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Mechanistic Modeling of Solids Separation in Solid/Liquid Hydrocyclones

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Abstract

Hydrocyclones have been used for many years for removing solids from continuum liquid media in the Mineral, Chemical, Petroleum, and Environmental industries; among others. In oilfield applications, the Solid-Liquid Hydrocyclone (SLHC) has emerged as a sound technological and economical alternative to conventional filtration systems where space, efficiency, reliability and continuous operations are critical. The SLHC is particularly attractive in offshore, subsea, and water injection applications; and other oilfield operations. Early and effective removal of solids in pipelines and process equipment help prevent erosion and premature failures that are costly and pose serious health, safety or environmental hazards.

To date, hydrocyclone design has mainly relied on empirical experience and, most recently, on costly and lengthy CFD simulations. The main objective of this work is the development of a mechanistic model for practical, yet reliable, SLHC design. The proposed model is capable of describing the hydrodynamic flow phenomenon inside the hydrocyclone, enabling the prediction of continuous-phase swirl intensity and the velocity profile used in determining particle trajectories, and hence, the Grade separation efficiency curves. The model is validated against oilfield experimental data run under a wide range of conditions and equipment configurations. Model agreement with Global and Grade separation efficiency data is 94.7% and 88.2% respectively.

Introduction

Hydrocyclones have been widely used for more than a century [3] in various applications and in different industries, including the Mineral [10], Chemical [7], Petrochemical [23], Petroleum [5] and Environmental [15, 26], among several others. With rising needs for efficient and reliable solids removal systems, the use of the SLHC has emerged as a sound alternative to conventional filtration and other solids' removal systems that are costly, bulky, and have greater pressure drop. The SLHC is particularly attractive in offshore and subsea applications where space and reliability are critical.

Design of the SLHC has mainly relied on empirical experience [14, 20], and more recently on costly and long-lasting CFD modeling [8, 19]. Very limited mechanistic modeling work has been performed to date, to describe solid-liquid separation phenomenon in hydrocyclones. Mechanistic models are an intermediate solution capable of describing the physical fluid flow phenomena, thus, providing a more practical and efficient, yet reliable, design tool.

This work is aimed at developing a comprehensive mechanistic model for SLHC design capable of predicting the hydrodynamic flow behavior inside the hydrocyclone. The proposed model draws from a model developed by *Gomez et al.* [11] for the Liquid/Liquid Hydrocyclone (LLHC). The SLHC model takes into consideration the fundamental differences between solid-liquid and liquid-liquid systems and the hydrodynamic implications of such differences on cyclonic phase separation. These differences are well described by *Thew* [27]. The model enables the prediction of the continuous-phase swirl intensity and velocity profile which are used to determine particle trajectories, and hence the Grade separation efficiency curves. The model can be utilized under a wide range of geometric configurations and operating conditions as it is based on the physics of the flow. Due to its simplicity and general formulation, the model also allows detailed and timely analysis of performance prediction for a given SLHC geometry and a set of operating conditions.

This proposed model has been verified against experimental data collected by *Culwell et al.* [6]. Tested equipment include different configurations of a 1-inch and a 10-mm SLHC. Experimental conditions include: particle size distributions ranging from 2 to 60 μm , solids concentrations from 40 to 370 mg/L, d_{32} from 12 to 32 μm , and liquid velocities from 14 to 24 m/s.