

A NOVEL SILT-WATER SEPARATION STRUCTURE FOR PIPES OFF-TAKING FROM IRRIGATION CANALS

UNE NOUVELLE STRUCTURE DE SÉPARATION LIMON-EAU POUR LES CONDUITES DÉRIVANT L'EAU DES CANAUX D'IRRIGATION

Dr. Venkata Ramamohan Ramachandrupa¹

ABSTRACT

The natural streams, rivers and artificial canals carry sediment particles along with them. Transmission and deposition of such sediments alter the flow regime and block the operation of hydraulic structures, gates etc. In order to exclude or eject the silt from irrigation canals, excluders, ejection tunnels, vortex chambers and vortex tubes are commonly used. A novel Silt-Water Separation Structure (SWSS) is developed that separates sediments from water and facilitates withdrawal of sediment-free water from open channels using a pipeline.

The structure involves construction of a low-head barrier across the stream or channel. The silt that settles down at the upstream is flushed out using a vent placed at the bed of the channel. A pipeline of 150 mm diameter was placed above the vent level will be capturing the silt-free water for further conveyance and utilization. A pilot physical model was made and its performance was observed during 2024-26. Computational Fluid Dynamics (CFD) simulations and Discrete Particle Modelling (DPM) analysis were carried out on the SWSS model to quantify its silt ejection efficiency. The model was tested with a mix of 0.1-2.0 mm diameter particles, mass flow of 5e-3 kg/s and for six flow depths between 0.04-0.15 m. 20.85-37.49% of flow diversion through pipe was achieved with a particle load of 0.238-7.608% and particle size finer than 0.8 mm diameter. By increasing the size of the pipeline, more water could be diverted that is relatively silt-free. 63.54-98.68% particle separation and disposal rate through the vent was achieved.

The novel SWSS has its potential applications in not only in irrigation systems but also in raw water intakes of thermal power projects, water treatment plants, storm water drainage systems etc. Further work to improve the silt ejection performance by optimizing geometric design of SWSS forms the future scope of work.

Keywords: Silt-water separation, Silt ejection, Conduit flow, Silt intensity.

RÉSUMÉ

Les cours d'eau naturels, les rivières et les canaux artificiels transportent des particules sédimentaires. Le transport et le dépôt de ces sédiments modifient le régime d'écoulement et entravent le fonctionnement des ouvrages hydrauliques, des vannes, etc. Des dispositifs d'exclusion, des tunnels d'éjection, des chambres tourbillonnaires et des tubes vortex sont couramment utilisés pour exclure ou évacuer le limon des canaux d'irrigation. Une nouvelle structure de séparation limon-eau (SWSS) a été mise au point afin de séparer les sédiments de l'eau et de permettre le prélèvement, par une conduite, d'une eau exempte de sédiments dans les chenaux à surface libre.

La structure comprend la construction d'un seuil de faible hauteur de charge en travers du cours d'eau ou du canal. Le limon qui se dépose en amont est évacué au moyen d'un orifice placé au fond du canal. Une conduite de 150 mm de diamètre, placée au-dessus du niveau de l'orifice, capte l'eau

¹ Executive Director, Water and Livelihoods Foundation (WLF), 12-13-451, Street no.1, Tarnaka, Hyderabad, India.
ramamohan.ramachandrupa@gmail.com, Mobile: +91 9440194866.

débarassée du limon en vue de son acheminement et de son utilisation ultérieurs. Un modèle physique pilote a été construit et ses performances ont été observées pendant la période 2024-26. Des simulations de mécanique des fluides numérique (CFD) et une analyse par modélisation des particules discrètes (DPM) ont été réalisées sur le modèle SWSS afin de quantifier son efficacité d'éjection du limon. Le modèle a été testé avec un mélange de particules de 0,1 à 2,0 mm de diamètre, un débit massique de 5×10^{-3} kg/s et six hauteurs d'écoulement comprises entre 0,04 et 0,15 m. Un taux de dérivation du débit dans la conduite de 20,85 à 37,49 % a été obtenu avec une charge particulaire de 0,238 à 7,608 % et des particules d'un diamètre inférieur à 0,8 mm. L'augmentation du diamètre de la conduite permettrait de dériver une quantité plus importante d'eau relativement exempte de limon. Un taux de séparation et d'évacuation des particules par l'orifice compris entre 63,54 et 98,68 % a été atteint.

La nouvelle structure SWSS peut être utilisée non seulement dans les systèmes d'irrigation, mais aussi dans les prises d'eau brute des centrales thermiques, les usines de traitement de l'eau, les réseaux d'évacuation des eaux pluviales, etc. Les travaux futurs porteront sur l'amélioration des performances d'éjection du limon grâce à l'optimisation de la conception géométrique de la SWSS.

Mots clés : Séparation limon-eau; Ejection du limon; Ecoulement de conduit; Intensity de limon.

1. INTRODUCTION

The water flowing in irrigation canals, especially those built in hilly areas to carry natural spring or stream water from hill-tops, carry significant amount of sand and silt, together called sediments. The sediments are broadly classified as bed-load that roll on the bed while the water flows and the finer suspended particles that float with the flowing water. These solids get deposited at the channel sections where there is mild slope or where weirs / gates / barriers are built across the channel to divert water into smaller distribution channels. Similarly, raw water drawn from rivers or streams contains finer silt particles that need to be treated with sedimentation and coagulation processes in the water supply treatment plants to exclude them from the raw water and to obtain clear water for further filtration processes. In thermal power plants, where water is used as an input to produce steam, the raw water should be free from silt particles for optimum performance. When water is drawn from reservoirs, tanks or water bodies using gravity pipelines or conduits, the silt deposition inside the pipelines not only affect the hydraulic performance, but could completely fill it up and make the pipeline dysfunctional.

Thus, water containing sediments (silt and sand) not only affects the functional capacity and performance of various hydraulic structures, but also imposes more economic burden in separating the silt from water. Some of the specific adverse effects of sediment-laden water are:

1. Unwanted deposition in reservoirs / tanks / water bodies and reduction in their storage capacity
2. Erosion of canal bed and lining, but deposition of eroded soil and silt downstream altering the hydraulic regime and reducing channel flow capacities
3. Silting up of pipelines /conduits at low-velocity sections, resulting in reduced discharges and sometimes complete blockage. Restoration of such pipelines is quite expensive, often leading to the decision to completely abandon the pipeline and lay a new pipeline
4. Internal damage to pipes due to particle and pipe wall collisions
5. Pitting on turbine impellers in hydropower stations, leading to their reduced life and failures
6. Increased process time and costs in sedimentation and coagulation processes in water treatment plants, thermal power plants and other industries where water is used as a process input
7. Silt deposition blocking the sluices, reduced discharge capacities and creating obstruction to gate operations at canal branching-out and off-take points, regulators, locks etc.

The current paper focuses on the sediment removal from irrigation canals and natural hill streams that are used for irrigating crops. A novel pipe off-take device / structure that separates sediments from water and facilitates withdrawal of sediment-free water through a pipe or conduit is detailed. A review of existing know-how and the merits of the proposed novel device are presented in detail.

2. REVIEW OF EXISTING TECHNOLOGIES

Most of the existing technologies related to the silt separation from water were specifically developed for irrigation canals. Broadly two types of silt separation structures, viz., (i) excluders, and (ii) ejectors, are defined in engineering literature and the same are found constructed on irrigation canals in India and elsewhere (**Figure 1**). The silt excluders separate the silt from water at the head-regulator / off-take point of a canal from a barrage so as to minimize the sediment entry into canal. Whereas, the ejector (also called extractor) structures are built on different points of canals for trapping and ejecting the silt particles flowing with water. The ejectors may be classified as ejector tunnels, vortex type settling chambers and vortex tubes. The vortex type chambers are particularly used for trapping and ejecting the finer sediment particles that float in the channel flows. Other designs are mostly suitable for ejecting heavier bed loads.

In Indian context, Bureau of Indian Standards (BIS) defined the design guidelines for excluders in the Standard IS13495 and for ejectors in the Standard IS6004 (BIS 2002 & BIS 2019b). IS13495 recommends construction of multiple tunnel structures at the head regulator of an irrigation canal to prevent the sediment entry into main canal. The tunnels are directed to escape into the downstream of the barrage. The IS6004 provides a design basis for the construction of sediment ejectors across irrigation or power canals. These ejectors employ a series of tunnels built at the bottom of the channel. The channel width is typically broadened to lower the velocity for the particles to reach their settling velocity. The tunnels are provided with curvature to eject the silt to an escape channel that is aligned typically at a right angle to the main channel.

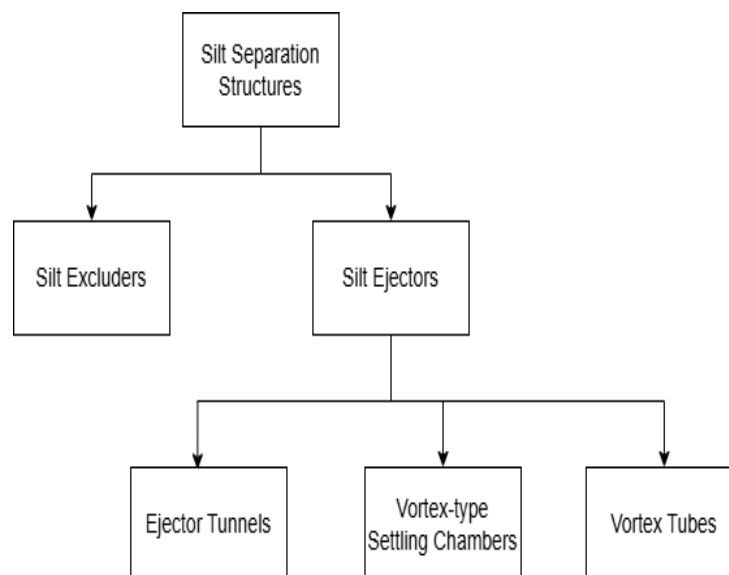


Figure 1. Classification of silt separation structures for irrigation canals

The guidelines provided by IS13495 and IS6004 are specific to the irrigation canals and are relatively complex in design. They are expensive structures requiring both approach and escape channel and bed level modifications. These designs do not suit the situations of the pipe or conduit diversions to be made from the open channels in hilly rugged terrain. Also, these designs do not suit different kinds of real-life problems that are encountered in water management and fluid dynamics. For example, separation of silt load in the raw water carried by the feeder channel to a water treatment plant helps

to reduce sedimentation and coagulation process time in the main plant. Secondly, the urban storm water channels carrying sediments. Trapping and ejection of the sediments at the intermittent points of the storm water drain helps in smooth flow of storm water in them. Such applications require more versatile and simpler designs of silt separation structures.

In the case of off-taking canals from a parent canal, two more designs are suggested by BIS. IS7880 describes a method of separating the silt using a skimming platform built on the parent channel upstream of the off-taking channel (BIS 2019c). The off-taking channel gets relatively free from the bed-load of heavier sediments from the parent channel. IS6522 suggests construction of vanes on the bed of parent channel to carry the bed sediments away from the off-taking channel, delivering relatively sediment-free water into the same (BIS 2019a). However, both these designs above are appropriate when the off-taking canal is expected to function as a branch canal and to carry much lesser flows (typically, less than 1/3rd) compared to the parent canal.

Various researchers across the world studied the sediment trap performance of vortex chamber type ejectors and suggested various design variants. For example, Keshavarzi and Gheisi (2006) optimized its design with deflectors and tested a vortex chamber in a laboratory using the finer sediments of 0.074 to 0.3 mm size. The hydraulic efficiency (13 to 20%), which indicates the loss of water in flushing the sediments from the vortex chamber and the sediment trap efficiency (59 to 68%), which indicates the percentage of removed sediments from canal water were measured and reported.

In the vortex tube type ejectors, a tube is incorporated across the bed of the irrigation canal often at an inclined angle, so that the part of the bed load of heavier sediments enters the tubes and get ejected to the escape channel through a vortex motion of water. This system is found to be less space consuming, cheaper and more efficient in ejecting heavier particles without loss of much water. However, their primary purpose is to eject the sediment bed load from the irrigation canals and do not serve the purpose when off-taking canals are required to be fed with sediment-free water. Recent advances in this field include application of numerical models and application of artificial intelligence (AI) techniques to predict and quantify the trap efficiencies of different ejector tubes (Singh et al. 2021 and Kumar et al. 2023).

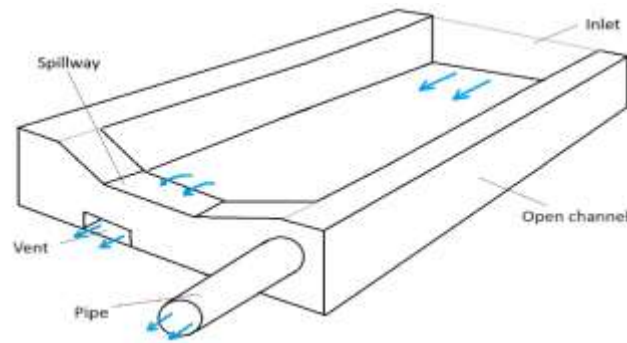
3. STRUCTURAL FEATURES OF THE NOVEL SWSS

As described before, various known technologies of silt excluders and ejectors are primarily meant for use with irrigation canals. They either prevent entry of sediments from a barrage or main canal into an off-taking irrigation canal or trap and eject the moving sediments, mostly bed load of heavier particles, in the reaches of irrigation channels.

In contrast to these situations in plain areas, the hilly and undulating terrains pose a different challenge. For example, alignment and construction of an off-taking open channel from the main canal may not be feasible due to undulating topography and intermittent land use constraints. A feasible alternative is to divert the water from the irrigation canal using a pipeline or conduit, that is laid mostly underground and water may be delivered at the other end of the pipeline at a gauge pressure. If a conduit is laid as an off-take from the canal, it is highly likely that the conduit gets filled with sediments in absence of a separation structure that prevent the entry of sediments into the conduit.

The novel SWSS mainly contains a low-head barrier constructed across the channel, in which three structural components, viz., a rectangular vent, a pipe off-take and a trapezoidal spillway are incorporated (**Figure 2a**). A physical model of the SWSS was field-tested in a remote tribal village, Podhili in Paderu mandal, ASR district, Andhra Pradesh, India (**Figure 2b**). The water that enters the approach channel will be obstructed by the low-head barrier. Part of the flow will pass through the vent at the bed level; and some part will pass through a pipeline. The pipeline is of 150mm diameter and for a length of 700m. The bottom of the pipe is kept just above the top of the vent to facilitate the flow of silt-free water into the pipe.

The water passing through the pipe will be used for irrigating crops. Any surplus water will over-flow from the spillway located on the top of the barrier. The sediments carried by the water get settled on the bed upstream of the barrier and gets washed out through the vent to the downstream of the structure. Some lighter particles may still be carried by water passing through the pipeline and over the spill. Since the water (and sediments) passing through the vent are joining the water flow downstream, there is no wastage of water. Addition of a sediment trap, in the form of a wider channel segment and a cross-pit, will help to eject the silt from the canal flows.



(a)



(b)

Figure 2. SWSS design, (a) a 3D model, and (b) pilot structure

4. PERFORMANCE SIMULATION AND FIELD EVALUATION

4.1. Methodology

The SWSS pilot structure was constructed in Dec 2024 and its performance was observed for about 18 months. However, due to the remoteness of the location and lack of instrumentation for accurate measurement of silt ejected by the structure, no field measurements were undertaken. Farmers who receive irrigation water through the pipeline reported high levels of satisfaction of receiving silt-free water.

In order to quantify the silt-removal performance of the SWSS, Computational Fluid Dynamics (CFD) simulations were carried out using Ansys Fluent software Ver. 2025 R2 (Student edition). The $k-\epsilon$ turbulent flow model coupled with Volume of Flow (VoF) two-phase (air and water) open channel model was employed for this analysis. The Discrete Particle Modelling (DPM) was also added for coupled fluid and particle flow simulations.

The geometry file used for the CFD simulation has a total channel segment length of 10 m, internal width of 1.1 m, channel depth of 0.5 m, and bed slope of 5%. The diameter of the pipe off-take is 150 mm. The inlet section is designated as section at far end of the channel. The vent, pipe and spill are designated as outlets. The fluid flow was simulated at 0.6 m/s velocity at the inlet, for six different flow depths (0.04 m to 0.15 m).

Steady state simulation settings were used for both fluid and DPM simulations. The convergence criteria were set on the inlet and outlet volume flow rates. The model simulations were run till the net flow rate through the inlet and outlets (vent, pipe and spill) approaches zero. The controls or under-relaxation factors (URFs) were adjusted on a trial-and-error basis in order to achieve a satisfactory convergence of the simulations. For the purpose of DPM analysis, a mix of 20 different particle sizes is taken in the range of 0.1 to 2.0 mm diameter. A constant particle mass flow rate of 5e-3 kg/s was used in these simulations. It was assumed that 16 particles streams randomly enter the inlet face at right-angle to the face. The particles are assumed to be of non-reactive anthracite. Since the particle loading and sizes are very small compared to the inlet water flow the influence of particle movement on the fluid flow is neglected.

4.2. Fluid flow simulation results

The volumetric flow rate of water phase through the inlet and three outlet components (vent, pipe and spill) are quantified for all the six flow depths simulated. Also, the average velocity magnitude values of the air-water mixture were recorded for inlet and three outlet components. **Table 1** presents the volumetric flow results, calculated net flow and the average velocities for the six different flow depths.

Table 1. Fluid flow simulation results

Depth of flow at inlet (m)	Flow Rate ¹ (m ³ /s)				Net Flow Rate (m ³ /s)	Average Velocity Magnitude ² (m/s)			
	Inlet	Pipe ³	Spill	Vent		Inlet	Pipe	Spill	Vent
0.15	0.1354	0.0282 (20.85)	0.0770	0.0289	0.00128	0.351	2.047	1.035	2.224
0.12	0.1014	0.0264 (26.02)	0.0485	0.0274	-0.00085	0.246	1.916	0.827	2.112
0.10	0.0808	0.0251 (31.01)	0.0360	0.0264	-0.00663	0.233	1.823	0.787	2.035
0.08	0.0614	0.0214 (34.88)	0.0112	0.0238	0.00502	0.259	1.572	0.705	1.835
0.06	0.0440	0.0165 (37.49)	0.0038	0.0210	0.00269	0.294	1.327	0.594	1.615
0.04	0.0278	0.0094 (33.71)	0.0001	0.0162	0.00217	0.111	1.034	0.269	1.371

Notes:

1. The flow rate corresponds to the water phase only
2. The average velocity calculated is area-weighted average and of water-air mixture
3. Numbers in the brackets are percentage of total inflow.

In case of lower flow depths (0.04 & 0.06 m) at inlet, the flow is predominantly through the vent and pipe. Since the flow rate through them is almost equal to the inlet flow rate, there is no spill flow of water. In case of higher flow depths at inlet (0.08 to 0.15 m), both the vent and pipes delivered water to their full capacity and there is a significant amount of surplus water spilling over the spillway structure. It is found that 20.85 to 34.88% of inflow may be diverted through the pipe for various depths of inlet flow. However, the outflow through pipe may further be increased by increasing the diameter of the pipeline. Since the outflow through the vent and spill are discharging into the same channel downstream of the structure, there is no loss of water.

The velocity of flow through vent varied from 1.371 to 2.224 m/s as the flow depth increased from 0.04 to 0.15 m. There is a 6 to 12 times increase in the flow velocity achieved through the vent compared to that at the inlet. This increase in velocity at the mouth of the vent facilitated in lifting and evacuation of silt particles settled at on the bed of the channel ahead of the vent. The vent mouth pulled those settled particles in its vicinity through an act of suction. As seen in the **Figure 3**, the suction zone of

the vent is marked by the turbulent viscosity contours spread for a distance of 2 m upstream of the vent.

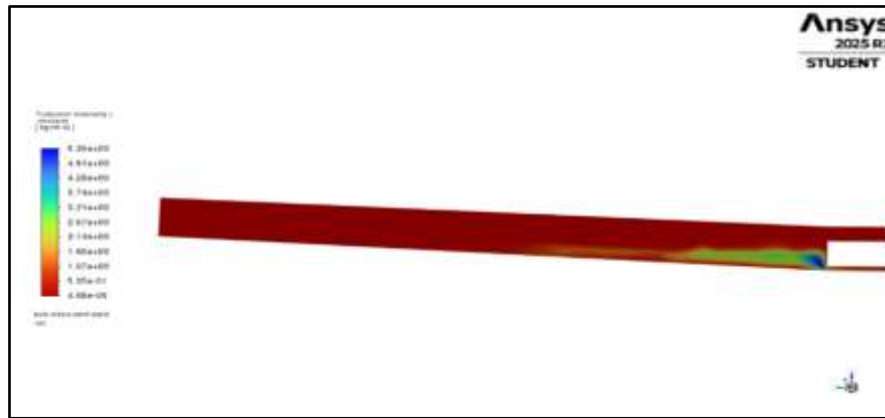


Figure 3. Suction zone of vent marked by turbulent viscosity contours (0.04 m flow depth)

4.3. Particle flow simulation results

The DPM simulation results are presented in **Table 2**. The mass flow of the particle streams escaped through the outlets are presented for six flow depths. In the case of 0.10 m depth of flow, there is some quantity of mass flow of particles that got aborted. This indicates that the simulation model lost track of those particles after tracing them for some time. Also, it was found that a small number of particles escaped through the inlet as the boundary is set to allow the ‘escape’ of particles.

Two important parameters that determine the functional efficiency of the SWSS are, (i) particle mass flow ejected through the vent, and (ii) particle mass flow that entered the pipe flow. For the SWSS to be functionally efficient, it is highly essential that the particle mass flow ejected through the vent is maximum and the same is minimum through the pipe flow.

Table 2. DPM simulation results

Flow Depth (m)	Particle mass flow at the Inlet (kg/s)	Particle mass flow (kg/s)					
		Incomplete ¹	Aborted	Spill	Pipe ²	Vent ³	Inlet
0.15	5.00e-3	5.623e-4 (11.246)	0	1.562e-5	1.178e-4 (2.356)	4.304e-3 (86.08)	7.346e-7
0.12	5.00e-3	1.052e-3 (21.040)	0	6.782e-6	3.804e-4 (7.608)	3.561e-3 (71.22)	1.837e-7
0.10	5.00e-3	1.409e-3 (28.180)	4.971e-6	5.761e-4	1.887e-4 (3.774)	3.392e-3 (67.84)	0
0.08	5.00e-3	1.466e-3 (29.320)	0	5.482e-6	9.306e-5 (1.861)	3.435e-3 (68.70)	9.183e-7
0.06	5.00e-3	1.728e-3 (34.560)	0	0	9.418e-5 (1.884)	3.177e-3 (63.54)	1.653e-6
0.04	5.00e-3	5.440e-5 (1.088)	0	0	1.188e-5 (0.238)	4.934e-3 (98.68)	0

Notes: 1,2 & 3. Numbers in the brackets are percentage of total mass flow at the inlet

As seen in **Table 2**, these simulation results indicated a 63.54-98.68% particle ejection rate through the vent for different flow depths at a constant particle mass inflow rates of 5e-3 kg/s. The water off-taking through the pipe outlet has only 0.238-7.610% silt load compared to the source water. Thus, the novel SWSS is able to separate the silt from water effectively and is able to deliver clear water through the pipe outlet. However, further functional optimization potential may be explored through improvements to the geometric configurations and dimensional improvements. 1.088-34.560% of

particles were found to be 'incomplete'. This indicates that some portion of the total particles got deposited upstream of the SWSS and could not be ejected. **Figure 4** below presents the particle tracks generated through simulation, classified by residence time and particle diameter.

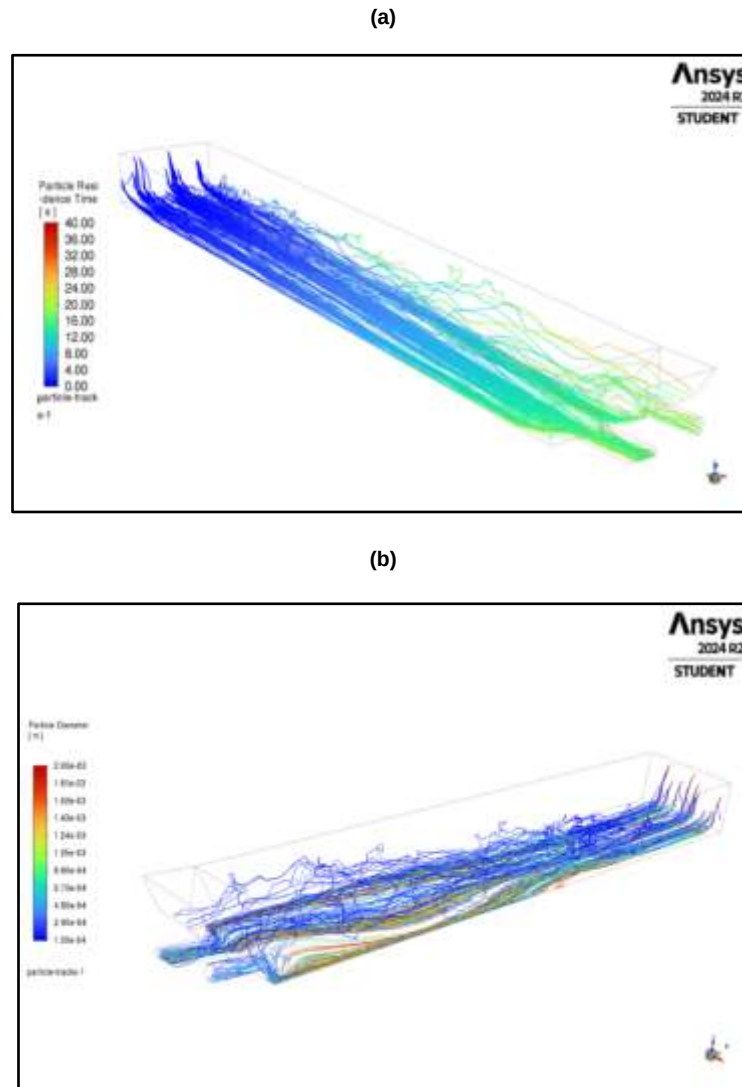
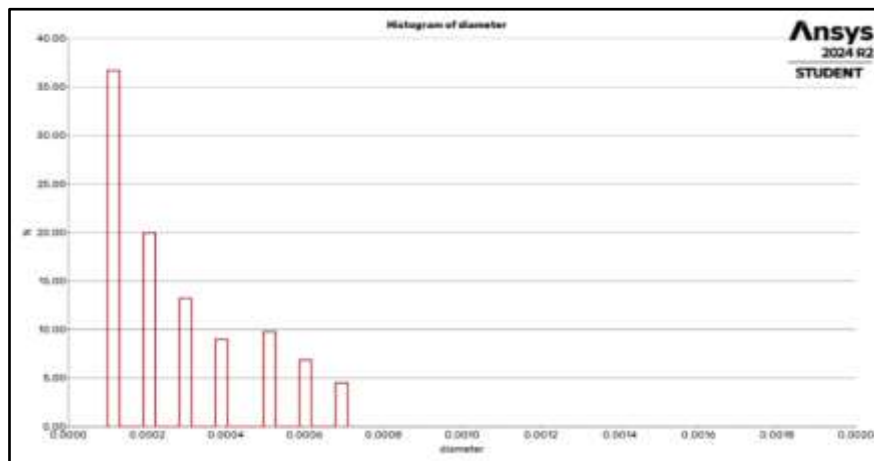
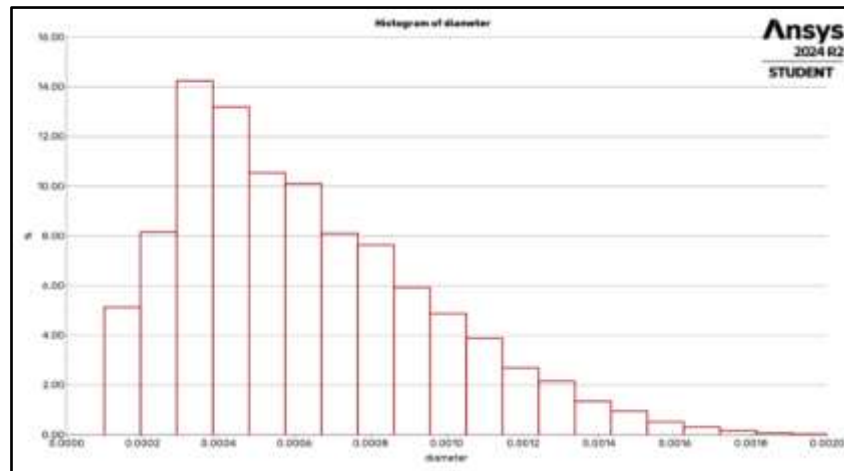


Figure 4. DPM simulation of particle tracks classified by, (a) particle residence time (0.15m flow depth), (b) particle diameter (0.08m flow depth)

It can be inferred from **Figure 4** that, the particle residence time increased as the particles approached the outlets. While most of the heavier particles either got ejected by vent or settled upstream of the structure, lighter particles in smaller number entered the pipeline. In order to under the distribution of particles of different sizes in the mass flow rate observed through the vent and pipe, histograms of particle size were generated for all the flow depth conditions. **Figure 5** presents these histograms for the case of 0.10 m flow depth. A mix of particles of different sizes in the entire range of 0.1-2.0 mm are present in different proportions in the particles ejected by the vent. In contrast, particles larger than 0.8 mm are not present in the flow through the pipe. This confirms the earlier observation that, the larger-sized particles are either ejected by the vent or getting retained in the structure. Since most of the smaller sized particles in the size range of 0.1-0.5 mm continue to be in floating condition and travel with the water passing through the pipe, there is no major risk of their settlement inside the pipeline leading to the blockage of flow in future.

(a)



(b)

Figure 5. Particle size histograms (0.10 m flow depth) for, (a) flow through the vent, and (b) flow through the pipe

CONCLUSION

The current research work attempts to develop a silt-water separation structure for pipe off-taking from irrigation canals. The proposed SWSS is a major step forward in addressing the silt load problems in flowing water in various applications contexts. This innovation may be utilized in many other functional contexts. For example, a raw water intake to a water treatment plant may be pre-treated to eject the silt load so that the time and resources spent on sedimentation and coagulation processes in the main plant significantly reduce. It is visualized that the proposed design of the structure will

be modular in design and may be adjusted to suit different geometric and functional requirements of different use cases. The proposed design is much simpler, cheaper and versatile in nature. Separating silt in urban storm water drains, pre-treatment of raw water input to thermal power plants are the other possible applications. However, there is scope and need for further improving the particle ejection rates through the vent and to reduce the silt load in the pipe flows. Geometric optimization of the novel SWSS for further improving its performance and testing its performance against varied quantities and sizes of sediment load in laboratory settings form the future scope of work.

REFERENCES

- BIS.2002. IS13495: Design of sediment excluders: Guidelines, New Delhi: Bureau of Indian Standards (BIS).
- BIS.2019a. IS6522: Criteria for design of silt vanes for sediment control in off taking canals, New Delhi: Bureau of Indian Standards (BIS).
- BIS.2019b. IS6004: Criteria for hydraulic design of sediment ejector for irrigation and power channels, New Delhi: Bureau of Indian Standards (BIS).
- BIS.2019c. IS7880: Criteria for hydraulic design of skimming platform for sediment control in off-taking canal, New Delhi: Bureau of Indian Standards (BIS).
- Keshavarzi, A.R. and A.R. Gheisi.2006. Trap efficiency of vortex settling chamber for exclusion of fine suspended sediment particles in irrigation canals. *Irrigation and Drainage*. 55: 419–434. <https://doi.org/10.1002/ird.263>.
- Kumar, S., C.S.P. Ojha, K. Tiwari, and S. Ranjan.2023. Exploring the potential of artificial intelligence techniques in prediction of the removal efficiency of vortex tube silt ejector. *International Journal of Sediment Research*. 38: 615-627. <https://doi.org/10.1016/j.ijsrc.2023.03.001>.
- Singh, B., P. Sihag, K. Singh and S. Kumar.2021. Estimation of trapping efficiency of a vortex tube silt ejector, *International Journal of River Basin Management*. 19(3): 261-269, <https://doi.org/10.1080/15715124.2018.1476367>.