DETERMINATION OF OPTIMUM SODIUM BICARBONATE ($NaHCO_3$) INJECTION RATES FOR ACID HYDROCHLORIC (HCl) SCRUBBING IN A CLINICAL WASTE INCINERATION PLANT

MOHD. SALLEH BIN SULEIMAN

UNIVERSITI TEKNOLOGI MALAYSIA

DETERMINATION OF OPTIMUM SODIUM BICARBONATE ($NaHCO_3$) INJECTION RATES FOR ACID HYDROCHLORIC (HCl) SCRUBBING IN A CLINICAL WASTE INCINERATION PLANT

MOHD. SALLEH BIN SULEIMAN

A thesis submitted in fulfillment of the
requirements for award of the degree of
Master of Engineering (Environmental)

Faculty of Chemical Engineering
Universiti Teknologi Malaysia

SEPTEMBER 2012

DEDICATIONS

To my respected and beloved father & mother
Hj. Suleiman Bin Harun & Rogayah Binti Abdullah
Thank you for your valuable sacrifice…

To my family and friends
Thank you for your support…

ACKNOWLEDGEMENTS

"In the names of Allah, the most gracious, the most compassionate"

I would like to express my appreciation and most sincere gratitude to my supervisor, Prof. Dr. Mohd Rozainee bin Taib for his endless support, invaluable guidance and supervision throughout completion of my Master Project. Without his guidance, I believe this research would not have been successfully completed.

I would like to convey my highest appreciation to Faber Medi-Serve Sdn. Bhd. for supporting me financially through the scholarship to complete the study. I am also grateful to AMR Sdn. Bhd. for assisting in collecting emission samples for conducting the laboratory analysis.

Lastly but certainly not the least, I am indebted to my friends and family for their endless support. For the name mentioned and not mentioned that involved in completion of my Master Project, only Allah swt could pay your kindness.

I hope this project will be beneficial for this field of research and gets the platform for future research.

ABSTRACT

Clinical wastes are heterogeneous in nature and fluctuations in the waste components have a direct effect on the sorbent capture rates. This research was conducted to determine the optimum sodium bicarbonate ($NaHCO_3$) injection rates for acid hydrochloric (HCl) scrubbing in a clinical waste incineration plant. The plant employs a rotary kiln system having burning capacity of 300 kg/h of clinical waste and operated on a 24 h/day basis. Currently the plant meets all the emission parameters set by the Department of Environment (DOE) even at excessive injection rates of $NaHCO_3$. The $NaHCO_3$ injection rate is 25 kg/h, which was recommended by plant manufacturer to meet maximum standard emission limit of 100 mg/Nm^3 HCl. Moisture content (relative humidity) and stoichiometric ratio of adsorbent and acid mist were the main parameters influencing the acid gases removal. To overcome the excessive injection of $NaHCO_{3,}$ analysis of HCl emission at various injection rates of 25, 20, 15 and 10 kg/h were conducted. The results on HCl emission after injection of $NaHCO_3$ were in the range of 0.58-7.13, 5.63-7.74, 0.07-2.99 and 3-28 mg/Nm^3, respectively. The results showed that $NaHCO_3$ injection rate as low as 10 kg/h could still meet the HCl stipulated emission limit. It can be concluded from this study that an optimum injection rate would not only save cost and reduce wastage but also reduce bag house loading rate and prolong the life span of filter bags. A further study was conducted for chlorine ($Cl_{2)}$ and HCl emissions at the point of before and after the injection point of $NaHCO_{3,}$ showed inverse proportional relationship between both parameters. Total Cl_2 concentration was lower at the point of after injection point of $NaHCO_3$, lower temperature was observed with higher water vapor (H_2O) present had reduced the amount of Cl_2 present. The reduction in emission concentration ranges from 56% to 97% after $NaHCO_3$ injection at a slight reduced temperature. Most of the chlorine atom will leave the incinerator as HCl, but a considerable part is in the form of $Cl_{2.}$

ABSTRAK

Ciri-ciri sisa klinikal yang tidak seragam dan kandungan yang berbeza-beza menyebabkan impak langsung kepada penggunaan kadar sodium bikarbonat ($NaHCO_3$). Kajian dilaksanakan untuk menentukan kadar suntikan yang optima bagi $NaHCO_3$ melalui proses penyingkiran asid hidroklorik (HCl) dapat dilakukan. Loji ini menggunakan sistem penunuan berputar dengan keupayaan pembakaran iaitu 300 kg/jam dan dikendalikan secara 24 jam sehari. Kini, loji beroperasi dengan menepati kesemua parameter yang di tetapkan oleh Jabatan Alam Sekitar (JAS) walaupun pada kadar suntikan $NaHCO_3$ yang berlebihan. Tahap suntikan $NaHCO_3$ adalah 25 kg/jam, disarankan oleh pengeluar untuk memenuhi piawaian iaitu tidak melebihi tahap perlepasan maksima HCl pada kadar 100 mg/Nm^3. Kandungan kelembapan (kadar kelembapan) dan kadar stoitiometri penyerap dan wap asid adalah merupakan parameter utama mempengaruhi penyingkiran gas asid. Ujian pelepasan HCl dilakukan bagi mengatasi masalah suntikan berlebihan $NaHCO_3$. Pelbagai kadar suntikan pada 25, 20, 15 dan 10 kg/jam telah dijalankan. Tahap kepekatan akhir HCl adalah dalam lingkungan 0.58-7.13, 5.63-7.74, 0.07-2.99 and 3-28 mg/Nm^3 telah dikenalpasti. Hasil ujian menunjukkan pada kadar suntikan $NaHCO_3$ serendah 10 kg/jam, loji masih mematuhi tahap pelepasan HCl yang ditetapkan. Kesimpulan dari kajian menunjukkan bahawa tahap suntikan optimum bukan hanya menjimatkan kos dan mengurangkan pembaziran malahan ia dapat mengurangkan beban penapisan dan memanjangkan jangka hayat penapis. Analisis lanjutan dilakukan terhadap klorin (Cl_2) dan HCl pada tempat sebelum dan tempat selepas suntikan $NaHCO_3$, telah menunjukkan hubungan berkadar songsang di antara kedua-dua parameter. Kepekatan Cl_2 berkurangan dengan pengurangan kadar suhu di mana Cl_2 bertukar kepada HCl pada suhu yang lebih rendah. Kepekatan keseluruhan Cl_2 adalah lebih rendah di tempat selepas suntikan $NaHCO_3$, suhu yang rendah dan kandungan wap air (H_2O) yang tinggi telah mengurangkan kandungan kepekatan Cl_2. Kepekatan berkurang di antara 56% ke 97% selepas suntikan $NaHCO_3$. Hampir keseluruhan atom klorin meninggalkan loji penunuan dalam bentuk HCl, dan jumlah yang kecil adalah dalam bentuk molekul gas Cl_2.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

$CaCO_3$	-	Limestone
CaO	-	Calcium Oxide (Quicklime)
$Ca(OH)_2$	-	Calcium Hydroxide (Hydrated Lime)
$CaCl_2$	-	Hydrated Salts
DOE	-	Department of Environment Malaysia
E.N.T	-	Ear, Nose and Throat
EPRI	-	Electric Power Research Institute
EU	-	European Union
FIBC	-	Flexible International Bulk Container
HCl	-	Hydrochloric Acid
HF	-	Hydrogen Floride
ITEQ	-	Index Toxic Equivalent
LPG	-	Liquefied Petroleum Gas
MoH	-	Ministry of Health Malaysia
NaCl	-	Sodium Chloride
$NaHCO_3$	-	Sodium Bicarbonate
Na_2SO_4	-	Sodium Sulfate
NO_2	-	Nitrogen Dioxide
O_2	-	Oxygen
OPD	-	Out Patient Department
PAC	-	Powdered Activated Carbon
PLC	-	Programmable Logic Controller
PVC	-	Polyvinyl Chloride
RH	-	Relative Humidity
SO_2	-	Sulfur Dioxide
TOC	-	Total Organic Carbon
UK	-	United Kingdom
U.S. EPA	-	U.S. Environmental Protection Agency

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Preamble

Medical wastes, also known as clinical wastes or hospital wastes are classified as scheduled wastes under the Environmental Quality (Scheduled Wastes) Regulations, 2005 under the category of SW 404: Pathogenic wastes, clinical wastes or quarantined materials (DOE, 2009). Clinical wastes are generated from various sources including hospitals, clinics and other medical, dental and veterinary practices, where it is estimated that 10-15% of the wastes are infectious.

Most countries have laws that prohibit direct disposal of infectious waste into landfills. Thus, incineration methods are introduced as alternative for clinical waste disposal. Facilities for the disposal of scheduled wastes are categorized as Prescribed Premises under the Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Facilities) Order, 1989 for which a license is required to occupy and operate such facilities. (DOE, 2009).

Incineration is the most preferred method for disposal of infectious wastes due to its ability to render the wastes innocuous through high temperatures. However, the air emissions from the incineration process have to comply with the limits imposed by the Department of Environment Malaysia (DOE). The emission limits which are stipulated in the Clean Air Regulations 1978 (C.A.R) ensure that the emissions from the incineration of clinical waste do not pollute the environment and its surrounding area.

Thus, in order to fulfill the requirements imposed by the DOE, incineration facilities must be equipped with flue gas cleaning system (FGCS) to meet stringent air emissions limits. Most commonly, a dry or semi-dry type of FGCS applying the combination of both the activated carbon and sodium bicarbonate or lime spray system as the adsorbent are used to treat the air pollutants in the flue gas emission.

1.2 Problem Statement

Table 1.1 presents the characteristics of typical clinical wastes which show that plastics are the largest constituent in the waste, consisting of plastic bins (rigid plastic) and bags (film plastic).

Table 1.1 : Characteristics of clinical waste

Category	Name	Average weight percentage	Range
1	Rigid plastic	30	16 – 38
2	Film plastic	8	4 - 10
Total plastic		38	-
3	Mixed paper	10	2 - 13
4	Surgery dress	3	1 - 5
5	Diapers	18	13 - 21
6	Absorbents	18	13 - 24
7	Gloves	13	9 - 17

Source: *"Detailed Environmental Impact Assessment for Proposed Upgrading of Clinical Waste Thermal Treatment Facility at Lot 65, Kamunting Raya Industrial Estate, Taiping Perak Darul Ridzuan"* (May 2007) conducted by Engineering and Environmental Consultants Sdn. Bhd. (EEC) in collaboration with Universiti Teknologi Malaysia (UTM).

Table 1.2 : Clinical waste composition and bulk density

Component Description	Bulk Density as Fired, kg/m^3
Human anatomical	800-1200
Plastics	800-2300
Swabs, absorbents	80-1000
Animal, disinfectants	800-1000
Animal infested anatomical	500-1300
Glass	2800-3600
Beddings, shavings, paper, fecal matter	320-730
Gauze, pads, swabs, garments, paper, cellulose	80-1000
Plastics, PVC, syringes	80-2300
Sharps, needles	7200-8000
Fluids, residuals	990-1010

Source: US EPA, 1990. Handbook on operation and maintenance of hospital medical waste incinerators.

Almost all clinical wastes are required to undergo a burning process through incineration, gases and solid ashes are formed by combustion reaction of the waste. During the phase of gas formation, components that are generated resulting from the incineration process react with the ambient air forming other chains of complex chemical compounds in particular acid gas in the form of hydrochloric acid (HCl), which is significantly generated in the incineration process due to high content of plastics in the wastes. In real municipal solid waste plant operation, the consumption of sodium bicarbonate ranges from 12 to 20 kg $NaHCO_3$ (Dvor_a´k Æ, et. al., 2008).

Although the HCl discharged from the stack complied with the emission limit set by the Department of Environment (DOE) through the deacidification process with sodium bicarbonate injection into the system, no study has been done to determine the optimum sodium bicarbonate injection rates for acid hydrochloric (HCl) scrubbing in actual plant conditions in Malaysia.

The clinical waste management services in Malaysia had specified that all the consumables are made of polyethylene (non-used of PVC), this policy will reduce the amount of HCl generated during the incineration process. Thus, the study to reduce the excessive injection rates of sodium bicarbonate needs to be analyzed. Excessive usage of sodium bicarbonate represents a loss in operating cost of the plant due to redundancy by injecting sorbents way beyond the rates required to adsorb the HCl to meet stipulated emission rates, as well as the resulting increase in disposal cost of fly ash (also classified as scheduled wastes by the code of SW104).

1.3 Objectives of the Study

The main purpose of the study is to determine the optimum injection rates of the adsorbent i.e. sodium bicarbonate to meet the permissible level of HCl discharged to the atmosphere. The finding will be useful to ascertain the economical amount of the adsorbent to be injected to reduce the HCl concentrations in the flue gas to meet its minimum regulatory limits imposed by DOE Malaysia. In order to achieve the purpose of the study, three objectives are required to be analyzed;

a) To establish the existing HCl emission level for the incineration plant.

b) To identify the stoichiometric ratio of absorbent and acid mist.

c) To determine the relationship between the temperature, moisture content, Cl_2 and HCl concentration.

1.4 Scope of the Study

A study to investigate the emission levels of HCl with respect to various absorbent injection rates was carried out at Faber Medi-Serve Sdn. Bhd's Clinical Waste Incineration Plant located in Kamunting, Perak. The facility is equipped with a unit of fabric filter flue gas cleaning system with both activated carbon and sodium bicarbonate injection system. Collective samples of flue gas were taken at the inlet and outlet of the fabric filter air pollution control unit. The flue gas was sampled for HCl concentrations under four (4) different amount of sodium bicarbonate injection rates of 10, 15, 20 and 25 kg/hr. A minimum of three samples were taken during each set of the sodium bicarbonate injection rates. The samples were taken to the laboratory and analyzed for HCl concentrations. The results obtained were then analyzed and interpreted accordingly.

1.5 Significance of the Study

The study in the determination of the HCl concentration with respect to different injection rates of sodium bicarbonate will help in estimating the adequate or the minimum amount of adsorbent needed for acid gas scrubbing namely HCl from clinical waste incineration process to comply with the regulatory imposed emission limit. To date, there is no such study being conducted in Malaysia specifically with the use of sodium bicarbonate as the flue gas cleaning agent in actual conditions of a clinical waste incineration plant. Therefore, this study will be able to help plant operators in minimizing wastage and cost pertaining to the use of adsorbents as acid gas removal agent.

REFERENCES

Adánez., J., Fierro, V., García-Labiano, F. and Palacios, J. M (1996). *Study of modified calcium hydroxides for enhancing SO2 removal during sorbent injection in pulverized coal boiler*, viewed 8 March 2008, available from www.mendeley.com/research/study-of-modified-calcium-hydroxides-for-enhancing-so2-removal-during-sorbent-injection-in-pulverized-coal-boilers.

Appleton, J. and Ali, M. (2000), *Healthcare or Health Risks? Risks from Healthcare Waste to the Poor*, viewed 3 December 2008, available from siteresources.worldbank.org/**HEALTH**NUTRITIONANDPOPULATION/.../Johannssen-**HealthCare**-whole.pdf.

Aracil., I., Fullana, A., Conesa, J., and S. Sidhu (2005), *Influence of Chlorine and Oxygen on the Formation of Chlorobenzenes during PVC Thermal Decomposition, Thermal Processes*, Viewed 30 September 2007, available from rua.ua.es/dspace/bitstream/10045/2309/1/congreso_4.pdf., 25th International Symposium on Halogenated Environmental Organic Pollutants and Persistent Organic Pollutants (POPs) – DIOXIN 2005, Toronto, August 21-26, 2005.

Atwell, M., and Wood, M., (2009), *Sodium sorbents for dry Injection control of SO2 and SO3. Solvay Chemicals Inc*, viewed on 21 December 2008, available from *www.scribd.com/doc/38474272/**Control**-de-SOX*.

Bakke E. (1982), *Process for dry scrubbing of flue gas*, viewed on 20 September 2007, available from www.**patent**storm.us/**patent**s/**4324770**.html.

Banks, D. (2010), *Chlorine Formation in Thermal Oxidizers*, viewed 11 August 2012, available from www.banksengineering.com.

Bausach, M., Krammer, G. and Cunill, F. (2004), *Reaction of Ca(OH)2 with HCl in the presence of water vapour at low temperatures,* viewed 25 December 2008, available from linkinghub.elsevier.com/retrieve/pii/S0040603104001546.

Bernard, J., Ole, H., Jurgan, V. (2000), *The Influence of PVC on the Quantity and Hazardousness of Flue Gas Residues from Incineration. European Commission,* viewed 30 September 2007 available from ec.europa.eu/environment/waste/ studies/**pvc**/incineration.pdf.

BIC (2012), *Waste Incinerators,* viewed 12 June 2012, available from www.bicgroup.com.sg.

Bicarb Buletin (1988), *Desulfurization of factory flue gases with sodium bicarbonate, viewed 2 September 2007,* available from www.ahperformance.com/techdata/ *Heilbronn_SO2_BagHouse.pdf.*

Bodénan, F. and Deniard, P. (2003), *Characterization of flue gas cleaning residues from European solid waste incinerators: assessment of various Ca-based sorbent processes, viewed 2* September 2007 available from www.ncbi.nlm.nih.gov/pubmed/12597999.

Bruner Mond (2010), *Sodium Bicarbonate for Flue Gas Treatment,* viewed 23 December 2008, available from www.brunnermond.com.

Carlsson, K., (2008), *Gas cleaning in flue gas from combustion of biomass, firma EcoExpert*, viewed 11 December 2008, available from w*ww.thermalnet.co.uk/.../2E-3_20**Gas_**20**cleaning_**20in_20**flue_** 20**gas_**20 from_20**combusti***.

Chang, M., B., and Huang, C., K., (2002), *Characteristics of Chlorine and Carbon Flow in Two Municipal Waste Incinerators in Taiwan, viewed 15* September 2007, available from cedb.asce.org/cgi/WWWdisplay.cgi?134015, Journal of Engineering, Vol. 128, No. 12, pp. 1182-1187.

Church & Dwight Co., Inc. (1988), *Desulfurization of Factory Flue Gases with Sodium Bicarbonate, viewed 25* December 2008, available from www.ahperformance.com/techdata/Omnical_SO2_BagHouse.pdf.

Cross, F., L., Hesketh, H., and Rykowski, P., K., (1990), *Infectious Waste Management,* viewed 7 March 2007, available from http://www.amazon.com/Infectious-Waste-Management-Frank-Cross/dp/0877627517, 1st edn, Publisher : CRC Press.

Danish EPA (1993), *A study commissioned by the German Federal Ministry for Research and Technology calculated that while PVC accounts for only 0.5% of municipal waste*, viewed 2 September 2007, available from www.mindfully.org/Plastic/PVC-Primary-Contributor-Dioxin.htm.

Davis, M. L. and Cornwell, D. A. (2008), *Introduction to environmental engineering,* 4th ed. New York, viewed 2 September 2007, available from www.valorebooks.com/Search/ISBN/9780072424119.

DOE (2009), *Guidelines on the Handling and Management of Clinical Wastes in Malaysia (Third Edition 2009)*, viewed 25 December 2009, available from http://www.doe.gov.my/files/u1/Management_Of_Clinical_Wastes_In_Malaysia_1.pdf.

Dumont, P. A. and Goffin, R. (1994), *Method and composition for treating flue or exhaust gases utilizing modified calcium hydroxide, viewed 3* September 2007, available from www.google.com.tw/patents/about?id=XSIkAAAAEBAJ, UA Patent.

Dvor_a´k Æ., R. and Parˇı´zek Æ., T. and Be´bar Æ., L., (2008), *Incineration and gasification technologies completed with up-to-date off-gas cleaning system for meeting environmental limits*, viewed 25 December 2008, available from cat.inist.fr/?aModele=afficheN&cpsidt=21044215.

Erdol-Aydin, N. and Nasun-Saygili, G. (2007), *Modelling of trona based spray dry scrubbing of SO2*, viewed 3 September 2007, available from www.elsevier.com/locate/cej, Chemical Engineering Journal, 126, no. 1, pp. 45-50.

Feldman, P., L., and Gleason, R., J., (1985), *Method for reduced temperature operation of flue gas collectors*, viewed 3 December 2008, available from http://www.google.com./patents? Query=PN/4559211. US Patent.

Fellows, K., T., and Pilat, M., J. (1990), *HCl Sorption by Dry NaHCO3 for Incinerator emission control, journal of the air & waste management association*, viewed 13 December 2008, available from faculty.washington.edu/mpilat/Fellows.pdf.

Fonseca, A. M., Orfao, J. J. and Salcedo, R. L. (2003), *A new approach to the kinetic modelling of the reaction of gaseous HCl with solid lime at low temperature*, viewed 3 September 2007, available from *linkinghub.elsevier.com/ retrieve/pii/S0009250903002197*.

Fonseca, V., A. and Salcedo, R. (2007), D*ry scrubbing of acid gases in recirculating cyclones*, viewed 3 September 2007, available from www.ncbi.nlm.nih.gov/pubmed/17360111.

Fernandez, J., Renedo, M. J., Pesquera A. and Irabien J. A. (2001), *Effect of CaSO4 on the structure and use of Ca(OH)2 /fly ash sorbents for SO2 removal*, viewed 3 December 2008, available from *elsevier.com/retrieve/pii/S0032591001002637*.

Garea, A., Marqués, J. A., Irabien, A., Kavouras A. and Krammer, G. (2003), *Sorbent behavior in urban waste incineration: acid gas removal and thermogravimetric characterization*, viewed 6 December 2008, available from *linkinghub.elsevier.com/retrieve/pii/ S0040603102003337.*

Geankoplis, C. J. (2003), *Transport process and separation process principles (includes unit operation*, viewed 20 December 2008, available from www.google.com.my/patents/US8043418, 4th Ed., Prentice Hall, pp. 840-841.

Grieco, E., and Poggio, A., (2009), *Simulation of the influence of flue ga*s *cleaning system on the energetic efficiency of a waste-to-energy plant applied energy,* viewed 20 December 2008, available from ideas.repec.org/a/eee/appene/v86y2009i9p1517-1523.html. Applied Energy, Volume 86 (9), pp. 1517-1523.

Grundon (2011), *Clinical Waste*, viewed 27 May 2012, available from www.grundon.com/how/clinicalWaste.htm.

Harvey, P. A., Baghri, S. and Reed, R. A., (2002), *Emergency Sanitation: Assessment and Programme Design, WEDC, Loughborough University, UK, viewed* on 12 September 2007, available from www.crid.or.cr/cd/cd_agua/pdf/eng/doc14616/ doc14616-introduccion.pdf.

Heap, B. M. (1996), *The continuing evolution and development of the dry scrubbing process for the treatment of incinerator flue gases, filtration and separation*, viewed 20 December 2008, available from linkinghub.elsevier.com/retrieve/pii/ S0015188297842978, Filtration & Separation, Vol. 33 (5), pp. 375-380.

Hemmer, G., Kasper, G., Wang, J., and Schaub, G. (2002), *Removal of Particles and Acid Gases (SO2 or HCl) with a Ceramic Filter by Addition of Dry Sorbents*, viewed 20 December 2008, available from *www.netl.doe.gov/publications/proceedings/02/GasCleaning/8.03paper.pdf.*

Jafari. A, and Donaldson. J, (2009). *Determination of HCl and VOC Emission from Thermal Degradation of PVC in the Absence and Presence of Copper, Copper(II) Oxide and Copper(II) Chloride*, viewed 8 March 2008, available from www.e-journals.net, E-Journal of Chemistry, 6(3).

Kaiser, S., Weigl, K., Spiess-Knafl, K., Aichnerg, C. and Friedl, A. (1999), *Modeling a dry-scrubbing flue gas cleaning process,* viewed 13 December 2008, Chemical Engineering and Processing. 39: 425-432.

Kilgallon P., J., (2007), *Effectiveness Of sodium bicarbonate for acid gas removal-. Conference session 2,* viewed 26 December 2008, available from www.carbonbaseddesign.co.uk/ciwm/papers/CS2PaulKilgallon.pdf.

Kobayashi, Y. (1990), *Dry method of purifying flue gas, viewed on* 13 December 2008, from patent.ipexl.com/US/4915920.html.

Krishnan, G. N., Canizales, A., Gupta, R. and Ayala, R. (1996), *Development of disposable sorbents for chloride removal from high-temperature coal-derived gases*, viewed on 11 December 2008, available from www.netl.doe.gov/publications/proceedings/96/96ps/ps_pdf/96pspb13.pdf.

Landrum, V. J (1991), *Medical waste management and disposal*, viewed 20 September 2007, available from http://store.elsevier.com/Medical-Waste-Management-and-Disposal/V_J_-Landrum/isbn-9780815512646, ISBN: 9780815512646, Publisher : Elsevier Ltd.

Lerner, B. J. (1989), *Removal of acid gases in dry scrubbing of hot gases, viewed* 13 September 2007, available from www.free**patent**sonline.com/**4795619**.html.

Lindau, L. V. and Ahman, S. O. H. (1984), "*Method of purifying flue gases from sulphur dioxide*". Retrieved on 2 September 2007 from www.free**patent**sonline.com/ **4454102**.html.

Liu, Z. S. (2005), *Advance experimental analysis of the reaction of Ca(OH) 2 with HCl and SO2 during the spray dry scrubbing process*, viewed 20 September 2008, available from www.sciencedirect.com, Fuel 84 (2005) 5–11.

Majeed, J. G., Korda, B., and Bekassy-Molnar, E. (1995), "*Comparison of the efficiencies of sulfur dioxide absorption using calcium carbonate slurry and sodium hydroxide solution in an ALT reactor*, *Gas separation purification".* Retrieved on December 2008 from www.springer.com › Home › New & Forthcoming Titles.

Management of Clinical Waste in the Delivery of Health and Social Care in the Community, (2002), viewed on 12 June 2012, available from www.dhsspsni.gov.uk/management-clinical-waste.pdf.

Method 1 (1980), *Sample and Velocity Traverses for Stationary Sources Note,* U.S. Environmental Protection Agency, Research Triangle Park, 12 pp., www.epa.gov/ttn/emc/promgate/m-01.pdf.

Method 2 (1980), *Determination of Stack Gas Velocity and Volumetric Flow Rate,* U.S. Environmental Protection Agency, Research Triangle Park, www.epa.gov/ttn/emc/promgate/m-02.pdf.

Method 3 (1980), *Gas Analysis for the Determination of Dry Molecular Weight Note,* U.S. Environmental Protection Agency, Research Triangle Park, www.epa.gov/ttn/emc/promgate/m-03.pdf.

Method 4 (1980), *Determination of Moisture Content in Stack Gases Note*, U.S. Environmental Protection Agency, Research Triangle Park, www.epa.gov/ttn/emc/promgate/m-04.pdf.

Method 26A (2009), *Determination of Hydrogen Halide and Halogen Emissions from Stationary Sources Isokinetic Method,* U.S. Environmental Protection Agency, Research Triangle Park, www.cleanair.com/epamethods/us_epa_airmession testmethods_html/m-26a.html.

MOH (2009), *Annual Report 2009 Ministry of Health Malaysia*, viewed 12 June 2012, available from http://www.moh.gov.my/images/gallery/ publications/md/ar/2009-2.pdf.

Mullan, R., (2003), *BIO-Medical Wastes Disposal Incinerator Systems - Understanding, Criteria and Analysis,* viewed 30 September 2007, available from www.mullanconsultants.com/systems.htm.

National Healthcare Establishment & Workforce Statistic 2008-2009 (Hospitals) (2008-2009), viewed 12 June 2012, available from https://www.macr.org.my/nhsi/ document/ Hospitals_Report.pdf.

Nema, S. K. and Ganeshprasad, K. S. (2002), *Plasma pyrolysis of medical waste, viewed* 21 December 2008, available from www.ias.ac.in/currsci/aug102002/271.pdf.

Niessen, L., W., (1995), *Environmental health perspectives volume 103, viewed* on September 2007, viewed from *ehp.niehs.nih.gov/members/1995/**103**-5/martens-full.html.*

Oxford Dictionary of Chemistry: (1999), *Sodium of soda; sodium bicarbonate A and, as it does not have strongly corrosive or strongly basic properties itself*, viewed 13 September 2007, available from www.highbeam.com/doc/1O81-sodiumhydrogencarbonate.html.

Patil, A.D., & Shekdar, A.V. (2001), *Health care waste management in India*, viewed 13 September 2007, available from www.faqs.org/abstracts/Environmental-issues/Health-care. Journal of Environmnetal Management 63(2), 2001, 2011-220.

Pinnavaia, T. J. and Jayantha, A., (1994), *Hydrated lime clay composites for the removal of SOx from flue gas streams, viewed* 6 December 2008, available from www.patentstorm.us/patents/5298473.html.

Randall, D. and Shoraka-Blair. S., (eds.) (1994), *An evaluation of the cost of incinerating Waste Containing PVC,* Special publication by ASME Center for Research & Technology, Publisher : ASME.

Reinhardt, P. A. and Gordon, J. G. (1990), *Infectious and medical waste management*, viewed 18 September 2007, available from http://www.amazon.ca/Infectious-Medical-Waste-Management-Reinhardt/dp/0873711580. Publisher : CRC Press, 1st Edn, 296.

Saleem, M. and Krammer G. (2007), *Effect of filtration velocity and dust concentration of cake formation and filter operation in a pilot scale jet pulsed bag filter,* viewed on 20 September 2007, Journal of Hazardous Materials.

Sargent & Lundy's. (2002), *Energy consumption. The major energy consumption is due to the pressure drop across the dry, viewed* 20 September 2007, available from scrubber.www.graymont.com/technical/Dry_Flue_Gas_Desulfurization.

Sarojini, E., et. al. (2007), *Performance Study on Common Biomedical Waste Treatment*, viewed 3 December 2008, available fromhttp://www.swlf.ait.ac.th/IntlConf/Data/ICSSWM_web/FullPaper/SessionIV/4_08_E.Sarojini.pdf, Proceedings of the International Conference on Sustainable Solid Waste Management, Chennai, India, pp. 182-188.

Scala, F., D'Ascenzo M. and Lancia, A. (2004), *Modeling flue gas desulfurization by spray-dry adsorption,* viewed on 20 September 2007, Journal : Separation and purification technology. 34: 143-153.

Siagi, Z.O., Mbarawa, M., Mohamed, A. R., Lee K. T. and Dahlan, I. (2007), *The effects of limestone type on the sulphur capture of slaked lime.* Fuel, 86, (17-18), 2660-2666.

Sodium Bicarbonate (material). Viewed 11 December 2008, available from http://en.wikipedia.org/wiki/Sodium_bicarbonate.

Solvay Chemical Technical Publication (1994), *HCl Removal with SBC injection at Colorado incineration services, Inc., Denver, co, viewed* 11 December 2008, available from www.solvaychemicals.us/static/wma/pdf/8/6/3/3/SSAcidgas.pdf.

Stein, J., Kind, M. and Schlunder, E. (2002), *The influence of HCl on SO2 absorption in the spray dry scrubbing process,* viewed on 11 December 2008, Chemical Engineering Journal, 86, (1-2), 17-23.

Stieglitz (1989), *Metal as catalysts for dioxin formation,* viewed 13 September 2007, available from www.ejnet.org/dioxin/catalysts.html.

Thorpe, B. (2009), *How to demand clean production in incineration campaigns, viewed 2* September 2007, available from www.cleanproduction.org/library/web_ CPAlts_Incineration.pdf.

Unified Facilities Criteria, Solid Waste Incineration, (2004), viewed 13 September 2007, available from artikel-software.com/file/**Solid_**20**Waste_**20Disposalb.pdf.

U.S. Congress, Office of Technology Assessment, Issues in Medical Waste Management-Background Paper, U.S. Government Printing Office, 1988.

Verdone, N., and Filippis, P., D., (2004), *Thermodynamic behaviour of sodium and calcium based sorbents in the emission control of waste incinerators,* viewed 13 September 2007, available from www.ncbi.nlm.nih.gov/pubmed/14637355. Chemosphere, 2004, Feb, 54(7), 975-85.

WHO (2000), *Lime (material,* viewed on 23 December 2008, available from http://en.wikipedia.org/wiki/Lime(mineral).

WHO (2000), *Sodium Bicarbonate,* viewed on 23 December 2008, available from *en.**wikipedia**.org/wiki/**Sodium_bicarbonate***.

WHO (2005), *Management of solid health-care waste at primary health-care centres*, viewed 30 May 2012, available from http://www.who.int/water_sanitation_health/ medicalwaste/decisionmguide_rev_oct06.pdf.

WHO (2011), *Health-care waste management*, viewed 30 May 2012, available from http://www.who.int/mediacentre/factsheet/fs281/en/index.html.

Withers, C. (1991), *Hot Gas Filters for Control of Emissions to Atmosphere,* viewed 23 December 2008, available from http://www.caldo.com/pdf_files/Hot Gas Filters for Control of Emissions to Atmosphere.pdf.

Wood (2006), *Reducing Emissions with Sodium Sorbents,* viewed 13 September 2007, available from www.ceramicindustry.com/Articles/Feature_Article/f6cd8e7.

Wu, C., Khang, S., Keener T. C., Lee, S. (2004), *A model for dry sodium bicarbonate duct injection flue gas desulfurization,* viewed 13 September 2007, available from linkinghub.elsevier.com/retrieve/pii/S1093019103000388. *A*dvances in Environmental Research, Volume 8, (3-4), 655-666.

Yarman, S., M., (2005), *PETKIM Petrochemical co. (PVC Plant)*, viewed 20 September 2007, available from http://www.ipen.org/ipepweb1/library/ipep.pdf.

Zaimastura Bt Ibrahim (2005), *Management and disposal of clinical waste (case study : Hospital Universiti Kebangsaan Malaysia),* viewed 27 May 2012, available from www.efka.utm.my/thesis/images/3PSM/2005/4JKAS/Part2/...

Zevenhoven, R., and Saeed, L., (2000), *Two-stage combustion of high-pvc solid waste with HCl recovery,* viewed 20 September 2007, available from www.environmental-expert.com/Files/22110/.../**twostage**.pdf.