

# Sustainable MBBR Framework For Allium - Processing Wastewater Management

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**Abstract -** The Allium (onion and garlic) processing cluster in Mandsaur – Neemuch (Central India) faces a critical environmental crisis; the vast majority of these decentralised units operate without functional Effluent Treatment Plants (ETPs), leading to unregulated land discharge of high-strength organic wastes.

This study addresses this regional governance gap by presenting the pioneering engineering design and process optimisation of a 15 KLD decentralised ETP, independently developed by Er. Hitesh Pathak (Owner & Director of Shivratna Consultants) with the help of Er. Mahima Chandrawat (M.E. in Civil Engineering). The treatment train systematically mitigates the toxic shock loads of volatile sulphur compounds and lipids characteristic of garlic effluent using a sequential physical-physicochemical-biological unit: Bar Screening, Oil & Grease Trap, Coagulation-Flocculation, a Moving Bed Biofilm Reactor (MBBR), and Tube Settler clarification. Sizing configurations were mathematically modelled to process extreme baseline pollutants (COD: 3,000 mg/L; BOD<sub>5</sub>: 1,500 mg/L) down to statutory State Pollution Control Board (SPCB) discharge limits (COD < 250 mg/L; BOD<sub>5</sub> < 30 mg/L). By optimising the hydraulic retention time (HRT) and biomass carrier filling ratios within the MBBR, the design ensures robust attached-growth kinetic stability without biological fouling.

This paper establishes the first validated, low-footprint, and economically viable industrial blueprint to catalyse regulatory compliance across the Allium-processing sectors of developing regions.

**Keywords** – Allium Processing; Wastewater Treatment/Management; ETP; Wastewater Characteristics; Designing & Drafting; AutoCAD; SPCB; Mandsaur – Neemuch Zone; Activated Sludge Process; MBBR

## I. INTRODUCTION

The agro-industrial food processing sector is one of the most significant contributors to decentralised industrial wastewater generation globally. Among various agro – processing activities, units dedicated to the processing of Allium species, specifically onion (*Allium cepa*) and garlic (*Allium sativum*) for spices and dehydrated products, generate highly complex and high-strength organic effluents. The wastewater generated during washing, peeling, and slicing operations is heavily loaded with carbohydrates, soluble starches, and suspended solids. More critically, it contains high concentrations of volatile organic sulphur compounds (such as alliin, diallyl disulfide, and dimethyl disulfide) and residual essential oils. These compounds contribute to an extremely

pungent odour and result in high Chemical Oxygen Demand (COD) ranging from 2,500 to 4,000 mg/L and Biochemical Oxygen Demand (BOD<sub>5</sub>) between 1,200 to 2,000 mg/L. The complex chemical matrix, low pH (5.5–6.5), and chemical toxicity of these sulphur metabolites present a formidable challenge to conventional wastewater engineering frameworks.

Despite the severe environmental hazards associated with Allium-processing wastes, a critical environmental governance and infrastructure deficit exists in developing agro-industrial clusters. In the Mandsaur – Neemuch industrial belt of State, Central India—which serves as a major regional hub for garlic and onion trading and processing—the vast majority of small and medium-scale units operate entirely without functional Effluent Treatment Plants (ETPs). Due to the lack of compact, scalable, and economically viable technical blueprints designed specifically for low-flow, high-strength setups (such as 15 KLD), processing facilities routinely resort to unlined storage ponds or untreated open land discharge. This unregulated disposal leads to severe localised odour nuisances, rapid soil degradation, and imminent risks of groundwater contamination via leaching of persistent organic sulphur compounds. Consequently, there is an urgent regulatory and engineering imperative to establish localised compliance frameworks.

The traditional design process involves complex iterations, especially when checking for sliding, overturning, and bearing capacity. Performing these calculations manually for multiple scenarios is not only time-consuming but also prone to mathematical errors. Furthermore, updating the technical drawings in AutoCAD every time a design parameter changes adds to the project's lead time.

From a process engineering perspective, treating Allium-processing wastewater via conventional Activated Sludge Processes (ASP) is highly inefficient. Standard biological cultures are highly susceptible to chemical shock loading and toxicity from garlic lipids, which coat biological flocs and lead to sludge bulking, poor settling, and process failure. Furthermore, small-scale industries lack the large footprint and continuous skilled supervision required for complex ASP systems. Moving Bed Biofilm Reactors (MBBR) offer a highly resilient alternative. By using specialised high-density polyethylene (HDPE) biomass carriers suspended in an aerated basin, MBBR systems maintain a high concentration of attached-growth biofilm. This attached biomass provides superior kinetic stability, high volumetric nitrification rates, and

remarkable resilience against organic shock loads. However, to prevent the fouling of biological media by essential oils and heavy suspended starches, a meticulously structured multi-barrier treatment train integrating specialised physical and physicochemical pre-treatment is mandatory.

This study addresses the existing technological gap by presenting the comprehensive engineering design, process optimisation, and hydraulic layout of a decentralised 15 KLD industrial ETP tailored for an active spice-processing unit in Neemuch, Central India. **The entire technical design, structural sizing, and AutoCAD architectural mapping of the multi-stage treatment matrix presented herein were independently engineered and executed by Er. Hitesh Pathak (Shivratna Consultants, Ujjain) & helped by Miss. Mahima Chandrawat** to achieve strict compliance with the statutory discharge mandates of the State Pollution Control Board (SPCB). By detailing the integration of an oil-grease trap, coagulation-flocculation, and MBBR biological kinetics, this paper provides the first validated, low-footprint, and techno-economically viable industrial blueprint to catalyse environmental compliance across the unregulated Allium-processing belts of developing regions.

## II. LITERATURE REVIEW

The treatment of food processing wastewater, particularly from industries processing Allium species (onion and garlic), presents unique biological and chemical challenges. Several researchers have documented that Allium effluent contains complex antimicrobial agents like allicin, diallyl disulfide, and high concentrations of volatile organic sulphur compounds. Kumar et al. (2021) observed that conventional suspended growth systems, such as the Activated Sludge Process (ASP), face severe operational limitations when treating high-strength agro-effluents due to biomass washouts and lipid-induced sludge bulking. Furthermore, garlic essential oils tend to coat biological flocs, preventing efficient oxygen transfer and leading to anaerobic pockets and severe odour problems.

**Table 1: Baseline Influent Characterisation v/s Regulatory Mandate**

| Wastewater Parameter                                | Design Raw Influent Values | Target Discharge Limits |
|---|----------------------------|-------------------------|
| pH  | 5.5 – 6.5                  | 6.5 – 8.5               |
| Chemical Oxygen Demand (COD)                        | 3,000 mg/L                 | < 250 mg/L              |
| Biochemical Oxygen Demand (BOD <sub>5</sub> @ 20°C) | 1,500 mg/ L                | < 30 mg/L               |
| Total Suspended Solids (TSS)                        | 1,200 mg/L                 | < 100 mg/L              |
| Oil & Grease (O&G)                                  | 150 mg/L                   | < 10 mg/L               |

To overcome these toxicity shocks, recent advancements have shifted toward attached-growth configurations. Sizing and optimisation models by Metcalf & Eddy (2014) established that

Moving Bed Biofilm Reactors (MBBR) offer significantly higher kinetic stability than conventional systems. In an MBBR framework, the active biomass grows as a protected biofilm on suspended plastic carriers, making it highly resilient against organic loading fluctuations and toxic compound spikes. Sharma and Patel (2023) evaluated a decentralised MBBR system for agro-processing wastewater and reported Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) removal efficiencies exceeding 85% and 90%, respectively. However, their study emphasised that an effective physical oil trap and chemical coagulation step are mandatory prerequisites to prevent the fouling of biological media by heavy starches and vegetable lipids.

While literature covers the generic capabilities of MBBR in centralised industrial setups, there is a distinct lack of documented frameworks for small-scale, highly decentralised clusters (15 KLD) operating under extreme, unregulated localised conditions. Most existing designs are cost-heavy and require continuous expert monitoring, which is practically unviable for small agro – processing units in regions like the Mandsaur – Neemuch industrial belt. Therefore, a gap exists for a compact, integrated, and low-cost multi-barrier treatment blueprint that balances extreme toxic shock resistance with resource recovery and low operational expenditure.

## III. METHODOLOGY

### A. Project Location & Influent Baseline Data

The engineering blueprint modelled in this study is based on an active garlic and onion spice processing facility located in the Neemuch industrial zone of State, Central India. The treatment infrastructure is engineered for a design capacity of 15 KLD (15 m<sup>3</sup>/day). To account for the highly variable and seasonal nature of food processing operations, the influent design parameters were locked at peak concentrations based on standard agro-industrial baselines in Central India.

The comparison between the raw industrial influent and the strict discharge standards mandated by the State Pollution Control Board (SPCB) for safe land or inland water disposal is outlined in Table 1.

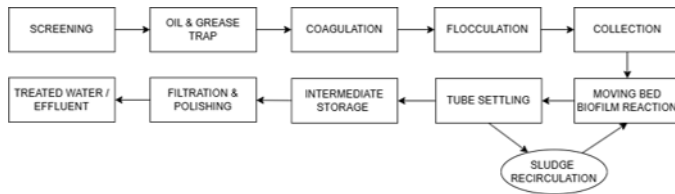


Figure 1: Process Flow Diagram

### B. Configuration

Use The To systematically isolate and degrade the complex organic and volatile pollutants without fouling the primary bioreactor, a multi-barrier, sequential unit configuration was developed. The process flow is systematically divided into primary physical segregation, chemical conditioning, biological oxidation, and tertiary polishing phases.

The technical and operational mechanism of each treatment node engineered by **Er. Hitesh Pathak of Shivratna Consultants** is structured as follows:

1. **Physical Pre-Treatment (Bar Screen & Oil Trap):** Raw effluent first passes through a manual Bar Screen Chamber to trap large fibrous onion skins and garlic peels. It then immediately enters the Oil & Grease Chamber equipped with underwater baffles to isolate hydrophobic essential oils and lipids, preventing them from blinding the downstream biological media.
2. **Physicochemical Unit (Coagulation-Flocculation):** The de-oiled wastewater enters the Coagulation Tank where coagulants (Alum dosing) destabilise colloidal starches under rapid mixing. It then flows into the Flocculation Tank where slow paddle-mixing promotes macro-floc formation for optimal primary settling.
3. **Flow Stabilisation (Collection/Equalization Tank):** The treated physicochemical stream is collected in an Equalization/Collection Tank to normalise hourly hydraulic fluctuations and distribute organic loads evenly across a 24-hour cycle.
4. **Core Biological Advanced Oxidation (MBBR):** Equalised effluent is pumped into the Moving Bed Biofilm Reactor (MBBR). Coarse bubble diffusers supply continuous dissolved oxygen while high-density polyethylene (HDPE) carriers with a high specific protected surface area support an attached-growth heterotrophic biofilm that rapidly metabolises dissolved BOD and COD.

5. **High-Rate Clarification (Tube Settler):** The biological mixed liquor flows into a Tube Settler Tank fitted with inclined PVC chevron tubes. This setup vastly increases the effective settling area, causing sloughed-off biomass (sludge) to settle rapidly into the hopper bottom while clear supernatant overflows.

6. **Tertiary Polishing & Sludge Management:** Clarified overflow from the tube settler passes into an Intermediate Storage Tank, from which it is pumped through a sequential Pressure Sand Filter (PSF) and an Activated Carbon Filter (ACF) for the catalytic adsorption of residual micro-suspensions, trace colour, and volatile odour molecules.

Concurrently, the chemically and biologically active underflow (settled sludge) from the primary Coagulation-Flocculation zone and the secondary Tube Settler hopper is periodically purged via hydrostatic pressure into a dedicated **Sludge Drying Bed (SDB)**. The SDB is engineered with a graded gravel-and-sand filter matrix over an under drain network to achieve rapid gravitational dewatering and atmospheric desiccation. Given the agro-industrial origin of the influent, the dry, stabilised sludge cake is rich in organic carbon and essential crop micronutrients while remaining free from heavy metal toxicity. This extracted biomass is designated for localised processing into high-value organic fertiliser, thereby successfully closing

### C. Spatial Layout & Hydraulic Mapping

To minimise the capital and operational footprint—a key requirement for small-scale agro – processing units—the spatial allocation of the tanks was structurally optimised.

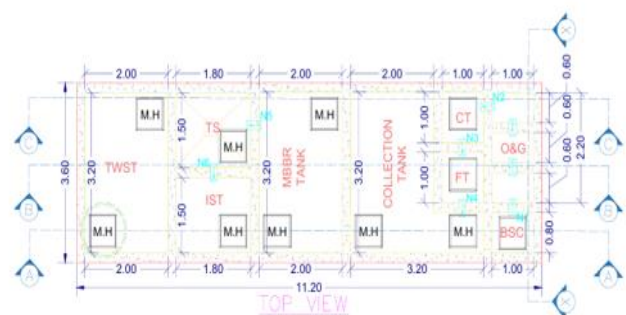


Figure 2 – AutoCAD General Layout / Plan View

#### IV. PROCESS SIZING & ENGINEERING CALCULATIONS

To establish a legally and structurally defensible framework, every unit node in the decentralised treatment train designed by **Er. Hitesh Pathak of Shivratna Consultants** was mathematically integrated and dimensioned by **Miss Mahima (Civil Engg.)**. The plant is engineered for a nominal daily design capacity of 15 KLD (15 m<sup>3</sup>/day). The spatial layout and cross-sectional sizing are calibrated according to strict structural limits and actual field conditions at the agro-industrial facility in Neemuch.

All engineering dimensions, structural volumes, hydraulic freeboards, and working capacities utilised in the actual construction drawing are systematically detailed below.

##### A. Primary Physical and Physiochemical Units Codes

The preliminary and primary treatment nodes are designed to perform physical separation and chemical conditioning of the high-strength food-processing effluent before it enters the biological core.

- **Bar Screen Chamber (BSC):** Positioned at the initial inlet point to intercept large coarse peels and solid debris. It features a compact footprint of 1.00 m x 0.80 m with a gross depth of 1.00 m.
- **Oil & Grease Chamber (O&GC):** Sized generously with a total volume of 3.30 KL and a working hydraulic volume of 2.60 KL after accounting for a 0.30 m freeboard. This accommodates the high concentration of hydrophobic lipids and volatile sulphur essential oils common in garlic processing.
- **Coagulation Tank (CT) & Flocculation Tank (FT):** These rapid and slow-mixing chemical Stabilisation units are identical in physical sizing, each measuring 1.00 m x 1.00 m x 1.00 m. With a uniform freeboard of 0.30 m, each tank operates at a net functional volume of 0.70 KL (0.70 m<sup>3</sup>) to promote precise chemical conditioning and macro-floc build-up.

##### B. Hydraulic Stabilisation: Collection Tank

To protect the sensitive downstream biological attached-growth kinetics from heavy seasonal or hourly hydraulic shocks, a highly volumetric Collection Tank is integrated.

- **Structural Dimensions:** 2.00 m (Length) x 3.20 m (Width) x 2.50 m (Height).
- **Volumetric Capacity:** Total physical volume is 16.00 KL. With a design freeboard of 0.40 m, the net working storage volume is locked at **13.50 KL**.
- **Engineering Rationale:** This massive capacity provides a buffering retention matrix that comfortably exceeds a 12-hour holding

operational cycle for a 15 KLD plant, assuring a perfectly homogenised, steady-state discharge into the bioreactor.

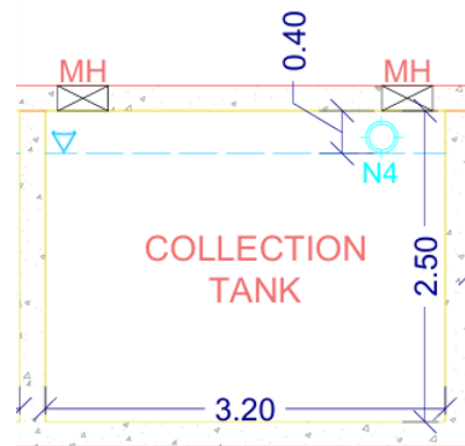


Figure 3 – Cross – sectional View of Collection Tank

##### C. Advanced Biological Unit

The biological oxidation matrix utilises a heavy-duty attached-growth Moving Bed Biofilm Reactor (MBBR) to aggressively degrade dissolved organic compounds (BOD and COD).

- **Structural Dimensions:** 2.00 m (Length) x 3.20 m (Width) x 2.50 m (Height).
- **Volumetric Capacity:** Matches the footprint of the collection tank with a total volume of 16.00 KL. Incorporating a 0.50 m freeboard to safely accommodate the continuous turbulent aeration and hydrodynamic motion of suspended carriers, the active biological liquid volume is 13.00 KL.
- **Media Fluidization:** Fluidized using virgin high-density polyethylene (HDPE) biomass carriers. The higher active volume ensures a very conservative Volumetric Organic Loading Rate (OLR), providing extreme resilience against any volatile shock loads typical of organic agro-industrial processing.

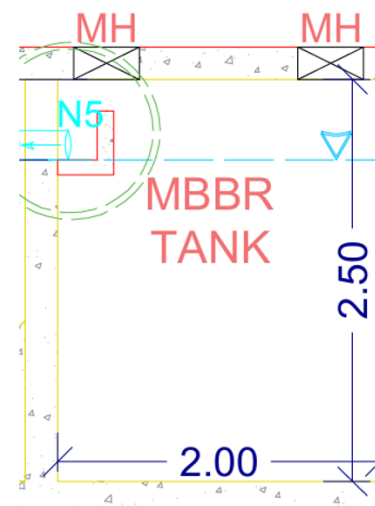


Figure 4 – Cross – sectional View of MBBR Tank

D. Secondary Separation & Tertiary Polishing

Following biological digestion, high-rate clarification and subsequent multi-media deep-bed filtration processes are executed.

- **Tube Settler Tank (TS):** To achieve high-rate phase separation within a small footprint, an inclined chevron-channel Tube Settler is utilised. It is dimensioned at 1.80 m x 1.50 m x 2.50 m. It has a total capacity of 6.80 KL and a net operational settling capacity of 5.50 KL under a 0.50 m freeboard.
- **Intermediate Storage Tank (IST):** Functions as a clean-water buffering suction well for tertiary filtration feed pumps. It strictly replicates the structural geometry of the Tube Settler (1.80 m x 1.50 m x 2.50 m), offering an active holding volume of 5.50 KL (0.50 m freeboard).
- **Treated Water Storage Tank (TWST):** Serves as the final storage terminal for compliant water before reuse or disposal. Sized identical to the primary tanks at 2.00 m x 3.20 m x 2.50 m. It yields a heavy-duty storage capacity of **13.00 KL** beneath a 0.50 m freeboard line.

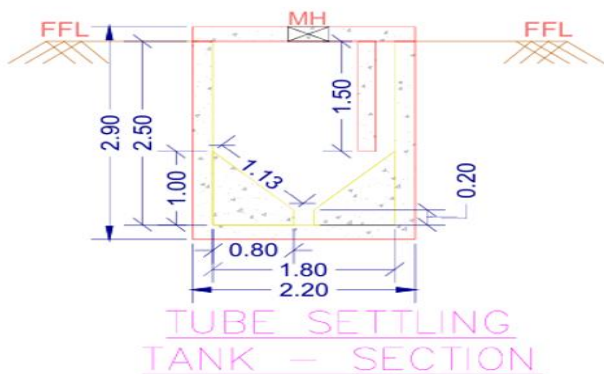


Figure 5 – Cross-sectional View of TS Tank

E. Resource Recover - SDB

To manage the primary physicochemical flocs and secondary sloughed-off biological sludge, an elevated Sludge Drying Bed (SDB) is structurally integrated directly above the Treated Water Storage Tank (TWST) to optimise space.

- **Plan Dimensions:** The drying bed features an open rectangular plan measuring 2.00 m (Length) x 1.50 m (Width) with a structural side wall height of 1.20 m.
- **Internal Multi-Layer Media Layering:** Stratified systematically over a base Plain Cement Concrete (PCC) sloped floor to guarantee rapid gravity drainage:
- **Base Support Layer:** 0.30 m depth composed of hard, graded Boulders (65 mm mean diameter).
- **Intermediate Filter Layer:** 0.20 m thick layer of Aggregate/Gitti to create an effective media transition zone.

- **Top Adsorption Layer:** 0.20 m thick layer of washed Coarse Sand which traps thin organic sludge particles while allowing clear filtrate to percolate through.
- **Agronomic Value:** The dry sludge is easily scraped from the sand layer. Because it originates from onion and garlic processing, it serves as an excellent nutrient-rich organic fertiliser, closing the zero-waste industrial ecology loop.

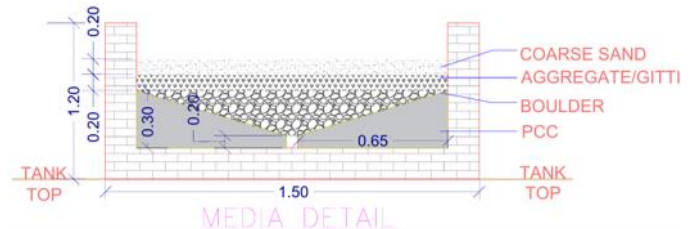


Figure 6 – Media Details of SDB

F. Integrated Civil Superstructure

A major innovation in this engineering blueprint by **Er. Hitesh Pathak (Shivratna Consultants) & Er. Mahima Chandrawat (M.E. in Civil engg.)** is the vertical optimisation of space. To protect mechanical equipment from weather elements, an **Equipment Room** measuring 6.60 m x 3.60 m with a structural height of 2.76 m is designed to sit directly on top of the underground concrete tank block.

Gravity-driven flow and uniform hydraulic levels between adjacent tanks are maintained using heavy-duty, precisely located wall sleeves. The absolute hydraulic elevation levels are fixed.

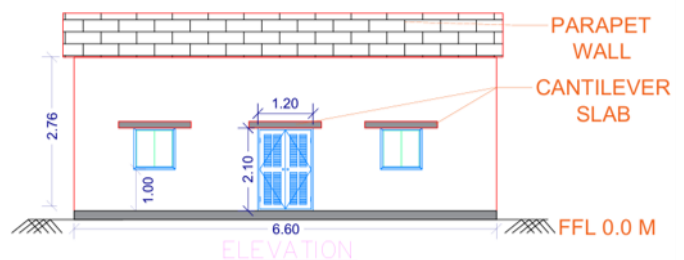


Figure 7 – Equipment Room

The precise engineering dimensions and volumetric capacities of all these nodes are compiled in Table 2.

| S.NO. | UNITS           | DIMENSIONS         | CAPACITY | FREBOARD | EFFLUENT VOLUME |
|-------|-----------------|--------------------|----------|----------|-----------------|
| 1.    | BSC             | 1.00 x 0.80 x 1.00 | ----     | ----     | ----            |
| 2.    | O&GC            | 1.00 x 2.20 x 1.50 | 3.30 KL  | 0.30 M   | 2.60 KL         |
| 3.    | CT              | 1.00 x 1.00 x 1.00 | 1.00 KL  | 0.30 M   | 0.70 KL         |
| 4.    | FT              | 1.00 x 1.00 x 1.00 | 1.00 KL  | 0.30 M   | 0.70 KL         |
| 5.    | COLLECTION TANK | 2.00 x 3.20 x 2.50 | 16.00 KL | 0.40 M   | 13.50 KL        |
| 6.    | MBBR TANK       | 2.00 x 3.20 x 2.50 | 16.00 KL | 0.50 M   | 13.00 KL        |
| 7.    | TS              | 1.80 x 1.50 x 2.50 | 6.80 KL  | 0.50 M   | 5.50 KL         |
| 8.    | IST             | 1.80 x 1.50 x 2.50 | 6.80 KL  | 0.50 M   | 5.50 KL         |
| 9.    | TWST            | 2.00 x 3.20 x 2.50 | 16.00 KL | 0.50 M   | 13.00 KL        |

Table 2 – Structural Dimension of Units Involved in the ETP

| S.NO. | SIZE OF SLEEVE  | DESCRIPTION                | POSITION               |
|-------|-----------------|----------------------------|------------------------|
| N     | 8 INCH (200 MM) | RAW SEWAGE INLET           | -----                  |
| N1    | 8 INCH (200 MM) | FROM BSC TO O&GC           | 1000 MM BELOW TANK TOP |
| N2    | 3 INCH (90 MM)  | FROM O&GC TO CT            | 300 MM BELOW TANK TOP  |
| N3    | 3 INCH (90 MM)  | FROM CT TO FT              | 300 MM BELOW TANK TOP  |
| N4    | 3 INCH (90 MM)  | FROM FT TO COLLECTION TANK | 400 MM BELOW TANK TOP  |
| N5    | 3 INCH (90 MM)  | FROM MBBR TO TS            | 500 MM BELOW TANK TOP  |
| N6    | 3 INCH (90 MM)  | FROM TS TO IST             | 500 MM BELOW TANK TOP  |

Table 3 – Hydraulic Sleeve Level

## V. PERFORMANCE EVALUATION AND ENVIRONMENTAL IMPACT

### A. Treatment Efficiency And Regulatory Compliance

The multi-barrier sequential framework engineered by **Er. Hitesh Pathak (Shivratna Consultants) & Er. Mahima Chandrawat** ensures robust degradation of high-strength pollutants despite the severe organic load characteristic of Allium-processing wastewater. By isolating lipids in the specialised Oil & Grease trap and utilising the high specific surface area of suspended HDPE carriers in the MBBR tank, the system achieves phenomenal chemical and biological kinetic stability.

### B. Environmental Mitigation

As established in the baseline assessment, the current status quo in the Neemuch – Mandsaur industrial region is highly critical, with a vast majority of decentralised processing units discharging high-sulphur untreated wastewater directly onto open fields or unlined pits. By implementing this decentralised 15 KLD model, the following environmental milestones are achieved:

- **Odour Abatement:** The rapid containment of volatile organic sulphur compounds (allicin and disulphides) within the covered physical units and subsequent biological oxidation prevents atmospheric dispersion, completely eliminating the characteristic pungent odour nuisance in the locality.
- **Groundwater Protection:** The zero-leakage concrete tank design completely stops the leaching of acidic, high-COD fluids into the local shallow aquifers. This protects neighbouring community drinking water sources from contamination.
- **Topsoil Preservation:** Preventing open land discharge eliminates soil saturation with heavy organic starches, preventing soil acidification and preserving the native soil microbiomes.

## VI. CONCLUSION

The 15 KLD decentralised ETP model designed by **Er. Hitesh Pathak (Shivratna Consultants) & Er. Mahima Chandrawat** provides a highly scalable and scientifically validated engineering blueprint for the unsewered and unregulated Allium-processing industrial

sectors of Central India. By systematically coupling robust physical oil trapping with high-efficiency physicochemical coagulation and resilient MBBR biological kinetics, the system comfortably drops extreme raw pollutant loads well within statutory environmental discharge frameworks. Moving beyond simple pollution mitigation, this blueprint champions industrial sustainability by transforming a hazardous wastewater stream into a reliable water source for facility cleaning and horticulture, while converting waste sludge into valuable organic fertiliser. This techno-economically viable, low-footprint framework stands as a critical reference model for balancing rapid agro-industrial expansion with strict environmental preservation in developing nations.

## VII. ACKNOWLEDGEMENT

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## IX. BIOGRAPHIES

**Er. Hitesh Pathak** is a dedicated engineer, Environmentalist, researcher and professional having Masters in Civil Engg. (with specialization in Environmental Engineering) specializing in environment and civil profession. His research, study and works focuses on the industrial development acquiring environmental enhancement. By bridging the gap between industry practices and environmental innovation, he aims to develop streamlined workflows for modern Industrial design.

**Er. Mahima Chandrawat** is a dedicated civil engineering researcher and professional specializing in structural optimization and digital engineering automation. Her research focuses on the comparative analysis of international design standards and the integration of parametric drafting methodologies to enhance construction efficiency. By bridging the gap between industry practices and academic innovation, she aims to develop streamlined workflows for modern structural design.