

PROCESS INTENSIFICATION: THE OPPORTUNITY PRESENTED BY SPINNING DISC REACTOR TECHNOLOGY

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In this paper the potentials of intensified spinning disc reactors for handling fast exothermic reactions and reactions which are either heat or mass transfer limited have been discussed. Such reactors can lead to reduced volumes of hazardous materials for handling and transportation, and reduction of the dangers associated with thermal runaway and thermal ignition. Research by the Process Intensification on spinning disc reactors is ongoing and results to date are promising.

Keywords: spinning disc reactors, fast exothermic reactions, polymerisation

INTRODUCTION

Due to the substantial accelerations which can be generated, thin highly sheared films can be produced on rotating surfaces(Plate 1). Recent studies have indicated that the fluid dynamics within these films result in significant enhancement in the heat and mass transfer rates(1,2). It is therefore expected that a reactor based on this technology should have the following advantages:

- (1) Rapid mixing in the liquid film
- (2) Short liquid residence time
- (3) Rapid solid/liquid heat/mass transfer
- (4) Rapid liquid/vapour heat/mass transfer

This makes the spinning disc reactors strong contenders for performing fast exothermic reactions and reactions which are limited by mass transfer rates. A typical example for the mass transfer limited reaction is the polymerisation of unsaturated esters where the reaction is driven by the removal of glycol from the reaction system. Previous studies at Newcastle University (3) have shown that the total reaction time for the manufacture of unsaturated polyester can be significantly reduced by using a spinning disc reactor having a cascade of discs instead of a conventional stirred tank batch reactor. As the spinning disc reactors operate in a continuous mode and markedly reduce the inventory of hazardous chemicals, they could play an important role in improving the intrinsic safety of the plant. In addition it has also been shown that the molecular weight distribution of the polymer products obtained from the spinning disc reactor is extremely tight.

The spinning disc reactors could also be used for the sulphonation of linear alkyl benzene (LAB) by using SO_3 for the detergent industry. This reaction is extremely exothermic and industrial processes control the exotherm by diluting the SO_3 in the gas phase. The requirement for a sulphonation reactor are dilution of SO_3 in air, cocurrent flow of reactants, minimum backmixing of sulphonated product with fresh reactants, short residence time, high cooling area to reactor hold-up ratio and good local mixing [4]. The use of a spinning disc reactor in such cases will potentially reduce the need for SO_3 dilution in air, due to the enhanced heat transfer characteristics of spinning discs. It may be possible to use a feed of liquid SO_3 in place of a mixture of gaseous SO_3 and air.

SPINNING DISC EXOTHERMIC REACTOR

Research on the exothermic reactor is currently underway and the schematic diagram of the proposed spinning disc reactor for the sulphonation reaction can be seen in Figure 1. It is anticipated that due to the enhanced heat transfer characteristics of spinning discs, it will be possible to control the exotherm using internal disc cooling rather than by the dilution of gaseous SO_3 . Cocurrent flow can be achieved by introducing the reactants close to the centre of the rotating disc. The effect of rotational speed on backmixing is to be studied but it is anticipated that very little backmixing will be achieved. The residence time within the spinning disc reactor is of the order of seconds. While the main cooling area is that of the disc additional cooling is provided by the reactor housing (Figure 1). The reactor hold-up is expected to be small as it is essentially the volume of liquid on the disc (diameter of 0.2m) and is dependent on liquid feed rate to the disc. It is also anticipated that good local mixing will be achieved on the disc. Additional benefits of the spinning disc reactor are improved intrinsic safety and mobility. The smaller reactor hold-up volume and short residence times will ensure a smaller volume of hazardous material present at any one time. It is also proposed that the complete reactor unit will be of a size that can easily be transported, which will reduce the need for transportation of potentially hazardous liquid product, by following a policy of distributed manufacture.

Preliminary calculations for the sulphonation of LAB indicate a temperature rise for the reaction of 22 °C (based on 1 cc/s of liquid SO_3) with a corresponding cooling water temperature rise of 8 °C (based on cooling water at 10 °C and 100 cc/s). The estimated overall heat transfer coefficient is 4 - 5 kW/m²°C.

SPINNING DISC POLYMERISER

Spinning disc reactors can also be used for carrying out free radical polymerisation reactions such as polymerisation of styrene where good mixing is essential for linking small chain lengths to form a long chain length of desired molecular weight. At Newcastle University a spinning disc reactor has been built and is currently being used for the polymerisation of styrene. Details of the test facility, experimental procedure and the results have been described in the following sections.

Experimental facility

The apparatus used for the experimental work is outlined in Figure 2. A batch reactor consisting of a 250 ml capacity volume glass vessel surrounded by a digitally controlled water

bath is used to bench mark the performance of the spinning disc reactor. A magnetic stirrer is used to provide uniform temperature and good mixing levels throughout the reaction mixture. The top end of the vessel is fitted with a vertical condenser to prevent loss of volatile material. The spinning disc reactor, as shown in Figure 2, consists of five main sections: the spinning disc surface, the slip ring assembly incorporating thermocouples, the radiant heaters, the prepolymer feed distributors and the cooling coils. The rotating disc (0.36m in diameter) is made of brass and has concentric grooves at varying radial distances to provide better mixing and increased surface area. The disc surface temperature is measured using thermocouples embedded at chosen locations and connected to the data acquisition computer.

Experimental procedure

In a typical spinning disc run the polymerisation of styrene is carried out in two stages: First the prepolymer stage and then the spinning disc stage. In the prepolymer stage 200 ml of styrene monomer and 40 ml of toluene solvent are preheated for about 15 minutes in the batch reactor to the operating temperature of 88°C which is maintained constant throughout the reaction by the water bath. The magnetic stirrer is switched on and a thermocouple is inserted through the inclined arm of the vessel to monitor the temperature of the reaction mixture. Water is allowed to flow at a reasonable rate through the condenser. 0.3 g of the initiator (benzoyl peroxide) is then added to the monomer through the vertical arm of the vessel. This time is taken as zero. When the time selected for termination of the prepolymer stage is reached, the melt is poured down onto the spinning disc surface via the feed distributor.

When the prepolymer is ready to enter the spinning disc stage the temperature of the disc surface is raised to 88°C and its rotational speed is set. The flow of air to the slip ring assembly and cooling water to the condenser and skirt jacket is turned on. After the prepolymer is poured down the feed port, the disc is allowed to rotate for about 4-5 minutes to ensure that almost all of the feed introduced has sufficient time to flow down the distributor tubes and come into contact with the disc surface. After passing over the disc surface, the polymer melt is thrown off the disc surface into the collecting trough. Product samples of the spinning disc product are taken immediately after the disc stops rotating and they are crash-cooled in cold water. The conversion is obtained by weighing the samples before and after polystyrene has been precipitated from the monomer and polymer mixture. Methanol is used as precipitating agent; the monomer styrene remains in solution, leaving polystyrene as a white precipitate which is washed with more methanol and dried at 65-70°C to constant weight. The conversion was also obtained by using a HPLC system.

Discussion of results

The change in conversion of the polymer melt as it passes from the batch reactor onto the spinning disc surface have been displayed in Table 1. These results can be more clearly interpreted by analysing the time-saving achieved on the spinning disc polymeriser (Figures 3 and 4). As seen in Table 1 and Figure 3, the spinning disc reactor gives bigger savings in reaction time as the feeding times increase from 40 to 80 minutes. In fact the time saved is almost doubled from 15 to 28 minutes for feeding at times 40 and 80 minutes respectively. This saving in time is because the spinning disc reactor out performs the batch reactor when the viscosity of the polymer melt increases. As the viscosity increases mixing in the batch reactor becomes poor and therefore it takes longer to achieve a given conversion. Therefore,

the use of a cascade of spinning surfaces (Figure 5) in a semi-continuous process scheme could help to drastically reduce styrene polymerisation times of the reacting mixture from over 100 minutes to around 50 minutes while still attaining conversions of the order of 0.9.

Merits of the Proposed Technology

In the application of the spinning disc technology to polymerisation processes, two major potential benefits can be identified. Firstly the intrinsic safety of the process is expected to improve. The spinning disc polymerisers will hold very small volume of the reacting material at any given time, thereby substantially decreasing the risks associated with handling large volumes of hot, viscous polymer melts from batch reactors. Also the dangers of thermal runaways and thermal ignition frequently encountered in batch-mass reactors due to poor temperature control can be largely reduced.

Secondly the energy efficiency of the spinning disc reactors is expected to be considerably higher than their conventional counterparts. The experimental results presented in this study have been arrived by using a disc temperature of 88°C. In industry, conventional stirred tank and linear flow reactors would require temperatures of at least 150°C in order to achieve similar conversions levels. In addition, the process time of a conventional batch reactor is 14 hours for complete polymerisation while the spinning disc reactor would take about 1.5 hours in total including the prepolymer stage in a semi-batch process. With such reduced process time combined with a low operating temperature, the spinning disc polymeriser is expected to be very energy efficient.

CONCLUSIONS

Experimental investigation carried out at the University of Newcastle suggest that the spinning disc reactors could strongly influence the manner in which industry carries out reactions which are fast, exothermic and are limited by either mass or heat transfer rates or both. Successful development and use of such reactors would eventually result in a move away from batch processing and towards continuous or semi-continuous processing giving significant capital cost savings. Spinning disc reactors would also improve the intrinsic safety of the process whilst reducing the energy consumption. The control of product quality is also expected to be significantly improved.



Plate 1: View of the Surface Waves on Spinning Discs.

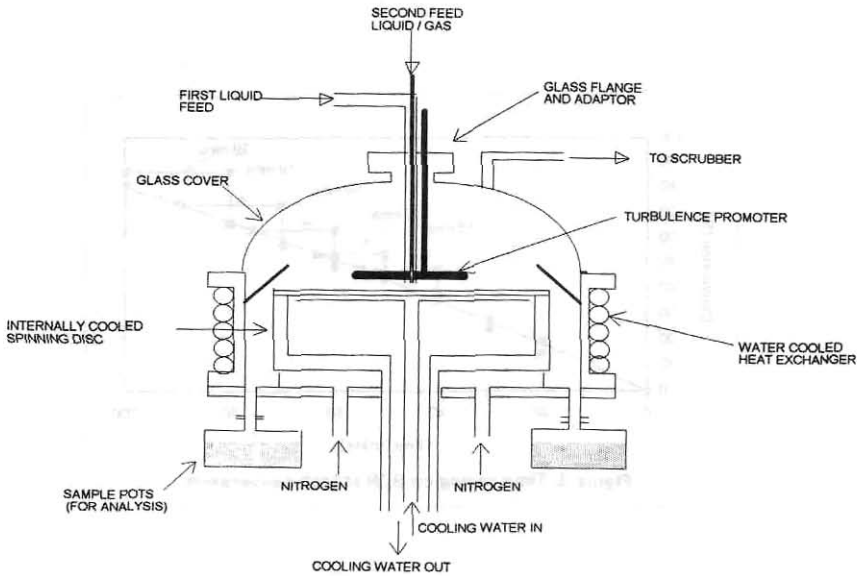


Figure 1. Schematic Diagram of the Exothermic Spinning Disc Reactor.

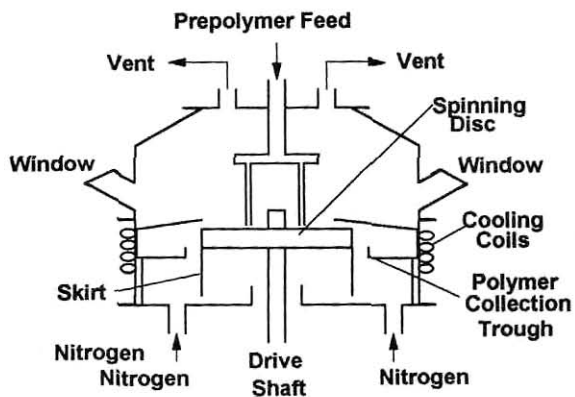


Figure 2. Schematic Diagram of the Spinning Disc Polymeriser

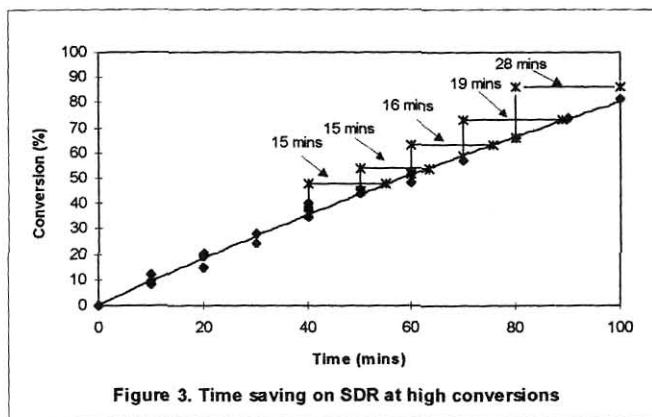


Figure 3. Time saving on SDR at high conversions

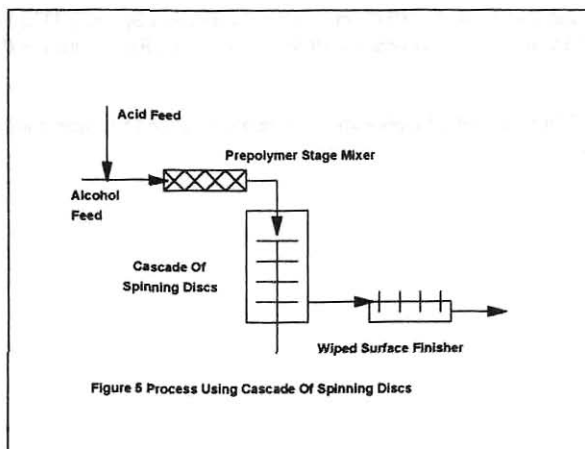
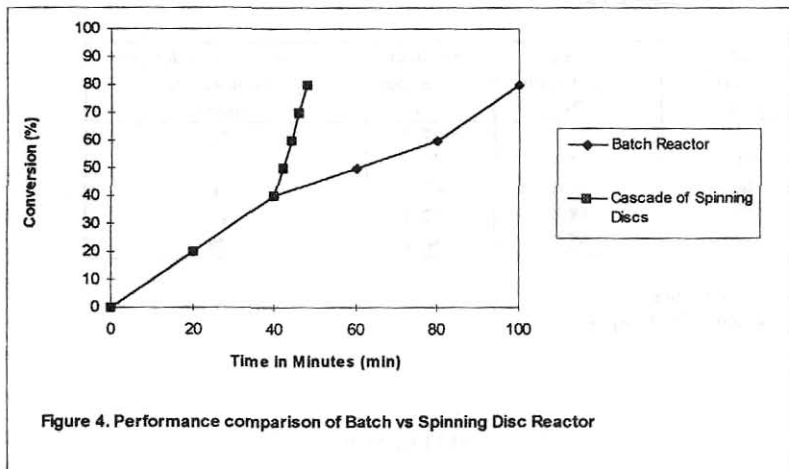


Table 1: Changes in conversion and time savings in Spinning Disc Reactor (SDR) at different degrees of prepolymerisation.

Feeding time into SDR (mins)	Feed conversion (%)	Product conversion (%)	Equivalent batch time (Time saving) (mins)
40	35.7	47.7	15
50	44.9	53.6	15
60	51.4	63.1	16
70	58.8	72.9	19
80	65.9	86.1	28

Disc temperature: 88°C
 Disc speed: 350-400rpm

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