Waste Water Management

For the Residential Zone Part 1&2

Phase C: Part 1

Comparative study on the waste water treatment (wwt) Technology

a) DEWATS or b) MBR

F I N A L   R E P O R T

Study and Report done by *Aqua Engineers*, Auroville

Commissioned and Financed by

L'avenir d'Auroville

Auroville's Planning & Development Organization

Auroville, February/March 2009

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1. Executive Summary

L'avenir has commissioned and financed in spring/ summer of 2008 a study on *"Water Management And Infrastructure Master plan For the Residential Zone 1 and 2 in Auroville"*. The study has been conducted by the Auroville engineering office "Aqua Engineers".

The Masterplan study provides clear concepts for most of the water infrastructure needs of the Residential Zone, Sectors 1 and 2 but the future waste water treatment technology was one point where a final recommendation could not be defined.

Following the proposal of Aqua Engineers, a follow up study focusing on recommendations for the waste water treatment (wwt) technology, (Part C) has been financed and commissioned by L'avenir.

This study is based on data from the DEWATS systems installed in and around Auroville and MBR systems installed in India, Germany and Australia.

The solutions to the question "What would be the best waste water treatment technology for Auroville and its Bioregion?" were discovered by identifying the major topics that needed to be researched, evaluated and reviewed with other experts in the industry. As a result, six important aims were defined that have varying weights:

1. Easy handling and maintenance
2. State-of-the-Art treatment, high quality effluent
3. Economical Investment in combination with a long lifetime
4. Flexibility and easy extendibility
5. Energy efficiency and environmental impact
6. Optimal use of the land

All the Aims were identified, rated and assessed using a matrix. The results of the evaluation support the construction and installation of an MBR based wwt plant. The MBR plant in our opinion is the best solution with another side benefit of providing a sustainable waste water management program. Furthermore, the plant size of the MBR systems allows a better scalability which fits well in the "LEGO" system.

One of the disadvantages is the upfront investment costs for MBR technology. The economical cost calculation indicates that water with a MBR plant can be treated for Rs. 26 per m^3 where as the DEWATS plant runs at Rs. 21 per m^3.

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Nevertheless, it must be understood that for the actual costs of the system a design study is required. It's possible that a small MBR plant based on disk module technology is a better investment and performance than the one based on hollow fibers. The dynamic cost estimate can therefore only give a projection for the treatment rate per m^3.

MBR technology has a wide range of advantages providing one accepts the energy requirement and investment costs. One of our recommendations to the authorities of the Auroville is to design and construct a test plant to study the performance at the same time conducting a cost benefit analysis comparing the different systems.

Auroville February 2009

Dirk Nagelschmidt (M. Eng.) / Aqua Engineers

Date of commission: 31.03.2009, L'avenir Auroville

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2. Introduction

2.1. DEWATS [1]

(DEWATS) **D**ecentralized **W**aste **W**ater **T**reatment **S**ystems was introduced by a German NGO **BORDA** (**B**remen **O**verseas **R**esearch and **D**evelopment **A**ssociation) through Ludwig Sasse one of their engineers.

DEWATS applications are based on the principle of low-maintenance since most important parts of the system work without technical energy inputs. These systems can not intentionally be shut down. DEWATS applications provide state-of-the-art-technology at affordable prices because all of the material used for construction are available locally.

Without considering facilities for necessary chemical pre-treatment of wastewater from industries, DEWATS applications are based on four basic technical treatment modules that are combined according to demand:

Primary treatment: sedimentation and floatation

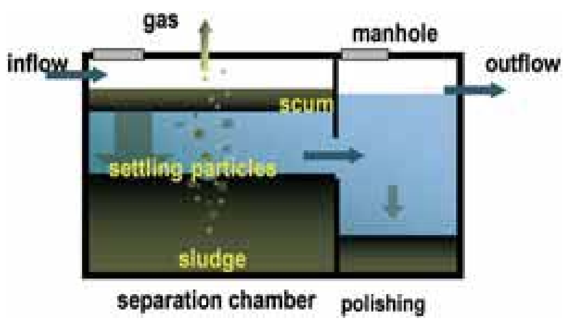

Image 1: Separation of solids [1]

Secondary anaerobic treatment in fixed-bed reactors: baffled upstream reactors or anaerobic filters

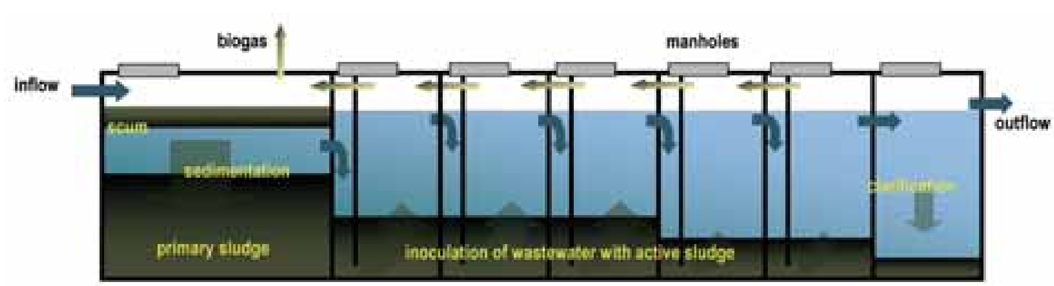

Image 2: Baffled Reactor system [1]

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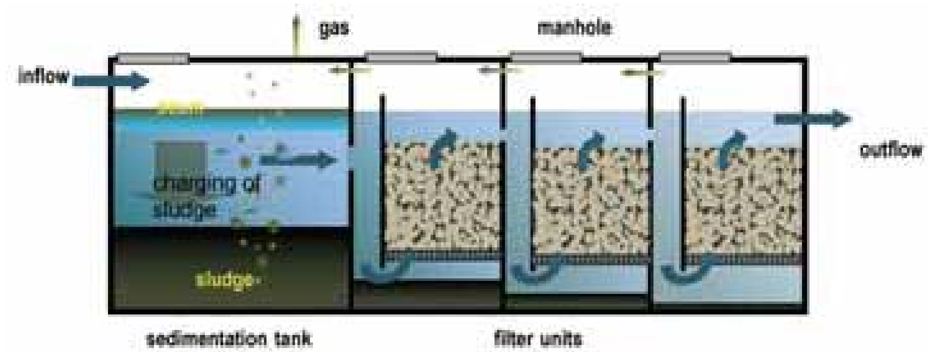
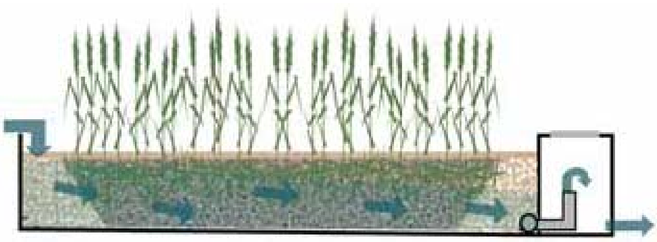


Image 3: Anaerobic Filter [1]



Tertiary aerobic treatment in sub-surface flow filters [1]

Image 4: Planted Filter

Tertiary aerobic treatment

DEWATS applications are designed and dimensioned so the water can subsequently be stored in a polishing pond and re-used as irrigation water.

The advantages of this kind of system are:

2.1.1. <u>Advantages and disadvantages of DEWATS technology:</u>

+ treatment for organic wastewater flows from 1-1000 m3 per day and it doesn't need electricity because the flow is driven by gravity;
+ reliable, long lasting and tolerant towards inflow fluctuation;
+ modular design of all components;
+ tolerant towards inflow fluctuations;
+ applications do not require complicated and costly maintenance;
+ treated water meets all the requirements stipulated in environmental laws and regulations ;
+ powerful low costs system;
– a minimum of 6 months before the performance and results are reached because the anaerobic bacteria needs time to develop;

- large footprint is required and land is expensive;
- floating material is a problem requiring special equipment, for example a flow above 25 m^3/d requires a technical screening device; and
- it is sensitive to chemicals and disinfection materials.

2.2. MBR technology

MBR (**M**embrane **B**io **R**eactor) technology became available sometime in the late 1960s, as soon as commercial scale ultra filtration (UF) and micro filtration (MF) membranes were on the market.. Dorr-Olivier Inc. introduced the original process and it combined the use of an activated sludge bioreactor with a cross flow membrane filtration loop. [2]

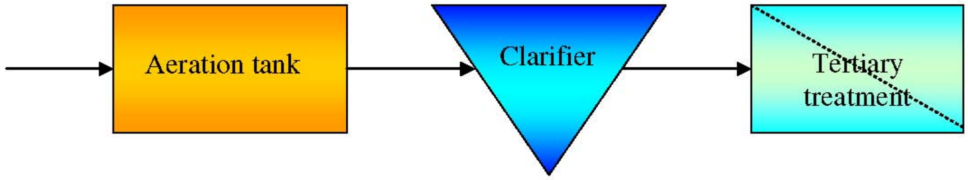
Membrane technology has led to a revolutionary new concept in wastewater treatment. Membranes act as a barrier to bacteria and suspended solids to produce a low turbidity treatment plant effluent with very low bacteria counts. [3]

When used in a membrane bioreactor, submerged membrane modules are useful in treating both municipal wastewater and wastewater from various industrial sources such as, paper mills, beverage ingredient processors, food processors, chemical plants, tank truck cleaning operations to name a few. [4]

In a conventional biological system, performance and efficiency is limited by the ability of the clarifier to settle the solids in the mixed liquor stream. This function depends on operator skill, sludge settle-ability, basic clarifier design, management of solids and the variability of hydraulic or organic load. When upsets occur, solids can be lost which will compromise the performance of the system. Therefore, in order to maintain adequate settling characteristics, suspended growth activated sludge plants are limited to **MLSS (M**ixed **L**iquor **S**uspended **S**olids) (= Biomass in the Aeration Tank) concentrations of less than 3500 mg/l. [3]

The membrane modules are submerged in the activated sludge to combine the biological step and the solid-liquid separation step into a single process. [3]

CONVENTIONAL SYSTEM



MBR SYSTEM

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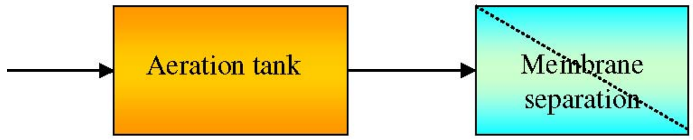

Image 5: Comparison sketch, conventional / wwt-system and MBR system

Since the membrane acts as a barrier to microorganisms, the effluent quality is much better than that produced by a conventional plant. Also, the membrane barrier eliminates the secondary clarifier and allows the activated sludge to be more highly concentrated. This reduces the capacity needed for biological tanks, saving space and money. [4]

Image 6: MBR module, Koch Membrane systems “Puron”[4]

Image 7: Submerged MBR module during operation, Koch Membrane Systems, Puron[4]

The entire plant including pre-treatment, mesh, biology, and membranes can be designed in such a way that it can be installed in Container Modules, see Image 8. The advantage is the plant can easily be moved to another site. This might become necessary e.g. if the land does not belong to Auroville.

Image 8: MBR plant in container, Fa. Huber, Germany [6]

2.2.1. Types of MBR systems

There are different types and models of MBR systems on the market. The authors has done some research on the systems in order to do some comparison of the different aspects and functions.

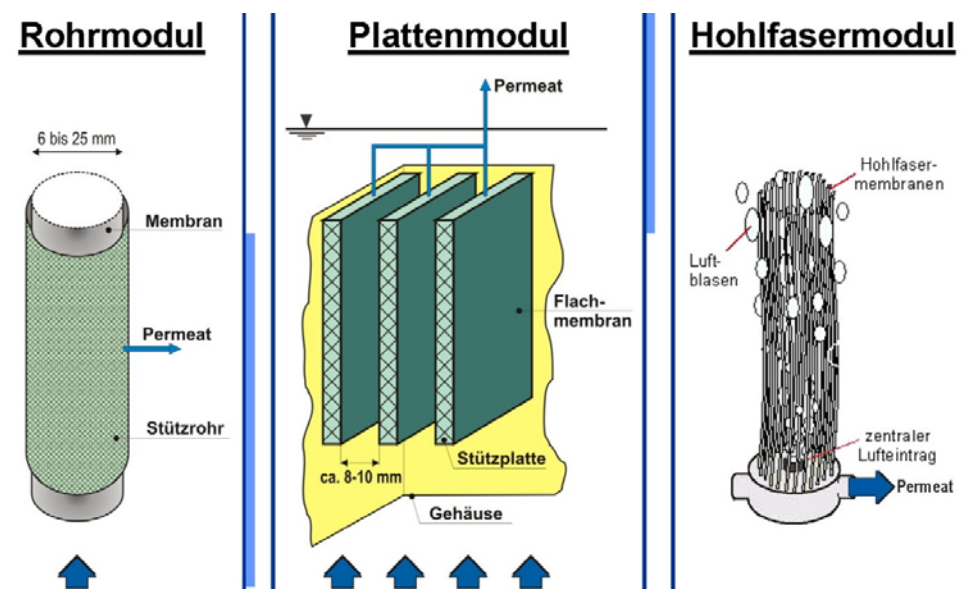

Image 9: MBR Models, from left to right: Pipe model, Disk model, Hollow fiber module [7]

The most advanced and reliable system seams to be the “Hollow fiber Module” e.g. “Puron” of Koch’s, Germany. The system has advantages in the areas of clogging, cleaning, chemical and electrical use.

2.2.2. Advantages and disadvantages of MBR systems [3]

+ high quality of treated waste water;
+ reliable - simple-to-operate barrier technology;
+ small compact footprint, 1/3 of space of conventional plants - the intensive nature of the process minimizes space requirements;
+ robust - resistance to shock sewage loads;
+ reduces sludge - the production of solid waste is reduced therefore lowering the cost of disposal;
+ economical - advanced aeration and membrane technology minimizes the demand for power
+ longevity - the life expectancy of the membrane is anywhere from, 5 to 7 years;
+ quick and easy installation;

– a small amount of chemicals are needed to clean the membrane - these acids ‘break down’ in a short period of time;
– regular monitoring is required as part of the maintenance program;
– electricity is required; and
– sludge has to be removed weekly.

3. Economic dynamic Costs calculations

The basis for the economic cost calculation involved listing the capital and operational cost for the plant. The cost reflect only the treatment of the waste water. Not included in these calculations are storage tanks and network systems for the irrigation water supply.

The capital nominally invested is simply the sum of capital costs, whereas the present value of the capital considers the discounting of the capital by the efficient discount factor. This means that the value of capital is referred to the starting time of the plant. The efficient discount factor is influenced by the discount factor due to the consideration of interest rates and inflation. It is calculated by:

$$\text{Effective Discount Factor} = (1 + \text{discount factor}) \times (1 + \text{Inflation factor}) - 1$$

Beginning with the planning and construction of the plant all profits and yields are allocated by the year. The amounts are multiplied with the efficient discount factor referring to each year, which is calculated by:

$$(1 + \text{eff. Dis. factor})^{\Delta t}$$

The sum of all the discounted investment and operational costs are in the right hand column as one of the results of the calculation.

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The water production for each year is measured in accordance to inflation instead of the efficient discount factor. In the column of the results, the sum of the discounted water production assuming an inflation-indexed price can be seen.

The water costs can then be calculated by dividing the discounted investment and operational costs by the discounted production of water.

3.1. Land value

The land value is an important factor and has normally to be considered in the costs analyze, but in the case of Auroville. But for this study, the author and L'avenir came to the conclusion that the land belongs to Auroville as a whole, meaning no land has to be purchased (no investment) for the treatment plant as such. Considering the land value would have given a wrong price per m^3.

Nevertheless, it must be mentioned that the planner have to be careful in the planning, land should not be wasted because the present land costs vary from 30 to 80 lakh/acre. At the Bomayapalayam road, rates have touched almost 1 crore Rs/ acre.

For general information: If one would consider an average price of app. Rs 55 lakh/acre, this would be equal to ~ 1350Rs/m^2.

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3.2. Costs for DEWATS systems

The costs of the DEWATS plant was determined by calculating the average installation cost for the wastewater treatment systems in Auroville and its Bioregion.

The cost of construction which includes labor and material in the Auroville area are between 15 to 50 thousand RS/m³ for a wwt systems. The least expensive systems are made out of brick that crack after a few years. An alternative is to use the Ferro cement tanks, however they are limited in capacity and have a short life span. The author has laid the weight for the treatment system based on the longevity of the material. The costs/m³ of the wastewater treatment system was based on using first class re-enforced concrete with a minimum steel thickness of 14 mm and 5 cm covering of steel mortar. The cement recommended is L&T with a water and cement ratio of 0,5. [3].

In [3] the author has calculated the cost of the installation per m³ at Rs. 35.000/m³. Also, taken into consideration was inflation and an increase in material and labor. At the moment the average installations costs are Rs. 45.000/m³ (January 2009)

The following charts provide a cost estimate for building the plants . The plant vary in size stating at 50, 100, 200, 300 up to 450 m³. They have all been evaluated and the calculations are based on a formula outlined in chapter three.

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3.2.1. DEWATS plant sizes and footprint

The below given foot print of the DEWATS plants was calculated based on an average waste water production of 175 l/ per person each day. The actual size may vary due to the variation of the load. Therefore, the calculated foot print can only be seen as an indication with an accordance of ± 15%. Nevertheless, the given factors are sufficient for this stage of planning and study.

	Capacity: 50m³	Area required in m²
1	balancing tank	0
2	Settler	15
3	Baffle	100
4	Filter	5
5	Rootzone	100
6	Polishing pond = storage	100
	Total:	320

Image 10: DEWATS footprints, 50m³/d

	Capacity: 100m³	Area required in m²
1	balancing tank	15
2	Settler	20
3	Baffle	200
4	Filter	10
5	Rootzone	150
6	Polishing pond = storage	200
	Total:	595

Image 11: DEWATS footprint, 100 m³/d plant

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	Capacity: 200m³	Area required in m²
1	balancing tank	45
2	Settler	50
3	Baffle	350
4	Filter	20
5	Rootzone	250
6	Polishing pond = storage	400
	Total:	1115

Image 12: DEWATS footprint, 200 m³/d plant

	Capacity: 300m³	Area required in m²
1	balancing tank	70
2	Settler	75
3	Baffle	460
4	Filter	30
5	Rootzone	300
6	Polishing pond = storage	550
	Total:	1485

Image 13: DEWATS footprint, 300 m³/d plant

	Capacity: 450m³	Area required in m²
1	balancing tank	90
2	Settler	100
3	Baffle	700
4	Filter	45
5	Rootzone	400
6	Polishing pond = storage	700
	Total:	2035

Image 14: DEWATS footprint, 450 m³/d plant

3.3. Economic dynamic Costs calculations for the DEWATS systems

Economical cost calculations for 50 m³ DEWATS plant

Assumptions of costs:

Capital costs for 50 m³/d in Lakh		**Operational costs in Lakh/a**		**Results of Calculation**	
land costs	0 lakh	Electricity	0.50 lakh		Lakh Rs.
DEWATS Plant	23 lakh	Maintenance	0.50 lakh	discounted Investment +operation cost	46
		Spare parts	0.0 lakh		
sludge treatment and biogas unit	5 lakh	Labour (1 employees)	1.5 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	0 lakh		189,226
generator	3 lakh	operational costs per year	2.5 lakh		
capital nominally invested	36 lakh	nominal operational costs	405 lakh	water treatment rate/m³ in first year of operation, which growths annually with inflation	Rs/m³
present value of capital	43 lakh	present value of operational costs	3 lakh		24.34

availability of plant	100%	
waste water production	18,263	m³/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m³/a
	1	371%	0.0			0.00			
	2	193%	5.0			9.63			
Start	3	100%	30.5	2.5		32.96	18,263	100.0%	18,263
	4	51.9%		2.7		1.41	18,263	90.9%	16,602
	5	27.0%		3.0	0.5	0.94	18,263	82.6%	15,093
	6	14.0%		3.3		0.46	18,263	75.1%	13,721
	7	7.3%		3.6	0.5	0.30	18,263	68.3%	12,474
	8	3.8%		4.0		0.15	18,263	62.1%	11,340
	9	2.0%		4.4	0.5	0.10	18,263	56.4%	10,309
	10	1.0%		4.8		0.05	18,263	51.3%	9,372
	11	0.5%		5.3	0.5	0.03	18,263	46.7%	8,520
	12	0.3%		5.8		0.02	18,263	42.4%	7,745
	13	0.1%		6.4	0.5	0.01	18,263	38.6%	7,041
	14	0.1%		7.0		0.01	18,263	35.0%	6,401
	15	0.0%		7.7	0.5	0.00	18,263	31.9%	5,819
	16	0.0%		8.5		0.00	18,263	29.0%	5,290
	17	0.0%		9.3	0.5	0.00	18,263	26.3%	4,809
	18	0.0%		10.3		0.00	18,263	23.9%	4,372
	19	0.0%		11.3	0.5	0.00	18,263	21.8%	3,974
	20	0.0%		12.4		0.00	18,263	19.8%	3,613
	21	0.0%		13.7	0.5	0.00	18,263	18.0%	3,285
	22	0.0%		15.1		0.00	17,349	16.4%	2,837
	23	0.0%		16.6	0.5	0.00	18,263	14.9%	2,715
	24	0.0%		18.2		0.00	18,263	13.5%	2,468
	25	0.0%		20.0	0.5	0.00	18,263	12.3%	2,243
	26	0.0%		22.0		0.00	18,263	11.2%	2,040
	27	0.0%		24.2	0.5	0.00	18,263	10.2%	1,854
	28	0.0%		26.7		0.00	18,263	9.2%	1,686
	29	0.0%		29.3	0.5	0.00	18,263	8.4%	1,532
	30	0.0%		32.3		0.00	18,263	7.6%	1,393
	31	0.0%		35.5		0.00	18,263	6.9%	1,266
	32	0.0%		39.0		0.00	18,263	6.3%	1,151

Image 15: DEWATS, 50 m³/d plant

Economical cost calculations for 100 m³ DEWTAS plant

Assumptions of costs:

Capital costs for 100 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0 lakh	Electricity	0.60 lakh		Lakh Rs.
DEWATS Plant	45 lakh	Maintenance	2 lakh	discounted Investment +operation cost	77
		Spare parts	0.0 lakh		
sludge treatment and biogas unit	6 lakh	Labour (1 employees)	1.5 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	0 lakh		378,451
generator	3 lakh	operational costs per year	3.6 lakh		
capital nominally invested	59 lakh	nominal operational costs	586 lakh	water treatment rate/m³ in first year of operation, which growths annually with inflation	Rs/m³
present value of capital	72 lakh	present value of operational costs	5 lakh		20.30

availability of plant	100%	
waste water production	36,525	m³/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m³/a
	1	371%	0.0			0.00			
	2	193%	10.0			19.25			
Start	3	100%	49.0	3.6		52.56	36,525	100.0%	36,525
	4	51.9%		3.9		2.03	36,525	90.9%	33,205
	5	27.0%		4.3	0.7	1.35	36,525	82.6%	30,186
	6	14.0%		4.7		0.66	36,525	75.1%	27,442
	7	7.3%		5.2	0.7	0.43	36,525	68.3%	24,947
	8	3.8%		5.7		0.22	36,525	62.1%	22,679
	9	2.0%		6.3	0.7	0.14	36,525	56.4%	20,617
	10	1.0%		6.9		0.07	36,525	51.3%	18,743
	11	0.5%		7.6	0.7	0.04	36,525	46.7%	17,039
	12	0.3%		8.4		0.02	36,525	42.4%	15,490
	13	0.1%		9.2	0.7	0.01	36,525	38.6%	14,082
	14	0.1%		10.2		0.01	36,525	35.0%	12,802
	15	0.0%		11.2	0.7	0.00	36,525	31.9%	11,638
	16	0.0%		12.3		0.00	36,525	29.0%	10,580
	17	0.0%		13.5	0.7	0.00	36,525	26.3%	9,618
	18	0.0%		14.9		0.00	36,525	23.9%	8,744
	19	0.0%		16.4	0.7	0.00	36,525	21.8%	7,949
	20	0.0%		18.0		0.00	36,525	19.8%	7,226
	21	0.0%		19.8	0.7	0.00	36,525	18.0%	6,569
	22	0.0%		21.8		0.00	34,699	16.4%	5,674
	23	0.0%		24.0	0.7	0.00	36,525	14.9%	5,429
	24	0.0%		26.4		0.00	36,525	13.5%	4,936
	25	0.0%		29.0	0.7	0.00	36,525	12.3%	4,487
	26	0.0%		31.9		0.00	36,525	11.2%	4,079
	27	0.0%		35.1	0.7	0.00	36,525	10.2%	3,708
	28	0.0%		38.6		0.00	36,525	9.2%	3,371
	29	0.0%		42.4	0.7	0.00	36,525	8.4%	3,065
	30	0.0%		46.7		0.00	36,525	7.6%	2,786
	31	0.0%		51.4	0.7	0.00	36,525	6.9%	2,533
	32	0.0%		56.5		0.00	36,525	6.3%	2,303

Image 16: DEWATS, 100 m³/d plant

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AQUA ENGINEERS

Economical cost calculations for 200 m³ DEWTAS plant

Assumptions of costs:

Capital costs for 200 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs		Electricity	2.00 lakh		Lakh Rs.
DEWATS Plant	90 lakh	Maintenance	5 lakh	discounted Investment +operation cost	154
		Spare parts	0.0 lakh		
sludge treatment and biogas unit	10 lakh	Labour (2 employees)	3.0 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	0 lakh		756,902
generator	5 lakh	operational costs per year	10.0 lakh		
capital nominally invested	110 lakh	nominal operational costs	1,645 lakh	water treatment rate/m³ in first year of operation, which growths annually with inflation	Rs/m³
present value of capital	133 lakh	present value of operational costs	21 lakh		20.29

availability of plant	100%	
waste water production	73,050	m³/a
discount factor	50.00%	/a
inflation	10.00%	/a
eff. discount factor	65.00%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m³/a
	1	272%	0.0			0.00			
	2	165%	20.0			33.00			
Start	3	100%	90.0	10.0		100.00	73,050	100.0%	73,050
	4	60.6%		11.0		6.67	73,050	90.9%	66,409
	5	36.7%		12.1	1.0	4.81	73,050	82.6%	60,372
	6	22.3%		13.3		2.96	73,050	75.1%	54,884
	7	13.5%		14.6	1.0	2.11	73,050	68.3%	49,894
	8	8.2%		16.1		1.32	73,050	62.1%	45,358
	9	5.0%		17.7	1.0	0.93	73,050	56.4%	41,235
	10	3.0%		19.5		0.59	73,050	51.3%	37,486
	11	1.8%		21.4	1.0	0.41	73,050	46.7%	34,078
	12	1.1%		23.6		0.26	73,050	42.4%	30,980
	13	0.7%		25.9	1.0	0.18	73,050	38.6%	28,164
	14	0.4%		28.5		0.12	73,050	35.0%	25,604
	15	0.2%		31.4	1.0	0.08	73,050	31.9%	23,276
	16	0.1%		34.5		0.05	73,050	29.0%	21,160
	17	0.1%		38.0	1.0	0.04	73,050	26.3%	19,236
	18	0.1%		41.8		0.02	73,050	23.9%	17,488
	19	0.0%		45.9	1.0	0.02	73,050	21.8%	15,898
	20	0.0%		50.5		0.01	73,050	19.8%	14,453
	21	0.0%		55.6	1.0	0.01	73,050	18.0%	13,139
	22	0.0%		61.2		0.00	69,398	16.4%	11,347
	23	0.0%		67.3	1.0	0.00	73,050	14.9%	10,858
	24	0.0%		74.0		0.00	73,050	13.5%	9,871
	25	0.0%		81.4	1.0	0.00	73,050	12.3%	8,974
	26	0.0%		89.5		0.00	73,050	11.2%	8,158
	27	0.0%		98.5	1.0	0.00	73,050	10.2%	7,416
	28	0.0%		108.3		0.00	73,050	9.2%	6,742
	29	0.0%		119.2	1.0	0.00	73,050	8.4%	6,129
	30	0.0%		131.1		0.00	73,050	7.6%	5,572
	31	0.0%		144.2	1.0	0.00	73,050	6.9%	5,066
	32	0.0%		158.6		0.00	73,050	6.3%	4,605

Image 17: DEWATS, 200 m³/d plant

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Economical cost calculations for 300 m³ DEWTAS plant

Assumptions of costs:

Capital costs for 300 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0 lakh	Electricity	5.00 lakh		Lakh Rs.
DEWATS Plant	135 lakh	Maintenance	5 lakh	discounted Investment +operation cost	236
		Spare parts	0.0 lakh		
sludge treatment and biogas unit	20 lakh	Labour (1 employees)	6.0 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	0 lakh		1,135,354
generator	10 lakh	operational costs per year	16.0 lakh		
capital nominally invested	170 lakh	nominal operational costs	2,632 lakh	water treatment rate/m³ in first year of operation, which growths annually with inflation	Rs/m³
present value of capital	214 lakh	present value of operational costs	22 lakh		20.77

availability of plant	100%	
waste water production	109,575	m³/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	Disc.Factor for Waste water treatment assuming the water-price rises with inflation: water prod. m³/a	10.00% %/a	discounted water prod. m³/a
	1	371%	0.0			0.00			
	2	193%	30.0			57.75			
Start	3	100%	140.0	16.0		156.00	109,575	100.0%	109,575
	4	51.9%		17.6		9.14	109,575	90.9%	99,614
	5	27.0%		19.4	2.0	5.76	109,575	82.6%	90,558
	6	14.0%		21.3		2.99	109,575	75.1%	82,325
	7	7.3%		23.4	2.0	1.85	109,575	68.3%	74,841
	8	3.8%		25.8		0.97	109,575	62.1%	68,037
	9	2.0%		28.3	2.0	0.60	109,575	56.4%	61,852
	10	1.0%		31.2		0.32	109,575	51.3%	56,229
	11	0.5%		34.3	2.0	0.19	109,575	46.7%	51,118
	12	0.3%		37.7		0.10	109,575	42.4%	46,470
	13	0.1%		41.5	2.0	0.06	109,575	38.6%	42,246
	14	0.1%		45.6		0.03	109,575	35.0%	38,405
	15	0.0%		50.2	2.0	0.02	109,575	31.9%	34,914
	16	0.0%		55.2		0.01	109,575	29.0%	31,740
	17	0.0%		60.8	2.0	0.01	109,575	26.3%	28,855
	18	0.0%		66.8		0.00	109,575	23.9%	26,231
	19	0.0%		73.5	2.0	0.00	109,575	21.8%	23,847
	20	0.0%		80.9		0.00	109,575	19.8%	21,679
	21	0.0%		89.0	2.0	0.00	109,575	18.0%	19,708
	22	0.0%		97.9		0.00	104,096	16.4%	17,021
	23	0.0%		107.6	2.0	0.00	109,575	14.9%	16,288
	24	0.0%		118.4		0.00	109,575	13.5%	14,807
	25	0.0%		130.2	2.0	0.00	109,575	12.3%	13,461
	26	0.0%		143.3		0.00	109,575	11.2%	12,237
	27	0.0%		157.6	2.0	0.00	109,575	10.2%	11,125
	28	0.0%		173.4		0.00	109,575	9.2%	10,113
	29	0.0%		190.7	2.0	0.00	109,575	8.4%	9,194
	30	0.0%		209.8		0.00	109,575	7.6%	8,358
	31	0.0%		230.7	2.0	0.00	109,575	6.9%	7,598
	32	0.0%		253.8		0.00	109,575	6.3%	6,908

Image 18: DEWATS, 300 m³/d plant

Economical cost calculations for 450 m^3 DEWTAS plant

Assumptions of costs:

Capital costs for 450 m^3/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0 lakh	Electricity	8.00 lakh		Lakh Rs.
DEWATS Plant	203 lakh	Maintenance	10 lakh	discounted Investment +operation cost	351
		Spare parts	0.0 lakh		
sludge treatment and biogas unit	25 lakh	Labour (3 employees)	6.0 lakh	discounted water treatment assuming an inflation-indexed price	m^3
operation office	5 lakh	membrane replacement (every 8 to 10 years)	0 lakh		1,703,031
generator	15 lakh	operational costs per year	24.0 lakh		
capital nominally invested	248 lakh	nominal operational costs	3,948 lakh	water treatment rate/m^3 in first year of operation, which growths annually with inflation	Rs/m^3
present value of capital	318 lakh	present value of operational costs	33 lakh		20.59

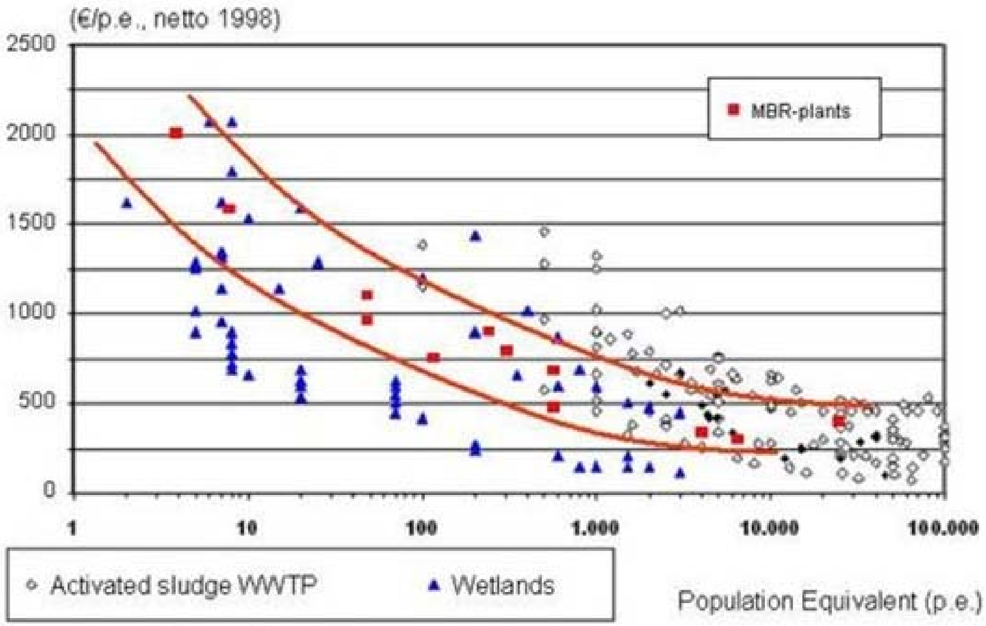
availability of plant	100%	
waste water production	164,363	m^3/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m^3/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m^3/a
	1	371%	0.0			0.00			
	2	193%	50.0			96.25			
Start	3	100%	197.5	24.0		221.50	164,363	100.0%	164,363
	4	51.9%		26.4		13.71	164,363	90.9%	149,420
	5	27.0%		29.0	2.5	8.51	164,363	82.6%	135,837
	6	14.0%		31.9		4.48	164,363	75.1%	123,488
	7	7.3%		35.1	2.5	2.74	164,363	68.3%	112,262
	8	3.8%		38.7		1.46	164,363	62.1%	102,056
	9	2.0%		42.5	2.5	0.88	164,363	56.4%	92,778
	10	1.0%		46.8		0.48	164,363	51.3%	84,344
	11	0.5%		51.4	2.5	0.29	164,363	46.7%	76,676
	12	0.3%		56.6		0.16	164,363	42.4%	69,706
	13	0.1%		62.2	2.5	0.09	164,363	38.6%	63,369
	14	0.1%		68.5		0.05	164,363	35.0%	57,608
	15	0.0%		75.3	2.5	0.03	164,363	31.9%	52,371
	16	0.0%		82.9		0.02	164,363	29.0%	47,610
	17	0.0%		91.1	2.5	0.01	164,363	26.3%	43,282
	18	0.0%		100.3		0.01	164,363	23.9%	39,347
	19	0.0%		110.3	2.5	0.00	164,363	21.8%	35,770
	20	0.0%		121.3		0.00	164,363	19.8%	32,518
	21	0.0%		133.4	2.5	0.00	164,363	18.0%	29,562
	22	0.0%		146.8		0.00	156,144	16.4%	25,531
	23	0.0%		161.5	2.5	0.00	164,363	14.9%	24,431
	24	0.0%		177.6		0.00	164,363	13.5%	22,210
	25	0.0%		195.4	2.5	0.00	164,363	12.3%	20,191
	26	0.0%		214.9		0.00	164,363	11.2%	18,356
	27	0.0%		236.4	2.5	0.00	164,363	10.2%	16,687
	28	0.0%		260.0		0.00	164,363	9.2%	15,170
	29	0.0%		286.0	2.5	0.00	164,363	8.4%	13,791
	30	0.0%		314.6		0.00	164,363	7.6%	12,537
	31	0.0%		346.1	2.5	0.00	164,363	6.9%	11,397
	32	0.0%		380.7		0.00	164,363	6.3%	10,361

Image 19: DEWATS, 450 m^3/d plant

4. Costs for MBR systems



(Reicherter, 1999, und Boller, 1997)

The costs for the MBR plants depend on the size of the system the manufacture and MBR technology, see Image 20. Another factor includes the estimate for the total consumption and it's load. The cost for the treatment system is reduced if less water is used. At this stage the author remarks to [4] and the proposals related to reduce the waste water production and total water consumption. In Germany, water consumption has been reduced from 150l/head to 125l/d over the past 10 years.

Image 20: Tendency of Investment costs for MBR and conventional wastewater treatment systems in relation to the cost per head. [8]

Included in this study, is the average draft costs which were found in various publications along with estimated costs from the different manufactures.

Basically, smaller systems are more expensive than larger. The price spam for MBR < 100 m^3/d ranges from 50.000 Rs/m^3d to 80.000 Rs/m^3d. (= average: 65.000 Rs/m^3)

Medium systems are in a range of 40.000 Rs/m^3d to 50.000 Rs/m^3d. (= average: 45.000 Rs/m^3). Large capacity plants cost approximately Rs.30.000 Rs/m^3d to 40.000 Rs/m^3d. (= average: 35.000 Rs/m^3)

The below Economical costs calculation is therefore based on average investment costs. It must be understood that for the actual costs an implementation study is needed as well as a comparison of the different systems in order to select the best treatment technology.

4.1. Economic dynamic Costs calculations for the MBR systems

Economical cost calculations for 50 m³ MBR plant

Assumptions of costs:

Capital costs for 50 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0.00 lakh	Electricity	3 lakh		Lakh Rs.
MBR Plant	33 lakh	Maintenance	1 lakh	discounted Investment +operation cost	63
		Spare parts	0.3 lakh		
sludge treatment and biogas unit	5 lakh	Labour (1 employees)	1.5 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	2 lakh		189,226
generator	3 lakh	operational costs per year	5.7 lakh		
capital nominally invested	46 lakh	nominal operational costs	939 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	56 lakh	present value of operational costs	8 lakh		33.55

availability of plant	100%	
waste water production	18,263	m³/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m³/a
	1	371%	0.0			0.00			
	2	193%	5.0			9.63			
Start	3	100%	41 lakh	5.7		46.21	18,263	100.0%	18,263
	4	51.9%		6.3		3.26	18,263	90.9%	16,602
	5	27.0%		6.9		1.86	18,263	82.6%	15,093
	6	14.0%		7.6		1.07	18,263	75.1%	13,721
	7	7.3%		8.4		0.61	18,263	68.3%	12,474
	8	3.8%		9.2		0.35	18,263	62.1%	11,340
	9	2.0%		10.1	1.5	0.23	18,263	56.4%	10,309
	10	1.0%		11.1		0.11	18,263	51.3%	9,372
	11	0.5%		12.2		0.06	18,263	46.7%	8,520
	12	0.3%		13.5		0.04	18,263	42.4%	7,745
	13	0.1%		14.8		0.02	18,263	38.6%	7,041
	14	0.1%		16.3		0.01	18,263	35.0%	6,401
	15	0.0%		17.9		0.01	18,263	31.9%	5,819
	16	0.0%		19.7		0.00	18,263	29.0%	5,290
	17	0.0%		21.7		0.00	18,263	26.3%	4,809
	18	0.0%		23.9	1.5	0.00	18,263	23.9%	4,372
	19	0.0%		26.2		0.00	18,263	21.8%	3,974
	20	0.0%		28.9		0.00	18,263	19.8%	3,613
	21	0.0%		31.8		0.00	18,263	18.0%	3,285
	22	0.0%		34.9		0.00	17,349	16.4%	2,837
	23	0.0%		38.4		0.00	18,263	14.9%	2,715
	24	0.0%		42.3		0.00	18,263	13.5%	2,468
	25	0.0%		46.5		0.00	18,263	12.3%	2,243
	26	0.0%		51.1		0.00	18,263	11.2%	2,040
	27	0.0%		56.3	1.5	0.00	18,263	10.2%	1,854
	28	0.0%		61.9		0.00	18,263	9.2%	1,686
	29	0.0%		68.1		0.00	18,263	8.4%	1,532
	30	0.0%		74.9		0.00	18,263	7.6%	1,393
	31	0.0%		82.4		0.00	18,263	6.9%	1,266
	32	0.0%		90.6		0.00	18,263	6.3%	1,151

Image 21: MBR, 50 m³/d plant

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Economical cost calculations for 100 m³ MBR plant

Assumptions of costs:

Capital costs for 100 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0.00 lakh	Electricity	5 lakh		Lakh Rs.
MBR Plant	65 lakh	Maintenance	2 lakh	discounted Investment +operation cost	105
		Spare parts	0.5 lakh		
sludge treatment and biogas unit	6 lakh	Labour (1 employees)	1.5 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	2 lakh		378,451
generator	3 lakh	operational costs per year	9.0 lakh		
capital nominally invested	79 lakh	nominal operational costs	1,474 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	93 lakh	present value of operational costs	12 lakh		27.63

availability of plant	100%	
waste water production	36,525	m³/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m³/a
	1	371%	0.0			0.00			
	2	193%	5.0			9.63			
Start	3	100%	74 lakh	9.0		82.96	36,525	100.0%	36,525
	4	51.9%		9.9		5.12	36,525	90.9%	33,205
	5	27.0%		10.8		2.93	36,525	82.6%	30,186
	6	14.0%		11.9		1.67	36,525	75.1%	27,442
	7	7.3%		13.1		0.96	36,525	68.3%	24,947
	8	3.8%		14.4		0.55	36,525	62.1%	22,679
	9	2.0%		15.9	2	0.35	36,525	56.4%	20,617
	10	1.0%		17.5		0.18	36,525	51.3%	18,743
	11	0.5%		19.2		0.10	36,525	46.7%	17,039
	12	0.3%		21.1		0.06	36,525	42.4%	15,490
	13	0.1%		23.2		0.03	36,525	38.6%	14,082
	14	0.1%		25.6		0.02	36,525	35.0%	12,802
	15	0.0%		28.1		0.01	36,525	31.9%	11,638
	16	0.0%		30.9		0.01	36,525	29.0%	10,580
	17	0.0%		34.0		0.00	36,525	26.3%	9,618
	18	0.0%		37.4	2	0.00	36,525	23.9%	8,744
	19	0.0%		41.2		0.00	36,525	21.8%	7,949
	20	0.0%		45.3		0.00	36,525	19.8%	7,226
	21	0.0%		49.8		0.00	36,525	18.0%	6,569
	22	0.0%		54.8		0.00	34,699	16.4%	5,674
	23	0.0%		60.3		0.00	36,525	14.9%	5,429
	24	0.0%		66.3		0.00	36,525	13.5%	4,936
	25	0.0%		72.9		0.00	36,525	12.3%	4,487
	26	0.0%		80.2		0.00	36,525	11.2%	4,079
	27	0.0%		88.3	2	0.00	36,525	10.2%	3,708
	28	0.0%		97.1		0.00	36,525	9.2%	3,371
	29	0.0%		106.8		0.00	36,525	8.4%	3,065
	30	0.0%		117.5		0.00	36,525	7.6%	2,786
	31	0.0%		129.2		0.00	36,525	6.9%	2,533
	32	0.0%		142.1		0.00	36,525	6.3%	2,303

Image 22: MBR, 100 m³/d plant

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Economical cost calculations for 200 m³ MBR plant

Assumptions of costs:

Capital costs for 200 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0.00 lakh	Electricity	10 lakh		Lakh Rs.
MBR Plant	130 lakh	Maintenance	4 lakh	discounted Investment +operation cost	207
		Spare parts	1.0 lakh		
sludge treatment and biogas unit	10 lakh	Labour (1 employees)	1.5 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	3 lakh		756,902
generator	5 lakh	operational costs per year	16.5 lakh		
capital nominally invested	150 lakh	nominal operational costs	2,708 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	185 lakh	present value of operational costs	22 lakh		27.34

availability of plant	100%	
waste water production	73,050	m³/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m³/a
	1	371%	0.0			0.00			
	2	193%	20.0			38.50			
Start	3	100%	130 lakh	16.5		146.46	73,050	100.0%	73,050
	4	51.9%		18.1		9.41	73,050	90.9%	66,409
	5	27.0%		19.9		5.38	73,050	82.6%	60,372
	6	14.0%		21.9		3.07	73,050	75.1%	54,884
	7	7.3%		24.1		1.76	73,050	68.3%	49,894
	8	3.8%		26.5		1.00	73,050	62.1%	45,358
	9	2.0%		29.2	3	0.63	73,050	56.4%	41,235
	10	1.0%		32.1		0.33	73,050	51.3%	37,486
	11	0.5%		35.3		0.19	73,050	46.7%	34,078
	12	0.3%		38.8		0.11	73,050	42.4%	30,980
	13	0.1%		42.7		0.06	73,050	38.6%	28,164
	14	0.1%		47.0		0.03	73,050	35.0%	25,604
	15	0.0%		51.7		0.02	73,050	31.9%	23,276
	16	0.0%		56.8		0.01	73,050	29.0%	21,160
	17	0.0%		62.5		0.01	73,050	26.3%	19,236
	18	0.0%		68.8	3	0.00	73,050	23.9%	17,488
	19	0.0%		75.6		0.00	73,050	21.8%	15,898
	20	0.0%		83.2		0.00	73,050	19.8%	14,453
	21	0.0%		91.5		0.00	73,050	18.0%	13,139
	22	0.0%		100.7		0.00	69,398	16.4%	11,347
	23	0.0%		110.7		0.00	73,050	14.9%	10,858
	24	0.0%		121.8		0.00	73,050	13.5%	9,871
	25	0.0%		134.0		0.00	73,050	12.3%	8,974
	26	0.0%		147.4		0.00	73,050	11.2%	8,158
	27	0.0%		162.1	3	0.00	73,050	10.2%	7,416
	28	0.0%		178.4		0.00	73,050	9.2%	6,742
	29	0.0%		196.2		0.00	73,050	8.4%	6,129
	30	0.0%		215.8		0.00	73,050	7.6%	5,572
	31	0.0%		237.4		0.00	73,050	6.9%	5,066
	32	0.0%		261.1		0.00	73,050	6.3%	4,605

Image 23: MBR, 200 m³/d plant

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Economical cost calculations for 300 m^3 MBR plant

Assumptions of costs:

Capital costs for 300 m^3/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0.00 lakh	Electricity	12 lakh		Lakh Rs.
MBR Plant	195 lakh	Maintenance	5 lakh	discounted Investment +operation cost	299
		Spare parts	1.5 lakh		
sludge treatment and biogas unit	15 lakh	Labour (1 employees)	1.5 lakh	discounted water treatment assuming an inflation-indexed price	m^3
operation office	5 lakh	membrane replacement (every 8 to 10 years)	4 lakh		1,135,354
generator	10 lakh	operational costs per year	20.0 lakh		
capital nominally invested	225 lakh	nominal operational costs	3,283 lakh	water price in first year of production, which grows annually with inflation	Rs/m^3
present value of capital	273 lakh	present value of operational costs	27 lakh		26.37

availability of plant	100%	
waste water production	109,575	m^3/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh		Disc.Factor for Waste water treatment assuming the water-price rises with inflation	discounted
	1	371%	0.0			0.00	water prod.	10.00%	water prod.
	2	193%	30.0			57.75	m^3/a	%/a	m^3/a
Start	3	100%	195 lakh	20.0		214.96	109,575	100.0%	109,575
	4	51.9%		22.0		11.41	109,575	90.9%	99,614
	5	27.0%		24.2		6.52	109,575	82.6%	90,558
	6	14.0%		26.6		3.72	109,575	75.1%	82,325
	7	7.3%		29.2		2.13	109,575	68.3%	74,841
	8	3.8%		32.1		1.22	109,575	62.1%	68,037
	9	2.0%		35.4	4	0.77	109,575	56.4%	61,852
	10	1.0%		38.9		0.40	109,575	51.3%	56,229
	11	0.5%		42.8		0.23	109,575	46.7%	51,118
	12	0.3%		47.1		0.13	109,575	42.4%	46,470
	13	0.1%		51.8		0.07	109,575	38.6%	42,246
	14	0.1%		57.0		0.04	109,575	35.0%	38,405
	15	0.0%		62.6		0.02	109,575	31.9%	34,914
	16	0.0%		68.9		0.01	109,575	29.0%	31,740
	17	0.0%		75.8		0.01	109,575	26.3%	28,855
	18	0.0%		83.4	4	0.00	109,575	23.9%	26,231
	19	0.0%		91.7		0.00	109,575	21.8%	23,847
	20	0.0%		100.9		0.00	109,575	19.8%	21,679
	21	0.0%		111.0		0.00	109,575	18.0%	19,708
	22	0.0%		122.1		0.00	104,096	16.4%	17,021
	23	0.0%		134.3		0.00	109,575	14.9%	16,288
	24	0.0%		147.7		0.00	109,575	13.5%	14,807
	25	0.0%		162.5		0.00	109,575	12.3%	13,461
	26	0.0%		178.7		0.00	109,575	11.2%	12,237
	27	0.0%		196.6	4	0.00	109,575	10.2%	11,125
	28	0.0%		216.3		0.00	109,575	9.2%	10,113
	29	0.0%		237.9		0.00	109,575	8.4%	9,194
	30	0.0%		261.7		0.00	109,575	7.6%	8,358
	31	0.0%		287.9		0.00	109,575	6.9%	7,598
	32	0.0%		316.6		0.00	109,575	6.3%	6,908

Image 24: MBR, 300 m^3/d plant

Economical cost calculations for 450 m³ MBR plant

Assumptions of costs:

Capital costs for 450 m³/d in Lakh		Operational costs in Lakh/a		Results of Calculation	
land costs	0.00 lakh	Electricity	15 lakh		Lakh Rs.
MBR Plant	248 lakh	Maintenance	10 lakh	discounted Investment +operation cost	403
		Spare parts	3.0 lakh		
sludge treatment and biogas unit	20 lakh	Labour (1 employees)	1.5 lakh	discounted water treatment assuming an inflation-indexed price	m³
operation office	5 lakh	membrane replacement (every 8 to 10 years)	5 lakh		1,703,031
generator	15 lakh	operational costs per year	29.5 lakh		
capital nominally invested	288 lakh	nominal operational costs	4,846 lakh	water price in first year of production, which grows annually with inflation	Rs/m³
present value of capital	363 lakh	present value of operational costs	39 lakh		23.64

availability of plant	100%	
waste water production	164,363	m³/a
discount factor	75.00%	/a
inflation	10.00%	/a
eff. discount factor	92.50%	/a

assumed life time 30 years

	Year	Disk.F.	Investm. Rs lakh.	Runing Cost Rs lakh	special costs Rs lakh	disc. Cost Rs lakh	water prod. m³/a	Disc.Factor for Waste water treatment assuming the water-price rises with inflation 10.00% %/a	discounted water prod. m³/a
	1	371%	0.0			0.00			
	2	193%	50.0			96.25			
Start	3	100%	238 lakh	29.5		266.96	164,363	100.0%	164,363
	4	51.9%		32.4		16.83	164,363	90.9%	149,420
	5	27.0%		35.6		9.62	164,363	82.6%	135,837
	6	14.0%		39.2		5.50	164,363	75.1%	123,488
	7	7.3%		43.1		3.14	164,363	68.3%	112,262
	8	3.8%		47.4		1.79	164,363	62.1%	102,056
	9	2.0%		52.2	5	1.12	164,363	56.4%	92,778
	10	1.0%		57.4		0.59	164,363	51.3%	84,344
	11	0.5%		63.2		0.33	164,363	46.7%	76,676
	12	0.3%		69.5		0.19	164,363	42.4%	69,706
	13	0.1%		76.4		0.11	164,363	38.6%	63,369
	14	0.1%		84.1		0.06	164,363	35.0%	57,608
	15	0.0%		92.5		0.04	164,363	31.9%	52,371
	16	0.0%		101.7		0.02	164,363	29.0%	47,610
	17	0.0%		111.9		0.01	164,363	26.3%	43,282
	18	0.0%		123.1	5	0.01	164,363	23.9%	39,347
	19	0.0%		135.4		0.00	164,363	21.8%	35,770
	20	0.0%		148.9		0.00	164,363	19.8%	32,518
	21	0.0%		163.8		0.00	164,363	18.0%	29,562
	22	0.0%		180.2		0.00	156,144	16.4%	25,531
	23	0.0%		198.2		0.00	164,363	14.9%	24,431
	24	0.0%		218.0		0.00	164,363	13.5%	22,210
	25	0.0%		239.8		0.00	164,363	12.3%	20,191
	26	0.0%		263.8		0.00	164,363	11.2%	18,356
	27	0.0%		290.2	5	0.00	164,363	10.2%	16,687
	28	0.0%		319.2		0.00	164,363	9.2%	15,170
	29	0.0%		351.1		0.00	164,363	8.4%	13,791
	30	0.0%		386.2		0.00	164,363	7.6%	12,537
	31	0.0%		424.9		0.00	164,363	6.9%	11,397
	32	0.0%		467.3		0.00	164,363	6.3%	10,361

Image 25: MBR, 450 m³/d plant

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5. What would be the right technology for the future semi centralized waste water treatment system for Auroville

This is the primary question which is not easy to answer. The author has defined important criteria and requirements, which should be fulfill as much as possible. The so called "Aims" are explained followed by an evaluation matrix.

5.1. Aims

5.1.1. Flexibility and easy extendibility

The plant must fit into the "LEGO" concept of installation and building. Therefore it is important that he plant has the ability to expand with minimumal cost, easy of construction and modification in order to increase the capcity and size... The main reason is the growth and the development of Auroville and its Bioregion. Another reason is the deteriorating situation of the groundwater, which requires re-use of all the produced wastewater for commercial agriculture and domestic gardens and for the recharge of ground water.

A detailed report on the next five years development of the city is part of the "Water and Infrastructure Master plan for the residential Zones 1 and 2".

5.1.2. State-of-the-Art treatment, high quality effluent

The Area of the Residential Zone is classified as a high Groundwater recharge Area. [3]. In order to reduce the risk of Groundwater pollution the effluent has to be of high quality. Furthermore, the demand on irrigation water is less during the rainy season, so the effluent can be infiltrated into the ground. (Groundwater recharge, see recommendations [3]). However, this can only be achieved if the effluent is of a certain standard. (WHO, ISO Norm)

5.1.3. Economical Investment in combination with a long lifetime

Our objective is to recommend the most economical and efficient system for Auroville and its Bioregion. The lifetime of the system should be a minimum of 30 years.

The plant investment should amortize as fast as possible

5.1.4. Energy efficiency and environmental impact

The energy consumption of the proposed plant should be as low as possible. A lower consumption of energy allows for the introduction of alternative energy sources.. The CO_2 emission resulting from energy production and its impact on the world climate are undeniable. It is clear that electricity produced and used by conventional means has a negative impact on world climate. [5]

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The fact that prices for commercial energy sources will increase and the price for alternative energy, such as photovoltaic, biofuel, wind or concentrated solar energy will decrease. Because of this, plants powered by conventional energy over time will have higher treatment costs. [5]

At the present time our source of energy comes from the TNEB (Tamil Nadu Electricity Board). Electricity is often interrupted and unavailable sometimes for days depending on the season. A hybrid facility is necessary due to these circumstances.. The facility should be designed according to the energy consumption. If the plant consumes a lot of energy, the price for the hybrid power will also increase. [5]

Another factor is to choose a treatment technology which has the lowest negative impact on the environment. Modern treatment technologies require chemicals such as flocculants that become disposed with the sludge. The aim must be to use a system which uses the least amount of chemicals.

The occupational health and safety of the employees working in the plants must also be taken into consideration in the selection of the system..

5.1.5. Easy handling and maintenance

The plant should be simple in design, construction and maintenance. The operation and maintenance of the plant should also be simple and cost effective.

The plant should be highly reliable to minimize the cost of maintenance. This guarantees not only constant treatment, meaning less balancing tanks, and less flow fluctuation, it also guaranties constant quality of the treated wastewater which reduces the total treatment costs.

If an easy maintenance of the plant is possible, jobs can be created for Aurovillian and locals without higher education degree. The jobs created would include for example, mechanics, gardeners, security guards, and cleaning staff.

5.1.6. Optimal use of the land

The value of land has dramatically increased over the years. Speculators from various parts of India have discovered that Pondicherry, Auroville and the surrounding areas up to Chennai are excellent investment opportunities for the construction of hotels, gated communities, villas, guest houses, commercial units and land exchanges. Therefore, the footprint of the wastewater treatment plant is a consideration that is of paramount importance. The plant should be compact and mobile in the event it needs to be moved to another location.

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5.2. Rating of the Aims

The Aims are defined in chap. 4.1 and the rating of the Aims are in %, listed on the right below, They are listed according to priority.

1.	Flexibility and easy extendibility	30 %
2.	State-of-the-Art treatment, high quality effluent	25 %
3.	Economical Investment in combination with a long lifetime	15 %
4.	Easy handling and maintenance	10 %
5.	Energy efficiency and environmental impact	10 %
6.	Optimal use of the land	10 %

The highest percentage rate of 30%, was assigned to Flexibility and easy extendibility due to the LEGO principle. The LEGO concept is a key concern for the development of a sustainable water treatment system for the growing city of Auroville.

The second highest rating was 25 % the aim State-of-the-Art treatment, high quality effluent. This parameter is very important because the potential areas for the waste water treatment plant are located in high groundwater recharge areas.[3]. In Germany for example, special rules have been developed and implemented to protect these areas. Furthermore, it provides better quality of effluent that has wider range for re-use.

The author considers economical investment in combination with a long lifetime as third strong aim, but less important as the previous, therefore 15%.

All three aims, easy handling and maintenance, Energy efficiency and environmental impact and Optimal use of the land are on the same level of importance. These aims are crucial factors for the operation and feasibility/ land availability of the plant, but less important than for example. the lifetime of the plant. Therefore, the rating is 10%.

To conclude the understanding of the assessment Matrix is necessary.

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5.3. Assessment Matrix

For the Matrix (Image 26) the appraisal factor is fixed through the following scale.

0 = ***none***

1 = ***very poor***

2 = ***poor***

3 = ***acceptable***

4 = ***good***

5 = ***very good***

6 = ***best***

For the evaluation we developed and used the matrix to a compare the difference in the Aims.

Proposals		No.
DEW	50 m3 / d	I
MBR	50 m3 / d	II
DEW	100 m3 / d	III
MBR	100 m3 / d	IV
DEW	200 m3 / d	V
MBR	200 m3 / d	VI
DEW	450 m3 / d	VII
MBR	450 m3 / d	VIII

AIMS		PW	ARF	VA	ARF	VA	ARF	VA	ARF	VA	ARF	VA	ARF	VA	ARF	VA	ARF	VA
			I		II		III		IV		V		VI		VII		VIII	
			DEWATS		MBR		DEWATS		MBR		DEWATS		MBR		DEWATS		MBR	
			50		50		100		100		200		200		450		450	
Aim 1	Flexibility and easy extendibility	30	4	120	6	180	4	120	6	180	3	90	6	180	3	90	6	180
Aim 2	State-of-the Art treatment, high quality effluent	25	3	75	6	150	3	75	6	150	3	75	6	150	3	75	6	150
Aim 3	Economical Investment in combination with a long lifetime	15	5	75	2	30	5	75	2	30	5	75	2	30	5	75	2	30
Aim 4	Easy handling and maintenance	10	4	40	4	40	4	40	4	40	4	40	4	40	4	40	4	40
Aim 5	Energy efficiency and enviromental impact	10	5	50	2	20	5	50	2	20	5	50	2	20	5	50	2	20
Aim 6	Optimal use of the land	10	3	30	5	50	3	30	5	50	3	30	5	50	3	30	5	50
	Sum of Aim Power in %:	100		390		470		390		470		360		470		360		470
	Order of precedence :			2		1		2		1		2		1		2		1
	Explanation:	PW = Aim Power (Sum of PW = 100); ARF = Aim realizable factor (from 0 - 6) - 0 = none, 6 = best realization of the Aim; VA = valency (PW x ARF = VA)																

Image 26: Evaluation Matrix

5.4. Explanation of the Evaluation of the Aims

5.4.1. Aim 1: Flexibility and easy extendibility

As mentioned above and covered in chap. 3.3.2, MBR plants will be built in modules, thus making extentions economical and easy. The components can be built into the system with ease and low expense . The MBR plant modules can be build in containers and if needed the container can be shifted to another location, “very good”, 6

The DEWATS plants can also be built in modules however the extensions need to be made with concrete.. Furthermore, the larger the size of the plant the more difficult the extension, “good to acceptable:” 4 to 3 points.

5.4.2. Aim 2: State-of-the-Art treatment, high quality effluent

The MBR treatment system is considered to be the most modern technology on the market developed for wastewater treatment. For the effluent parameters Auqa Engineers will use the *Ihn, Saarland Germany* project which covers the following Parameters:

CSB = 8,3

BOD_5 1,8

Ammonium 0,1

NO_3 = 7,9

TP = 1,4

pH = 7,8

TDS = 0

E-Coli < 15

Enterokokken < 15

The above effluent covers all the criteria for swimming pools. Furthermore, the MBR system eliminates E-coli and reduces the risk of viruses leaving the system. Therefore the rating is “very good”, 6 points.

DEWATS was introduced in the developing countries as a low cost wastewater treatment system. The treatment technology as such is not very advanced compared to the existing systems that are available on the market. The DEWATS systems comprise of acceptable parameters that fulfill the

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criteria of WHO standards for irrigation. The DEWATS system does not eliminate or fully remove E-coli and viruses. Therefore the rating for this Aim is "acceptable", 3 points.

5.4.3. Aim 3: Economical Investment in combination with a long lifetime

The appraisal for the Economical Investment is based on the Economic Cost Calculation that was covered in chap. 3. Graduations were made according to calculated costs for the treatment of the waste water.

Costs for the waste water treatment systems in Rs/m³						
		Plant size in m³/d				
		50	100	200	300	450
a)	DEWATS	24.34	20.30	20.29	20.77	20.59
b)	MBR	33.55	27.63	27.34	26.37	23.64

Image 27: Costs in Rs/m³ for treating the waste water: a) DEWATS, b) MBR

The best economic scenario was the DEWATS system. The assessment therefore is "very good", 5 points.

The MBR system has a higher investment and running costs, therefore the assessment for this aim is poor, 2 points. Nevertheless, the investment costs for the MBR plant are variable in a range of ±15 to 25%. This can change the above figures.

5.4.4. Aim 4: Easy handling, maintenance

Treatment plants that operate without a minimum of maintenance and supervision that include regular inspections and cleanings, do not exist.

The maintenance of an MBR plant is very simple, smaller sizes are pre-built in containers that include the instruments and control panels. The system is controlled with computerized systems therefore and the plant can operate using two staff. Maintenance is also very easy, because of the design and accessibility of membranes and other components. Bigger systems are built as parallel connected "trains". This guaranties that in case of a failure of one "train" the other "train" can handle the treatment without the loss of capacity. Nevertheless, MBR systems requires skilled personal with regular follow ups. The MBR systems also requires regular chemical treatment which can be made in-situ e.g. at the sludge compartment and build as an automatic system. The overall rating for this aim is "good", 4 points.

Image 28: MBR system build in pre fabricated containers

The DEWATS system requires a daily to weekly maintenance program that should include re regular desludging. A big problem creates the scum which can build a barrier on top of the water level. This flow through the scum has to be controlled every day and in cases of a blockage removed. In principle require smaller DEWATS system very little attention where as larger DEWATS system needs more maintenance. In comparison for the rating of the aim, the DEWATS plants are equal to the MBR plants, “good”, 4 points.

5.4.5. Aim 5: Energy efficiency and environmental Impact

The MBR requires a 24/7 power supply where as the DEWATS plants require very little electricity. Image 30 shows that the average power consumption of a MBR medium plant size is app. 1,31 kWh/m³.

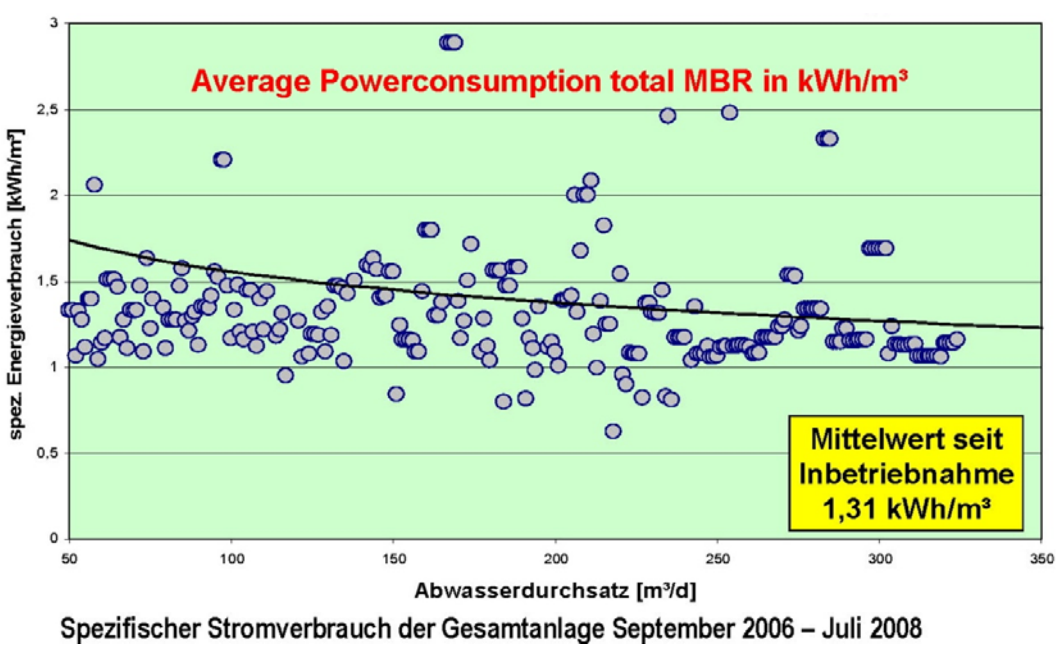

Image 29: Average power consumption MBR system [7]

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Furthermore, the MBR systems need chemicals for cleaning the membranes and for the scaling of the water (adjustment of pH etc.).Theses chemicals are 100% biodegradable and break down during the treatment processes and therefore are not considered harmful to the environment.

The DEWATS plants, which have been built and monitored by Aqua Engineers gets support from EM (Effective Microorganism). For more information on EM technology, please see [3].

The rating for this aim is: DEWATS, "very good", 5 points and MBR, "poor", 2 points.

5.4.6. Aim 6: Optimal use of the land

The land requirement from MBR plants is in relation to the treatment quantity very small, "very good", 5 points

The footprint of DEWATS systems are large. Nevertheless, the DEWATS plants can be integrated in the landscaping so that the negative effect on the land use is eliminated to an acceptable limit. "acceptable", 3 points.

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6. Conclusion

The question, "what would be the right waste water technology was complicated to answer. First of all not many MBR systems are in operation in India. This makes a direct comparison impossible for this study. Koch Membranes operates a MBR test plant at Mumbai. These plants treat industrial wastewater from a private company to the satisfaction of the owner and fulfill the required standards for the effluent.

DEWATS systems are in operation throughout India. A good treatment plant is installed at the Aravinda Eye hospital in Pondicherry.

After all one can say that with today's technical knowledge a MBR system provides better performance than the DEWATS plants. The main advantage from the MBR plants is the easy scalability and the excellent performance.

The study has shown that the waste water can be treated with a DEWATS plant for approximately. RS 21/m³ where as the treatment costs per m³ with an MBR system is in an average of approximately. Rs 26/ m³.

It is imperative that an implementation study and plan must be conducted to determine the actually cost of the system. The study should also cover the different systems that are available on the market, the costs and benefits with a plan for the implementation of the recommended system. It might be possible that a smaller MBR plant based on the disk module technology is better long term investment than the one based on hollow fibers. The dynamic costs estimate can therefore give only an indication for the treatment rate per m³.

Provided one accepts the energy requirement and the Investment costs, the MBR technology has a wide range of advantages. In the direct comparison, Image 27, the MBR technology has reached more points than the DEWATS systems. The best advice to the authorities of the Auroville International Township is to arrange for a test plant and to study the performance and its costs.

Dirk Nagelschmidt (M. Eng.)/ Aqua Engineers Auroville, February 2009

7. About the Author

Dirk Nagelschmidt started his career 1988 as professional draughtsman in civil engineering for water, roads and landscaping. From 1992 to 1998 he studied civil engineering at the University of Applied Sciences, Aachen. During his study he specialist in water, waste water and waste. He finished successfully the University with the German title “certified Diploma Engineer” (Dipl. Ing.) which is equal to Master of Engineering (M. Eng.).

Mr. Nagelschmidt has worked as project coordinator and planning engineer at different companies in Aachen and Cologne/ Germany.

In 2002 he came to Auroville/India where he started his company AQUA ENGINEERS.

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German Desalination Association DME e.V.

&

German Association for Water and Waste Water DWA.

8. Annexure

8.1. Bibliography

[1] **B**REMEN **O**VERSEAS **R**ESEARCH AND **D**EVELOPMENT **A**SSOCIATION, About DEWATS, Mai 2005.

[2] WIKIPEDIA, http://en.wikipedia.org/wiki/Membrane_bioreactor#MBR_history_and_basic_operating_parameterswww.wikipedia.org/

[3] NAGELSCHMIDT DIRK, Water and Infrastructure Masterplan for the Residential Zone 1&2 in Auroville, August 2008.

[4] KOCH MEMBRANE SYSTEMS, www.kochmembrane.com

[5] SCHIMANSKI MARTINA; WAGNER WALTER; NAGELSCHMIDT DIRK; A Sustainable Water Management Concept for Auroville and its Bioregion, Desalination, A Pre-Feasibility study; Auroville Mai 2007, unpublished.

[6] HUBER AG, Huber BioMem complete plant, www.huber.de

[7] HASSELBACH, RALF, Membrantechnik, Grundlagen, Konzepte, Anforderungen an die Vorreiningung, Betriebserfahrungen des EVS mit Hohlfaserpolymermembranen, Ensorgungsverband Saar, November 2008

[8] KOMPETENZ ZENTRUM WASSER BERLIN; ENREM-Enhanced Nutrients removal in Biomembrane Reactor, www. Kompetenz-wasser.de, 2004