National Conference with International Participation
ENGINEERING MECHANICS 2007
Svratka, Czech Republic, May 14 – 17, 2007

DEW POINT OF FLUE GASES: THEORETICAL MODELING AND PRELIMINARY EXPERIMENTS

P. Krejčí*, J. Hrubý*, V. Ždímal+, Z. Trávníček*

Summary: *Based on the industrial needs, the dew point temperature of flue gases is being re-examined, both theoreticaly and experimentaly, with mixture of sulphuric acid and water as a flue gas model, motivated by inconsistency and unsufficient accuracy of previous works, which differ significantly in data of sulphuric acid saturation pressure. Experimental setup based on the Laminar co-flow tube is used to exprress saturation pressure of sulphuric acid via measurements of binary homogeneous nucleation rate.*

1. Introduction

A *flue gas dew point temperature* (DPT) is a temperature to which the combustion gas must be cooled down at a constant pressure and vapours content to become saturated; any further cooling leads to condensation.

By burning a fossil fuel, one of the combustion products always formed, is sulphur dioxide, which after further oxidation and together with water vapour leads to formation of *sulphuric acid*, main cause of the *low temperature corrosion*. Moreover, sulphur oxides rise considerably the DPT even when present in a trace amount (*VDI 4670*, 2003).

Connection between sulphur oxides and DPT was first mentioned by (Johnstone, 1929), since then many methods to avoid the low temperature condensation were suggested and practiced (Barreras & Barroso, 2004; Ganapathy, 1989). However, the amount of suphur oxides produced is a function of many operating variables (Lampert, 1978; Lee & Yen-Shiang, 1985; Muller, 1983) and so every power station is a specific case of technical-economical optimisation (Corti, et al., 1999); none of the solution suggested is universal; an accurate estimate of the DPT is still desirable for an optimisation of existing and a design of newly built fossil power supplies with respect to their service life and efficiency (Dooley, 2006a; Dooley, 2006b).

---

* Ing. Petr Krejčí, Ing. Jan Hrubý, CSc., Ing. Zdeněk Trávníček, CSc.: Institute of Thermomechanics AS CR, v.v.i.; Dolejškova 1402/5; 182 00 Prague 8; +420 266 053 359, fax: +420 286 584 695; e-mail: pkrejci@it.cas.cz

+ Ing. Vladimír Ždímal, CSc.: Institute of Chemical Process Fundamentals AS CR, v.v.i., Rozvojová 135, 165 02, Prague 6, Czech Republic

2. Modelling and experiments

Estimates of the flue gas DPT based on an approximation of experimental data as a function of partial pressures of water and sulphuric acid in a flue gas are rather inconsistent (Halstead & Talbot, 1980) and fig.1, mainly due to the hardly measurable saturation pressure of sulphuric acid.

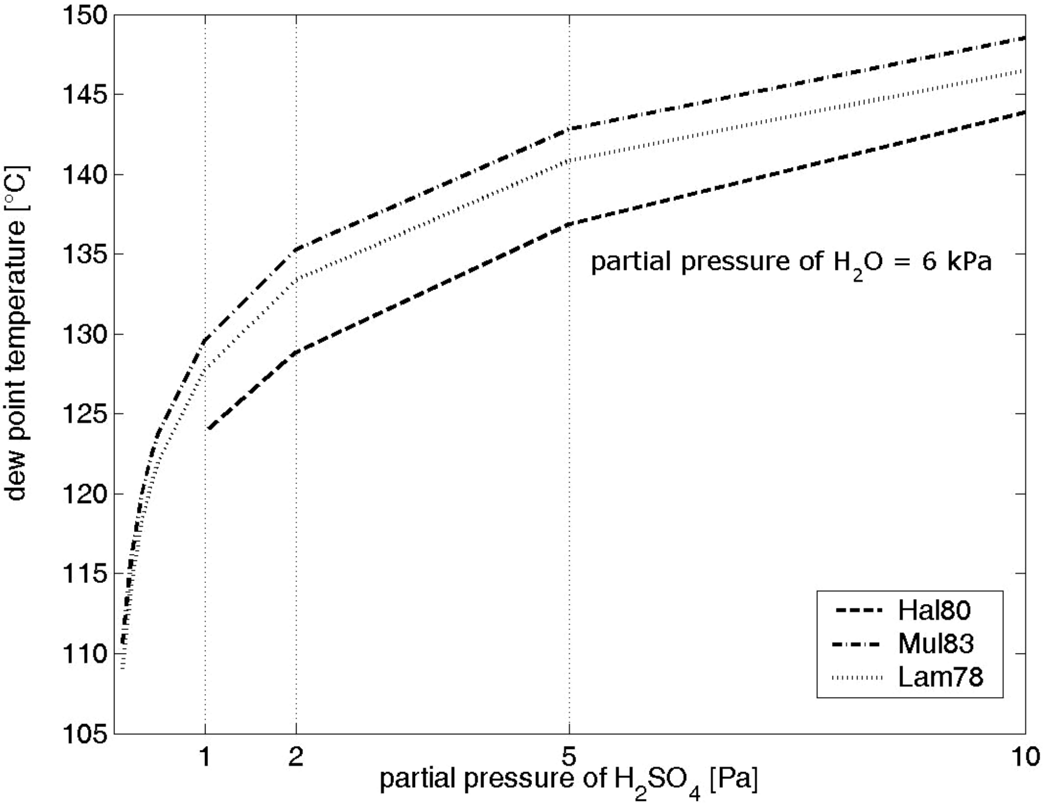

Figure 1: Comparison of several estimates of the DPT as a function of partial pressures of water and sulphuric acid, 6 kPa and 1 to 10 Pa: Hal80 – (Halstead & Talbot, 1980); Mul83 – (Muller, 1983); Lam78 – (Lampert, 1978).

In order to express the sulphuric acid saturation pressure more accurately, there may be used a device built for measurements of nucleation rate in binary homogenous systems with focus on corrosive mixtures (Krejčí, et al., 2004; Krejčí, et al., 2006) together with a model of transport processes inside the device. The nucleation rate is defined as a number of droplets formed in unit volume per second. Use is made of the facts that: the measured nucleation rate is a steep function of mixture composition; the mixture composition is known accurately; and a computational fluid dynamics model of experimental process leading to droplet formation does exist.

3. Experimental setup

The experimental setup, see fig.2, consists of the Mixture Preparation Device (MPD) (Krejčí, et al., 2004), capable to prepare mixtures of up to three vapours, the Laminar Co-Flow Tube (LCFT) (Krejčí, et al., 2006), where nucleation and droplet growth take place, and an Ultrafine Condensation Particle Counter (TSI Inc., UCPC 3025A). Each of the vapours, prepared in the MPD by saturating a dry gas flowing above the liquid surface, proceed separately to the LCFT, where they are mixed by molecular diffusion.

The operating conditions are chosen so that the flow is well within the stability limits as determined by flow visualization (Trávníček, et al., 2005). Due to high non-ideality of the sulfuric acid – water system, the vapour mixture becomes supersaturated. Binary homogeneous nucleation followed by droplet growth occurs in the co-flow region of the LCFT. Number concentration of the formed aerosol is determined by the UCPC. The resulting nucleation rate can be calculated using a computational fluid dynamics model of the flow and concentration fields in the LCFT, provided the known mixture composition, LCFT operating conditions and counted number concentration of droplets

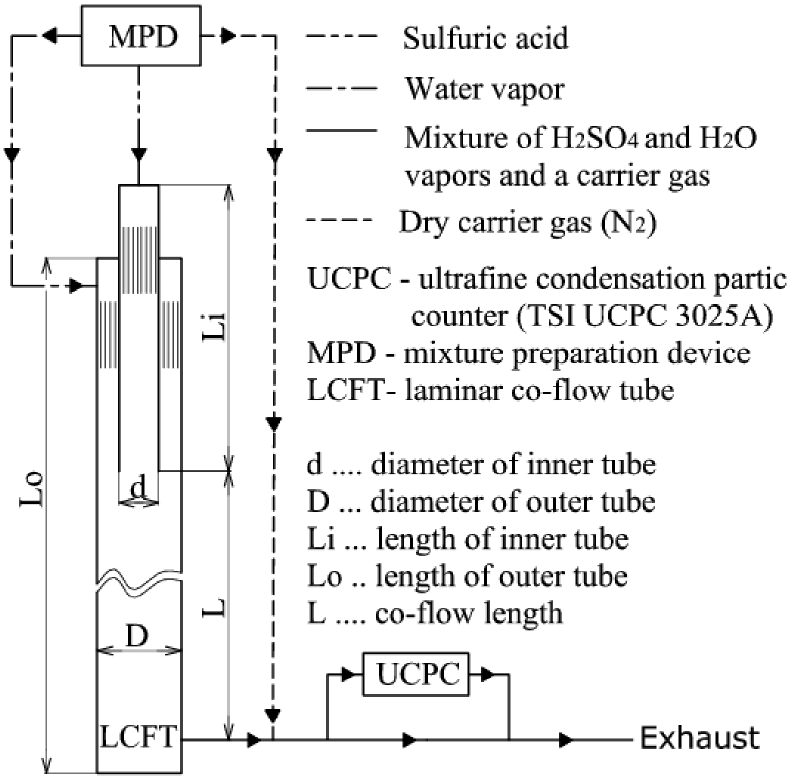

Figure 2: Schematics of the experimental setup, the binary case of sulphuric acid – water mixture depicted.

3. Results & Plans

Preliminary qualitative experiments approved that all parts of the experimental set-up work properly, see fig.3.

To proceed, a suitable method for analysis of mixture composition is being searched to verify repeatability of mixture preparation, after which qualitative experiments will be possible.

4. Acknowledgements

This work has been supported by the Grant Agency of the Academy of Sciences of the Czech Republic, grant no. IAA2076502 and the Czech Science Foundation grant no. 101/05/2524.

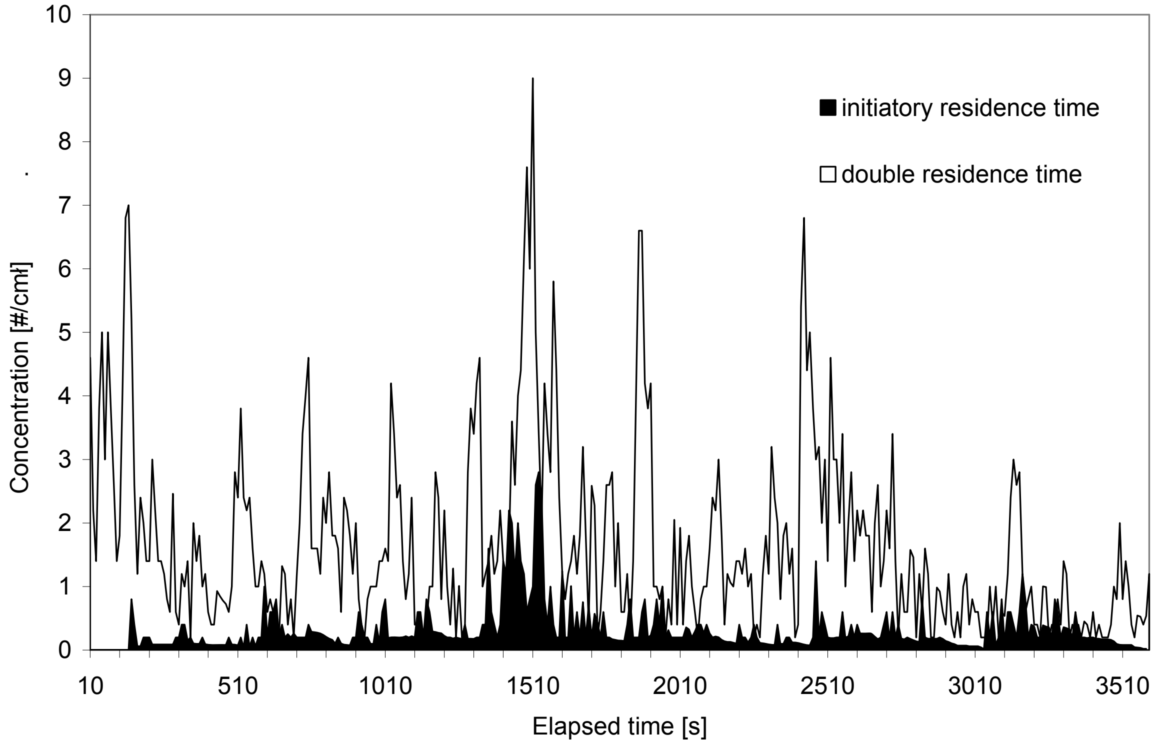

Figure 3: Time history of number concentration of droplets as a function of residence time in the LCFT, results of preliminary experiments: number concentration of droplets detected is proportional to time available for growth of droplets – residence time in LCFT.

5. Literature

Barreras, F. & Barroso, J. (2004): Behavior of a high-capacity steam boiler using heavy fuel oil Part II: Cold-end corrosion. *Fuel Processing Technology*, **86**, 107.

Corti, A., Fiaschi, D. & Manfrida, G. (1999): Thermoeconomic evaluation of the SCGT cycle. *Energy Conversion and Management*, **40**, 1917.

Dooley, B. (2006a): IAPWS Certified Research Need – ICRN: Thermophysical properties of humid air and combustion-gas mixtures. International Association for the Properties of Water and Steam, http://www.iapws.org/.

Dooley, B. (2006b): Minutes of the Meetings of the Executive Committee of the International Association for the Properties of Water and Steam. http://www.iapws.org/.

Ganapathy, V. (1989): Cold end corrosion: causes and cures. *Hydrocarbon processing*, 57-59.

Halstead, W. D. & Talbot, J. R. W. (1980): Acid smuts - the sulfuric-acid dewpoint In power-station flue-gases. *Journal Of The Institute Of Energy*, **53**, 142-145.

Johnstone, H. F. (1929): An electrical method for determination of the dewpoint of flue gases. *Illinois University, Engineering experiment station*, Krejčí, P., Hrubý, J. & Haartsen, J. (2004): New mixture preparation device used in measurement of the nucleation rate in a mixture of aggressive vapors in a shock tube., in *Proc. Ann. Conf.,* p. 47-49, 24. November 2004, in Prague.

Krejčí, P., Hrubý, J., Ždímal, V. & Trávníček, Z. (2006): Laminar co-flow tube for homogenous binary nucleation study, in *Finnish-Czech Aerosol Symp.,* p. 161-164, 8.-10. November 2006, in Helsinki.

Lampert, D. (1978): Low-temperature corrosion in feed-heaters heated by flue-gas. *Brown Boveri Review*, **65**, 691-695.

Lee, K. M. & Yen-Shiang, S. (1985): Dewpoints of flue gases for energy-recovery system design and operation. *Energy*, **10**, 785.

Muller, H. (1983): A Contribution To Studying So3 Formation And To Determining The Sulfuric-Acid Dewpoint In Boiler Plants. *Energietechnik*, **33**, 415-420.

Trávníček, Z., Hrubý, J. & Vogel, J. (2005): Coaxial Jets stability and control possibility. *Developm. Machinery & Control*, **4**, 121-130.

VDI 4670: Thermodynamische Stoffwerte von feuchter Luft and Verbrennungsgasen (2003): (Thermodynamic properties of humid air and combustion gases) VDI - Handbuch Energietechnik, Düsseldorf.