form CO and CO₂. This was proven when the analyzer starts detecting CO at this particular temperature. Cerium has a powerful oxidizing property which can bring new oxygen surface groups such as C–O, C=O

and COOH on the surface of AC [36,37]. Thus, the cerium's oxygen group is expected to be attracted to the oxidized reactions of PSAC with oxygen. Cerium dispersed on AC aids the oxidation of the carbon surface with the onset of additional oxygen surface group retained in cerium. Consequently this process indirectly lowers the conversion of NO [36].

Table 1 shows the sorption capacity of Ce/PSAC at different temperature. The best sorption capacity of SO₂ and NO by Ce/PSAC was obtained at temperature 150 °C, with the value 121.7 and 3.5 mg/g, respectively. For SO₂, when the operating temperature was less than 150 °C, the sorption capacity was high; whereas when the temperature was more than 150 °C, the sorption capacity started reducing. Whereas for NO at temperature from 100 to 250 °C the sorption capacity increased but when the temperature was 300 °C the sorption capacity reduced. It was reported that on a system of carbonaceous materials, removal of NO by adsorption and reduction could occur at temperature below 300 °C [26]. Hence at higher temperature adsorption did not take place or it was too slow that it could be neglected.

4. Conclusions

A process operating study is important to understand the behavior of SO₂ and NO simultaneous removal by Ce/PSAC. The process parameters affecting SO₂ and NO sorption activity of Ce/PSAC were studied. It was found that higher GHSV reduced the SO₂ and NO sorption capacity. RH was also found to enhance SO₂ sorption capacity but not for NO. For adsorber temperature effect, it was found that NO sorption enhanced as the temperature was raised from 100 to 250 °C. For SO₂ the sorption capacity increased up to 150 °C but beyond that the SO₂ sorption decreased. Small amounts of NO in the feed could improve the sorbent capacity for SO₂ however further increasing the concentration of NO in the feed strongly decreased the removal capacity of SO₂. The same phenomenon was observed for NO when a small amount of SO₂ was introduced into the feed.

From these parameters studies, it could be concluded that the optimal operating conditions to obtain the optimum sorption capacity of SO₂ and NO by Ce/PSAC (121.7 and 3.5 mg/g, respectively) were: an adsorber temperature of 150 °C, 15% of RH, 14116 h⁻¹ of GHSV and an intermediate feed concentration of SO₂ (1000–2000 ppm) and NO (300–500 ppm). Ce/PSAC could be a new and promising sorbent for simultaneous removal of SO₂ and NO. Moreover Ce/PSAC has an advantage of not requiring a reducing agent such as ammonia to remove NO.

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