High-volume kneading reactors

Combined processing of solid, liquid and highly viscous materials

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High-volume, industrial-type kneading reactors are used today to achieve processes which would otherwise need several individual operations in a combined one-step process. These processes usually take place in a concentrated phase, practically without solvents or diluent carrier phases. This article outlines the principal requirements of combined one-step processes, and highlights the multifunctional characteristics of the versatile process equipment in question.

Various developments over the past few decades have succeeded in using heavy-duty agitated vessels or Sigma blade kneaders for batch processing and screw-type or special thin-film equipment for continuous high-viscosity processing, e.g. polymerisation, solid-liquid reactions or combined mixing, reaction, evaporation and devolatilisation processes. Recently, versatile single and twin- shaft kneaders combining high working volumes and contact heat-exchange surfaces with a heavy-duty design were developed |1, 2| The large dimensions of the process chamber of this equipment permits long dwell times. It therefore opens up new possibilities for combined one-step processing with processes characterised by slow chemistry, the introduction of large amounts of process gases or the evolution of large amounts of vapours. The table shows the complex interdependencies between the design features of this equipment and the functional aspects of combined one-step processing in concentrated phases where mechanical, thermal and chemical operations interface.

Multistep processing in batch units

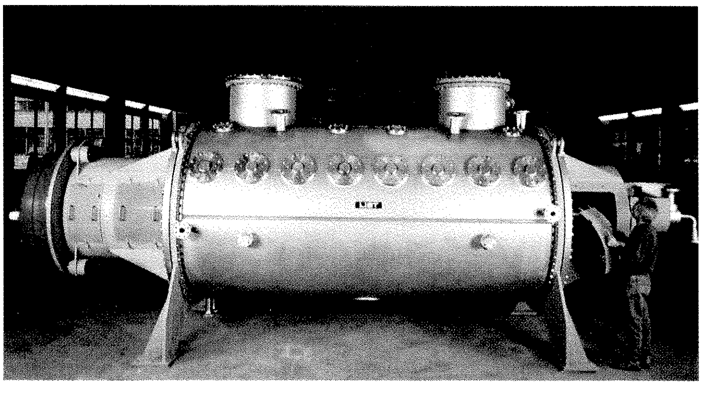

Fig. 1 Discotherm B 8000 batch reactor

Batch processing is generally more flexible because all the process parameters, such as the operating pressure, heating temperature or agitator speed, can be easily changed during a batch cycle according to the specific needs of each process step or product formulation. Two constraints should be borne in mind, however: the final product must be a freely flowing solid or liquid in order to be discharged by gravity and the installed torque must be high enough to overcome the peaks that occur during transitional stages, in which the entire batch exhibits maximum viscosity.

Kolbe synthesis

Sodium salicylate is used as an intermediate for the production of acetyl salicylic acid.
Large, single-shaft Discotherm B batch-type kneaders with a heavy-duty design (Fig. 1) and a total volume of up to 10 m^3 (working volume approx. 6 m^3) are used industrially for this typical multistep synthesis, starting with phenol and sodium hydroxide solutions.
There are several successive phase changes where the product repeatedly changes back and forth between liquid and pasty or solid granular. In order to achieve the best possible yield and degree of conversion with fewer by-products, therefore, it is important to ensure very tight control of the product temperature, particularly during the carboxylation reaction. This can be achieved with the aid of these kneaders, thanks to the combination of good mixing/kneading properties and interface renewal with large, self-cleaning heat-exchange surfaces (Fig. 2).

Combined continuous processing

Extruders or similar screw-type equipment are already widely used for high-performance, combined one-step continuous processes in the polymer and food industries, for example for:

- melting/compounding/devolatilising polymers,
- reactive extrusion and bulk polycondensation.

However, if slow, diffusion-controlled chemical or physical processes requiring long dwell times well in excess of 10 minutes are involved, or if large amounts of gases or vapours need to be removed, the relatively small working volumes and the restricted free cross-sectional area and vent port sections of extruders and similar screw-type processing equipment act as constraints.
The high-volume kneaders/reactors of the CRP/ORP types |1, 2| are able to avoid these constraints. They open up new means for developing customised continuous technologies in close collaboration between the producer and the equipment supplier.

Combined chemical reaction and drying processes

Urea resin production by combined one-step polycondensation and drying is a very effective way to obtain final product as shown in

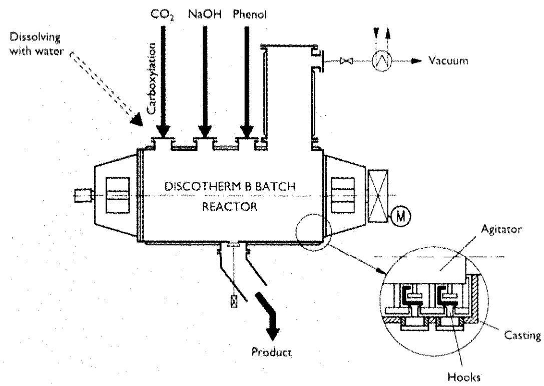

Fig. 2 Kolbe synthesis

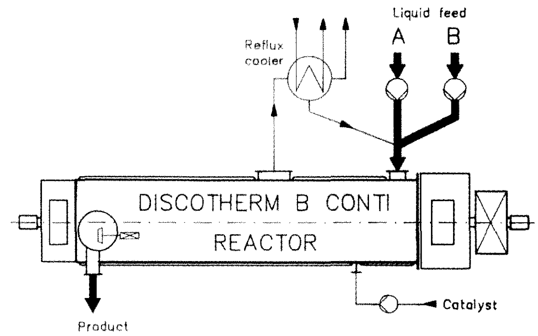

Fig. 3 Urea resin reactor

figure 3.
Concentrated hot urea solution and liquid aldehyde are continuously fed in a stochiometric ratio to a continuous, single-shaft reactor/dryer. The addition of catalyst initiates the exothermic reaction in the first section. The excess heat of reaction is partly removed by evaporation of aldehyde, which is condensed in a reflux condenser. The reaction mass undergoes a series of phase changes from a slurry through a pasty, sticky intermediate phase to a final, crumbly solid state, and is then dried in the second half of the unit. The whole process is autothermic in steady-state operation.

Continuous evaporation or drying combined with chemical conditioning

Continuous vacuum evaporation and drying of distillation residues, polymer solutions and food concentrates are important applications for heavy-duty kneaders/dryers. In most of these applications the drying process is combined with the necessary chemical modification of the product under controlled temperature and dwell-time conditions. The following are examples of this:

- Maillard reactions provide delicate flavouring for milk crumb, dried under vacuum from sugared milk concentrate.
- Toluene-di-isocyanate (TDI) is recovered from extremely sticky, toxic and chemically unstable distillation residues by continuous vacuum evaporation. A high yield and safe conversion of the residual tars to a non-toxic, granular matter by a chemical reaction can only be achieved in a low vacuum and with a long dwell time.

Future develoments

When fine chemicals or polymers need to be processed, heavy-duty kneaders/reactors allow several operations such as melting, the chemical reaction, devolatilisation and mixing or compounding to be combined in a single unit. New technologies with considerable potential are currently being developed in close cooperation between manufacturers and equipment suppliers.

Hall 4.1, stand F8
Further information **cpp-284**

High-volume kneading reactors

	Design features	Functions in combined one-step processing
Mechanical		
	● Intermeshing static and rotating mixing/kneading elements; adjustable geometry	● Intensive mixing/kneading in all phases, whether liquid, highly viscous, pasty or free flowing solids
	● High interface renewal frequency	● Efficient mass transfer; devolatilization
	● Large free sections	● Gas or vapour disengagement, narrow residence time distribution in continuous operation
	● Heavy design; installed torque up to 6 10^5 Nm	● Processing of pruduct viscosities up to 2 10^4 Pas; handling of any phase change
Thermal		
	● Large self cleaning heat exchage surfaces, up to 100 m^2/unit	● Tight control of product temperature profile ● Important heat transfer capacity for controlling highly endothermic or exothermic processes ● Effective removal of excess mechanical heat input
Chemical		
	● Large total volumes, up to 10 000 l	● Long residence times up to several hours or slow diffusion controlled processes. Typical fill level range: 50 to 80%
	● Closed design, operating pressure up to 1500 kPa abs; availability of vacuum/pressure locks	● Vaccum or pressure operation; product temp. control via boiling temperature (evaporation; chemical reactions)
	● Welded design in c.s., s.s., special alloys	● Handling of corrosive or abrasive materials
	● Units for batch or continuous operation	● Integration with existing processing equipment

Literature

|1| List, J.: High volume kneading reactors, cpp 2/94, pages 34-37
|2| List, J.: Großvolumige Knetreaktoren, cav 5/95, pages 164/165