LUND UNIVERSITY

Dept of Industrial Elect. Eng. & Automation (IEA)

ADM1 Implementation from Lund University

10 November 2006

Agreement with Lund University

To whom it may concern

Dear Colleague,

The models of the ADM1 (Batstone *et al.*, 2002) you have just received represent the implementations from the Department of Industrial Electrical Engineering and Automation (IEA), Lund University, Lund, Sweden. The work has been carried out by Dr Christian Rosen, Dr Darko Vrecko and Dr Ulf Jeppsson.

The models are available for the Matlab®/Simulink® platform and have been written in C (incorporated into Simulink as C MEX S-functions). You need to compile the C files for your own processor/computer (use the mex command within Matlab, the internal compiler will work fine). We have used Matlab release 13.1 (Matlab 6.5) but the models will also work fine on release 14 (Matlab 7, 7.1 & 7.2).

The models represent our interpretation of the ADM1 model and include some modifications compared to the original ADM1 report. Specifically, the implementations are made to fit into the framework of the Benchmark Simulation Model no 2 (BSM2), which is currently being developed by the newly formed IWA Task Group on Benchmarking of Control Strategies for WWTPs (Jeppsson *et al.*, 2006). This also means that some details of the current implementation may still change as the development of the benchmark continues. Gradually, detailed information concerning the work of the task group will become available on www.benchmarkwwtp.org.

The changes to the original model include:

- Extended stoichiometry to guarantee mass balances for nitrogen and carbon in the AD;
- Modification of default values for $f_{xI,xc}$, $f_{li,xc}$,N_I, N_{bac} and N_{xc} to correct an inherent nitrogen unbalance in the ADM1 and to add consistency with the ASM1 model (Henze *et al.*, 1987);
- Modification of default value for C_{XC} (carbon content of composite material) to correct an inherent carbon unbalance in the ADM1;
- Modification of the acid-base equations for better numerical properties in ODE implementation;
- Modifications of the $K_{A,B}$ parameters in the ODE implementation for more consistent results with DAE;
- Use of the second alternative in the ADM1 report (Eq 5.10) for calculation of the gas flow rate to avoid numerical problems and possible multiple steady-state solutions. Note that the output gas flow rate is normalized to

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atmospheric pressure (adjustment related the slight head space over-pressure);
- New inhibition functions (Hill functions) to avoid discontinuities and consequent associated numerical problems;
- Active temperature dependency of the model parameters for which such information are available in the original ADM1 report, i.e. K_w, $K_{a,va}$, $K_{a,bu}$, $K_{a,pro}$, $K_{a,ac}$, $K_{a,CO2}$, $K_{a,IN}$, $K_{H,H2}$, $K_{H,CH4}$ and $K_{H,CO2}$;
- Five dummy states (currently not used) are defined in the code for ease of future model expansions.

The details of these changes can be studied in Rosen *et al.* (2006a) and Rosen *et al.* (2006b).

However, the main contribution of these models is that they are available in three different versions:

1. A traditional model based on ordinary differential equations (ODE). This version leads to a very stiff numeric system and requires stiff numerical solvers to work. However, for steady state analysis it works well.
2. A DAE model based on differential equations but with an algebraic solution of pH (S_{H^+}). The algebraic solver uses a Newton-Raphson method and we acknowledge the support from BIOMATH, Ghent University, Belgium for providing us with this solver (Volcke *et al.*, 2005). The stiffness of the model is reduced but only to a very limited extent.
3. A DAE model based on differential equations but with algebraic solutions of both pH (S_{H^+}) and S_{h2}. The algebraic solver again uses a Newton-Raphson method. In this model the stiffness is drastically reduced and full dynamic simulations including stochastic inputs etc. become feasible (dramatically improved simulation speed using non-stiff solvers).

All three models provide (for any practical purpose) identical results (Rosen *et al.*, 2006a).

In principle we provide these implementations for free in a true academic spirit and can therefore not offer any traditional support. You may contact us to discuss various aspects of the models but we do not guarantee that we can find time to assist you. However, we do ask you to:

- **Send us feed back** in case you find errors or possible improvements to the implementations or if you come across operational situations where any of the three implementations behave differently or strangely compared to the others;
- **Send us copies of scientific papers** you write, which are to some extent based on the use of any of these three model implementations;
- **Please acknowledge the work that has been carried out by us** in any papers you publish, where the use of our model implementations have had an impact.

We hope that you will enjoy and benefit from the use of these models and also that it may lead to more scientific collaboration between our groups in the future. You are always welcome to contact us on such matters.

Sincerely,

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References

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