

As the world's population rises and the application of electronics increases, the demand for rare earth metals such as Cobalt and Nickel grows. Deposits of these metals can be found on land but with the increasing demand there is a great probability that these reserves will not be sufficient in the future. It therefore becomes interesting to investigate the possibility of mining these metals out of the ocean. At large depths (5000m) manganese nodules are formed by nature, these are rock shaped objects that contain various rare earth metals, Royal IHC is currently developing equipment to bring these manganese nodules to the shore. The nodules will be transported to the water surface using a Vertical Transport System (VTS). By means of vertical hydraulic transport in the VTS the nodules will be transported to the water surface where they are collected on a vessel.



An important demand of the VTS is that insight of the location of solid concentrations inside the riser is available, this information is required for different reasons: Monitoring the propagation of solid concentrations will enable anticipation of the coming flow at the vessel, it is required for controlling the pumps, it will indicate where plugs are likely to be formed and furthermore it will indicate if the aimed production is achieved. For the vertical transport system it has been proposed to measure the volumetric concentration of solids inside the booster stations located every 1000m and predict the propagation of solids in between these measurements, it was found that this configuration has the disadvantage that measurement error in the booster stations results in an error of the concentration estimation over the whole length of a riser section. An important aspect of the slurry flow is the particle diameter of the collected solids which is identified to be an unknown input of the system, this parameter influences the transport velocity of the solids and therefore needs to be estimated. These two topics gave rise to the following question: "How can the observation of solid concentrations inside a riser be improved?".

In order to evaluate this research question an observer is designed for a scaled test setup of the vertical transport system, on this setup designed improvements will be tested. The basic 1D Vertical Hydraulic Transport system has been chosen to form the basis of the observer, this model simulates the propagation of solids in a riser. Started is with an observability analysis of this model in order to find an improved measurement configuration, it was found that pressure difference measurements over a large distance of the riser will increase the observability of the system. In order to apply the observer to the test setup it has been investigated how the pressure difference measurements translate into a measured concentration, it was found that the pressure drop created by the wall friction of the mixture can be approximated with the pressure drop due to wall friction under liquid conditions. Using this knowledge about the measurements an observer is designed. The Ensemble Kalman Filter (Enkf) was used to observe the concentration through the riser. An addition of the observer is an estimator for the particle diameter, a method to estimate the particle diameter is investigated by evaluating what the effect of the particle diameter is on the slurry flow. It is found that the particle diameter can be correlated to the time to travel through a riser section, a proposal for an observer is therefore to adapt the particle diameter by using a proportional integral of the lag found between the concentration estimate over a large distance and the concentration measurement at that point.

The observer has been applied to the test setup which features a scaled riser section of 140m, first it was evaluated how different pressure difference configurations affect the concentration observation. It was found that by using a pressure difference measurement over the whole section of a riser, by which the mean concentration is measured, the concentration observation at the top of the riser can be significantly improved. With a different configuration the estimation of the particle diameter was investigated, using the observer designed it has been made possible to distinguish mixtures containing different combinations of solids fractions. There are errors in the outcome of the particle diameter estimate due to the fact that at the conditions of the test setup the influence of the particle diameter is only subtle, however it has been proven that by applying the particle diameter observer an improvement can be seen in the concentration observation. A sensitivity of the observer was found to be the relation of the pressure difference measurement to the changing wall roughness of the riser, the effect of this change needs to be accounted for by periodically redetermining the wall roughness.

Student  
Jeroen van Stappen

Sponsor  
IHC Mining

Thesis committee  
Dr. ir. S. A. Miedema  
Prof. dr. ir. J.W. van Wingerden  
Ir. B.M. Doekemeijer  
Ir. T.D. Schouten  
Dr. ir. J.M. van Wijk  
Ir. W.B.A. Boomsma