

An acoustic backscatter system (ABS) for the characterisation of legacy waste dispersions

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ABSTRACT

Due to the unique health and safety challenges within the nuclear waste industry, there is significant interest in the use of *in situ* monitoring techniques to characterise Legacy wastes during transport, storage and disposal. Acoustic backscatter systems are a potentially flexible and robust solution that can give information on sludge aggregation, sedimentation and particulate concentration. This paper details work completed with a multi-frequency ABS, which has been used to track settling and concentration changes of flocculated Spherglass dispersions. It was found that suspensions of the glass particles from 2 – 10 wt% gave linear signal responses, and a correlation was defined between attenuation gradient and particulate concentration. In dispersion settling tests, it was found that the movement of the upper cloud-front (where a clear supernatant formed) could be tracked by monitoring a peak in the backscatter signal for different time intervals. Further, changes to the bulk dispersion concentration as settling progressed were tracked by relating the backscatter attenuation to the concentration correlation plot. It was found that bulk dispersion concentration increased from the initial 5 wt% to ~7 wt% as settling progressed, which is indicative of hindered-settling effects from displaced water up-flow. Although the current tests were carried out on inert glass simulant particles, the system could be readily employed in an industrial environment, due to its minimal intrusion (as the control system is separated from the immersed transducers). This would allow such characterisation systems to be used in a range of industrial situations from nuclear waste deposits to multiphase clarifiers and thickeners.

INTRODUCTION

The problem of so called 'Legacy' nuclear waste deposits from first generation British nuclear sites is a major economic, logistical and technological barrier to advancement of the U.K nuclear power industry. The Legacy nuclear wastes mainly consist of dissolved magnesium alloy canisters from spent fuel rods. However, the specific nature of the resultant oxide sludges are highly complex, with properties varying extensively between sites, due to different storage conditions and other low and intermediate level wastes stored within the same deposits [1].

Characterisation of this waste is therefore an extremely difficult proposal. The task is made all the more complex due to the potential radiation risks, which also vary considerably between sites. This makes sampling analysis a time-consuming and logistically challenging process. One possible answer to the challenge of characterisation is to use an *in situ* measurement system, where equipment can be installed on site, separated from the operator and thus intrusion kept at a minimum.

An *in situ* system would allow a higher rate of data collection than sampling, however attainable system information is often more qualitative than available from a full laboratory analysis [2].

The basis for many multiphase *in situ* characterisation systems is to use a robust source signal, such as sound, electric capacitance or radiation, and measure the change in the signal through the testing medium [3-5]. The technical complexity arises from the de-convolution of the returned source signal to gain information on specific parameters, such as particulate or fluid flow rate, settling rates, particle concentration, aggregation state and size. As discussed in a previous paper [6] the use of ultrasonic systems as *in situ* monitors in engineering environments is potentially very advantageous, due to their relative robustness, low cost and flexibility. Ultrasonic techniques have also been used extensively in marine environments to track sediment transport [7], and thus there is a high level of precedence for their applicability in similar multi-phase systems.

This current paper details work completed in the analysis of an acoustic backscatter system (ABS) as a potential *in situ* characterisation probe to measure dispersion sedimentation and particle concentration. Essentially, the ABS consists of multiple high frequency transducers-receivers and the attenuation of transmitted ultrasonic pulses is measured in terms of the strength of the returned backscatter signal. Unlike the ultrasonic velocity profiler previously detailed [6], which converts acoustic Doppler shifts to measure settling rates quantitatively, the information acquired from the ABS is essentially qualitative in nature. However, by combining the raw data with appropriate correlations, a greater level system detail may be eluted from an ABS system and its operational flexibility makes it an attractive prospect for industry.

EXPERIMENTAL

The simulant particles used in the settling tests were Spheriglass 3000 (Potters Industries), flocculated with anionic polymer PolyDADMAC at 0.5 ppm. The multi-frequency Acoustic Backscatter System (ABS) employed was an Aquascat 1000 from Aquatek acoustics, borrowed on loan. It consists of 1, 2, 4 & 5 MHz transducers connected via cables to a controller box and computer. In the set-up used, The ABS measured the raw strength of the backscattered ultrasonic signal from each transducer in 2.5 mm 'bins' for a distance profile of 40 - 220 mm.

The experimental set-up was as follows. Known dispersions of the flocculated Spheriglass were mixed in a 5 L beaker using a magnetic stirrer. The ABS transducers were positioned in the top of the dispersion (fully submerged) about 180 mm above the base of the beaker. The magnetic stirrer was withdrawn from the well mixed dispersions on commencement of the acoustic measurements, to minimise signal interference.

The experimental programme consisted of two series of tests. Firstly, concentration correlations were made using dispersions of known concentrations from 2 – 10 wt%. The ABS was set to take 10 second averages through the homogenous dispersions to compare the backscattered acoustic signal as a function of concentration. Preliminary results indicated 10 s averages were statistically sufficient, but the time-step was small enough to ensure there would be no bulk changes within the dispersion during measurement. Secondly, the settling of particle dispersions was measured using the ABS. Here, dispersions at 5 wt% were left to settle for 10 minutes and the acoustic response was recorded throughout the sedimentation.

It is noted that although results were recorded for all transducers with frequencies 1 – 5 MHz, only

the 4 & 5 MHz results are shown for concision, as it was found these frequencies best highlighted the dispersion changes.

RESULTS

Equilibrium concentration profiles

Given in Figure 1 (below) are the 10 s averaged equilibrium profiles for the ABS through homogenous Spheriglass dispersions of various concentrations. Both the 4 MHz and 5 MHz transducer responses are shown.

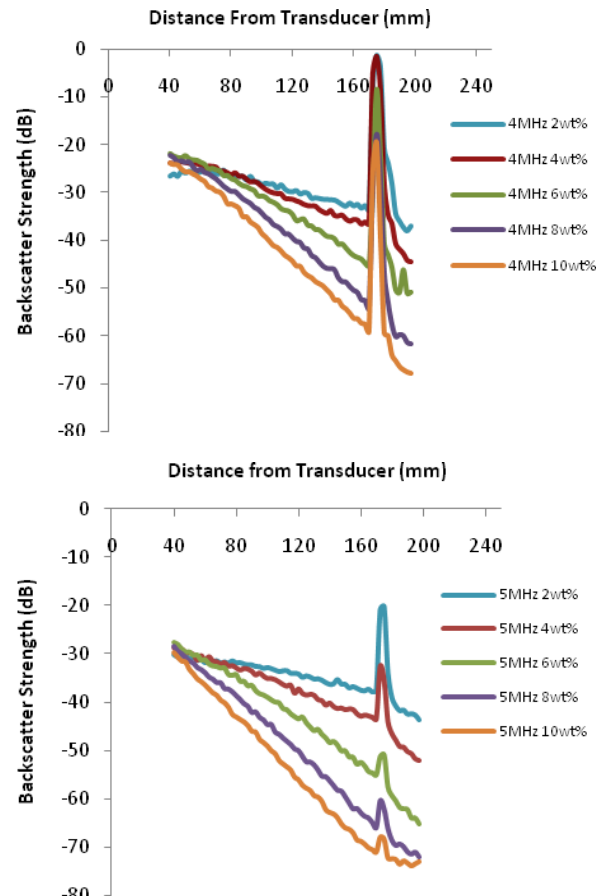


Figure 1 ABS equilibrium profiles for Spheriglass dispersions from 2 – 10 wt%. 4 MHz transducer (top) and 5 MHz transducer (bottom).

Both frequency responses highlighted in Figure 1 essentially suggest the same general trends. As Spheriglass particle concentration is increased from 2 – 10 wt% the backscatter signal through the dispersions become significantly weaker. It is also noted that, generally, the dB log signal is attenuated in a linear fashion with penetration distance for all suspensions, with the higher concentrations having greater linear gradients. These trends are expected for high concentration homogenous dispersions [8, 9]. As the acoustic signal travels through the dispersions, the cumulative effects of interparticle scattering and absorption increase the ultrasonic attenuation, and these effects are enhanced as particle concentration is increased. It is also observed in

both 4 & 5 MHz transducers, at all concentrations, that there is a peak in the signal strength at around 170 mm, which represents the peak from the beaker base.

Overall, the changes to the ABS response with particle concentration were associated by measuring the linear gradient at each concentration and producing a correlation plot. This is shown in Figure 2 for both the 4 MHz and 5 MHz transducers.

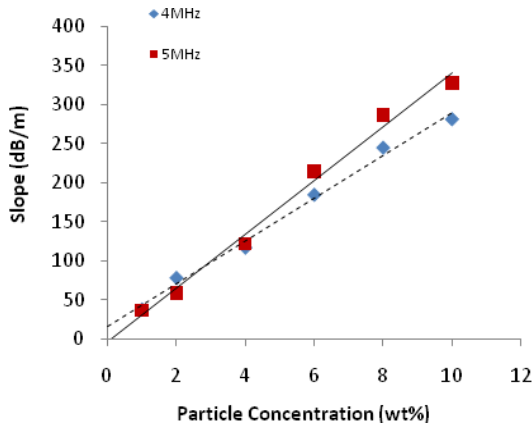


Figure 2 Spheriglass 3000 ABS concentration correlation plot, using 4 and 5 MHz transducer profiles.

The correlation plots for both 4 and 5 MHz transducers show excellent linear responses for the range studied, which is in line with previous research into concentrated dispersions systems [8]. The gradient of the 5 MHz correlation plot is slightly greater than the 4 MHz, due to the increased effect of signal attenuation from particle adsorption in higher frequencies. Figure 2 then gives the ability to gauge the concentration of any unknown Spheriglass 3000 dispersion simply from the linear slope of the backscatter signal. Importantly, by the comparing changes to the backscatter slope gradient in settling dispersions, it was hoped that any bulk changes to concentration during particle sedimentation could be observed.

Settling of particle dispersions

To monitor changes in the backscatter response during suspension settling, 5 second averaged profiles were extracted at different time intervals within the settling period. Averaged backscatter profiles for 1-5, 41-45, 61-65, 81-85 and 101-105 seconds are shown in Figure 3 below, for the 5 MHz transducer.

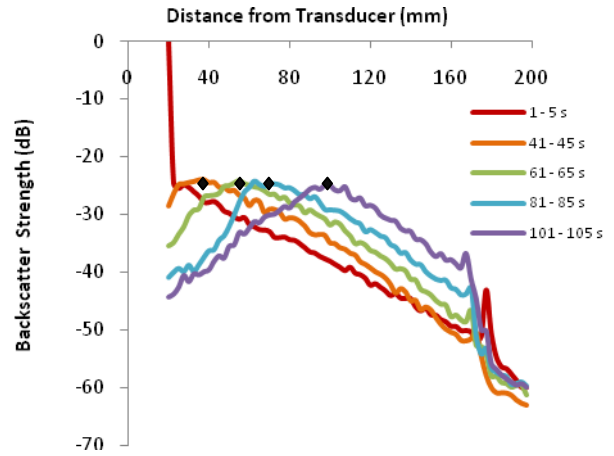


Figure 3 Averaged ABS profiles for a settling Spheriglass 3000 dispersion, over the first 105 seconds of sedimentation. 5 MHz Transducer. Black diamonds are used to highlight signal peaks.

It is firstly noted in Figure 3 that the 1-5 s signal demonstrates a similar linear response to the equilibrium concentration profiles, indicating the suspension is initially well mixed and homogenous. As particle sedimentation commences, a clear peak is seen in the signal, moving down the settling cylinder with time (highlighted by the black diamonds, for the time averages between 41 and 101 s). These peaks represent the movement of the cloud-front, above which a clear supernatant formed. This was correlated by manual observations of the cloud-front movement with time. A peak is generated, as the clear water in the supernatant zone will produce a very weak signal, while the cloud-front will act as a strong 'surface' to scatter the ultrasonic pulse. It is also noted in Figure 3 that as with the equilibrium responses; the backscatter from the settling profiles are again approximately attenuated linearly with penetration distance through the dispersion zone.

To illustrate the settling of the cloud-front, the signal peak distances (shown by the black diamonds in Figure 3) were plotted against time and are shown Figure 4 (page across). Figure 4 suggests the Spheriglass cloud front settles approximately at a constant rate, with the gradient slope giving a settling rate of 0.94 mm/s, which is in line with expectations. However, the movement of the cloud-front does not necessarily demonstrate the settling behaviour of the dispersion zone as a whole. Internally, any segregation of particles due to aggregate size differences and hindering flow-field effects could lead to changes within the bulk [10]. Importantly, the influence of hindrance should be observable by measuring any changes to the dispersion concentration during sedimentation.

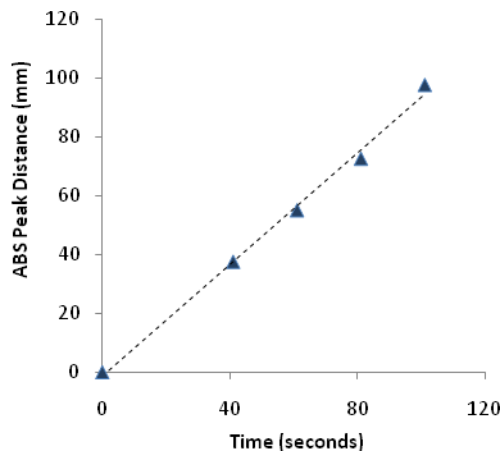


Figure 4 Cloud-front movement with time, indicating dispersion settling flux rate. Data is from the 5 MHz transducer (Figure 3).

To observe any bulk changes to particle concentration in the dispersion zone, the equilibrium correlation plot shown in Figure 2 was used. The ABS profiles within the dispersion zone during settling (Figure 3) were approximated as straight line relationships and the gradients measured. These gradients were then related to the equilibrium correlation plot, and thus any differences compared to changes in the bulk concentration. These changes are shown in Figure 5, with the data points representing the 5 second averaged time intervals given in Figure 3.

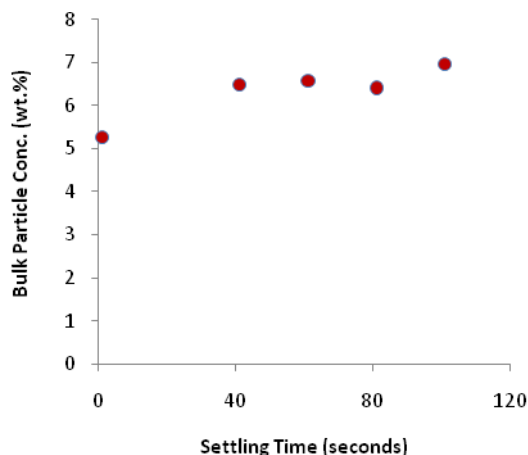


Figure 5 Changes to bulk particle concentration in the dispersion zone during sedimentation.

It is observed in Figure 5 that the bulk concentration increases from the initial 5 wt% to almost 7 wt% after 100 seconds. This increase is consistent with hindered-settling effects within the dispersion, likely caused by interaction between the particle aggregates. Water up-flow from aggregates settling lower in the dispersion will disrupt the flow of nearby particulates, slowing their settling rate [10]. If there is any segregation in the system due to differences in aggregate size, this effect will be even more pronounced. The most important observation however, is that these hindered effects are not seen in the cloud-front, which settles with a constant rate for the duration.

This emphasizes the importance of understanding segregation and concentration changes within the dispersion zone, and suggests that a complete understanding of the settling kinetics cannot be simply gained from study of the cloud-front. This highlights the power of ultrasonic techniques over traditional sedimentation tools such as light based turbidity meters, as the effectiveness of ultrasonic transmittance in visually opaque suspensions gives the ability to study these internal changes in much greater detail.

CONCLUSIONS

The settling of Spherglass dispersions were monitored using a multi-frequency ABS. Firstly, suspensions with known equilibrium concentrations were studied to create a concentration correlation curve. Secondly, dispersion settling was observed and the movement of the cloud-front was successfully monitored by measuring the peak in the backscatter response. Thirdly, changes in the concentration of the dispersion during sedimentation were measured using the correlation curve, and observed increases linked to hindered-settling effects.

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