FFG

K1 MET
metallurgical competence center

K1-MET
Competence Center for Advanced Metallurgical and Environmental Process Development
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Recurrence CFD - next-generation simulation methods

Complex flow phenomena can be pictured even with sufficient computer power only for short durations, which limits the applicability to many industrial problems. With a novel approach called recurrence CFD, however, it is possible to simulate dynamic flows with recurrent patterns, e.g. in fluidized beds or bubble columns, several orders of magnitude faster than before. This way, particularly long-lasting processes like chemical conversion or heat transfer can be described. Even real-time capability could be reached.

Can simulations help us for the understanding of industrial processes?

With the continuously increasing power of modern computers, simulations of various industrial processes, e.g. complex multiphase flows in metallurgical applications, have become popular. They enable numerical experiments, which are cheaper than conventional measurements, give a huge amount of easily accessible information and allow the safe investigation of critical states.

While state-of-the-art simulations can easily compete with lab-scale experiments, at least two challenges need to be faced for the application to industrial-size processes. Only for the last few years, a modelling technique called “coarse graining” has been developed to combine a detailed description of small-scale properties, e.g. the behaviour of single coke particles in a blast furnace, with the huge dimensions of the full plant. Regarding temporal aspects, there is a very similar problem. While the dynamics of several flows happens very fast, e.g. collisions in a fluidized bed, other processes like heat transfer or chemical conversion take much longer. Until now, there was no strategy to capture the fast variations and at the same time reach the long times necessary for a proper description of the slow processes. The usability for many industrial applications which exhibit both types of degrees of freedom was therefore strongly limited.

Next-generation simulation techniques

To solve this problem, it is necessary to decouple slow from fast degrees of freedom. Using detailed simulations, the dynamics of a flow is obtained for a short duration and subsequently analysed. So-called recurrence plots as shown in Fig. 1 provide information about the reappearance of characteristic patterns, e.g. bubbles in fluidized beds, and their evolution. This way, the approximate behaviour of such structures can be predicted for arbitrary long times without additional computation effort and any slow, long-lasting process can then be calculated easily.

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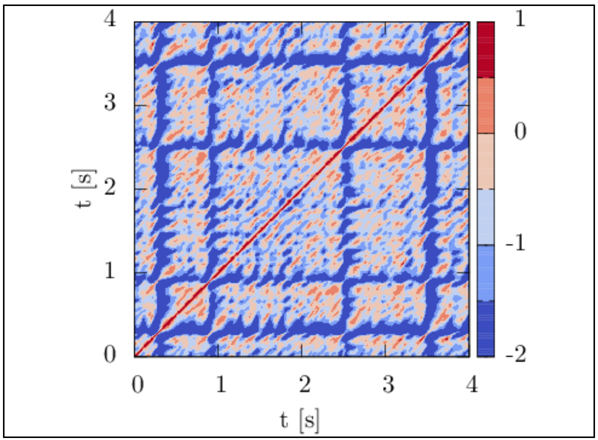

Fig. 1: Recurrence plot of a fluidized bed for four seconds. Each point's coordinates correspond to the times to be compared with each other. Red indicates "very similar states", blue "very dissimilar".

Within a cooperation of the Department of Particulate Flow Modelling, the Linz Institute of Technology (both Johannes Kepler University), the Eindhoven University of Technology and K1-MET, recurrence CFD was tested on a fluidized bed in which warm particles were mixed with cold air and slowly cooled. As shown in Fig. 2, the results agree very well with both experimental values and detailed calculations at 1/300 of their runtime!

Impact and effects

The fact that already first tests of recurrence CFD led to accelerations of conventional simulations of more than two orders of magnitude at almost the same accuracy indicates the huge potential of this completely new approach for dynamic flows with recurrent patterns. Given a consistent further development of the method, long-lasting processes in fluidized beds, bubble columns, the mould of continuous casting plants etc., which have hardly or not at all been possible to picture, will be simulated easily to gain new insights.

How far can this journey go? Which visions may be pursued? Real-time capability might be possible, i.e. simulation results would be available faster than they occur in the actual process. One could, for example, react to critical signals of a measurement device with a "glance into the future" to make a sensible decision how to proceed. The way recurrence CFD will develop eventually depends on several factors, especially on stable research collaborations. In any event, the foundation for a completely new generation of simulation methods has been laid.

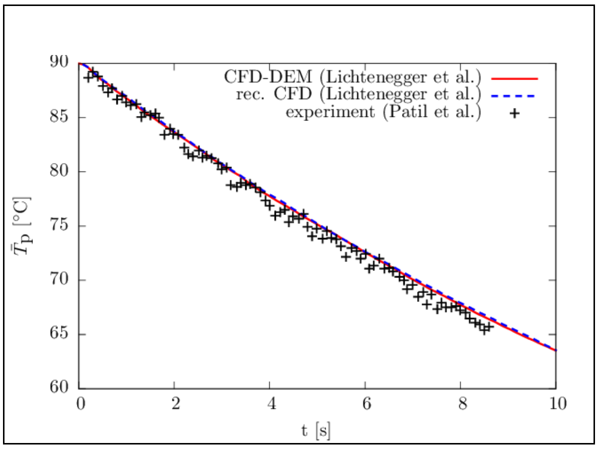

Fig. 2: Mean particle temperature over fluidization time. Both conventional CFD-DEM simulations and recurrence CFD (Lichtenegger et al., Chem. Eng. Sci. 2017) agree very well with experiments (Patil et al., Chem. Eng. J. 2015).

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