Advances in the Theory and Practice of Hydrocyclone Technique

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Abstract

With numerical simulation of hydrocyclone separation based on the Navier-Stokes and mass transfer equations, it is possible to perform hydrocyclone experiments on a computer. With the help of computational engineering, the cost of conducting hydrocyclone experiments in the planning phase of new hydrocyclone units can be cut drastically. The simulation models also enable a deeper insight into the static and dynamic process behaviour in hydrocyclones. It is shown that the solids stored in the hydrocyclone represents a sensitive process variable for separation in the hydrocyclone. On this basis, a new control concept for a hydrocyclone battery has been developed. As the solids concentration in the feed increases, the combined overflow of all the hydrocyclones in the battery is throttled. At the same time, the feed pump speed is increased. In this way, while the total throughput remains constant, the volume split changes to effect that more solid material is discharged in the hydrocyclone underflow. This computer-based process control system is ideally suited for hydrocyclones in separation plants for tunnel driving projects as well as for those integrated closed-circuit grinding processes.

Keywords: hydrocyclone, process control, numerical simulation, computational engineering

Introduction

In recent years, alongside the traditional use of hydrocyclones in mineral processing, new applications, particularly in the field of environmental engineering [1 – 4], have opened up for these separators. Examples in this context include their use for gypsum separation in wet flue gas desulphurization processes, in washing plants for contaminated soils and in separation plants for tunnel driving projects. To ensure that the potential of hydrocyclone engineering is fully utilized, the optimum hydrocyclone geometry specific to the respective application, the correct combination of materials and appropriate operating parameters are essential. Extensive experiments in pilot scale are therefore required in the planning phase. The effort involved in this process can be reduced substantially with the help of modern computational engineering. This paper reports on hydrocyclone experiments performed with a PC, on the basis of numerical simulation models. These simulation models enable a deeper understanding of the static and dynamic processes in hydrocyclones. From the results of these experiments, approaches for the development of a computer-based process control of hydrocyclone plants can be derived. The paper describes a computer-controlled battery of 150-mm hydrocyclones, to be integrated in separating plants with widely varying feed conditions.

Computer-Based Hydrocyclone Experiments

The flow conditions in a hydrocyclone are characterized by a three-dimensional, turbulent two-phase flow, which has still not been adequately understood and documented. In the past, analytical models were elaborated based on highly simplified conditions [5 - 7]. With these models, it is possible (allowing for turbulence) to describe the separation efficiency in the hydrocyclone in the form of a separation function. However, although this separation model may be correct on principle, in individual cases the difference between the measured and calculated values may be quite considerable. This discrepancy can be attributed to the simplified model conditions as well as an imperfect understanding of the fundamentals of hindered particle movement. The latter leads to difficulties particularly in the case of dense flow separations (high solids concentration). New possibilities for such applications are afforded by the numerical simulation of hydrocyclone separation on the basis of the Navier-Stokes and mass transfer equations. The elements of mathematical modelling in such simulations are the stable and exact discretization of differential equations while maintaining the essential model properties, and the elaboration of effective iterative algorithms for two-dimensional time-dependent processes. With utilization of the facilities for computer visualization, such simulation calculations can also be represented as hydrocyclone experiments on a PC. The theoretical basis for numerical modelling of hydrocyclone separation will not be discussed further in this paper as it has already be dealt with extensively in various other publications [8 - 10]. For the calculations, the material data, the hydrocyclone geometry and the operating parameters must be specified as the input values. As a result of the simulation experiments a complete balance of the separation process is obtained, i.e. the throughput, the volume split, the separation function as well as any parameters derived from these results.
Moreover numerical simulation can allow a deeper insight into the static and dynamic process behaviour of hydrocyclones and thus provide a basis for the development of new automatic process control strategies. In particular, for every point in the hydrocyclone, these models are able to yield the velocity of the fluid and the particles and the particle concentrations for each size class. From the example shown in Fig. 1, it can be seen that, as a function of the solids concentration and particle size distribution of the feed, a specific spatial concentration distribution is established in equilibrium conditions for each particle size class. At low feed concentrations (dilute flow separation), the particle sizes examined are largely separated at the walls of the hydrocyclones. With rising concentration of the feed, pronounced radial concentration distributions develop, in which the particles are forced increasingly towards the hydrocyclone axis and therefore in the direction of the overflow (Fig. 2). If the path of the individual particles is traced accordingly, the diagram plotted in Fig. 3 results. The figure shows that, as the feed concentration rises, the particles in the cut-point range demonstrate an increasing tendency towards large-area

convection. Depending on their size, however, the particles may travel on these vortex paths for considerable residence times.

Figure 1: Particles concentration of different fractions in the hydrocyclone
Inlet particles concentration 230 g/l

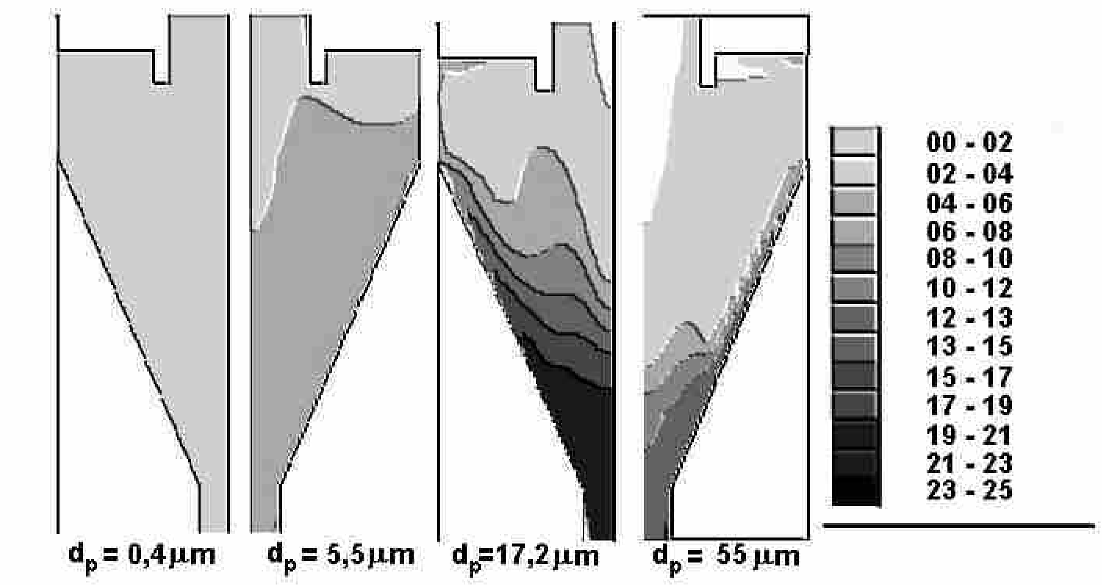


Figure 2: Particles concentration in the hydrocyclone of the fraction d_p = 50 µm

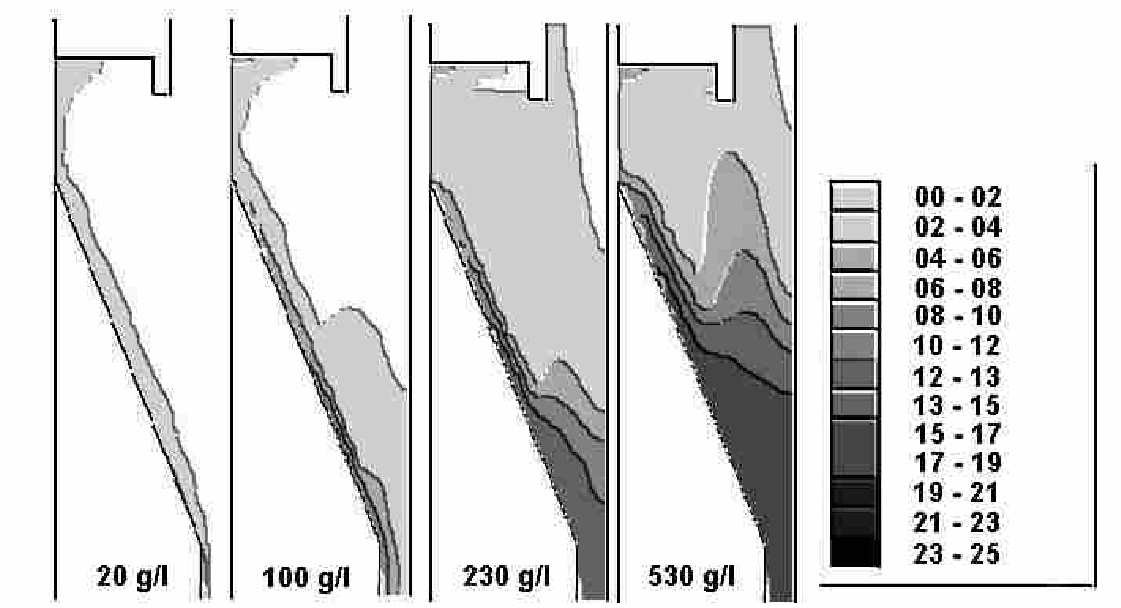
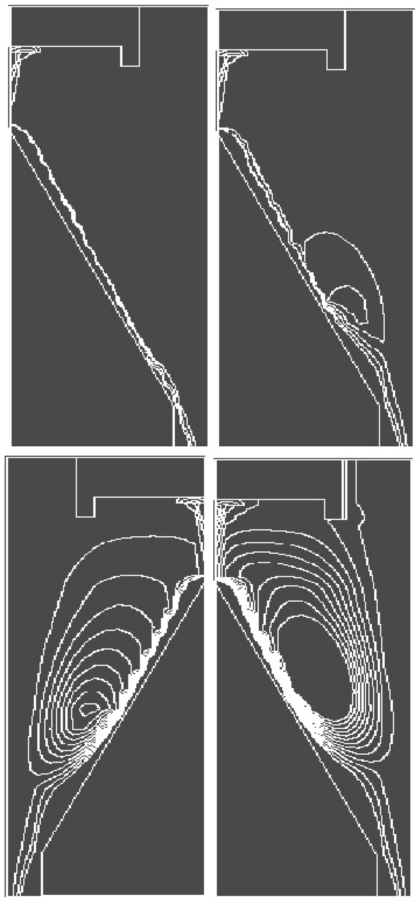


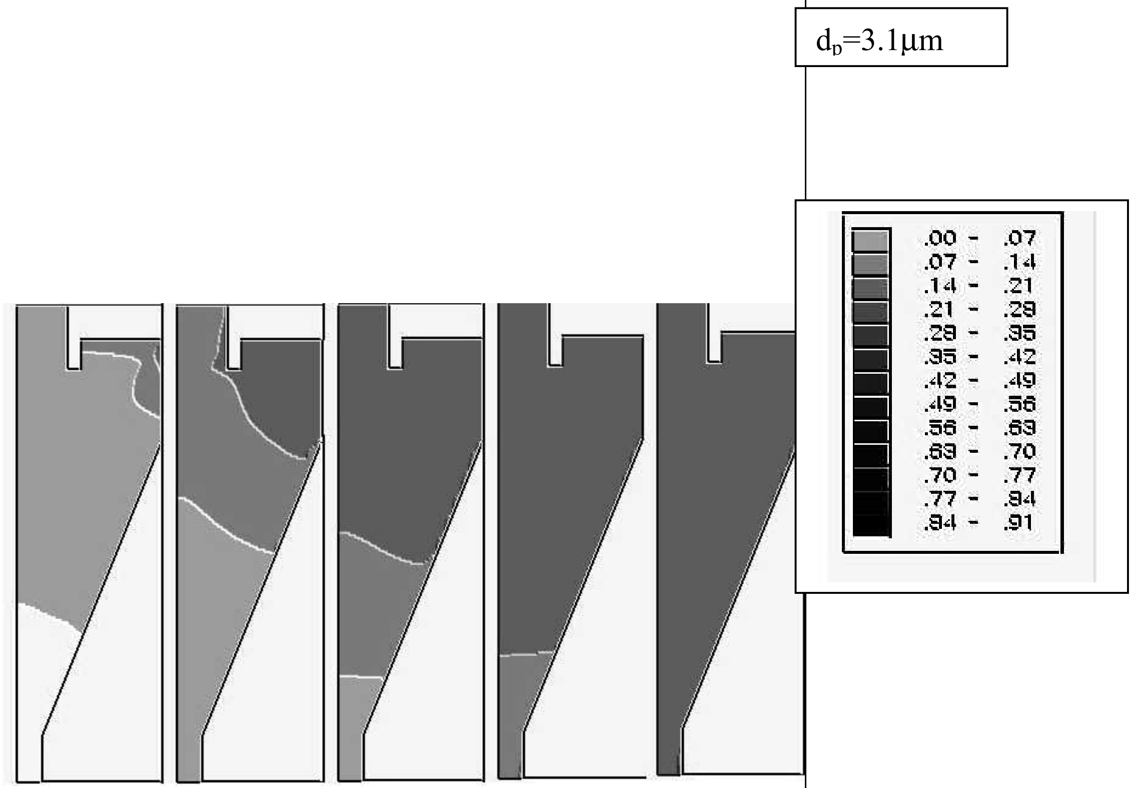
Figure 3: Particles trajectories dp = 55 mm



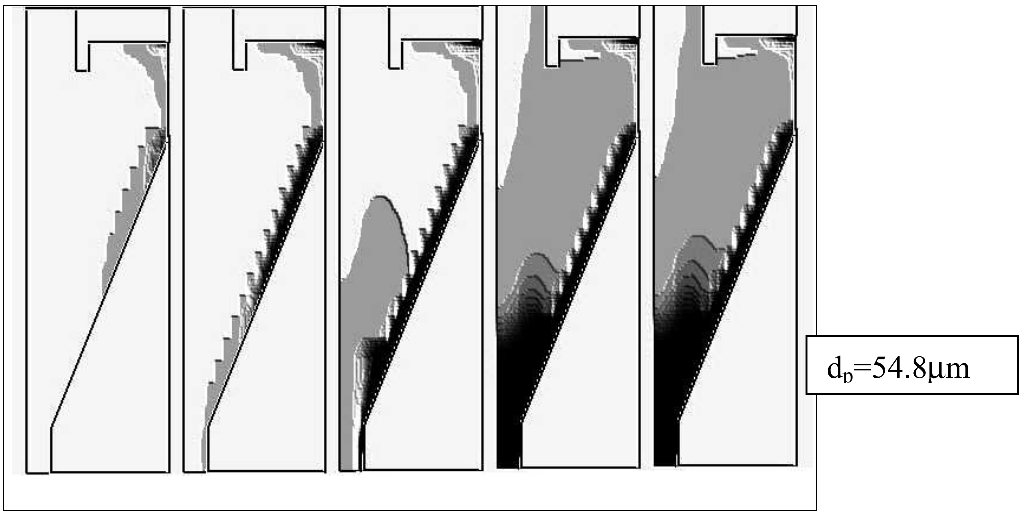
Inlet solid concentration: a – 20 g/l, b –230 g/l, c– 370 g/l, d – 530 g/l

In response to feed conditions that vary over time, the hydrocyclone demonstrates a very sensitive dynamic behaviour, i.e. in such cases, the time dependence of the spatial concentration distributions must also be considered. In Fig. 4, the time-dependent development of the concentration distribution is plotted for a leap in the concentration at the feed inlet from 0 to 200 g/l. These model calculations show that the spatial solids distribution or the particle mass stored in the hydrocyclone represents a characteristic process variable, which can be used for control purposes. This concept is explored further in the following section.

Figure 4:Hydrodynamik und Separation im Hydrozyklon



t=0.125s t=0.625s t=1.25s t=1.875s t=2.5s



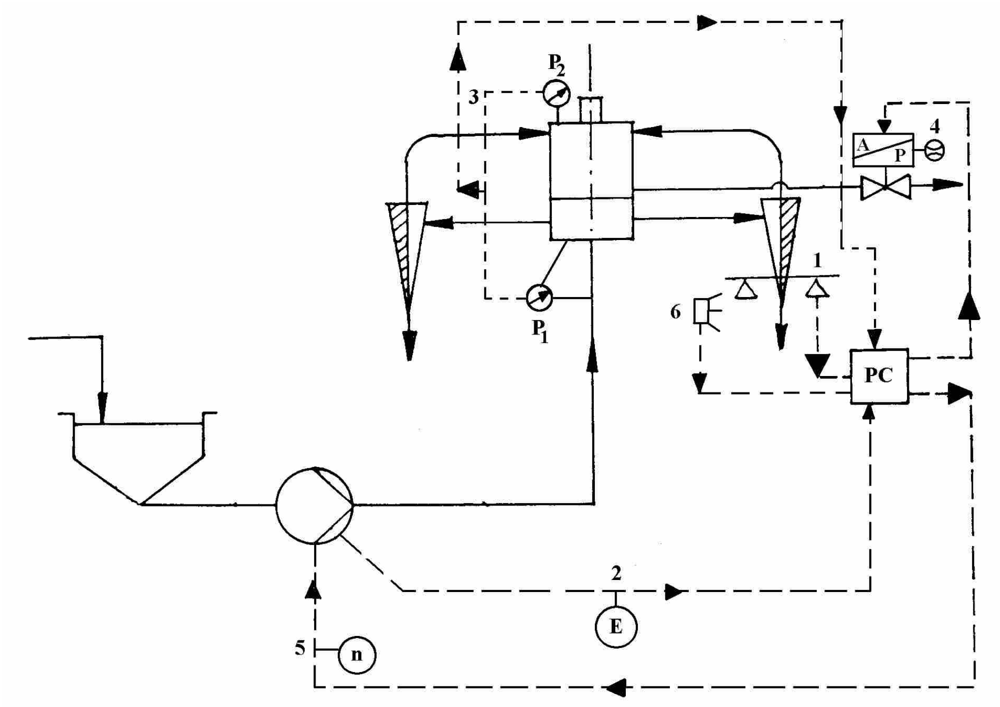
Computer-Controlled Hydrocyclone Battery

An important function of a process control system for a hydrocyclone plant is the stabilization of the cut-point or slurry density in the overflow respectively for feeds with varying solid concentrations and particle size compositions. Appropriate regulation of the volume split has so far been restricted to single hydrocyclones of larger diameters in which adjustable underflow nozzles have been fitted. For smaller hydrocyclones, interconnected in batteries, this concept is not feasible. Moreover, the following two premises must be created:

- measurable process variables for the characterization of separation in the hydrocyclone,
- regulated quantities for the process, without manipulation of the individual hydrocyclone

These criteria are met by a new control concept [11], which is shown in the schematic in Fig. 5. The process variables are simply determined at one measurement hydrocyclone within the battery of parallel-connected single hydrocyclones. One measurable value in this case is the mass of the solids stored in the hydrocyclone. The solids mass is determined by means of a special fastening means of the cyclone with a gravimetric measuring cell (1). Another measurable variable is the form of the underflow discharge (rope or fan-shaped discharge). These two process values are entered, together with the values for the power input (2) of the feed pump, pressure of the feed into the hydrocyclone and the pressure drop (3) over the hydrocyclone, into the process control computer. A throttle valve (4) for control of the combined overflow of all hydrocyclones and the feed pump speed (5) serve as regulated quantities. With increased throttling of the overflow, the volume split is changed to the effect that the solids discharge in the underflow is intensified. To stabilize the total throughput, at the same time the feed pump delivery rate is increased to the extent that the pressure drop over the hydrocyclone Δp remains approximately constant. However, this causes the pressure inside the hydrocyclone to build up, which results in a further intensification of the (unthrottled) underflow discharge. The control concept is oriented towards achieving the optimum operating state at the transition from rope to fan-shaped discharge. For this purpose, the shape of the discharge column of the underflow is monitored by means of a capacitive probe. The shape of the discharge flow (i.e. rope or fan) is influenced by the concentration distribution or the mass of the solids stored inside the cyclone, i.e. this signal of the capacitive (6) probe corresponds to the mass of solids stored in the hydrocyclone.

Figure 5: Principle of the hydrocyclone regulation



With this control system implemented in a 150-mm hydrocyclone, it is possible to stabilize separation for varying solid concentrations up to 500 g/l at a cut-point of approximately 30 µm (Fig. 6) or a slurry density of 1.1 kg/m³ in the overflow. Selected technological values of this 150-mm hydrocyclone separation process are listed in Table 1. The table shows that, at a feed suspension of the particle size range < 2 mm and feed concentrations of up to 500 g/l, a maximum solids recovery per cyclone in the underflow of up to 79 % can be achieved. This represents such an improvement in the discharge capacity of the 150-mm hydrocyclone that the installation of a preliminary cyclone of a larger diameter is no longer necessary. With such a computer-controlled process, it is also possible to replace a two-stage hydrocyclone circuit with a single-stage plant. Other benefits are derived from the possibility of a remote control of the hydrocyclone plant on the basis of remote data transmission. The control concept was initially developed for separation plants for tunnel driving projects, where the solids concentrations can vary over very wide ranges between 50 and 500 g/l, with a corresponding solids discharge between virtually 0 and 16 t/h per 150-mm hydrocyclone. The concept can be implemented for hydrocyclone batteries or for large-sized single hydrocyclones if, for example, especially high separation efficiency is required despite wide variations in the feed parameters. In particular, this concept is to be further pursued with regard to developing suitable control systems for hydrocyclones integrated in closed grinding circuits.

Figure 6:Separation curves of the 150 mm-hydrocyclone with or without throttling (solid feed concentration 420 g/l)

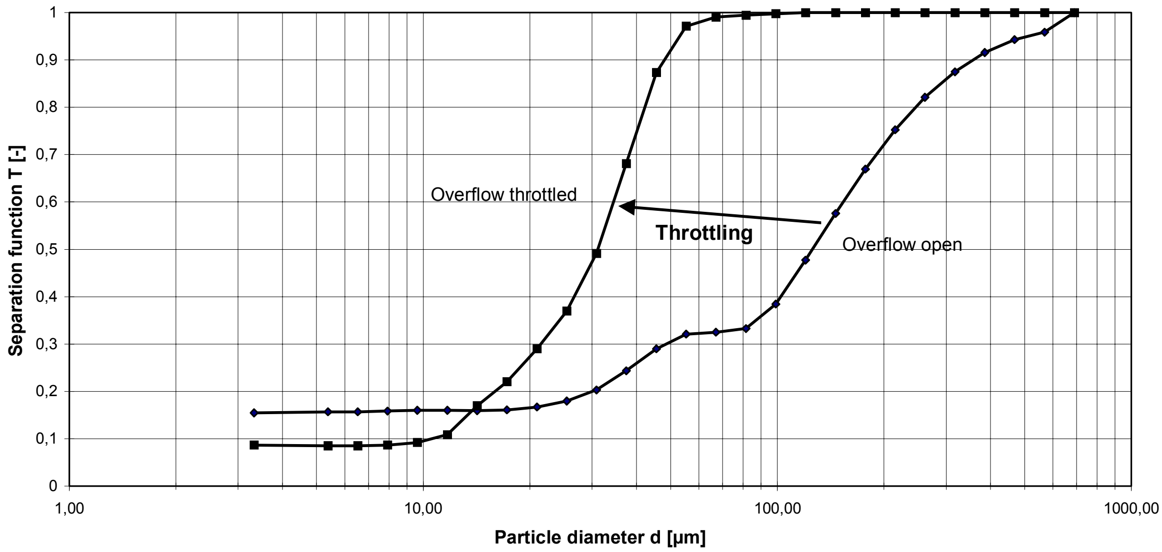


Table 1: Control of a 150-mm hydrocyclone, D_i = 50, D_O = 72 mm, D_U = 29 mm, with a solids concentration of 550 g/l (< 2mm) in the feed

Feed pump speed min^{-1}	Counterpressure in the overflow p_1 bar (throttling)	Split $\dot{V}_O / \dot{V}$ %	Solids recovery in the underflow t/h
1080	0	79	54
1140	0.10	78	54
1200	0.25	74	65
1260	0.30	73	70
1310	0.45	68	79

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