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Development of Ecological Purification Unit for Producing Drinking Water from Organically Polluted Raw Water (BOD~30mg/L)

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ABSTRACT

In inhabited islands of Maldives, the groundwater pollution is very serious due to underground seepage of domestic waste water. Pollution level (BOD) exceeds 30mg/L occasionally. Inhabitants drink rainwater collected on roofs, and use groundwater for daily purpose. But highly populated islands are water-hungry in dry-season. Groundwater consumption exceeds the rainfall and seawater invades and pollutes groundwater. Hence we propose to recycle living drainage with the water quality control system. The system circulates groundwater charged by rainwater and collects drainage through the perforated PVC pipes. This PVC pipe network will be installed underground beneath the roads and will store water. Collected raw water will be purified into drinking water by the Ecological Purification Unit (EPU) and supplied to each house. We have tested EPU at Shin Nippon Lanka in Sri Lanka, and proved the effectiveness for organically polluted water.

Keywords: ecological, recycle, energy-saving, easy maintenance, low cost, BOD 30 mg/L

INTRODUCTION

Developing countries have problems of river and groundwater pollution by human waste. In 192 inhabited islands of Maldives, inhabitants drink rainwater, collected from roofs, and use groundwater for domestic cleaning purposes. But groundwater is polluted by septic tanks and as a result infectious diseases spread out. From the reconstruction after the tsunami which caused tremendous disaster in 2004, some water treatment plants have been installed in 30 islands with the support of developed countries and international organizations. An organization donated RO (Reverse osmosis water purification) units to 40 islands but those have been left unused and damaged because of the difficulty in maintenance and expensive

operational cost. We researched these islands and developed the Ecological Purification Unit, which is safe, low-cost and easy to maintain for inhabitants without extensive plant operation and maintenance knowledge.

INTEGRATED GROUNDWATER MANAGEMENT

In Maldives, the rainfall exceeds 1900mm/year and "lens water (fresh water)" is formed in underground. But rainfall per month decreases to 30-40mm in dry-season. So it needs to keep the balance between consumption and rainfall throughout the year. For that, it is necessary to return living drainage to underground or use seawater for sanitary, especially in highly populated islands. The perforated PVC pipes network which collects and recycles groundwater will be installed beneath the roads. Recycled water and rainwater on roofs will be collected and then recharged to groundwater with the network. Then it will be purified into drinking water with the Ecological Purification Unit. Mainly, we examined Gulhi Island, which is a densely populated and water-hungry Island. This has been requested by Environment and Energy Ministry of Maldives for case studies.

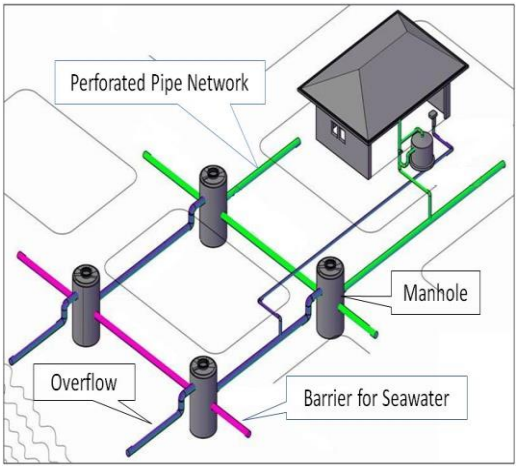


Figure 1: Underground perforated piping network

Figure 02: Gulhi Island of Maldives

Outline of Gulhi Island

- Name of Island: Gulhi Island at South Male Atoll (21.3km from Male)
- Population of Island: 863 persons (124 houses)
- Dimension of Island: Length 400m + Width 225m
- Effective area of the Island: 74,000 m^2 (85.7 m^2/persons)

Table 1: Average monthly rainfall for Maldives from 1990～2009

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	144.7	66.1	92.3	143.1	211.0	186.4	202.0	184.5	207.9	249.4	220.0	194.9

(Data from: Climate change knowledge portal-2. The World Bank Group)

Table 02: Minimum portable water requirement per capital Islanders in dry season

Description	Consumption per person	Source of Water	Method of Water Treatment
Toilet Flushing	40.0L/day	Sea Water	40.0L/day Sewage Treatment
Drinking and Cooking	10.0L/day	Rain Water Tank	Sewage Treatment **Ocean Discharge 20.0L/day/person**
Dishwashing	5.0L/day	Rain Water Tank	
Landry with Soap	5.0L/day	Purified Water	
Landry without Soap	20.0L/day	Purified Water	Seepage to Underground **Recycling Water 60.0L/day/person**
Bathing	30.0L/day	Purified Water	
Wash Basin	10.0L/day	Purified Water	
Total	**120.0L/day**	**65.0L/day Purified**	**80+40 L/day/person**

Rain water usage in the dry season of Gulhi Island

- Some of the year's minimum rainfall of Gulhi Island in February went down to 38mm/month.
- Minimum rainfall of February: 38mm/month×50%×74,000m^2=1,406m^3/month=46 m^3/day
  (50% of the rain water evaporates into the atmosphere.)
- Ocean discharge of waste water (rain water): 20 L/day×863 persons = 17.3m^3/day
- Comparison of the minimum rainfall and ocean discharge amount:
  Minimum rainfall 46 m^3/day＞Ocean discharge 17.3 m^3/day

Integrated water management of Gulhi Island

- 40L/day use of seawater, 15L/day from rainwater tank, 65 L/day from EPU,
- Capacity of EPU 65L/day/person ×863 persons/day = 56,095 L/ day(60 m^3/ day)

DEVELOPMENT OF ECOLOGICAL PURIFICATION UNIT

Structure of Ecological Purification Unit (EPU)

- EPU process starts with preprocessing stage of "Slanted Soil Chamber Unit" to purify the polluted water with BOD level of 30mg/L.
- Ecological Purification Unit consists of two other units; "Up-flow Roughing Filter Unit" for

middle-processing, and “Slow Sand Filter Unit for end-processing.

- EPU makes easy transportation, construction and maintenance by uniting with FRP (Fiber reinforced plastic).
- The usual capacity of EPU can be varied from 3m^3/day to 60m^3/day. When it exceeds 60m^3/day, multiple EPUs need to be installed.

Outline of Slanted Soil Chamber Unit (SSCU)

- Concept of slanted soil chamber unit (SSCU)” was developed by Yonden Consultant Inc (Yonden) as a purification system of kitchen drainage. Yonden and Shin Nippon Air Technologies Co. Ltd,(SNK) came into a license agreement and developed a purification unit.
- On average water process rate per unit area of SSCU is 0.2m3/m^2/day. SSCU occupies a large space, but it can be reduced by multi-stage installation.
- SSCU is 2m wide and has divided into two partitions of 1m wide for easy maintenance. A corrugated plate is used as the base plate for easy cleaning.
- Sands (3-8mm), anthracites, activated carbon and sponges have been adopted for filter media in the test. (In Maldives, coral sands will be applied.)
- We measured removal ratio of nitrate as nitrogen by planting Kangkung on the backward tray of SSCU, but we could not measure the quantitative removal ratio.However, organically grown vegetables will be favorable in there, because the inhabited islands of Maldives are in lack of vegetables.

Figure 03: Slanted Soil Chamber Unit (SSUC)

Outline of Up-flow Roughing Filter Unit (URFU)

- For URFU, we applied several filter media with different sizes. The roughing filter is parted into 3 tiers or steps. The filtration speed is 20m^3/day.
- Natural aspirators are consisted with the inlet pipe of URFU. It provides a stable dissolve oxygen level through the whole-day in the coarse filter.
- The sunshade covers are placed on the upper side of the URFU in order to facilitate the filter cleanliness. They prevent the filters from clogging with algae grown by photosynthesis.
- Air quantity by aspirators limit is 4-5% of processing water quantity. It provides stability to the saturated-dissolved oxygen in about 80%.

Figure 04: Up-flow Roughing Filter Unit (URFU)

Outline of Slow Sand Filter Unit (SSFU)

- SSFU was designed according to advices of an NPO (Community Water Supply Support Center of Japan). The filtration speed was standardized on 9.6m/day.

- The upper side of the SSFU is opened for photosynthesis.
- The floating overflow devices are fabricated for SSFU. It minimizes the amount of redundant drainage.

Figure 05: Slow Sand Filter Unit (SSFU)

EXPERIMENTAL CONDITION OF THE EPU

Quality of processing raw water

For the testify research in Sri Lanka, we mixed beer, soy milk and ammonia in gutter water to imitate Maldivian groundwater (organically polluted, BOD 30mg/L).

Quality of purified water level

Table 03: Targeted drinking water purification level of EPU

No	Content of analysis	Unit	WHO or Japanese Standard
01	pH	pH	• 5.8~8.6 (JWS)
02	Turbidity	NTU	Below 2.0 (JWS) Target 1.0
03	Dissolved Oxygen (DO)	mg/L	Above 5.0mg/L (JES-3 grade)
04	BOD	mg/L	3mg/L (JES – B3 grade)
05	Nitrate & Nitrite	mg/L	Below 10mg/L (JWS)
06	Nitrite (NO_2-N)	mg/L	Below 0.05mg/L (JWS)
07	Ammonium (NH_3)	mg/L	Below 1.5mg/L (WHO)
08	Total Coliform	pc/mm L	Below 100pc/mm L (JWS)
09	Fecal Coliform	pc/mm L	0pc/mm L (JWS)

JES – Japanese Environmental Standard JWS – Japanese Water Supply Standard

VERIFICATION RESULT OF THE EPU

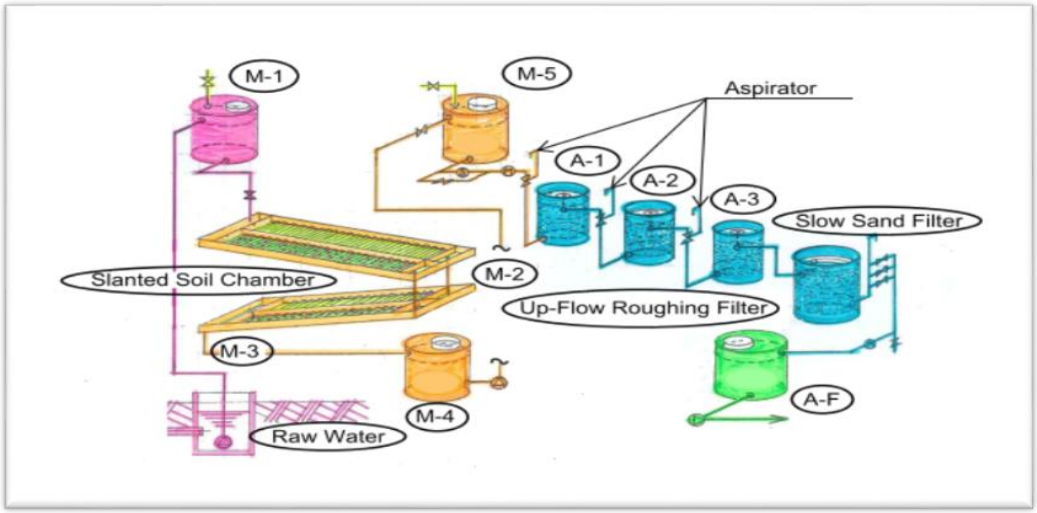
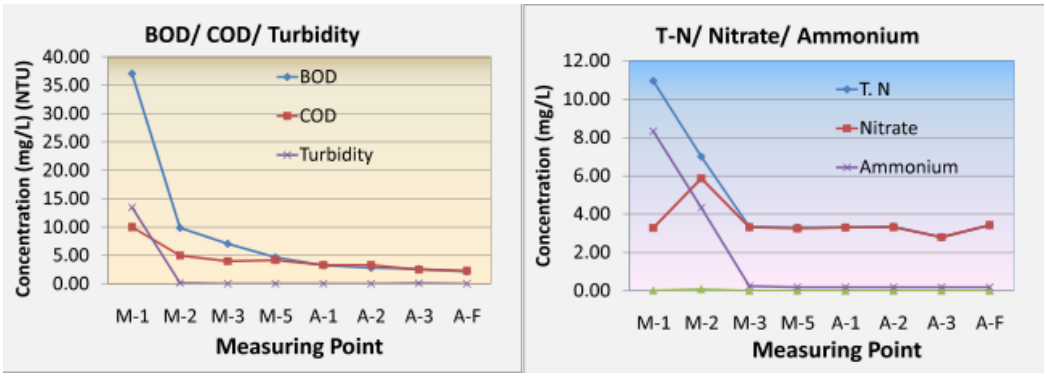


Figure 06: Verification test unit diagram

Table 04: Summary of the water purification result

Average of a Week Water Quality Tests Data										Period 18thOctober, 2013 to 26th October, 2013
Slanted Soil Chambers	Measuring Point	Dissolved Oxygen	Turbidity	T. N	Nitrate	Nitrite	Ammonium	COD Mn	BOD	Remarks
		mg/L	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
	Canal Water									Added Beer, Ammonia
	M-1	2.32	13.48	10.95	3.28	0.010	8.33	10.00	37.07	Flow rate: 8m^3/day
	M-2	1.24	0.14	7.00	5.87	0.080	4.33	5.00	9.87	Gravel Sands
	M-3	3.48	0.01	3.33	3.32	0.000	0.23	4.00	7.07	Anthracite with Kangkung
	Water Tank									
Removal Ration			100%	70%		100%	97%	60%	81%	
Up-flow Roughing filter + Slow sand filtration	M-5	5.95	0.00	3.30	3.25	0.000	0.18	4.17	4.67	Flow rate: 6m3/day
	A-1	6.61	0.00	3.31	3.30	0.000	0.18	3.33	3.27	Aspirator: ON
	A-2	6.66	0.02	3.35	3.32	0.000	0.18	3.33	2.83	Aspirator: ON
	A-3	6.57	0.11	2.80	2.80	0.000	0.18	2.50	2.63	Aspirator: ON
	A-F	7.11	0.01	3.43	3.42	0.000	0.18	2.33	2.13	
Removal Ration							0%	44%	54%	
Total Removal Ration (M-1 to A-F)			100%	69%		100%	98%	77%	94%	



(a) (b)

Figure 07: Graphical analysis of water purification: **(a)** BOD, COD, and Turbidity analysis **(b)** Total Nitrogen, Nitrate, and Ammonium analysis

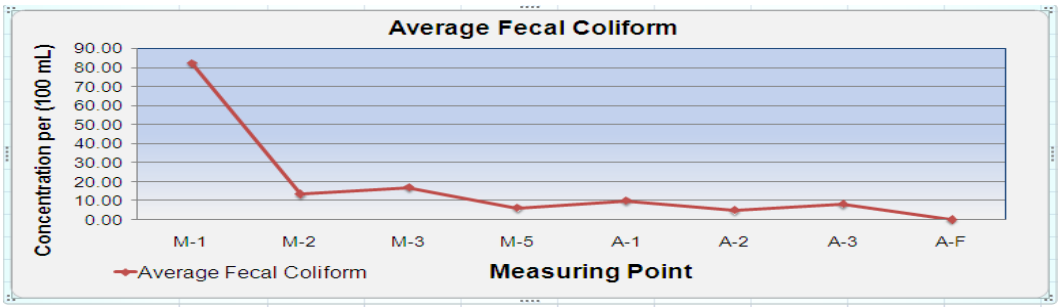


Figure 08: Graphical analysis of Fecal Coli form

Performance evaluation of each unit

- Turbidity removal rate of SSCU is almost 100% and BOD removal rate is 81%. BOD removal rate of the whole system is 94 %; its ability is very high.
- We measured COD by pack tests. The removal rate of the whole system is a little accurate but it was 77%.
- Oxidation of ammonia and nitrite nitrogen progressed rapidly; it is converted to nitrate nitrogen at the surface of the filter media of SSCU. On the other hand, TN (Total Nitrogen) removal ratio by denitrification is 70% and reduced rapidly at the bottom of the SSCU filter media in the anaerobic state.
- Aspirators are placed in higher level of inlet pipes of UFRF and operate with atmospheric pressure and gravitational flow. Dissolved oxygen level is maintained to 80% by continuous oxygen injection. The sunshade cover is placed on the upper side of UFRF to prevent filters from clogging by algal growth.
- Fecal Coliform can be removed by 90% in the SSCU and afterwards it can be removed by 100% in the SSFU bio-film.
- Analyzing Phosphorus level of water was unnecessary, because Phosphorus contamination in the groundwater of inhabited islands of Maldives is at a low level.

OPERATION COST COMPARISION OF EPU WITH RO-PLANT

- Comparison of the operation cost for the Gulhi Island.
- Depreciation and initial costs are not included.

・ Amount of the product water; 60m^3/day×365day=21,900 m^3/year.

Table 05: Operation cost for Seawater Desalination Plant (RO)

	Content	Amount/year (US$)
1	Power Consumption RO & Pumps, 609.3kWh/day×365day×US$0.487/kWh	US$ 108,306.00
2	Spare part and consumable items RO membrane, Pre filter, Chemicals, Pump spare parts	US$ 8,200.00
3	Man Power Expenses RO, Specialist US$3000×12month +Island staff US$1500×12month×2 persons	US$ 72,000.00
4	Indirect Expenses Administration Accommodation, Transportation, etc	US$ 30,000.00
	Total **Unit cost**	**US$ 218,506.00** **(US$ 9.98/m^3)**

Table 06: Operation cost for Ecological Purification Unit

	Content	Amount/year (US$)
1	Power Consumption Pumps, 1.1kW×4sets×8.3hr/day×365days× US$0.487/kWh	US$ 6,492.00
2	Spare part and consumable items Pump spare parts	US$ 1,000.00
3	Man Power Expenses, EPU Specialist 5days×3times/year ×US$200/day +Island staff US$1500×12month×2 persons	US$ 39,000.00
4	Indirect Expenses Administration Accommodation, Transportation, etc	US$ 16,000.00
	Total **Unit cost**	**US$ 62,492.00** **(US$ 2.85/m^3)**

Operation cost comparison of EPU with RO plant

・ Electric consumption of EPU is less than 1/16 of RO.
・ EPU costs US$ 2.85/m^3 although RO costs US$ 9.98/m^3 (1: 3.5).
・ Electric fee in Maldives is high because they use small inefficient diesel generators with diesel oil imported from other countries. The imported oil is tanked at the capital Male, transported to each island by small boats and then tanked again. Additionally, when the small inefficient RO unit is used with a diesel generator, the desalination cost would exceed US$9.98/m^3, which is more than three times of Tokyo.

CONCLUSION

・ We could testify that the Ecological Purification Unit is able to purify the organically polluted water, with our experiments in Sri Lanka. SSCU was developed for purification of kitchen drainage but the BOD and turbidity purification ability is worth a special mention. It will be a leading unit of moderate-scale purification systems.
・ It was said that RO unit is the only way to solve the Maldivian water problem, but RO was too difficult and expensive to maintain. Additionally it needed too much electricity and exhaled CO_2 too much. On the other hand, the Ecological Purification Unit is far easier to maintain, and it doesn't need much electricity. It works with solar power and wind-generation. On these accounts,

the Ecological Purification Unit is the best system for the inhabited islands of Maldives.

- Many people suffer from lack of water in small villages all over the world. This problem has not solved yet because there is no moderate-scale purification system for the organic contamination of groundwater and river water. We aim to popularize EPU globally, being routed the standard model of the inhabited islands of Maldives.

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