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Chapter

Microwave Radiated Sorption-Hazardous Emission Control by Popped Borax and Salted Pumice for Coal Combustion in Thermal Power Plants

Yıldırım İsmail Tosun

Abstract

Considerable research on emission control of coal combustion with popped borax and salted pumice has been conducted in this study. However, the packed bed column adsorption results are widely dispersed because of the complex chemistry of coal. Time-related hazardous emission, stack gas coal-mixing with slurries washing in microwave-heated packed bed column sorption units and cycling sorption modeling assumed basically first-order kinetic equations, or less sensitive for microwave heating rate. The other reactivity distributed on activation model was dependent on the microwave heating rate. The more advanced models for microwave radiation progressed sorption need three and four constants, respectively, which basically depend on the coal properties but also cover, to some extent, the effect of porosity and gas to salt mass transfer phenomena. That was the reactivity reason for the different conditions of sorbents values on the activation energy and pre-exponential factor. The same situation exists in the other sorbent case of coal-lead and CS, COS gas. The sorption reaction rate of popped borax and bed effected of the salt reaction of pumice and the specific surface area of pumice, which changed the sorption reaction cycle with the development of internal pores type.

Keywords: microwave activation, stack gas control, pollution control, postcombustion desulfurization, toxic emissions, char reactivity

1. Introduction

Marble wastes, fine limestone, or hydrated lime is used as sorbent in fluidized bed combustion as desulfurizing sorbent in postcombustion. Popped borax and Tatvan pumice waste and char waste are yielded in two different size forms over sand size and − 20 micron. The forest wood wastes is in lump size conventionally evaluated in char carbon industry and other may be evaluated as filling materials in fine size lower than 20 microns. The waste carbon may be evaluated as sorbent in fluidized combustion of coal in composite forms following solid-liquid separation thickeners. In this study, Şırnak asphaltite char and clayish char as sorbent coal waste or char in finer size lower than 10 mm pyrolyzed may avoid heat decrease and

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without deteriorate nature and environment near thermal power plants. The waste fine of marble processing plants may be very effective in neutralizing acidic industrial waste waters and avoiding water contamination in streams. The utility of coal char and clayish char waste in toxic gas emission control during fluidized bed combustion can efficiently be made possible. However, fluidized combustion is carried out below 8 mm solid fuel combustion with addition of sorbent at weight rate of 20–25%. In order to avoid this high amount of sorbent consumption, the clayish char or coal waste cold be sufficient in homogenous disturbing flow manner of that waste material, clayish coal waste and Şırnak asphaltite char or biomass waste char pellets following pyrolyzed manure and local wood waste were used in laboratory type combustion chamber at 20% weight rate.

About 40, 60, and 80% manure char containing Şırnak asphaltite pellets were used in our combustion experiments as 1–2 mm sized pellets. The popped borax and pumice waste pellets provided an 88% sulfur dioxide emission and also wood char and soot pellets provided 45% emission reduction in fluidized bed combustion. Microwave activity in wet pellet columns was found to be effective in desulphurization of flue gas and char occurrence.

In the Thermal Coal Power station in Silopi, Şırnak, Park Elektrik Co., 405 MW electricity was produced using fluidized bed combustion in three boilers by burning 232 kg coal per MW [1]. Şırnak asphaltite contained 6.7% pyrite and 3.8% organic sulfur and combusted with local limestone as 92% calcium carbonate and 4% magnesium carbonate at 10% weight rate in the fluidized bed for desulfurizing sorbent [2]. Processing technologies using animal manure and combustible municipal waste should be under contribution to the fuel side for energy production in European countries (**Figure 1**) [3]. About 49% of the total municipal waste in Sweden was converted to energy in 2014 and this rate was 39, 7, and 22% for the Netherlands, the USA, and the EU27, respectively.

Regarding advanced technological developments in energy production, the low-quality municipal wastes needed the most economical technologies. In order to make it possible to produce waste-derived fuel products as Char and even coal waste diverted source in China [4–9]. Combustible municipal waste rate reached

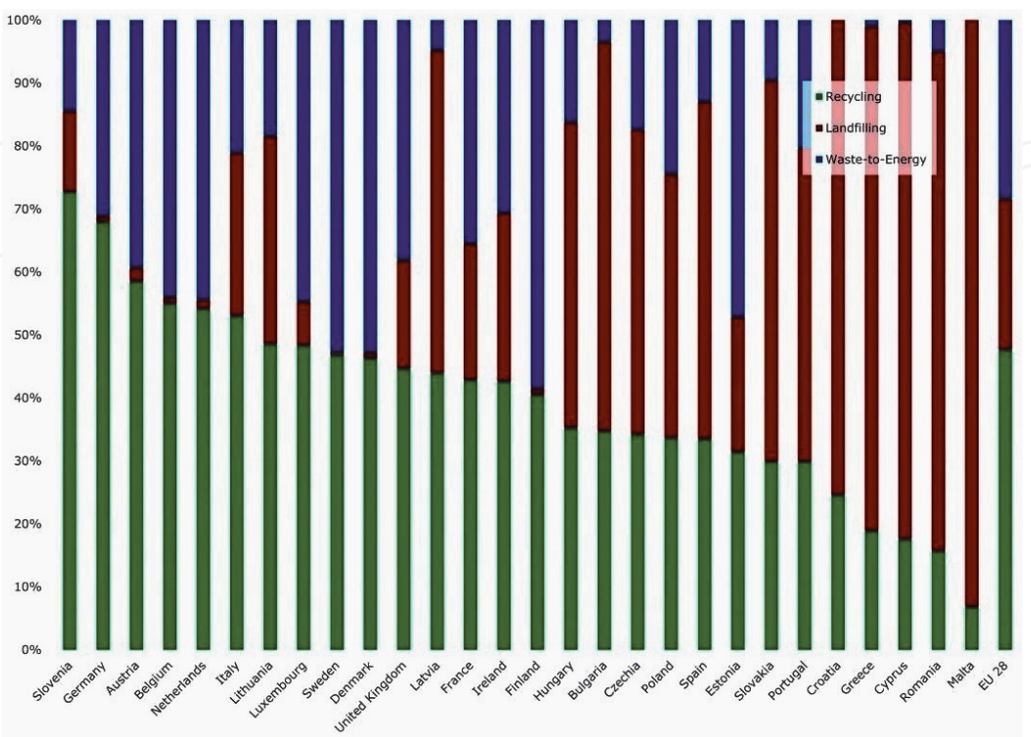


Figure 1.
Waste-to-energy production and distribution of countries according to the European waste [3].

27.0% as paper and cardboards, and additionally, dried food waste was 14.6% and the yard waste was 13.5% after suitable segregation of the total collected waste in China in 2015 as seen in **Figure 2**.

On the way of washing and processing characteristics of the lignite as considered environment are distinctly separated in utilization and classification. In the view of producing high-value cleaned products, pyrolysis municipal waste or lignite char are being processed for their final products, managed on this active carbon purpose. Carbonized char waste and amount could also be evaluated in sorption and energy need in this study.

1.1 Carbonization to char

Effective carbonization processes depend on numerous factors including coal rank in carbonization and the volatile gaseous matter of coal such as the presence of hydrogen, carbonyl gas, and carbonization rate [11]. For stabilizing the desorption, the settings of optimal diffusion conditions including structure defects (nitrogen, phosphorus, sulfur, etc.), temperature, and oxygen content of coal and the optimizing carbon dioxide concentration ratios [12] added to the adsorption–desorption balance, the residence time, and the spatial distribution of molecules in coal pores among other factors that determine the efficiency of carbonization. Guerrero et al. [13] also included the carbon reactivity and the adsorption characteristics as factors affecting the rate and extent of carbonization that is dependent on the site activation, its gas desorption properties, and its porosity [14]. Carbonization is a prerequisite step for oil generation and soot formation from tire waste, biomass wastes, and coal. TGA results of waste materials showing sufficient carbon conversion are shown in **Figure 3** [15].

1.1.1 Coal particle size

A major reason is that the retention time in fixed film processes is longer than that in solid–gas processes. This allows more time for carbonization by cracking the

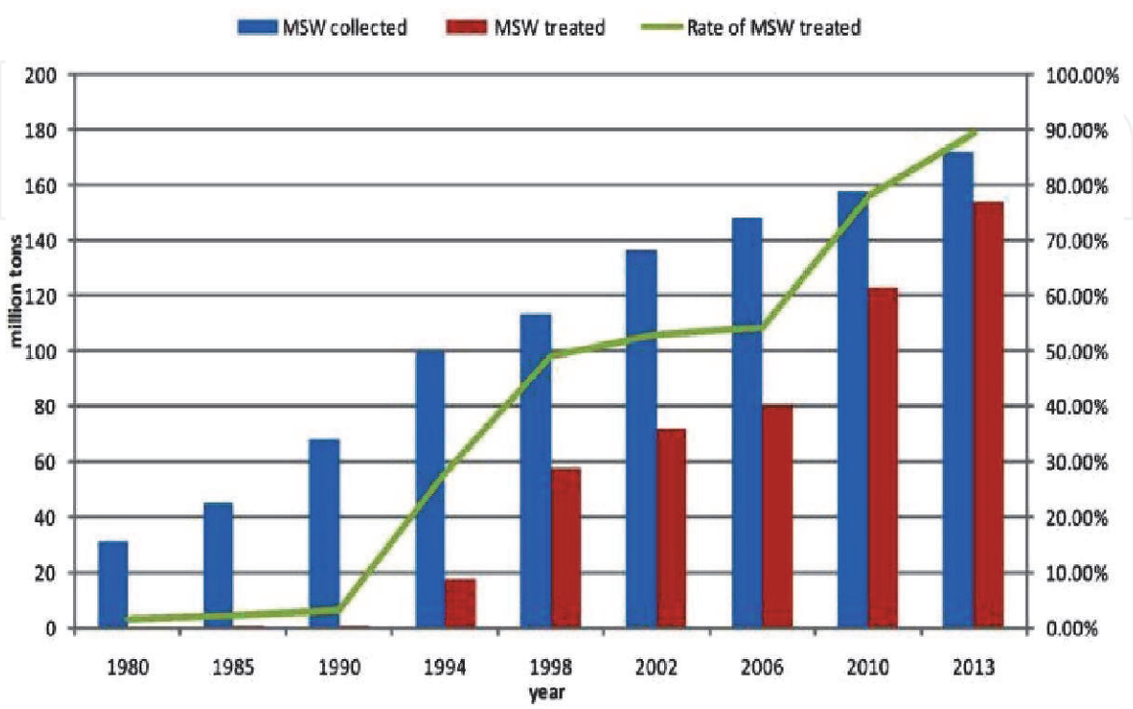


Figure 2.
Municipal solid waste (MSW) management in China from 1980 to 2013 [10].

desorbed persistent compounds. Furthermore, high-rank coals allow sufficient intimate contact between surface pores and gas atmosphere in the furnace due to more gas desorption [16, 17].

1.1.2 Coal porosity

The porous structure of activated carbon is a factor that determines to a great extent both the rate and degree of carbonization [18]. Sharma et al. [19] found that a mesoporous coal carbonized more efficiently than a microporous coal.

Phenol molecules that may undergo an oxidative coupling reaction may be irreversibly adsorbed on coal, which in column back flow may result in low carbonization efficiency. Phenol radicals formed by the removal of a hydrogen atom from each phenol molecule can participate in direct coupling with other phenol-type radicals at even room temperature, with the coal surface serving as a catalyst. The types of catalysts are given in **Table 1**.

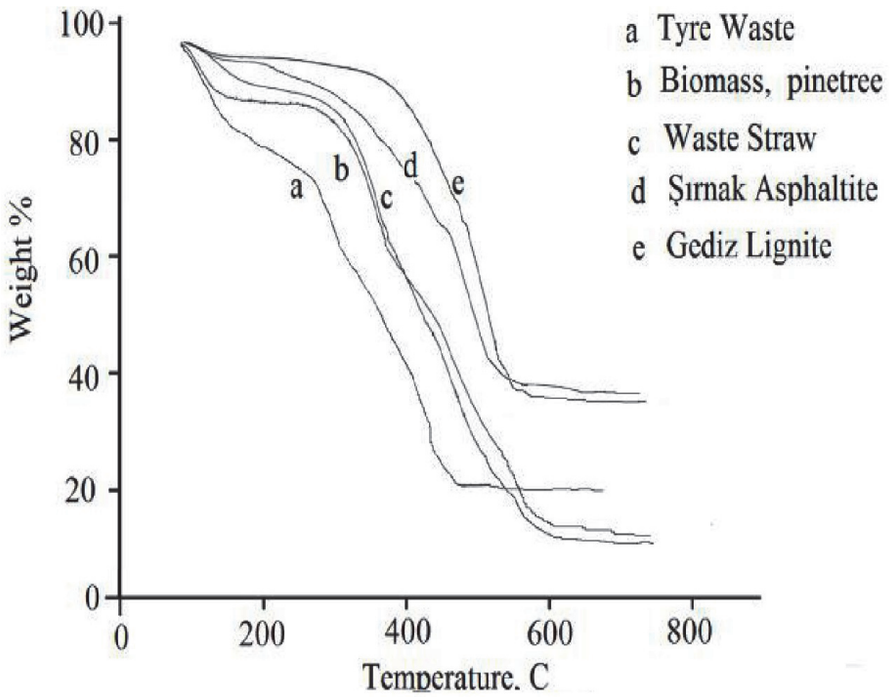


Figure 3.
TGA analysis showing carbon conversion of different waste materials used for carbon production.

Type	Surface area m^2/gr	Weight rate, %	Reaction performance	Contamination	Reference
Hematite over clay	43	34	45	Strong	
Ferrite over fly ash	20	56	33	Strong	[20]
Titanium oxide over ZEOLİTE	120	12	55	Strong	
Vanadium oxide over alumina	78	23	57	Weak	
Cobalt oxide over alumina	54	12	45	Weak	
Nickel/Pt	2	77	33	Strong	

Table 1.
The types of catalysts and substrates and properties used in gas conversion syngas production.

Carbonization efficiencies exceeding the total desorption abilities during increased fast pyrolysis on coal and wood were also reported by Tosun [21].

1.1.3 Surface properties of coal reactivity

The specific surface area measured as BET N_2 sorption, total surface activity, oxygen functional groups, total surface impurities, metal concentrations, dielectric value, free radical concentration, and reactivity of coal were related to the carbonization activity. However, in some investigations, the pore size distribution of coal is also greatly to reduce pyrolysis kinetics [15].

Although molecular gas diffusion is described to be the primary mass transport process in the combustion chamber, complex convective gas emissions proliferated the alkali clusters below 1–2 mm size and exothermic combustion reactions increased toxic substances in the gas form, and a relatively porous structure of expanded clay interstitial spaces and cracks reduced over 5 mm size. The combustion gas substances toward the expanded clay surface through this surface alkali are primarily accomplished by molecular diffusion across the microcracks and alkali clusters. In the combustion experiments, the experimental condition is calculated on the basis of the ash composition in the ambient state. So neither the contained water vapor nor the condensing hydrocarbons are taken into account. Expanded clay and limestone sorbent use in asphaltite combustion provided sufficient hold-up gas as shown in **Figure 4**.

1.2 Pyrolysis to char of waste coal, tire, wood, and biomass

Soot matter removal during BC treatments results from the combined effect of adsorption and degradation. The efficiency of the combined combustion of waste

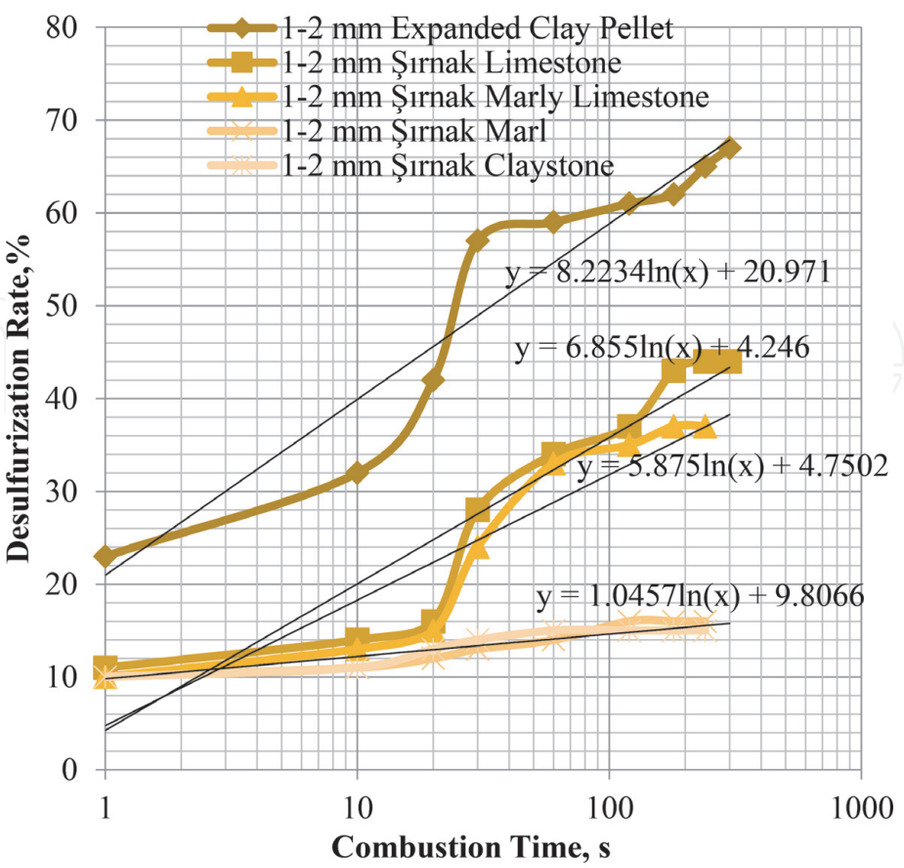


Figure 4.
The sulfur sorption effect of expanded clay and limestone in combustion of Şırnak asphaltite [18].

for soot formation needs lack of oxygen combustion method. The process is higher than expected for either soot formation or carbon without oil alone. The carbon surface for pollutants protects them from shock loadings of toxic and inhibitory materials, such as carbon. High inert gas processes using catalyst carbon as carrier for iron film attachment are efficient to remove soot from ethylene. However, in catalytic systems, the gas attachment to surface is less efficient than that in iron film or in fluidized bed reactors using CO_2 and pellets as iron film carrier [22].

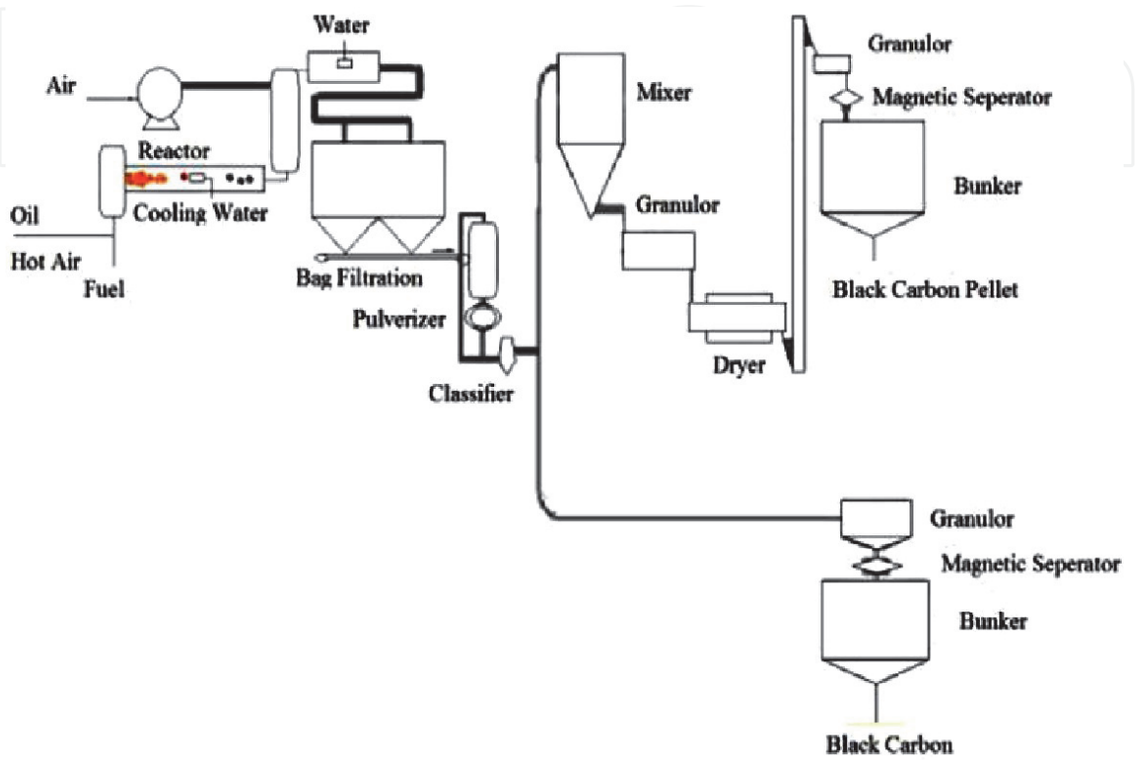


Figure 5.
Black carbon production system, purposed plant flowsheet from waste oil and pyrolysis oil and natural gas [17].

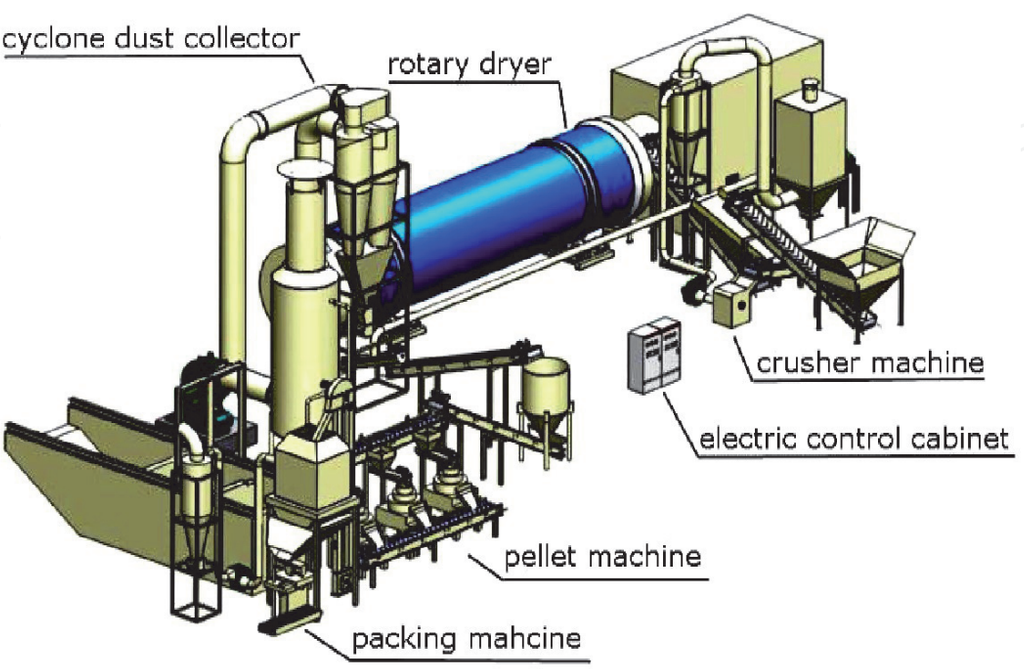


Figure 6.
Waste carbon production system proposed for waste pyrolysis purposed furnace unit.

This is because, in the latter, then retention time of solids is generally much higher than in black carbon processes, allowing more time for gas attachment to BC. **Figure 5** shows the flowsheet used in BC production from pyrolysis oil, waste oil, and natural gas and sometimes oil mixtures [20]. Waste char was proposed to produce from local waste sources in terms of agricultural and forest biomass waste in waste char carbon production system in waste pyrolysis purposed furnace unit for Şırnak as illustrated in **Figure 6** [20].

Carbonization of oil waste, asphalt or bitumen for active carbon production in slurries could evaluate efficiently sorption Au in pulp was commonly gold extraction systems, they use AC in fine size and as slurries gold cyanide solutions passed through. Fine activated carbon or char is more advantageous than granule AC. Additionally, powder AC provided uniform carbon site distribution on solids and agitation slurries without contamination or active site blocking. Additionally, less energy is required for milling of carbon considering the oily structure. It is a fact that pyrolysis of oil could become at low temperature carbonization blocking the active carbon sites even contaminated carbon pores when the condensate is removed from the liquid phase through furnace. The oil gradient should be determined for a suitable char production used as sorbent.

2. Solid sorbent use in emission control

Alkali salts such as burned lime and hydrated lime, fluorite and calcium borates, limestone, and fly ash could be used in desulfurization in coal combustion. Marble wastes, coal, and wood char produced in two different forms in size may be also evaluated as sorbent in postcombustion. One type of sorbent, carbonized wood char is in lump size and can easily be evaluated in carbon industry and other fine size may be evaluated as filling materials in paint, rubber, and plastic as fire barrier mixed at fine size under 5 microns, which are collected following solid-liquid separation and milling. Char as carbonized from coal and coal waste in finer size may deteriorate nearby environment and may be used in water treatment and avoid contamination in industrial waste streams. Beneficiating from char waste in toxic gas emission control during combustion can efficiently be made possible. However, fluidized combustion is carried out below 7 mm solid fuel combustion. Fine matters below 100 microns may deteriorate flow manner, so to avoid this disturbing flow manner of that fine char waste material, clayish char pellets were used in combustion chamber. Fine char wastes may also be evaluated with lime as sorbent raw material. The coal fly ash and Şırnak asphaltite fine could manage remediation of soil as sorbent utility without carbonation and neutralizing humate material as waste [23]. The black carbon used in industrial sectors such as rubber, paper, and animal food production may evaluate as much as 40% marble waste fine coal char and fly ash. The fly ash of Silopi Power Plant combusting Şırnak asphaltite fine containing Ca ferrite and alkali ferrite pellets could be used as sorbent in postcombustion. In this study, TGA experiments with 1–2 mm sized ash ferrite pellets of Silopi Power Plant were evaluated and compared with char.

Microwave activity and chemical activity in postcombustion were found to be effective in desulphurization of flue gas and soot occurrence. Microwave activation of fly ash with Ca ferrite and metallic slag was much efficient in humidified exhaust gas reactions. Fine chemical washing during microwave absorption columns and heating may also be evaluated as active site formation at raw material without destroying chemical form for industrial sectors such as active chemical reactivity.

3. Theory of adsorption on sorbent

According to the Clapeyron Equation, there is a direct proportionality between the concentration c adsorbent gas mixture and p partial pressure:

$$\mathrm{p} = \mathrm{cRT} \tag{1}$$

$$c = \frac{-P}{\mathrm{RTLnK}} \tag{2}$$

For sorbents that have microporous mesoporous structure, Dubinin Equation for first-order isotherm

$$(w_{Ads})^n = \frac{v\ pore}{V} e^{\left[-\mathrm{B}\frac{\mathrm{T}^2}{ß^2}\left(\log\frac{p}{\mathrm{P}}\right)^2\right]} \tag{3}$$

For meso- and nanoporous sorbents,

$$\log p_2 x = \log p_2 - \mathrm{B}\frac{\mathrm{T}^2}{ß^2}\log\frac{p_2}{\mathrm{P}} \tag{4}$$

For second-order isotherm in which dynamic rate of adsorption by Shilov Equation

$$t = KH - t \tag{5}$$

$$t = \frac{\mathrm{a}}{\mathrm{vc}}\left[\mathrm{H} - \frac{\mathrm{T}^2}{ß^2}\left(\log\frac{p_2}{\mathrm{P}} - 1\right)\right] \tag{6}$$

For third-order heterogeneous adsorption, where K = B/v = a/vc, thermal power generation causes gas pollution by nitrogen oxide sulfur oxide and heavy toxic cyanide and lead emissions due to fuel contamination in Austria (**Figure 7**) [24] and coal firing power plant data for Turkey is given in **Table 2** [24].

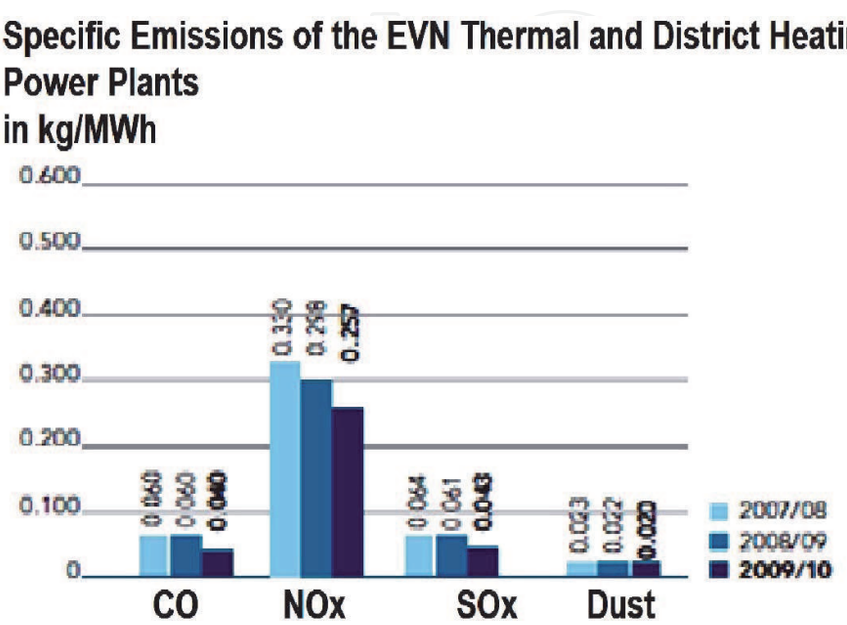


Figure 7.
Emission of thermal power plants in Austria.

Pollution	Emission kg/MWh	Emission %/MWh
CO_2	1.650	13
Particle	0.174	0.3
SO_2	0.011	0.01
NO_x	0.046	0.02

Table 2.
Polluting gas emission of thermal power plants in Turkey.

3.1 Adsorption of SO_x at combustion

The sulfur oxide emissions greatly concerned the thermal boilers and energy sector, and caused more efficient new methods for postcombustion SO_2 capture from the stack gas. Among procombustion and postcombustion systems, wet flue gas washing was carried out in higher and wider shower stacks, and lime slurry sorption one, which was used for a gas cleaning separation for many years. The characteristic features of adsorption column provide long life of the sorbents used, low energy consumption, and less effect on the environment. However, sorption column by lime slurries at postcombustion application required distinct preparation of the stack gas fed into the washing tower of SO_2 separation so that the flue gas temperature is as low as possible and with a lack of steam in it.

3.1.1 Langmuir model

The gaseous matter reacts with adsorbent and then adsorbs the sorbent in certain amount that is equal to the amount of previous adsorbent that was partially degraded on the surface of the expanded clay, removing aliphatic hydrocarbons and phenols/chlorinated phenols and carbonyl toxins, along with organic matter–related odor substances.

The Langmuir model [25, 26] is the common one sorption explanation for well-known reacting column packed explaining sequential diffused and concentrated adsorbed matter and kinetics. Although the linear concentration sequentially followed, sequential adsorption packed bed column was usually experimented by various researchers for the sorption diffusion process of fuel carbon materials, and it can also be used for the sorption over leafy composites. The carbon material is soaked in fluid in an ethanol extraction vessel, and after some time, the solute is diffused from the leafy composite substrate matrix and gets adsorbed on the active surface sites, which further mass transfers to the separator vessel in the solvent. The Langmuir extraction model is presented in the following form:

$$Y = Y_f.t\,(K_L + t) \tag{7}$$

where Y is % extraction yield (w/w) and Y_f and K_L are constants (Y_f is the yield at infinite time).

The temperature dependence of the adsorption coefficient is governed by an Arrhenius equation as follows [27]:

$$K_L = K_{0L} \exp(-ERT) \tag{8}$$

where E is the activation energy (kJ/mol), K_{0L} is the pre-exponential coefficient, and R is the universal gas constant.

3.2 Microwave activation of wet char

This type of microwave treatment may be advantageous in internal selective heating and activating coal grains and provides selective surface oxidation of pyrite in coal desulfurization.

Microwave energy with frequency nonionizing electromagnetic radiation in the range of 300 MHz to 300 GHz stopped. The radiation includes tri-band microwave frequency (UHF: 300 MHz to 3 GHz), super high frequency (SHF: 3 GHz and 30 GHz), and extremely high frequency (EHF 30 GHz to 300 GHz) [28]. The microwaves penetrate the depth of the sample in the form of electromagnetic energy, which increases the temperature of the sample volume, unlike conventional heating [29].

Mineral leaching in slurries under microwave thermal effect, melting of the microwave wet roasting of sulfide concentrates, wet oxidation of refractory gold concentrates, and activated carbon regeneration can be accomplished in wet solutions [30, 31]. There will be wet solutions of ferrite affected by microwave heating as sorbent effect of fly ash of Şırnak asphaltite same as that of limestone rock [20, 21, 32].

Microwave heating technology provides oxidation heating and the interaction was determined to be applicable successfully [28]. Microwave interaction parameters of rocks, microwave penetration, expansion of different mineral grains, and grain boundary cracking properties were examined. The temperature varies according to the thermal effects of microwave on mineral species [33]. **Table 3** showed microwave radiation, the higher penetration of mineral grains of pyrite as given and has lead 1019°C like a temperature change.

Pore structure of the coal sıde rock, shale texture, contained pyrite at grain size in microns and determined the resistance at intergranular interaction with microwave. The wet heat sorption of the coal's texture of side rocks and coal was determined with TGA standard test.

Mineral	Maximum temperature, °C	Time, min
Albite	69	7
Chromite	155	7
Chalcopyrite	920	1
Zinabar	144	8.5
Gehlenite	956	7
Hematite	1082	7
Magnetite	1258	2.75
Marble	74	4.25
Molybdenite	192	7
Orthoclase	67	7
Pyrite	1019	6.75
Pvrotine	586	1.75
Quartz	79	7
Sphalerite	88	7
Zircon	52	7

Table 3.
Mineral microwave thermal interaction values [33].

4. Materials and method

The biochar and char waste with clay produced from different combustion temperatures at 700–900°C were tested in three column series for adsorption of SO_2 as seen in **Figure 5**. Test results were determined as weight change in TGA.

The experimentation studied weight adsorbed matter presenting decrease or increase at TGA analyzer and simulated numerical calculations of the carbon porous counted system for letting sequential passage of the flue gas fed as the wet SO_2 sorption, by primarily under vacuum pressure swing sorption separation unit, containing the absorption chiller (AC). Steam matter in flue gas affected resulted numerical concept, Mainly it is assumed that gas flowing as the wet flue gas which occurred in comparison upper and lower heat source for AC; the flue gas, which is larger heat carrier so that required by the AC, heat exchangers must be practiced.

4.1 Microwave acted hollow fiber membranes use for gas sorption

The SEPURAN® hollow membrane was effective in gas separation and cleaning. The gas cleaning unit compromised various membrane systems for different applications. SEPURAN® Green is tailored exactly to the specific application, which was ideally clean biogas due to its high CO_2/CH_4 selectivity.

4.2 The reactivity for gas sorption

Gas sorption sequential columns and composite sorbent membranes provided adsorption work according to the principle of selective gas permeation through the char and composite membrane surface. The reactivity and active site pore improve permeation and the inner site mass rate of each gas depend on its solubility on the char surface and active composite membrane material and on the diffusion rate of the gas.

The active char could improve reactivity and high mobility of molecules that pass through the composite membrane. The larger gas molecules take more time to permeate the membrane. The experiments showed that different type of composite polymer membrane materials could work heavier gas separately. The mainly selective gas passage through the membrane in order to clean the flue gases was achieved by means of a partial pressure gradient.

4.3 Active char production from municipal waste

Municipal solid waste (MSW) yielded worthless litter as disposed matter and recycled or covered by land in certain areas, and in many states, it may evaluate as a renewable energy source by incineration. Totally, about 130 million tons of MSW are incinerated annually in waste-to-energy facilities that produce electricity and steam for district heating and even metal contents may be recovered in recycling plants. A large amount of paper is recycled in China, evaluating a significant amount of paper sludge and residue during the paper production process. The incineration plants [34] can use that sludge and provide waste elimination. Currently, two incineration methods, distinguished as either direct incineration of partially dewatered sludge (generally 80% water content) or dried sludge incineration (dried to about 40% water content), are available. Research on comparison of fixed cost, operating cost, and pollutant emissions between the two systems is presented. Fixed cost and steam consumption increase for the dried sludge

incineration system though this method possesses many advantages; these include the decrease in consumption of auxiliary coal, service power, and flue gas purification.

4.4 Adsorption of SO_x at combustion

The distinct character of adsorption column sorption in packed bed layer was mainly long life use of the sorbents, consuming low energy. The alkali and lime slurries used for washing protect the environment from acid rains and acidic gas emissions such as chlorides and sulfates. Higher column units are used sequentially and in cycling manner provide much efficient capture of the toxic gases in the flue gas fed into the postcombustion system with SO_2, even lead and cyanide gases

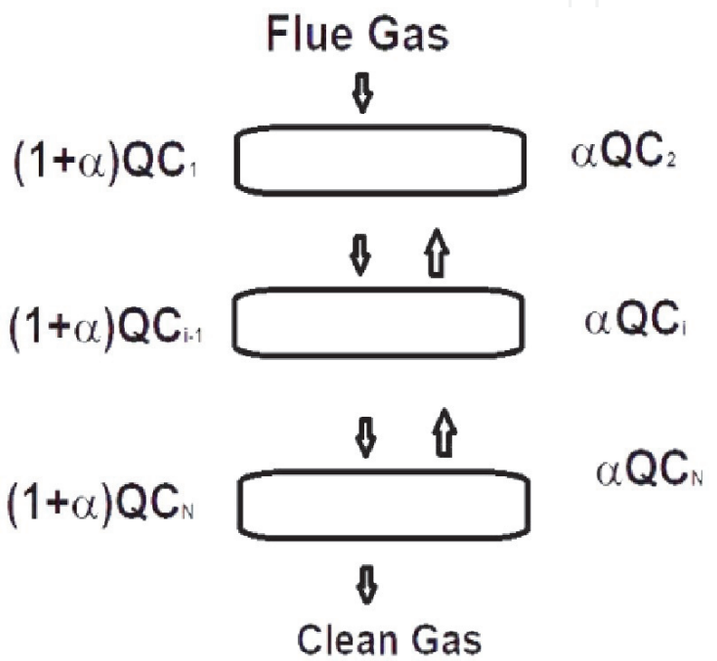


Figure 8.
Adsorption amount sequent at back mixing model for column sorption [23].

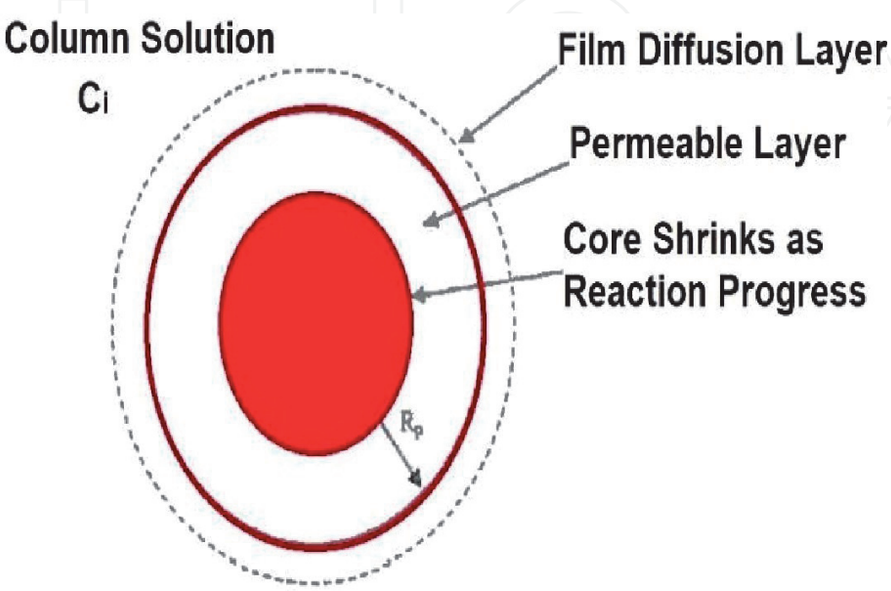


Figure 9.
Proposed adsorption model, sequential column series in fluidized bed combustion of Şırnak asphaltite.

separated on char and composite waste char clay composites so that the flue gas temperature is as low as possible, and there is no water content in it.

Microwave heating of wet coal char samples containing pyrite of minerals may provide the inner thermal stress and interfacial cracks. In this work, following microwave sorption and pellets to a size of minus 1–2 mm from 200 μm and especially, the effect of microwave radiation on char sorption of those char and ferrite fly ash samples was investigated. Limestone and lime mixed pellets were also tested by TGA with microwave wet sorption in columns on combusted Şırnak asphaltite; marl from Şırnak Coal Mine and shale taken from coal mine waste dumps were also tested. In the experiment, microwave power of 900 W microwave radiation was practiced at 20 min cycling sorption bed in Bosch-type microwave laboratory equipment, as shown in **Figure 8** [35–37].

Hydrodynamic parameters investigated pressurized column (**Figure 9**), and simulation results of the output of concentrations (step curve $F(t/\tau)$, where τ is the mean residence time of fluid in the column) are shown in **Figure 10**. According to

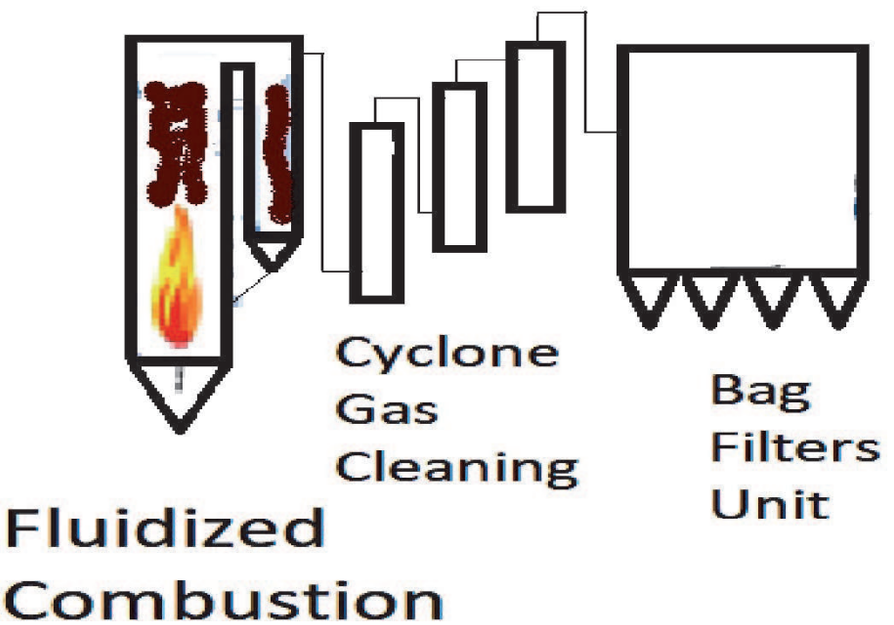


Figure 10.
Microwave radiation carried out in wet steam of stack gas flow in pressurized packed counter current flow matter.

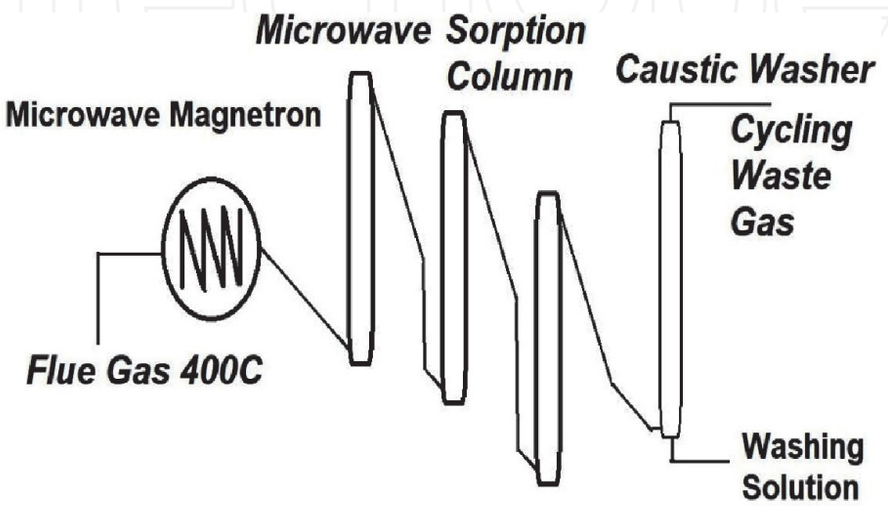


Figure 11.
Spherical core shrinking sorption reaction model [23].

the shape of the curves in column adsorption shown in **Figure 11**, the response of the stage-wise back mixing model changes from a mixed flow condition managed at low pressure.

5. Results and discussions

The popped borax-char column temperature produced from different combustion flue gas exit level or long duration of cooling of exhaust system (**Figures 12** and **13**). The temperatures at 50–200°C were tested in three column series for adsorption of SO_2 as seen in **Figure 14**. Test results were determined as weight in TGA.

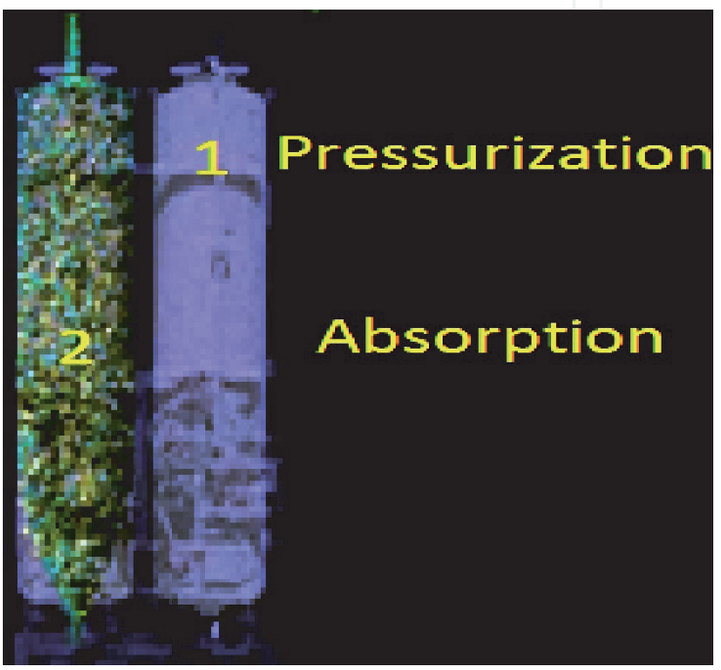


Figure 12.
Adsorption column used in postcombustion with packed popped borax-char carbon tubes.

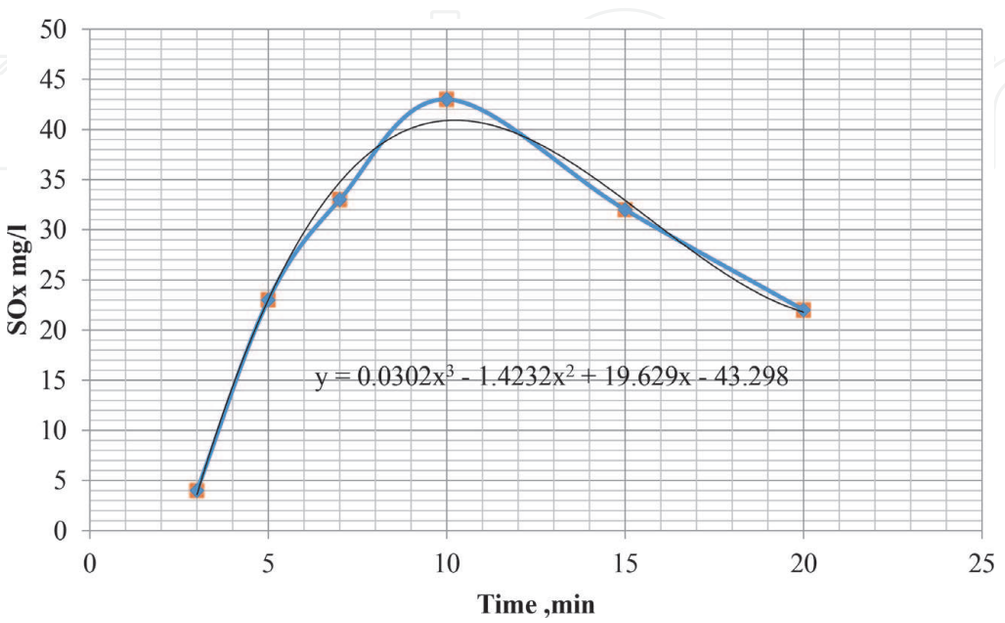


Figure 13.
SO_x output concentrations packed bed residence time of waste gas in the column unit.

The popped borax-char column humidity produced from different combustion fuel and combustion temperature exit or fuel moisture content in the exhaust system. The steam amount in flue gas at exhaust chamber that varied at 5–20% was tested in three column series for adsorption of SO_2 as seen in **Figure 15**. Test results were determined as weight in TGA.

Advanced materials and technologies should be used to prevent pollution of exhaust gas; the material used in this study is finally concluded as efficient and high cut with ecological environmental protection (**Figure 16**).

The representative poped borax composite samples at 1–3 mm sized pellet fractions of combustion Şırnak asphaltite, shale and coal waste raised SO_2 sorption weight by the microwave radiation increased to 23, 21, and 12% at decreasing pressure., respectively, and all those valuse with char raised to 46, 24, and 14% at decreasing pressure. Microwave wet heating of porous coal did not change. The optimum sorption with char and ferrite using column was effective far more than waste coal and limestone as was discussed in microwave heating ability and heat conduction in the wet column designed in laboratory TGA.

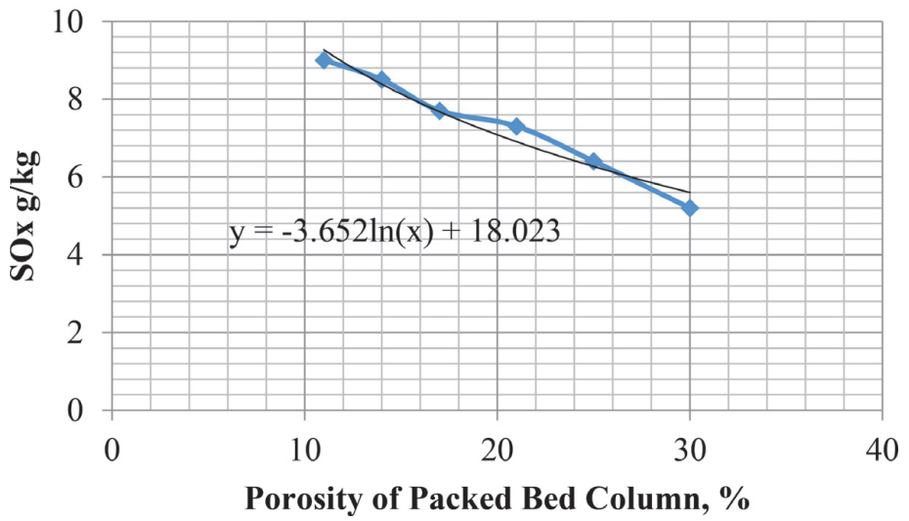


Figure 14.
The effect of adsorption pressure effect on sorbent pore change as %.

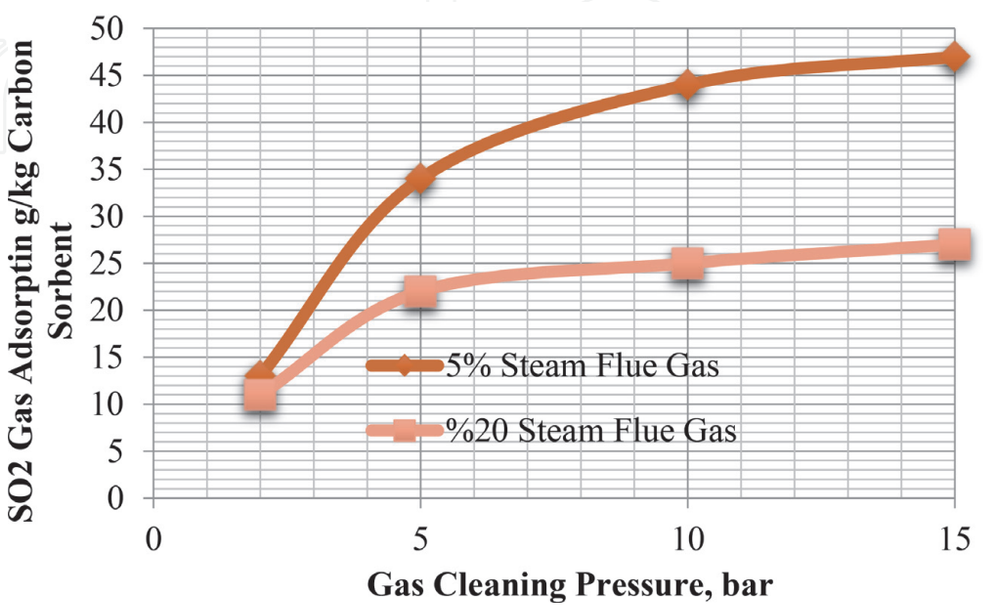


Figure 15.
The effect of adsorption pressure effect on sorbent weight change as %.

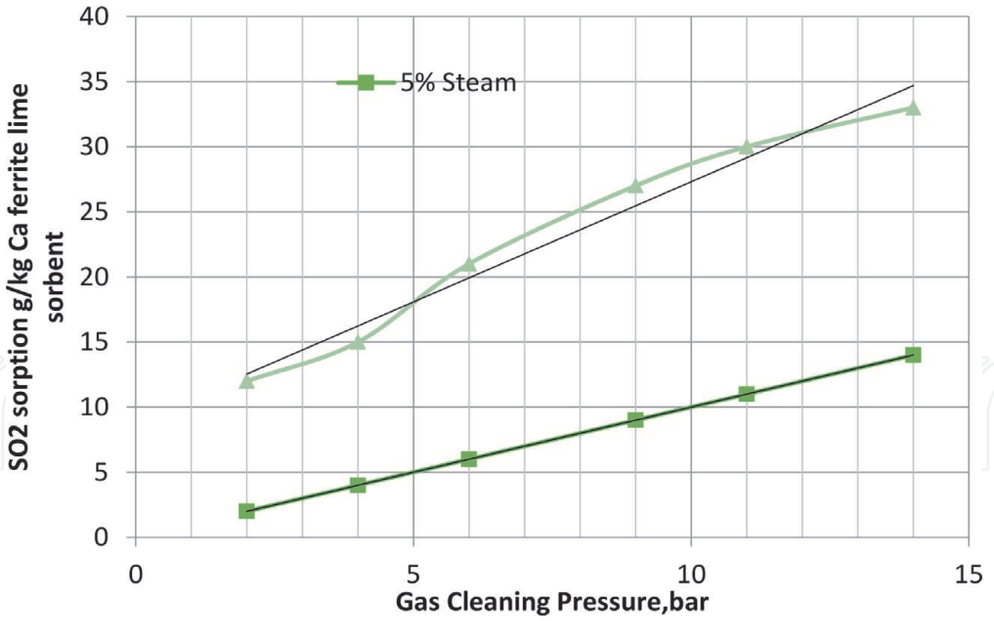


Figure 16.
The effect of adsorption pressure effect on pumice popped borax compost sorbent weight change as %.

6. Conclusion

Fine marble waste and char composite may also be evaluated as lime raw material for sorbent material in power sectors and industrial furnaces such as rubber, paper, and wood plants.

The popped borax and char waste pellets managed at 10 minutes in packed bed with a porosity of 21 and 88% sulfur dioxide emission hold up and soot reduced 45% emission reduction in fluidized bed combustion.

The results showed expansion of the operational envelope for gas having much steam carryover and improved performance of the modified column. For low pressures, the modified column can remove all the toxic emissions from the gas stream, resulting in low steam carryover (separation efficiency = 70%). The study of emission control at sustainable development from many aspects in power generation was compulsory, and then advanced materials and technologies should be used to prevent pollution of exhaust gas. The material used in this study is finally concluded as efficient and high cut with ecological environmental protection.

Abbreviations

AC	activated carbon
C	constant defined in Eq.(1)(g/kg)
Dp	mean pore diameter of adsorbent (nm)
PD	intraparticle diffusion
kp	rate constant (mg/(g $min^{1/2}$))
V	surface of adsorbate (cm^2 g^{-1})
r	volume of adsorbate (mL)
D	distance in radial direction of adsorbent; 0< r < R (cm)
ε	adsorbent dose (g L^{-1})
ρP	void fraction in the adsorbent
d	particle density of adsorbent (g cm^{-3})

m	weight of adsorbent (g)
Ea	activation energy (J mol^{-1})
R	gas constant (8.314 J mol^{-1} K^{-1}) or Radius of the particle of adsorbent in the Crank model (cm)
T	temperature (K)
S_{ext}	specific area of the adsorbent due to external surface(m^2/g)
Sp_{BET}	specific surface area of the adsorbent (m^2/g)tadsorption time (min)
t_{ref}	the longest time in adsorption process (min)
Vmicro	micropore volume of the adsorbent (cm^3/g)
Vpore	total pore volume of the adsorbent (cm^3/g)
D_{effA}=1−YAYB/DAB +YC/DAC+YD/DAD	Diffusivity
(k_a)	adsorption and
(k_b)	desorption rate constants
k_i	is the IPD rate constant [mg/(g·$min^{0.5}$)], and
B	is the initial adsorption (mg/g)

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