Available online at http://www.ijabbr.com

International journal of Advanced Biological and Biomedical Research

Volume 2, Issue 4, 2014: 1248-1256

Investigation of Sediment Discharge Hydro-Induction for Preventing Sediment In Dams (a Review)

Mohsen Norouzi

Department of water engineering, Shahrekord University, Shahrekord, Iran

Abstract

Hydro-induction sediment discharge technique (HSDT) aims to prevent reservoir sedimentation by withdrawing the discharge water from the reservoir bottom to suck up and discharge sediments, and by inducing vertical vortexes and undercurrents in the reservoir bay to keep sediments agitated and moving. The technique is facilitated with an innovative discharge conduit system having bottom intakes that are engineered and configured to suit individual dam situation for maximum process efficacy. Analyses of the hydraulics and operating principles of the bottom intake discharge system are presented. Guidance for designing and configuring the discharge conduit system is provided. Several key issues concerning the practical application of the technique are discussed briefly. The process feasibility and functionality of the bottom intake discharge system have been demonstrated with a small test setup. Testing with large scale models and field tests are needed to develop design data for big dam application.

Key words: Sediment removal, Hydro-induction, Sediment discharge, Dam design

Introduction

For hydropower dams having power plants at or by their toes, the appurtenant setups for releasing the reservoir water to the power generators are all similar. They all provide the water release gates at about just below the reservoir's lowest operating water level with some kind of valve to stop or regulate the water flow. The discharge water then flow down the penstock to the generator. These text book arrangement has-beens followed for decades and accepted as a golden model by hydropower dam engineers all over the world. A major problem with this traditional arrangement is the deposition of sediments in the bottom of the dam reservoirs, especially for those with influents carrying large amount of sediments. Sedimentation occurs as the influent flow diverges and slows down upon entering the reservoir causing sediments to deposit and accumulate in the reservoir bottom. The process continues until the bed of the reservoir reaches a steady state slope at which point all the sediments carried by the influent water would be moving right through the reservoir and carried away with the effluent water. At this stage, unfortunately, the reservoir would have lost most of its usable storage capacity and its capability for flood control. Detention of soils and sediments in large reservoirs also causes degradation of downstream

Corresponding Author E-mail: mohsen.norouzi48@gmail.com

farmlands and flora as well as erosion of downstream riverbed. Organic wastes released to upstream river are also trapped in the deep water of the reservoir to possibly cause serious detrimental effects to fish life.

The author proposes a hydro-induction sediments discharge technique (HSDT) that can head off the sedimentation process and minimize the negative environmental impacts from river damming. Briefly, the technique involves: 1) employing a bottom intake discharge system (BIDS) that draws the discharge water from the dam bottom enabling the discharge water to pick up sediments and carry them to the downstream river, 2) by inducing vertical vortexes and strong undercurrent flow in the reservoir bay to keep sediments agitated and moving toward the reservoir outlet end, and 3)operating the water discharge system based on a comprehensive operation scheme that is programmed with considerations for the hydrology and seasonal conditions of the reservoir and power generation requirements to maintain effective discharging of sediments at various water discharge rate conditions.

The bottom intake discharge system is the key of the technique and is instrumental in making the process work. Figures 1a, 1b and 1c show graphically three basic water discharge setup arrangements based on the BIDS design. One would readily notice that these setups share some common characteristics: 1) they all draw discharge water from the reservoir bottom by the dam base, 2) the discharge water needs to flow in the upward direction for some distance on route to the generator (as the generators are at some elevation level above the reservoir bottom). These two characteristics are typical of the BIDS setups and are in drastic contrast to the conventional water discharge setups. Other important issues are whether the sediments can be carried along by the discharge water flowing in the upward direction, and whether the discharge water drawn from these BIDS setups would provide the same amount of mechanical energy (available total mechanical energy per unit mass of water) as that from the conventional systems. These issues as well as the hydraulics and mechanics of the BIDS setups are discussed in the following text. It will be shown that the mechanics of the BIDS setup is sound and functional, and that the process feasibility of the technique is based on established principles of particle mechanics and supported by data from slurry transport studies.

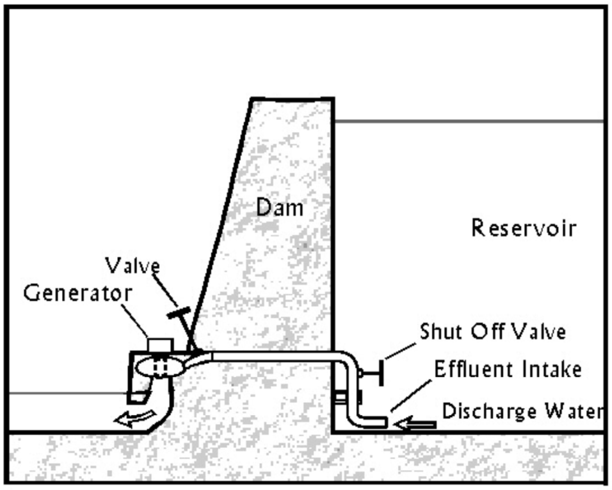

Fig. 1a. New Effluent Discharge Setup, Arrangement No. 1

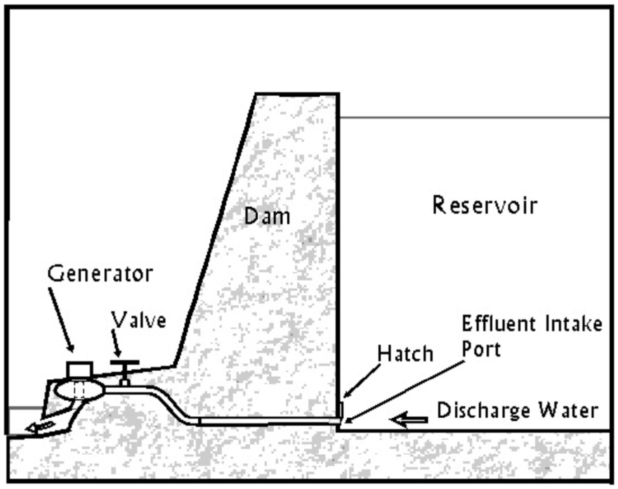

Fig. 1b. Effluent Discharge Setup Arrangement No. 2

An analysis of the hydraulics of a BIDS setup and a comparison of the energy contents of the effluent water from BIDS and conventional water discharge systems are made to answer some of the questions mentioned above. Fig. 2 is a schematic diagram showing three alternate water discharge setups. The new BIDS arrangement No. 1, also shown in Fig. 1a, is represented by a setup with solid outline conduit reaching to the reservoir bottom; a typical conventional water discharge setup having the water intake gate located at about 2/3 way up of the dam height; and a weir overflow type system in which the water intake is always at the reservoir water level.

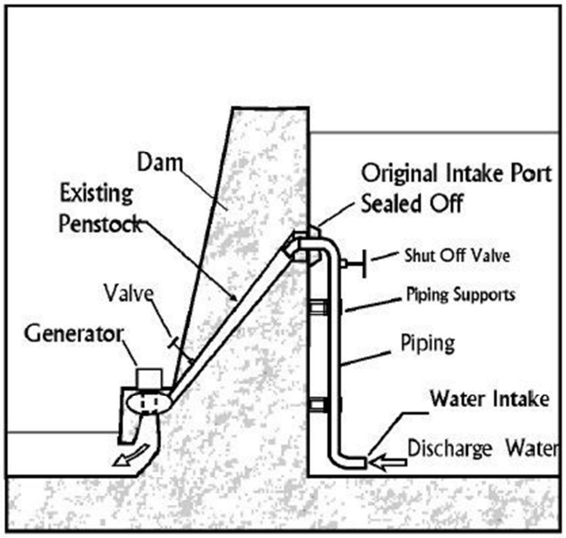

Fig. 1c. New Effluent Discharge System Arrangement No. 3 (Modification of an existing discharge setup)
(jerry, 2004)

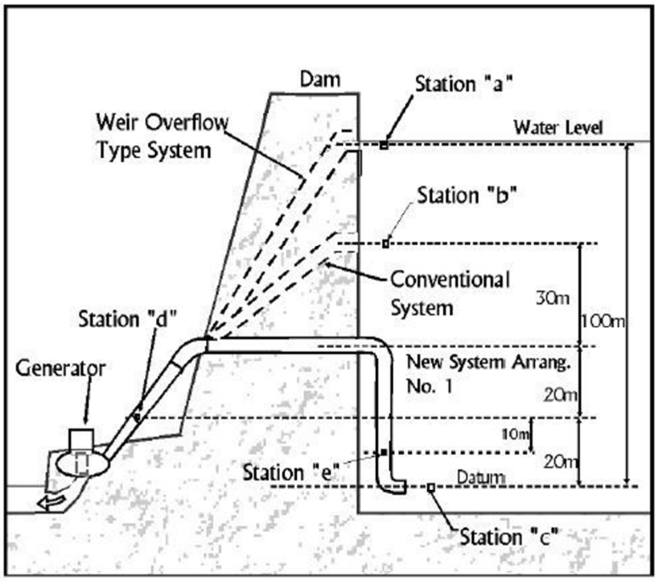

Fig. 2. Schematic Diagram of Three Alternate Effluent Discharge Arrangements
(jerry. 2004)

Water always flow downward, but in a pipeline it can be forced to flow upward by pressure as in the discharge pipe of a pump. The feasibility of drawing water from the reservoir bottom with the BIDS arrangement No. 1 can be understood by considering a thin layer of water having unit cross sectional surface in the intake pipe at point “e”. The driving force that is available to push this element of water up through the intake piping to discharge at point “d” can be determined by the following analysis. Assuming the pipeline is terminated right at point “d” and plugged. At the very instant the plug is removed, the resultant force available for pushing this element of water from point “e” toward point “d” is the difference between the upward force acting on its lower surface, pressure at elevation “e”, less the opposing force acting on its top surface, the sum of the atmospheric pressure plus the elevation difference between stations “d” and “e”, as shown below:

Available driving force = [1 atm + 90 m water] – [1 atm + 10 m water] = 80 m water column.

The above analysis shows that the pressure at the bottom intake port is capable of pumping **the** discharge water to an elevation as high as that of the reservoir water level.

To determine whether the water drawn from the BIDS setup would provide same amount of mechanical energy per unit mass of water as that from the conventional system, we can simply compare the per unit mass mechanical energy of the discharge water at point “d” for the three alternate systems shown in Fig. 2, all based on the same reservoir water level of 100 m as shown. For convenience, assuming the piping losses for all three systems are all negligible (frictionless) and the initial velocity of the water at points “a”, “b”, and “c” are all at 3 m/s. In each case, the system is at a steady state, and the water density is assumed constant. Based on the principle of energy conservation and Bernoulli theorem for inter-convertibility of pressure, kinetic, and potential energies for streamline flow of incompressible fluids, the total mechanical energy per unit mass of water at point “d” for any of the three alternate systems may be expressed as follows: (Notations used: V = velocity in m/s; Z = fluid elevation height in m; P = pressure in kPa; = density of fluid in kg/m3; g = gravitational acceleration constant in m/s2; and a, b, c, and d denote the stations respectively) Unit mass mechanical energy of water at point “d” = Unit mass mechanical energy at point “x” = Vx2/2 + gZx + Px/ , wherein “x” denotes the intake station of any of the three alternate systems.

With the above equation, the per unit mass of mechanical energy of water at point “d” for each of the three alternate systems may be calculated by simply substituting the values of V, P, and Z at the respective station as shown in Fig. 2, and using water density of 1,000 kg/m3 and g at sea level of 9.807 m/s2. The results show that they all come out to be 1086.5 joules per kg mass of water. This confirms that regardless of which discharge setup is used, they all provide same amount of mechanical energy per unit mass of water for power generation for a given reservoir water level. A review of the mechanics and fluidization of particles in moving fluids would also be appropriate before going into the process mechanisms and means proposed for discharging sediments. Solid particles can be lifted up and entrained in the carrier fluid when the carrier fluid velocity exceeds the particle’s “terminal velocity”. This velocity depends on the particle size, and properties of the particles and the carrier fluid. Reliable equations and simplified methods have been developed for its estimation.

Recent Studies

For example, the calculated terminal velocities using a simplified method by Schiller(Schiller and Neumann 1933) for 1 mm and 3.2 mm diameter round sand particles in water are 0.16 m/s and 0.35 m/s respectively. For slurry heavily laden with high concentration of solid particles, the flow velocity of the fluid must be much higher than the terminal velocity of the particles to be able to successfully carry the solids through a pipeline. The minimum velocity required to transport slurry through a pipeline system is known as the “critical transport velocity” for that slurry-pipeline system. The feasibility of transporting slurry is not just in theory but has been in use for over some forty years in dredging operations and in mining industries (Subramanian, 2001). Data on slurry transport and pumping have become available recently in the literature and from research institutions such as that presented by Weidenroth (Wiedenroth 1978) and Ni (Ni and Matousek 1999). Very useful data on transport of phosphate matrix slurries through large 18” and 20” pipelines have been published by FIPR (FIPR 1989). Slurries containing as much as 50% by weight of phosphate pebbles and fines were reported still transportable through pipeline. These data are useful as a database for the detailed design of the BIDS. In general, the design flow velocity for the discharge pipeline must be well above the critical transport velocity of the effluent slurry to assure its free passage; and the operating velocity of the pipeline must be maintained at all time above the required transport velocity for the highest sediment content that can be anticipated for any specific operating period.

While complete fluidization or entrainment of the sediments is necessary to transport sediments through pipeline, the velocity of the undercurrent flow through the reservoir bed may be somewhat below the terminal velocity of the sediments to drag them forward on level ground. When there is a slight downward pitch toward the outlet direction, even lower velocity may be adequate. From data on the characteristics of the sediments and the bed profile of the reservoir, it is possible to determine the required undercurrent flow velocity for any specific area of the reservoir bed to keep sediments from settling.

The mechanics and principles of fluidization of particles in moving fluids clearly explain how the BIDS can pickup sediments in the immediate area before the dam wall, and passing them to the downstream river. To keep the main reservoir bay from sediment buildup, it is necessary not only to keep the sediments being carried in with the inflow water from depositing but also to remove that already deposited during low flow periods. The author proposes that these tasks can be accomplished by inducing vertical vortexes and strong undercurrents in the reservoir bay and that such vortexes and undercurrents can be induced by the drafts of the outgoing jet streams accelerating toward the BIDS intakes. The vigorous motion of vortexes can keep the sediments in Suspension or in a semi-suspended state (partial fluidization) while the undercurrents can stir up that already deposited and drag them along to the reservoir outlet end. The arrangement and configuration of the intakes of a BIDS should be made to suit a specific dam situation in such a way to guide the induced undercurrents to flow along the deep valleys of the reservoir bay to keep them clean.

Having the valleys kept clean, sediment buildups will be limited to areas on both sides of the valleys. These sediment mounds, however, will be confined and curbed by their sides that are established based on characteristics of the sediments, their angle of repose, and local current flow conditions. As such most of the reservoir's working capacity, in various degrees. Depending on the geometry of the dam, would be retained even after some long period of operation. In contrast, the reservoirs with traditional penstock setups would have lost most of their useful water storage capacities at the final stage of sedimentation process. The effectiveness of this technique depends substantially on the formation of vertical vortexes that can store and amass the kinetic energies of the outgoing jet streams and the inflow water into a big mass of whirling water to keep the reservoir water agitated. With the vortexes in motion, the influent river water would be deflected toward the reservoir bottom preserving much of its momentum to start off the undercurrent flows. For short reservoirs having influent water entering at the reservoir upper water level, it may be necessary to modify the reservoir inlet mouth to provide a downward pitch to allow the influent water to dive directly toward the reservoir bottom to preserve much of its momentum for pushing undercurrent flows. The geology, the reservoir geometry, the bed profile, and the influent flow pattern of a specific dam all have to be studied carefully to properly position the conduit intakes and to select the types and arrangement of the intake ports for producing the desired effects. For a reservoir with a V-shape bed, the main intake ports should be located at the deep apex where sediments collect. Big dam with wide flat bottom would require several intake ports spaced along the length of the dam wall to pick up sediments across the whole width of the reservoir. Using expander shape intake ports can be effective in spreading the undercurrent flows to sweep over a wide span of reservoir bottom for broad coverage. Non-regular shape expanders can be designed to direct currents to sweep at some specific areas where sediments are likely to collect. The strength of the vortexes and undercurrent flows in are savoir will depend largely on the speed and the flow volume of all the contributing jet streams in comparison to the total volume and size of the reservoir. A run of the river type reservoir with a narrow reservoir bed is possible to have its undercurrent flow at flow speed even higher than that of the upstream river flow.

While the size of the reservoir and the hydrology have much to do with the number and size of the discharge conduit setups for a given dam, the requirement for operating the generators on partial load conditions necessitates some consideration on the design of the overall water discharge system and its conduit arrangement. Instead of using a single large conduit to transport discharge water to a big generator or a group of generators, two or more conduits may be used. This multi-conduit arrangement would allow operation at reduced load conditions by shutting off some of the conduits while maintaining the flow velocity in the operating ones sufficiently high to prevent sediments from dropping out in the conduit. For big dams having multiple discharge conduit systems and multiple number of generators, operating with just a limited number of the systems at a time on a rotation basis is another way of cutting down the total power output. Having strong undercurrents and vortex in a dam reservoir could also cause some erosion of the reservoir bed over a long period of operation, especially for beds of alluvial type composition. This possibility would accentuate the capability of the BIDS for removing sediments and preventing sediments from building up in the dam reservoir. In Fig. 3 is shown a comparison between the potential long-term bed profile of a dam using the new BIDS setup and that with the traditional setup, assuming the influent river water is heavily laden with fine alluvial sediments. With the new system, the reservoir bed would maintain deep down close to its original profile. As such the operable water level could be extended to much below that is possible with the conventional setup. A large volume of reserve water storage therefore becomes available which could be released during a draught for irrigation and for power generation uses. The cascading effect from deep reservoir bed and low current flow path through the reservoir should also help to alleviate the sedimentation problem in the immediate upstream riverbed.

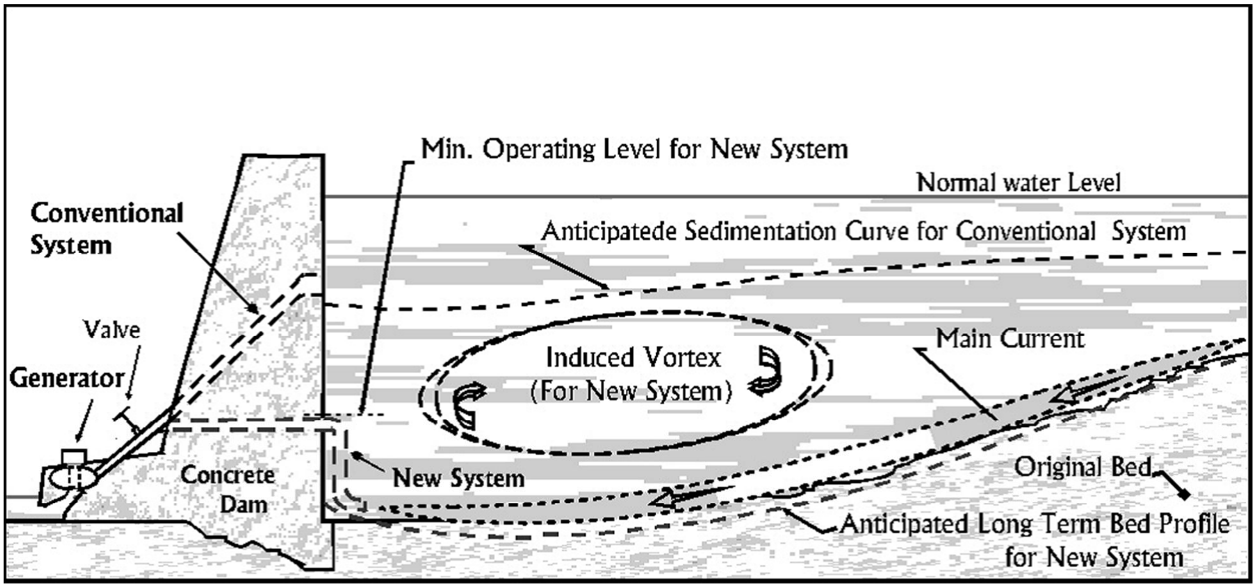

Fig. 3. Comparison of Anticipated Long Term Reservoir Bed Profiles Between New and Conventional Systems (Note: The horizontal ordinate is on an arbitrary condensed scale) *(Jerry , 2004)*

Pilot tests have been conducted with a small bottom intake discharge setup constructed with 3” PVC pipes and fittings and arranged similar to that shown in Fig. 1a but of open discharge at the discharge pipe end (see Fig. 4 for the pilot test setup).

The elevation height of the discharge pipe end was made adjustable by using elbows of thread ends. Fine sands and soils were charged into the bottom of the reservoir vessel to simulate sediments. The water level in the reservoir vessel was kept constant by adjusting the feed water rate to balance off the discharge flow. Tests were made to determine the effect on the discharge flow rate by varying the differential elevation height between the water level and the discharge pipe end, and also by changing the elevation height of the water intake port. Test results showed that the discharge water rate varied approximately directly to the square root of the differential elevation height between the water level and that of the discharge pipe end. The actual discharge flows through the discharge pipe were in good agreement with that calculated by the Bernoulli equation after pipeline friction losses were accounted for. For a given differential elevation height between the water level and the discharge pipe end, raising or lowering the intake port showed no effect on the discharge rate as long as the intake port was well submerged under the water. Satisfactory removal of sediments from the reservoir bottom within the area bound by the feed water distributor and the included angle lines of the water intake expander was noted at discharge flow of over 0.65 cubic meter per minute (corresponds to discharge pipe velocity of 2.63 m/s). The areas behind the included angle lines of the intake expander, however, had some sediments buildup. Especially around the two corners. There has been no difficulty experienced for the discharge flow to pick up sediments around the intake port area and passing them through the 3” pipeline at the pipe flow velocity down to 1.2

m/s tested (no attempt was made to test pipe velocity less than 1.2 m/s). These results clearly confirmed that the design of the bottom intake discharge setup is sound and functional, and that the available mechanical energy of the effluent water depends only on the reservoir water level and the elevation at point of discharge. Tests also confirmed the feasibility of Discharging sediments with the technique presented.

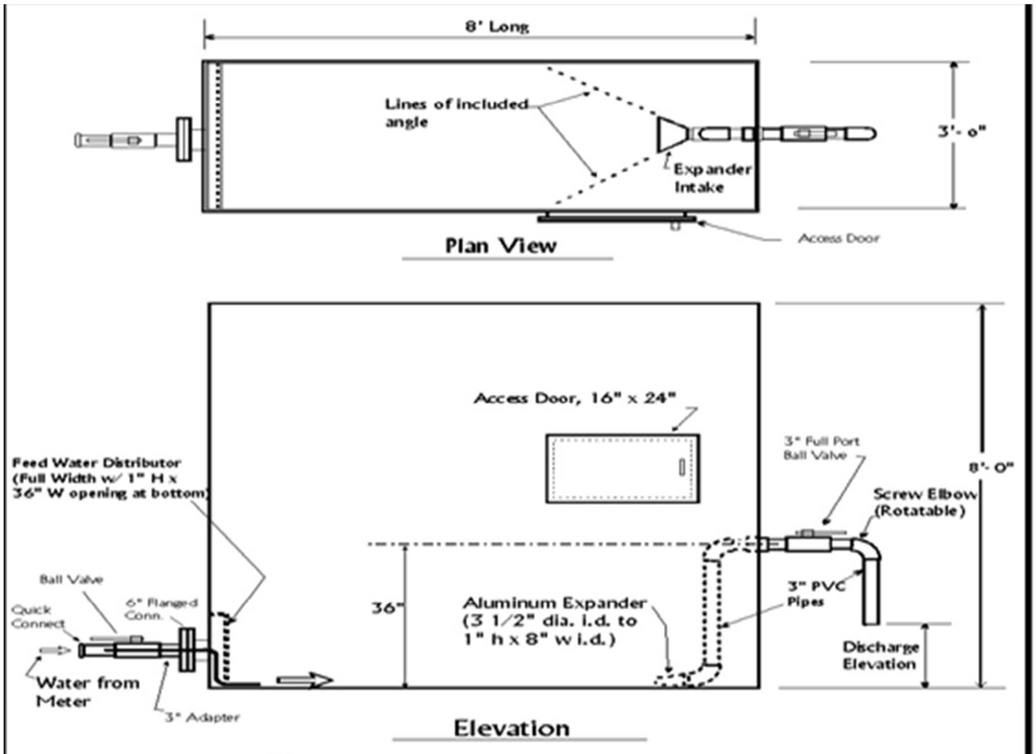

Fig. 4 General Arrangement of Pilot Test Setup

Costs for installing bottom intake conduit systems, effects of higher sediment loading in discharge water on the operation and maintenance of hydroelectric generators, and means for guarding the bottom water intakes from debris are issues weigh heavily on the practical applicability of the proposed technique. These issues are examined briefly below in the context of high sediment content river water environment for which the technique is developed. For new dams, the cost for installing BICS could be much cheaper than the traditional down flow penstocks not only because the conduit distance between the water intakes and the generators is much shorter but also because BICS conduits can pass through the dam wall horizontally to minimize the dam reinforcement requirement. For existing dams, modifications could be made by simply adding new intake conduit sections to the old intake gates as shown in Fig. 1c. The new intake conduits may be constructed of prefabricated sections with the bottom sections weighted with concrete blocks. These sections may simply be dropped into the water with crane then bolted together and secured to the dam wall. Such prefabricated and field assembled conduit systems should be relative inexpensive to install. The sediment content of the discharge water from a dam with BICS would be somewhat higher than that of its counterpart with traditional penstock on account for the portion of larger sediments not dropping off in the reservoir. Somewhat higher sediment content would have no effect on the operation of the hydroelectric generators except a slight increase in wear of the turbine runner blades might be experienced. Any increase in turbine Wear should be slight, as there would be no increase in the fluid velocity through the turbine generators. Should any excessive wear of runner blades is evident in any specific case condition, using runner blades made of abrasion resistant alloy steel should solve the problem. For preventing debris from clogging the water intakes of BICS, circular shape trash rack having motorized lift is a ready candidate for this use. With the operating experiences learned from similar trash racks used in traditional dam systems, it should not be difficult to engineer one that will work in deeper water. From above, it appears that there is no real problem in adopting the proposed technique for practical uses.

Aside from preventing sedimentation in dammed reservoirs, many secondary benefits are obtained from drawing discharge water from dam bottom. First, there is a large reserve water storage made available by this technique. This large reserve storage may be released for irrigation or for power generation use during a drought. By passing the soils and sands normally carried with the inflow river water right through the dam, the technique would also help to maintain the regular supply of nutrient rich soils to the downstream river to benefit agriculture and flora and preventing erosion of downstream river bed and river bank. Drawing water from reservoir bottom also facilitates flushing out trapped underwater semi-suspended organic wastes to prevent harmful pollution and minimize any negative impact to the ecology of the river system. Thus the new effluent discharge technology has a far reaching influence than just preventing reservoir sedimentation but could also help to minimize the disruption of the natural rhythm of the river system due to damming.

Conclusions

An inventive technique is presented for discharging sediments to prevent sedimentation in hydropower dams. The technique does not rely on any dredging machinery or huge conveyor for the task but simply makes use of the kinetic energy of the water to perform the task. In essence, the process is carried out by routing the river flow through the bottom of the reservoir to pick up and carry away the sediments with the aid of an innovative water discharge system with bottom intakes. A comprehensive scheme for operating the water discharge system serves to further maximize the Removal of sediments at various discharge rate conditions. The bottom intake conduit system, which is instrumental in carrying out the task, is described in details. Analyses and discussions presented show that its mechanics and functionality are on sound foundations. A brief review on the principles of particle mechanics and slurry transport provides the theoretical bases for the process mechanisms involved and explains how the process works. Most convincing are the affirmative pilot test results that give a clear confirmation to the process feasibility as well as the functionality of the bottom intake conduit system. Also important is the result of the discharge water mechanical energy comparison showing that the available mechanical energy of the discharge water for power generation is the same for a given reservoir water level regardless of at what elevation level the water is drawn. This means that using the new discharge system would not incur any loss in the mechanical energy of the reservoir water for power generation. Discussions on locating and arranging the conduit water intakes, and guidelines on the design and operation of the new water discharge system are provided to assist dam design engineers in drawing up an effective BICS for a specific dam requirement. Testing with large scale setups and field tests would be required to provide more realistic correlation data among the discharge flow rate, undercurrent flow velocity, reservoir size and volume factors for the design of a specific dam system.

References

1. FIPR, (1989). Phosphate Matrix Pipeline Design Data and Tools for Efficiency Improvement, Florida Institute of Phosphate Research, Bartow, Florida.

2. Ni, F. & Matousek, V., (1999). "Flow of Aqueous Mixture of Sand Composed of Fractions of Different Particle Size", Proc. Hydrotransport 14, BHRG, Cranfield, UK, 31- 44.

3. Schiller and Naumann, (1933). Z. Ver. deut. Ing., 77, 318.

4. Subramanya, K., (2001). "Pipeline Transportation Technology: An Overview", <http//www.iisc.ernet.in/~currsci/october/articles32.htm> (March, 2002).

5. Wiedenroth, W., (1978). "Experimental Work on the Transportation of Solid-Liquid Mixtures through Pipeline and Centrifugal Pumps". Hydrotransport 5, May,1978, Paper A2, 13 – 36.

6. Jerry Chi Wang, P E., (2004). "Hydro-Induction Sediment Discharge Technique for Preventing Sedimentation in Hydropower Dams"1Chief Engineer of Advanced Industrial Technology Corp., Post Office Box 493, Paramus, NJ 07653-0493; Ph: 201 265 1414.