Development of Geyser Pump for Lifting Solid Particles in a continuous Rotary Dissolver

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Geyser pump is a passively operated pump working on the principle of airlift pump. A prototype of the geyser pump was designed and fabricated in order to study its efficacy for handling fine solid particles in a Continuous Rotary Dissolver. Experimental studies were conducted initially to generate two-phase flow characteristics of the geyser pump using compressed air as motive fluid. This was followed by experiments involving three-phase (solid-liquid-gas) flow conditions to study the pumping performance. Flow characteristics were determined by varying motive fluid flow rate and submergence. Design and operating parameters like submergence, riser diameter, particle density and particle size were varied to investigate the pumping performance under different flow conditions. Based on these studies an engineering scale prototype of geyser pump was fabricated and tested successfully.

Introduction

Continuous Rotary Dissolver (CRD) is the equipment developed for dissolution of spent nuclear fuel in continuous mode of operation [1]. A schematic of a CRD is shown in Fig. 1. The chopped spent fuel pieces are received in perforated buckets of CRD periodically. The dissolution of spent fuel takes place while in contact with leaching acid after which the hulls are discharged. The metallic fines and other solid particulates smaller than the perforation are expected to settle at the bottom of the vessel during this process. In order to ensure trouble free operation of the equipment, these solid particles have to be periodically removed from the bottom of the tank. The tank has been provided with a slopping bottom to facilitate accumulation of the solid particles at one area so that it can be removed using a pumping device. Thus, a pumping device is necessitated which could facilitate removal of these fine particles while being remotely operated.

The working area being highly radioactive precludes the use of conventional pumps owing to the maintenance requirements that is associated with any moving part. Airlift pump, being passive in nature, is a natural choice for such an application. However, the suction produced by a traditional

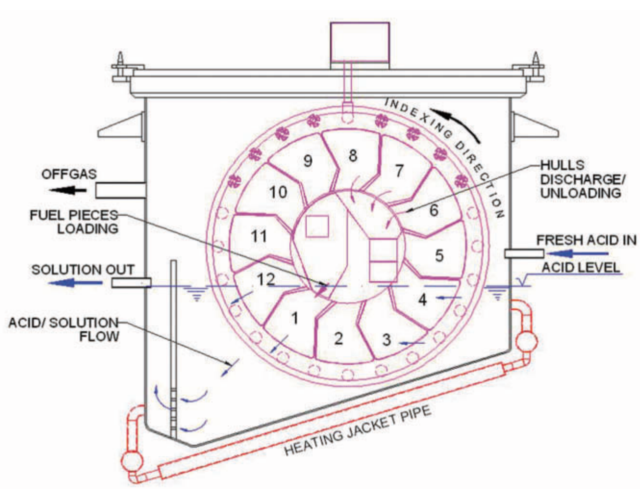

Fig.1: Schematic of a Continuous Rotary Dissolver

airlift pump is not very effective in pumping solid particles immersed in water.

Geyser pump, a variant of airlift pump offers a plausible alternative to the aforesaid application. Passive operation, high buoyant force and high suction are three vital features of geyser pump that makes it favorable for the current application.

Working Principle of Geyser Pump

Airlift pump is a device for raising liquids or mixtures of liquids (mostly water) and solids through a vertical pipe partially submerged in the liquid, by means of compressed air introduced into the vertical pipe (called as riser) near its lower end by means of an opening. As a result, a mixture of air and water is formed within the riser which flows upward as the density of the air-water mixture is much less than that of water alone. The performance of an airlift pump depends mainly on two groups of parameters. The first group includes geometrical parameters such as pipe diameter, submergence ratio, and geometry of the riser (tapered or straight), while the other group involves operational parameters such as, injected gas flow rate, gas injection pressure, and nature of lifted phase.

A geyser pump (see Fig. 2), unlike an airlift pump, allows air to accumulate in an air chamber (which acts as temporary storage of compressed air) and then lets the entire accumulated air to rush into the riser. This sudden release of air pocket inside the riser pipe creates a significant pressure drop at the bottom of the riser leading to a high suction enabling even the solid particles immersed in water (such as a sludge) to be pumped effectively. The geyser pump essentially performs two functions during the course of transferring the liquids and solids viz. ejection and suction.

I. Ejection: Accumulation of air in the air chamber results in the release of large air pocket instantaneously into the riser. Consequently, a large air bubble is formed in the riser. This large air bubble acts like an air piston, thereby, effectively ejecting water and solids in the riser.

ii. Suction: The presence of single large air bubble in the riser creates higher suction at the riser bottom than several smaller air bubbles for the same air flow rate. And higher the suction better is the chances for the solid particles deposited in the tank to gush into the riser.

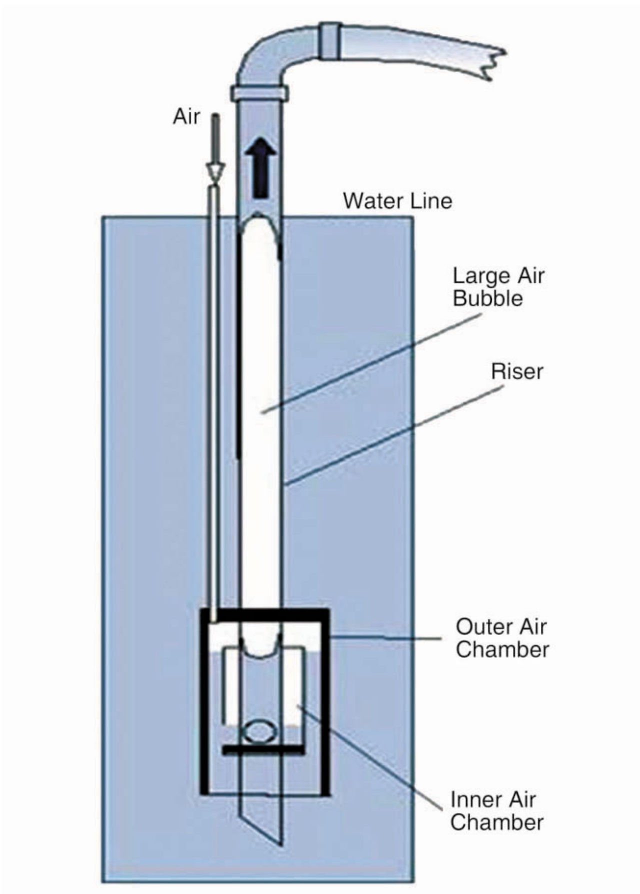

Fig. 2: Schematic of a Geyser pump

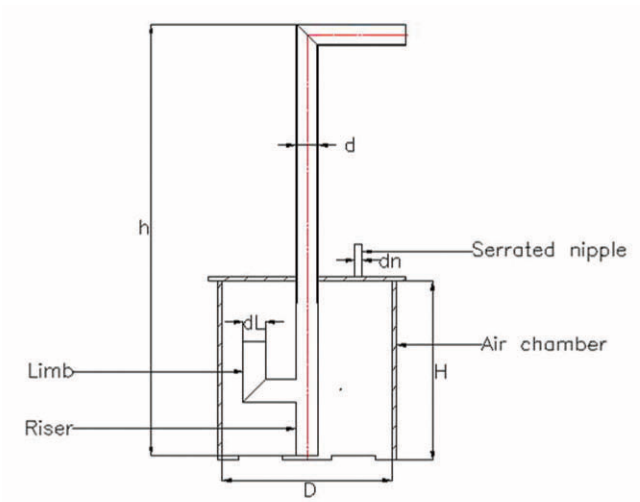

Fig. 3: Geyser pump configuration investigated

Experimental Set Up

Fig. 3 shows the geyser pump configuration used for the experimental study. The body of the geyser pump consists of an air chamber, a riser pipe with a limb and a serrated nipple. The air chamber has a cylindrical configuration having well sealed top lid and a bottom kept open for the entry of the liquid and solid phases to be pumped. The top lid of the air chamber is provided with two threaded holes. The bigger threaded hole is for the insertion of riser and the smaller one for the serrated nipple. The air carrying pipe is connected to the air chamber by means of serrated nipple. The air chamber is also provided with a number of slots on its periphery close to the bottom for the liquid and solid phases to flow into it. It mainly facilitates the accumulation of compressed air which results in liquid level going down and as soon as the liquid level reaches the limb of the riser column, releases the accumulated air instantaneously into the riser. The riser is a pipe which eventually discharges the mixture from bottom floor of the reservoir to a higher desired elevation.

The experimental setup consists of air header, pressure regulating valve, rotameter, flow control valve, water reservoir and geyser pump as shown in Fig.4. Compressed air from the air header is set to the requisite pressure by means of the pressure regulating valve. Air rotameter is used for monitoring the air flow rate. The flow regulating valve attached at the downstream of rotameter is used to control the air flow rate before being sent to the geyser pump.

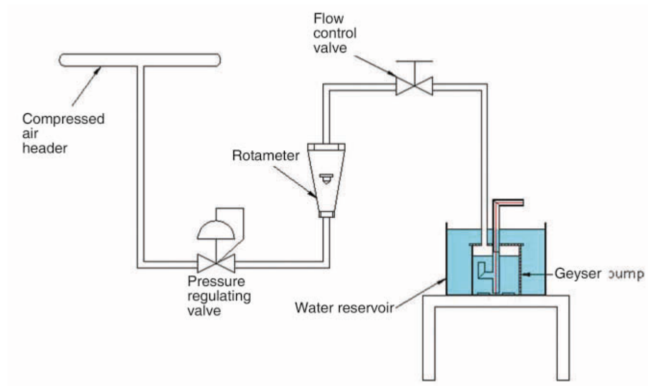

Fig. 4 Schematic of the Experimental Setup

Experimental Procedure

Experiments under Two-phase conditions:

Initially, the water level in the water reservoir was fixed so that the required submergence ratio is achieved. Submergence ratio can be defined as the ratio of vertical distance of free liquid surface in the water filled tank above the air inlet to the vertical distance of the discharge point above the air inlet.

Compressed air supplied from the air header was set to a fixed pressure of 1.5 kg/cm^2 by means of a pressure regulating valve. The air flow rate was adjusted using a flow control valve and was then varied sequentially to obtain corresponding volumetric flow rates of water in order to generate the performance curves. As the air supply was turned on and a particular air flow rate was set, the geyser pump was allowed to establish a stable periodic operation. Once the stability was achieved, the water being discharged at the top end of riser pipe was collected in a calibrated flask for a sampling time of one minute. The experiment was conducted in a closed loop to maintain the submergence constant.

Thus, pumping rate of the water as a function of motive fluid (compressed air) flow rate was found experimentally.

Parameters like submergence and air chamber diameter were systematically varied to examine their influence on the performance of geyser pump.

Experiments under Three-phase conditions:

Three–phase experiments involved parametric studies on the effects of solid particle conditions on the performance of geyser pump. Two different solid materials (glass beads with a density of 2.5 g/cc and mild steel chips with a density of 7.85 g/cc) and two different particle sizes (average particle diameter 2.80 mm and 3.35 mm) were used for the study.

The water level in the water reservoir was fixed and the solid particles were introduced in the water reservoir such that the required submergence ratio was achieved. The solid particles settled at the floor of the water reservoir and were maintained in the vicinity of the air chamber. Compressed air supplied from air header was fixed to a requisite pressure by means of pressure regulating valve. This pressure was maintained constant throughout the experiment. The flow rate of air was controlled using a flow control valve and was varied sequentially to obtain corresponding solid and water mass flow rate readings. Adequate mass of solid particles in the water reservoir was ensured in order to maintain a sufficient concentration of particles in the riser throughout the sampling time of all the experimental runs. Several trials were conducted to ensure repeatability.

For a given air flow rate, the quantity of solids being pumped for a sampling time of one minute was collected and weighed to obtain the solid mass flow rate. Simultaneously, the water being pumped was also collected in a calibrated flask for the measurement of volume flow rate of water. This step was repeated for the other air flow rates to obtain corresponding solid and water flow rate to generate the performance curves. Influence of particle size and particle density on the performance was also quantified and studied during the course of three phase operation of geyser pump.

Experimental Results

Performance of geyser pumps under two-phase flow:

Influence of submergence and air chamber diameter on the performance of geyser pump operating in two-phase flow was investigated. Fig. 5 depicts the flow characteristic curve which shows the rise of water flow rate with the increase in air flow rate for a given submergence ratio. It also shows that the water flow rate increases with the increase in submergence for a given air flow rate.

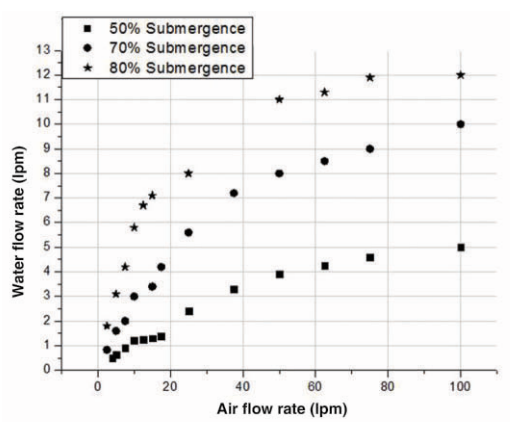

Fig. 5: Effect of Submergence of liquid pumping rate (riser diameter = 25 mm)

Two different air chamber diameters (viz. 150mm and 200 mm) were used to study the influence of air chamber diameter on the performance of geyser pump. It was observed that variation in air chamber diameter did not have any significant effect on the water flow rate [2].

Performance of geyser pump under three-phase flow:

The ultimate objective of the geyser pump is to lift the metallic fines from the tank floor of the continuous rotary dissolver assembly. Thus, conditions replicating the actual situation were adopted for the geyser pump operating in three-phase (gas-liquid-solid) flow situation. Performance of geyser pump lifting solids was obtained by measuring mass flow rate of solids and volumetric flow rate of water corresponding to each air flow rate for a given submergence ratio and solid particle conditions.

Solid mass flow rate corresponding to each air flow rate value was measured to generate the performance curve of a geyser pump pumping solids. The conditions maintained during the experiment are indicated in the Table 1.

Table 1: Test Conditions

Pipe diameter		25 mm
Pipe length	Riser length Suction length	710 mm 50 mm
Air chamber	Length Diameter	200 mm 200 mm
Solid particles	Material Diameter	Glass beads (2.5 g/cc) 2.80 mm
Submergence Ratio		0.8 , 0.7 and 0.5

As illustrated in Fig.6, solid mass flow rate increases with the increase in air flow rate for a given submergence ratio and solid particle conditions. Also, the solid mass flow rate increases with the increase in submergence for a given air flow rate.

Further studies were carried out by varying the particle size, density and riser diameter [2]. The following observations were made.

- The mass flow rate of solids decreases with the increase in the particle size for a given air flow rate and submergence. This is attributed to the increase in the free settling velocity with the increase in particle diameter which leads to an increase in the slip between the particles and the mean flow
- The pumping rate of solids is reduced when a higher density of solid material is used. The mixture density in

case of a higher material density will be higher which results in reduced driving force and therefore, reduction in solid mass flow rate is observed.

- The superficial velocity of liquids decreased with increase in the riser diameter for a given gas superficial velocity and submergence ratio. For example, for a gas superficial velocity of 1 m/s, liquid superficial velocity reduces from 6 mm/s to 2 mm/s when the riser diameter is increased from 25 mm to 40 mm. Since, the drag force of water is responsible for the lifting of solids, any decrease in liquid superficial velocity causes a reduction in drag force and hence solid superficial velocity is found to be decreased with an increase in riser diameter

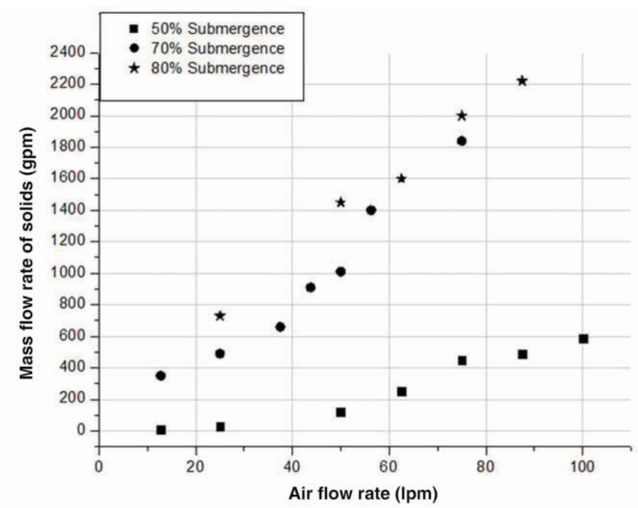

Fig. 6: Effect of Submergence on particle mass flow rate for conditions given in table 1

Engineering Scale Prototype and Trials

An engineering scale prototype simulating actual operating condition was fabricated as shown in Fig.7. In actual operating condition ziracloy fines are expected to be lifted from the vessel bottom filled with 8 M Nitric acid solution the actual. To simulate the particles, chips generated from machining of stainless steel material with a density of 7.85 g/cc were used which consisted of chips of varying size. Water was used in place of Nitric acid. Trials were carried out keeping the submergence condition (60 %) as desired in actual condition. Trials were carried out at varying air flow rates and the solid particulates collected at each trial were measured and recorded as in earlier cases. The results are shown in Fig 8.

Summary

The developmental effort undertaken highlights the suitability of geyser pump in slurry pumping applications. Experimental results establish the significance of motive fluid flow rate and submergence as the pumping performance was found to be extremely sensitive to them. The experimental study especially pertaining to the three –phase flow conditions gave an insight on the pumping performance under different test conditions like particle size, particle diameter and riser diameter. Increase in particle diameter and density was associated with the fall in the particle mass flow rate. Superficial velocity of water and particle were found to be decreased with an increase in the riser diameter. Trials with actual sized prototype confirmed the effectiveness of this system for handling fines / particulates for application similar to that of CRD.

Fig. 7: Engineering scale prototype

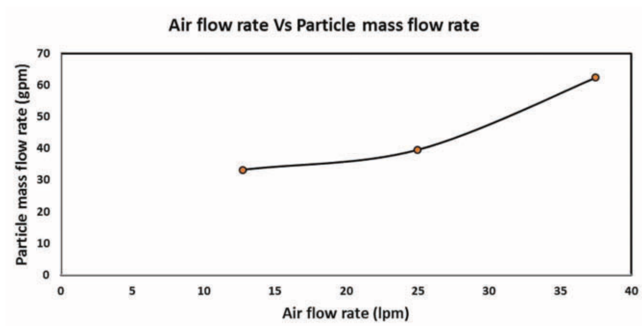

Fig. 8: Solid transfer for the engineering scale prototype at 60 % submergence

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References

1. Shaji Karunakaran, G Sugilal, K. N. S. Nair, *Development of continuous rotary dissolver*, BARC Internal Report, BARC/2012/I/023,
2. R. Srinath, *Flow characteristics of geyser pump for continuous rotary dissolver*, M. Tech. Thesis, Homi Bhabha National Institute, 2015