Overview Ôść. *Fuel* 72: 731-736.

Cordoba, P. (2015). Status of Flue Gas Desulphurisation (FGD) Systems from Coal-Fired Power Plants: Overview of the Physic-Chemical Control Processes of Wet Limestone Fgds. *Fuel* 144: 274-286.

Diaz-Somoano, M., Unterberger, S. and Hein, K.R.G. (2007). Mercury Emission Control in Coal-Fired Plants: The Role of Wet Scrubbers. *Fuel Process. Technol.* 88: 259-263.

Dodla, V.B.R., Gubbala, C.S. and Desamsetti, S. (2017). Atmospheric Dispersion of $PM_{2.5}$ Precursor Gases from Two Major Thermal Power Plants in Andhra Pradesh, India. *Aerosol Air Qual. Res.* 17: 381-393.

Fraboulet, I., Gouriou, F., Ungar, A., Joos, E., Chaucherie, X., Gautier, F.ž., Fiani, E. and Le-Bihan, O. In (Ed.)^(Eds.) Cem, 2007.

Frandsen, J.B.W., Kiil, S. and Johnsson, J.E. (2001). Optimisation of a Wet Fgd Pilot Plant Using Fine Limestone and Organic Acids. *Chem. Eng. Sci.* 56: 3275-3287.

Garea, A., Marques, J.A. and Irabien, A. (2005). Mechanistical and Non-Linear Modelling Approaches to in-Duct Desulfurization. *Che. Eng. amp; Process. Process Int.* 44: 709-715.

Ghosh-Dastidar, A., Mahuli, S., Agnihotri, R. and Fan, L.S. (1996). Selenium Capture Using Sorbent Powders:Ôçë Mechanism of Sorption by Hydrated Lime. *Environ. Sci. Technol.* 30: 447-452.

Honghe, W., Minghua, X., Lei, C. and Yue, Z. (2016). Operation Status Analysis and Optimization Measures of Double-Tower Double-Cycle Desulfurization System. *Electric Power* 49: 132-135.

Hrastel, I., Gerbec, M. and Stergar, A. (2007). Technology Optimization of Wet Flue Gas Desulfurization Process. *Chem. Eng. Technol.* 30: 220-233.

Huang, Y.J., Jin, B.S., Zhong, Z.P., Xiao, R. and Ren, H.F. (2003). Emission Features of Trace Elements in a Pulverized Coal Boiler. *Proc. Csee*.

Jiang, J., Zhou, W., Cheng, Z., Wang, S., He, K. and Hao, J. (2015). Particulate Matter Distributions in China During a Winter Period with Frequent Pollution Episodes (January 2013). *Aerosol Air Qua. Res.* 15: 494-U157.

Jianyi, L. and Dingkai, L. (2006). A Study of the Effect of Cao Sddition on Primary Particle Characteristics after Pulverized Coal Combustion. *J. Eng. Therm. Energ. Power* 21: 373-377.

Ke, Z. (2013). Research on Emission Characteristics and Environmentalimpacts of the Particulate Matter Emitted from a Coal-Firedpower Plant in Peking, Chengdu university.

Kiil, S., And, M.L.M. and Damjohansen, K. (1998). Experimental Investigation and Modeling of a Wet Flue Gas Desulfurization Pilot Plant. *Ind. Eng. Chem. Res.* 37: 2792-2806.

Lancia, A., Musmarra, D. and Pepe, F. (1997). Modeling of SO_2 Absorption into Limestone Suspensions. *Ind. Eng. Chem. Res.* 36: 197-203.

Li, H., Liu, G. and Cao, Y. (2014). Content and Distribution of Trace Elements and Polycyclic Aromatic Hydrocarbons in Fly Ash from a Coal-Fired Chp Plant. *Aerosol Air Qua. Res.* 14: 1179-1188.

Li, Y., Suriyawong, A., Daukoru, M., Zhuang, Y. and Biswas, P. (2009). Measurement and Capture of Fine and Ultrafine Particles from a Pilot-Scale Pulverized Coal Combustor with an Electrostatic Precipitator. *J. Air Waste Manage. Assoc.* 59: 553-559.

Li, Z., Ji, Y., Ma, H., Zhao, P., Zeng, X., Liu, S., Jiang, Y., Wang, L., Liu, A., Gao, H., Liu, F. and Mwangi, J.K. (2017). Characterization of Inorganic Elements within $PM_{2.5}$ and PM10 Fractions of Fly Ashes from Coal-Fired Power Plants. *Aerosol Air Qua. Res.* 17: 1105-1116.

Ma, Z., Li, Z., Jiang, J., Deng, J., Zhao, Y., Wang, S. and Duan, L. (2017). $PM_{2.5}$ Emission Reduction by Technical Improvement in a Typical Coal- Fired Power Plant in China. *Aerosol Air Qua. Res.* 17: 636-643.

Meij, R. (1994). Trace Element Behavior in Coal-Fired Power Plants. *Fuel Process. Technol.* 39: 199-217.

Meij, R. and Winkel, B.T. (2004). The Emissions and Environmental Impact of PM_{10} and Trace Elements from a Modern Coal-Fired Power Plant Equipped with Esp and Wet Fgd. *Fuel Process. Technol.* 85: 641-656.

Nielsen, M.T., Livbjerg, H., Fogh, C.L., Jensen, J.N.Ş., Simonsen, P., Lund, C., Poulsen, K. and Sander, B. (2002). Formation and Emission of Fine Particles from Two Coal-Fired Power Plants. *Combust. Sci. Technol.* 174: 79-113.

Niemela, V., Lamminen, E. and Laitinen, A. (2009). *A Novel Method for Particle Sampling and Size-Classified Electrical Charge Measurement at Power Plant Environment*. Springer Berlin Heidelberg.

Pan, D., Hao, W.U., Bao, J., Huang, R., Bin, H.U., Zhang, Y. and Yang, L. (2016a). Removal Effect of Wet Flue Gas Desulfurization System on Fine Particles and SO_3 Acid Mist from Coal-Fired Power Plants. *Proc. Csee.*

Pan, D., Yu, R., Bao, J., Wu, H., Huang, R. and Yang, L. (2016b). Emission and Formation

Characteristics of Aerosols from Ammonia-Based Wet Flue Gas Desulfurization. *Energy Fuels* 30.

Ratafia-Brown, J.A. (1994). Overview of Trace Element Partitioning in Flames and Furnaces of Utility Coal-Fired Boilers. *Fuel Process. Technol.* 39: 139-157.

Rochelle, G.T. and King, C.J. (1977). The Effect of Additives on Mass Transfer in $CaCO_3$ or CaO Slurry Scrubbing of SO_2 from Waste Gases. *Ind. Eng. Chem. Fundam.* 16: 67-75.

Shengyu, L., Wende, X., Pei, L. and Zhixiang, Y. (2010). Feasibility Study of New Limestone Flue Gas Desulfurization Process. *CLEAN - Soil, Air, Water* 36: 482-487.

Sieminski, A. (2016). International Energy Outlook 2016.

Sun, J.M., Yao, Q., Liu, H.Y., Lu, J., Yin, G.X. and Zhao, C.M. (2004). Distribution of Arsenic in PM_{10} and $PM_{2.5}$ Caused by Coal Combustion and Its Enrichment Mechanism. *Meitan Xuebao/journal of the China Coal Society* 29: 78.

Taylor, M.R., Rubin, E.S. and Hounshell, D.A. (2005). Control of SO_2 Emissions from Power Plants: A Case of Induced Technological Innovation in the U.S. *Technol. Forecast. Soci. Ch.* 72: 697-718.

Wallin, M. and Bjerle, I. (1989). A Mass Transfer Model for Limestone Dissolution from a Rotating Cylinder. *Chem. Eng. Sci.* 44: 61-67.

Wang, A., Song, Q., Tu, G., Wang, H., Yue, Y. and Yao, Q. (2014). Influence of Flue Gas Cleaning System on Characteristics of $PM_{2.5}$ Emission from Coal-Fired Power Plants. *Int. J. Coal Sci. Technol.* 1: 4-12.

Wang, H., Song, Q., Yao, Q. and Chen, C.H. (2008a). Experimental Study on Removal Effect of

Wet Flue Gas Desulfurization System on Fine Particles from a Coal-Fired Power Plant. *Proc. Csee* 28: 1-7.

Wang, S.J., Chen, C.H., Xu, X.C. and Li, Y.J. (2008b). Amelioration of Alkali Soil Using Flue Gas Desulfurization Byproducts: Productivity and Environmental Quality. *Environ. Pollut.* 151: 200.

Weiguo, W., Pei, Y., Chengxian, W. and Xi, X. (2015). Experimental Research on Properties of Inhalable Particulate Matters Affected by Wet Flue Gas Desulfurization System. *Environ. Pollut. Control* 37: 20-24.

Ylatalo, S.I. and Hautanen, J. (1998). Electrostatic Precipitator Penetration Function for Pulverized Coal Combustion. *Aerosol Sci. Technol.* 29: 17-30.

Yong, Y., Qiang, Y., Li, S.Q. and Qiang, S. In (Ed.)^(Eds.) Asia-Pacific Conference on Combustion, 2005.

Yue, Y., Chen, L., Yao, Q. and Li, S.Q. (2005). Experimental Study on Characteristics of Particulate Matter Size Distribution and Trace Elements Enrichment in Emissions from a Pulverized Coal-Fired Boiler. *Pro. Csee* 25: 74-79.

Zhou, K., Nie, J., Zhang, G. and Dunxi, Y.U. (2013). Emission Characteristics of Particulate Matter from Coal-Fired Plant Equipped with Wfgd. *Therm. Power Generat*.

Zhuang, L., Haitao, W., Heming, D. and Dong, L. (2015). Experimental Study on the Influence of Wet Desulfurization on $PM_{2.5}$ Emissions from a 660MW Pulverized Coal Boiler. *Energy Conservaion Technology* 33: 398-402.

Table 1. Main design parameters of the desulfurization system

Parameter	Design
Desulfurization efficiency	≥ 99%
pH value	First 4.6、Second 5.8
Flue gas temperature	First inlet 146 ℃ Second outlet 54 ℃
Flue gas velocity	About 4 $m\cdot s^{-1}$
Residence time of flue gas in the tower	About 5 s
Ca / S	< 1.03 $mol\cdot mol^{-1}$
demister	Double-stage flat plate

Table 2. Total particle concentration

Serial number	Sampling position	Unit	Test value	Average value
1	Desulfurization inlet	mg/Nm^3	25.07	23.77
2		mg/Nm^3	22.42	
3		mg/Nm^3	23.81	
4	Desulfurization outlet	mg/Nm^3	10.73	11.63
5		mg/Nm^3	12.04	
6		mg/Nm^3	12.11	

Table 3. Content of various elements in the particulate matter before and after desulfurization by ICP

element	inlet（mg/g）	outlet（mg/g）	gyspum（mg/g）	limestone（mg/g）
Al	28.27	18.33	1.87	0.48
Ba	0.60	0.22	0.03	0.03
Ca	3.77	8.19	229.50	388.30
Cu	0.11	0.06	ND	ND
Fe	18.04	7.30	1.93	1.57
Mg	0.35	23.75	13.69	8.35
Mn	0.23	0.96	0.08	0.11
S	89.73	96.96	164.30	1.04
Si	156.44	54.78	0.34	ND

Note: " ND " represents the measured element mass below 0.01mg/g.

Figure Captions

Fig. 1. The technological process of a Cascade of Double Towers WFGD system

Fig. 2. Flue gas particle size distribution before and after WFGD system

Fig. 3. Accumulative removal efficiency of particles

Fig. 4. Particles size accumulative distribution experimental results and R-R fitting curves before and after desulfurization

Fig. 5. SEM images of flue gas particles at inlet and outlet of desulfurization tower

Fig. 6. EDS result of flue gas particles at inlet and outlet of desulfurization tower

Fig.7. X-ray diffraction of flue gas particles

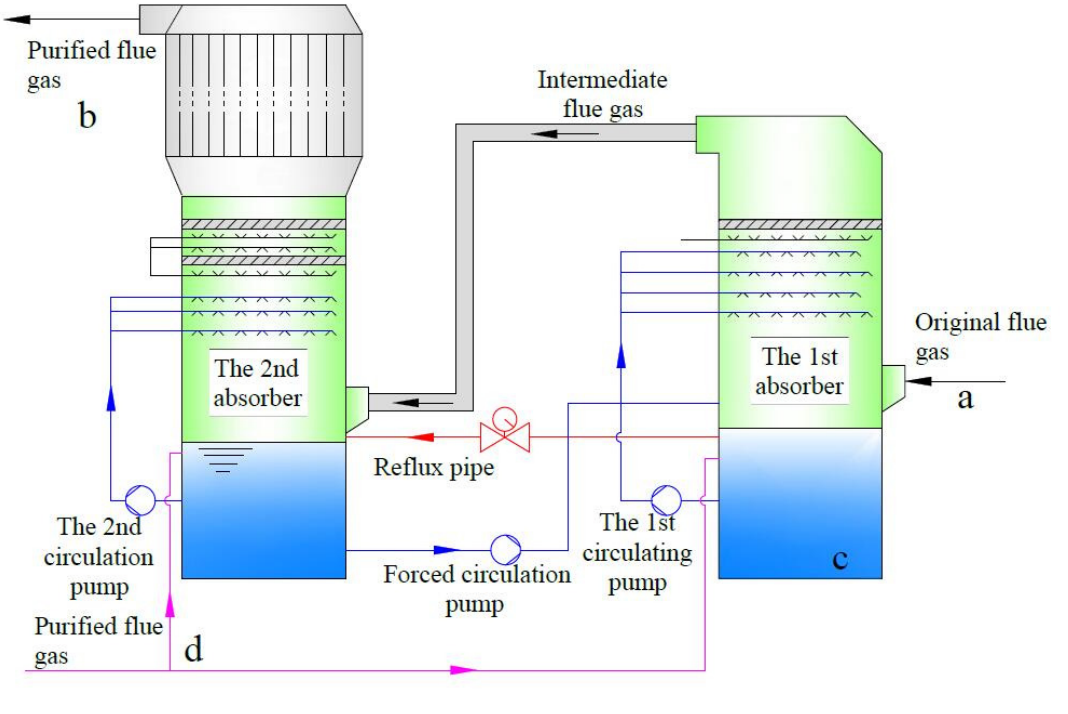

Fig. 1. The technological process of a Cascade of Double Towers WFGD system

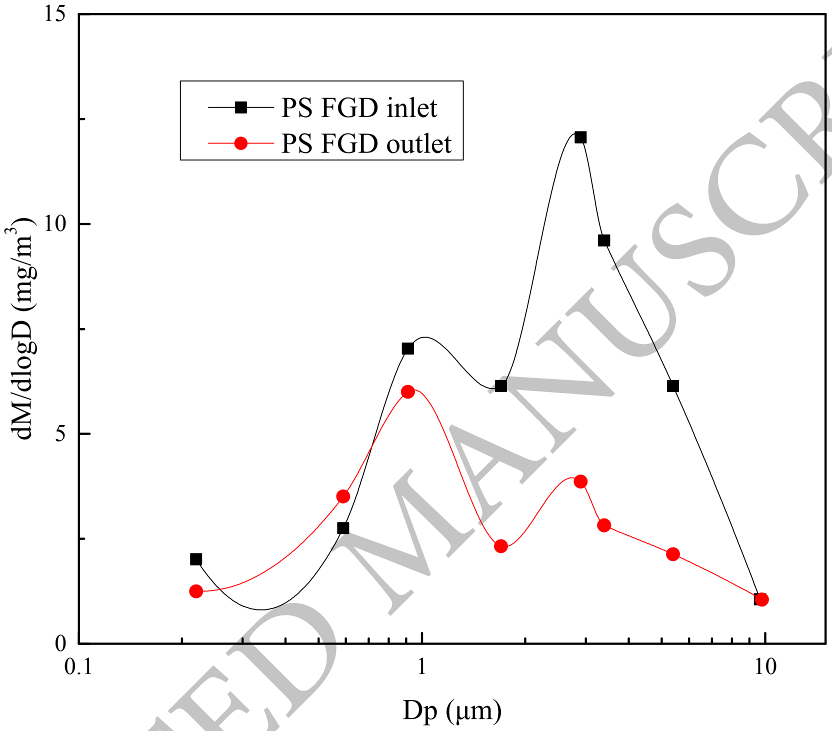

Fig. 2. Flue gas particle size distribution before and after WFGD system

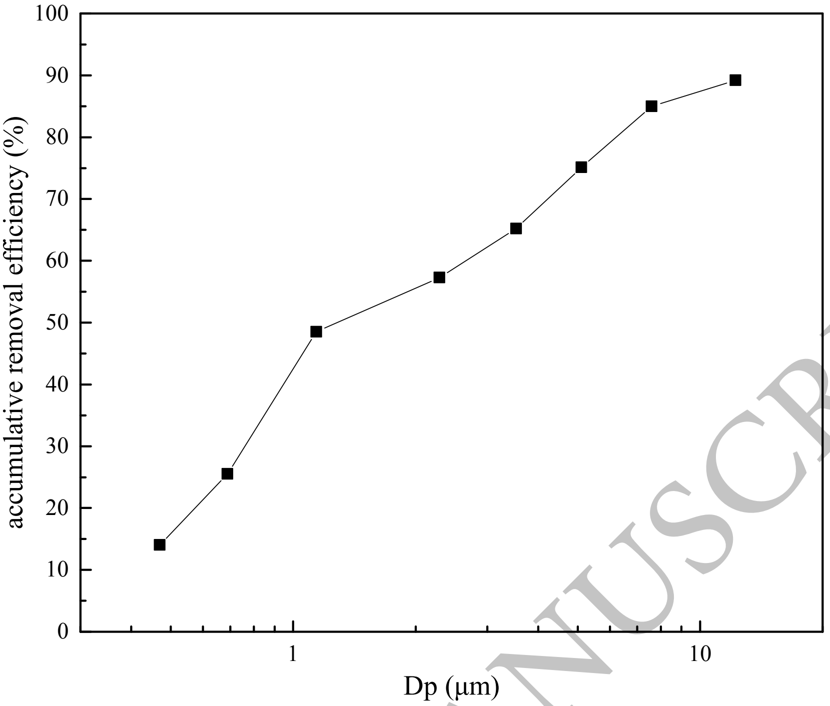

Fig. 3. Accumulative removal efficiency of particles

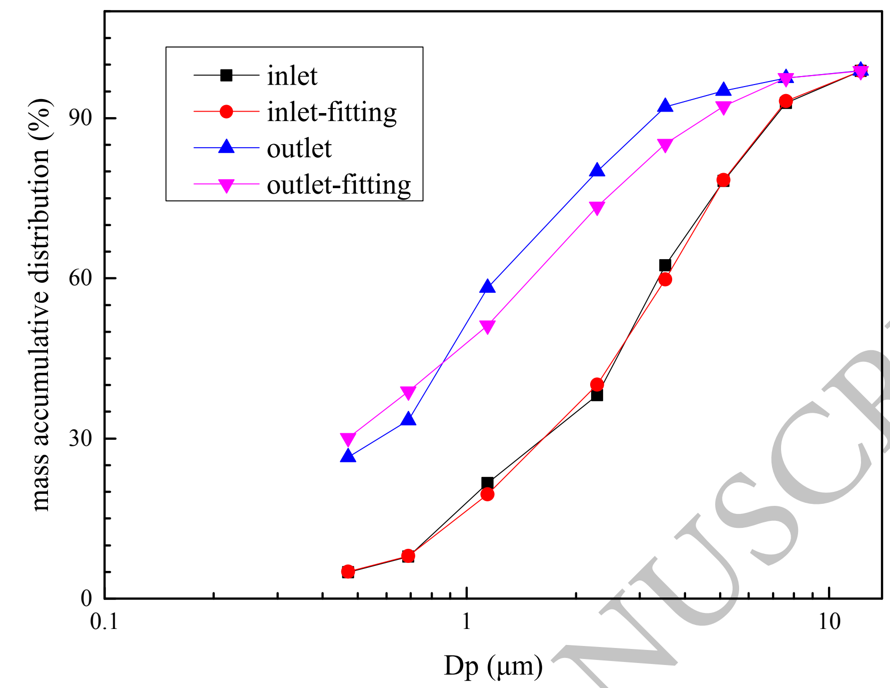

Fig. 4. Particles size accumulative distribution experimental results and R-R fitting curves before and after desulfurization

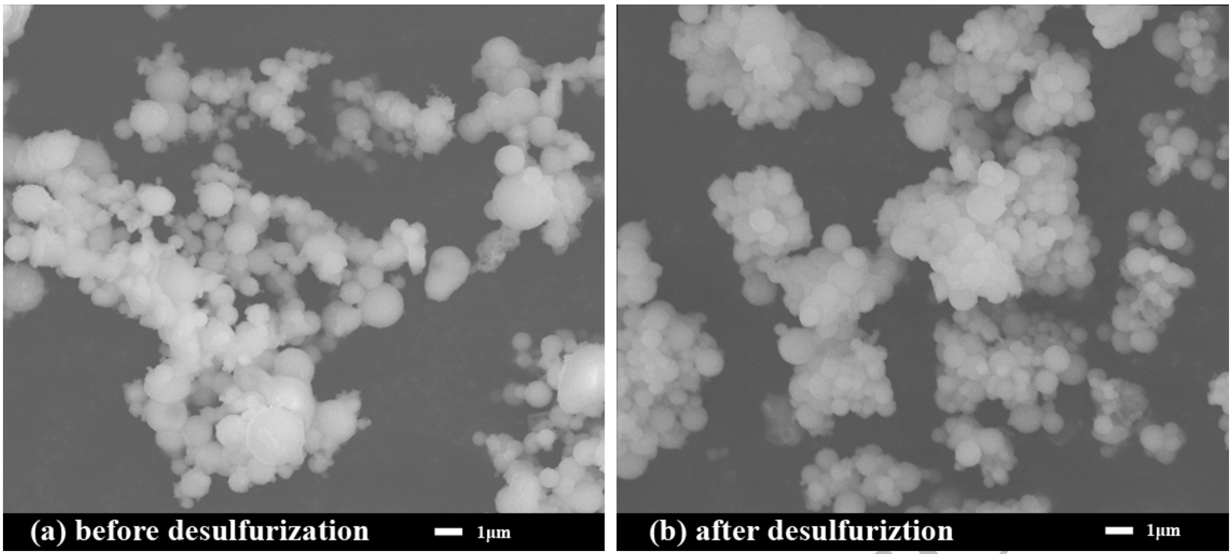

Fig. 5. SEM images of flue gas particles at inlet and outlet of desulfurization tower

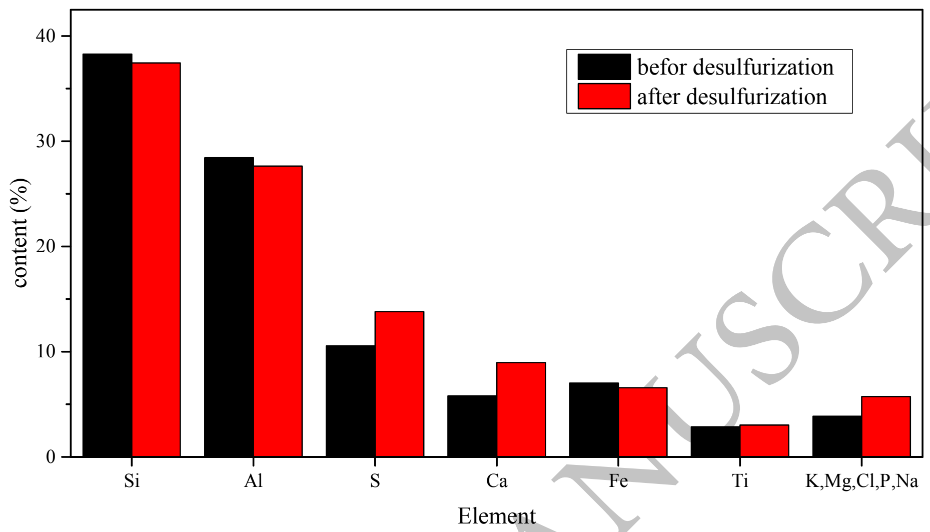

Fig. 6. EDS result of flue gas particles at inlet and outlet of desulfurization tower

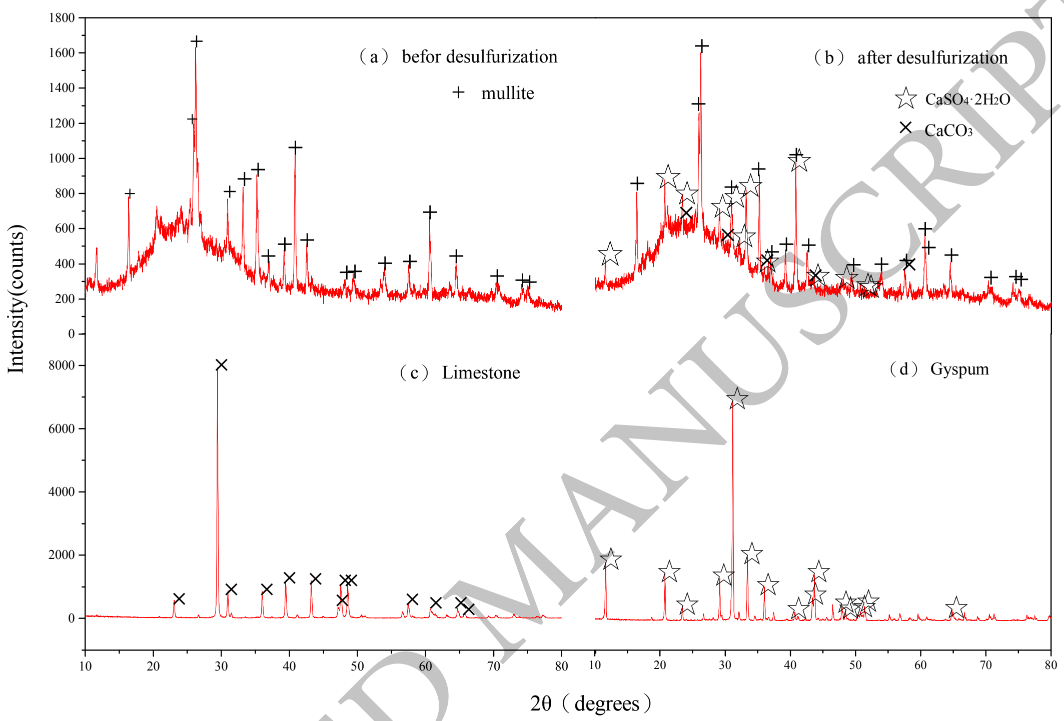

Fig. 7. X-ray diffraction of flue gas particles