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Survey of advanced nuclear technologies for potential applications of sonoprocessing

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ABSTRACT

Ultrasonics has been used in many industrial applications for both sensing at low power and processing at higher power. Generally, the high power applications fall within the categories of liquid stream degassing, impurity separation, and sonochemical enhancement of chemical processes. Examples of such industrial applications include metal production, food processing, chemical production, and pharmaceutical production. There are many nuclear process streams that have similar physical and chemical processes to those applications listed above. These nuclear processes could potentially benefit from the use of high-power ultrasonics. There are also potential benefits to applying these techniques in advanced nuclear fuel cycle processes, and these benefits have not been fully investigated. Currently the dominant use of ultrasonic technology in the nuclear industry has been using low power ultrasonics for non-destructive testing/evaluation (NDT/NDE), where it is primarily used for inspections and for characterizing material degradation. Because there has been very little consideration given to how sonoprocessing can potentially improve efficiency and add value to important process streams throughout the nuclear fuel cycle, there are numerous opportunities for improvement in current and future nuclear technologies. In this paper, the relevant fundamental theory underlying sonoprocessing is highlighted, and some potential applications to advanced nuclear technologies throughout the nuclear fuel cycle are discussed.

Contents

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1. Introduction

Sonoprocessing involves the use of ultrasound to deliver energy for producing physical or chemical effects at both laboratory scale and in a medium to be found in an industrial process stream. Sonoprocessing is generally divided between sonomechanical and sonochemical applications [1]. Sonomechanical applications utilize the agitation induced in the medium by sonic energy, and sonochemical applications, in general, utilize cavitation effects to enhance or catalyze a targeted chemical reaction. An example of sonomechanical processing is degassing of molten metals [2]. There are many sonochemical applications including those used in food processing, chemical manufacturing, and pharmaceutical production [3,4].

Currently in the nuclear industry, the most common use of ultrasound is non-destructive testing/evaluation (NDT/NDE), where it is used for inspections at the time of construction and for periodic inspections that seek to detect and characterize significant material degradation [5]. There have also been a limited number of investigations that consider how sonoprocessing can potentially improve efficiency in interactions and add value to important process streams throughout the nuclear fuel cycle [6]. In this paper, we review and discuss the potential uses for sonoprocessing to process streams that are found in advanced nuclear technology throughout the nuclear fuel cycle.

A process stream can be defined as a fluid, or slurry, which undergoes some process or reaction using either batch or steady state flow through reactor. There are three general ways in which ultrasonic technology has been used to impart ultrasonic energy in to a process stream. The first of these is by direct immersion of a horn into the process fluid. The second is by attaching a transducer to the surface of the reactor pipe, and the third is by indirect coupling of the energy from a transducer through an intermediate fluid into the process stream. All three of these methods of imparting ultrasonic energy can be used to deliver higher power ultrasonic energy. Examples of basic designs for reactors which illustrate these approaches are shown in Figs. 1–3 [7]. The design illustrated in Fig. 2 would be difficult to implement in a cylindrical geometry due to the difficulty of producing and powering cylindrical transducers. In order to get around that constraint, transducers have been mounted in hexagonal or pentagonal configurations directed at the active region of pipe.

The efficiency and effectiveness of the various options for industrial sonoprocessing systems have been considered by several researchers including Thompson and Doraiswamy [7] and Gogate et al. [8]. In sonoprocessing there are in general two general classes of interaction which are usually classified in terms of the nature of the resulting interaction process and the intensity of the ultrasonic energy employed. The simplest classification is that by dividing processes into those interactions which are above the cavitation threshold and those where cavitation does not occur and where energy is delivered to induce phenomena, such as streaming.

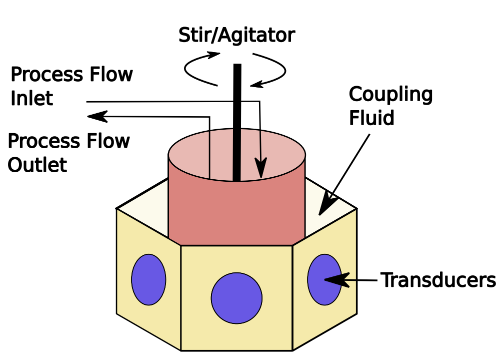

Fig. 1. Implementation of indirect sonication is using a coupling fluid jacket around a cylindrical reaction volume [7].

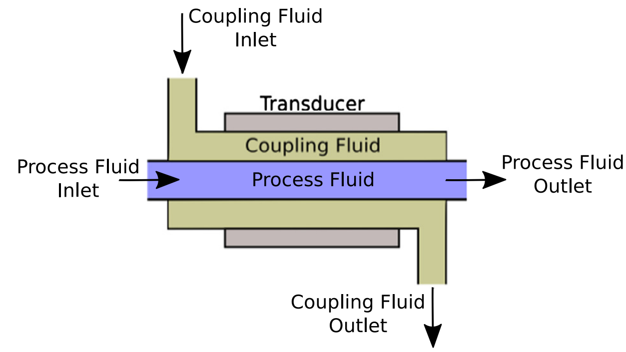

Fig. 2. Process stream flowing through a coupling fluid jacket. [7].

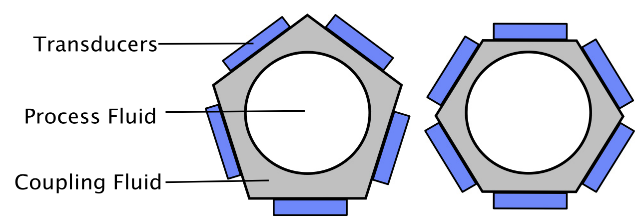

Fig. 3. Cross sections of the ultrasonic coupling fluid jackets [7].

Ultrasonics generally is used to increase yield or enable a chemical reaction, by delivering energy, or provide a method of separation, such as degassing two constituents. In looking at potential new applications for sonoprocessing there are several challenges to consider when investigating the potential use of power ultrasonics to nuclear fuel-cycle process streams. First there is scale-up when moving from a prototypical pilot plant to a fully integrated industrial process. This is an issue for any proposed chemical reactor design and can, in many ways, be approached in a similar manner to non-nuclear applications. Second, the use of sonoprocessing for nuclear applications typically involves process streams operating under harsh conditions oftentimes including high temperature and pressure, as well as challenging radiation fields, and a more stringent regulatory environment, than is found for non-nuclear chemical processes. Finally, one must factor in the economic performance of the sonoprocessing technology where often times power ultrasonics involves a significant energy cost. Historically, the use of sonoprocessing has in general only been justifiable when there is a high value product being produced, such as in the pharmaceutical industry. Other industries that have been looking to increase the use of ultrasonics have included petrochemical processing. A recent feasibility study has shown that implementing ultrasonic technology in the heavy oil industry gave