MARAPUR - a new process combination for the optimization of MBR

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Abstract The MARAPUR concept is a biological wastewater treatment process based on the MBR functional principle. The ultrafiltration of activated sludge takes place in pressure-driven hollow fiber membranes. The vertical membrane modules are installed compactly in a MEGAMODUL. The permeate extraction is accomplished in the cross-flow, which is supported by rinsing aeration. The main process advantages are high filtration performance, excellent operation reliability provided by wastewater fine sieving and reduced cleaning chemicals demand. Wastewater fine sieving with a mesh size of 0.25 mm is an effective measure against membrane clogging by hair and fibers.

Keywords MBR, pressure-driven UF, wastewater sieving

INTRODUCTION

MBR´s were developed in the 1980s for the treatment of landfill leachate and industrial wastewater (Krauth, 1996). For this purpose, pressure-driven tubular membranes with an inside to outside flow were employed. With the introduction of submerged hollow fiber and flat sheet membranes, which were rinsed intensively with air, the MBR treatment of municipal wastewater also became accessible. Moreover, the specific requirements for submerged membrane filtration in the treatment of municipal wastewater quickly emerged. As compared to industrial effluents, municipal wastewater allows higher specific filtration performance, but in the case of combined sewers, this advantage is counterbalanced by the need to treat storm water. Therefore, ultrafiltration in municipal MBR´s is determined by the storm water flow, which results in substantially larger membrane areas for the filtration (liquid/biomass separation). In addition, municipal wastewater also contains fibers and hair, which cause clogging and the formation of pigtails in submerged MBR systems. This causes a reduced, effective membrane filtration area. Accordingly, the installed membrane area has to be increased in advance in order to compensate for the aforementioned negative effects.

Pressure-driven, cross-flow ultrafiltration systems employ tubular or hollow fiber membranes, which can be operated at higher pressures due to their more robust design. Thus substantially higher filtration performance (fluxes) can be accomplished. Due to their tubular design, the membranes are installed horizontally in bundles, an arrangement that does not allow the use of rinsing air as in submerged membrane systems. This evident technical disadvantage has to be compensated for through increased flow velocities in the tubular membranes. The higher system pressure and flow velocities require larger amounts of energy, which negatively influences the economics of pressure-driven MBR systems.

The problem of clogging with fibers and hair does not allow the employment of pressure-driven, tubular, hollow fiber membrane systems (with inside/outside flow) without adequate pretreatment for the certain removal of the aforementioned undesirable wastewater constituents.

The MARAPUR process for the biological treatment of municipal and industrial wastewater employs pressure-driven, hollow fiber membrane modules. These modules are installed vertically and are operated in a cross-flow, which is intensified with rinsing air. Pretreatment for the removal of fibers and hair is essential and is accomplished through the sieving of the wastewater. This process chain (MARAPUR including wastewater sieving) provides high specific filtration performance in combination with a compact ultrafiltration unit design.

METHODS

The Marapur process concept

The principle of the MARAPUR process is shown in Figure 1.1. It combines the classical features of a MBR system, i.e. pretreatment by screening, sand and fat removal with subsequent fine sieving, an activated sludge tank and a downstream ultrafiltration unit.

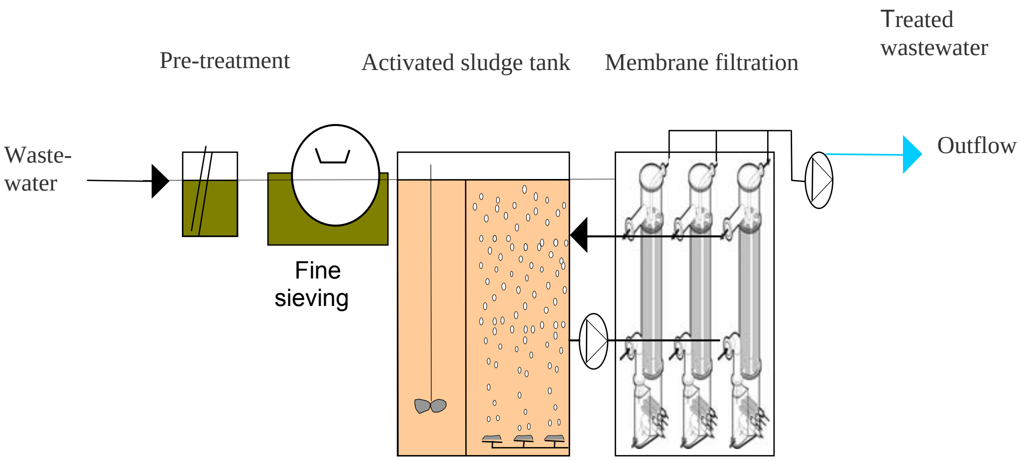
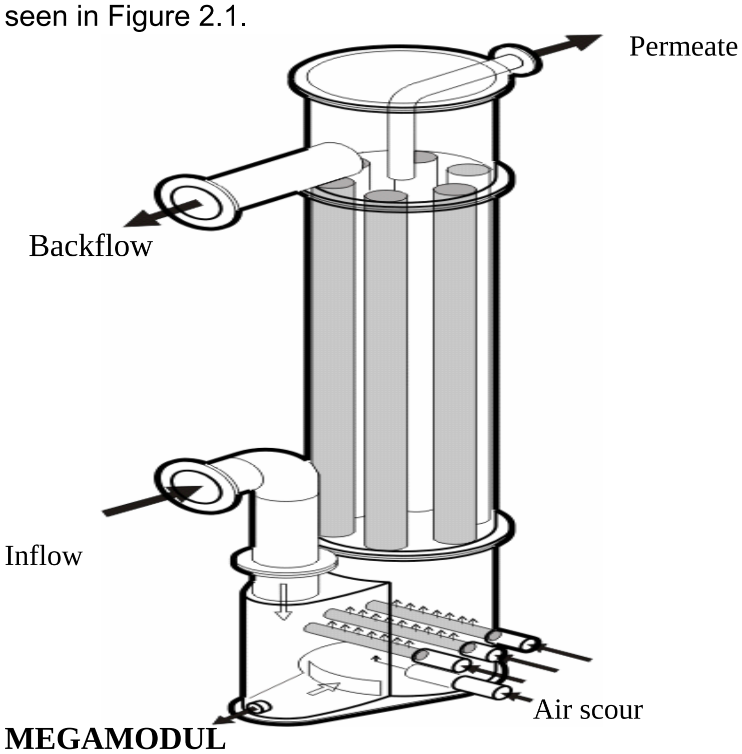


Figure 1.1 MARAPUR process concept

The activated sludge is pumped from the nitrification cascade to the ultrafiltration unit. Only a small part of this stream is extracted over the membrane. The retentate is led back to the aerated nitrification tank. The permeate (i.e. the treated wastewater) is pumped out of the ultrafiltration unit. The new development in this process is the so-called MEGAMODUL, which is pressure-driven and operated in a cross-flow mode. The main design features of the MEGAMODUL can be seen in Figure 2.1.



MEGAMODUL

Figure 2.1 Main design features of the MEGAMODUL

The MEGAMODUL consists of a foot, a membrane part and a header. The activated sludge is pumped into the pre-chamber of the foot, where it is homogenized. The sludge then flows into the main chamber, from where it is fed in a plug flow to the membrane part. Fine bubble, equally distributed rinsing air is provided by membrane aerators, which are installed in the main chamber of the MEGAMODUL foot. Activated sludge and rinsing air flow upward through the hollow fiber membranes. The inner diameter of the membranes measures approx. 5 mm. The upflow velocity of the activated sludge and the rinsing air is approx. 1 m/sec, whereby the air makes up approx. 10 % of the total flow. The hollow fiber membranes are fixed in perforated tubes (modules). Each module comprises a membrane area of approx. 30 m^2. The membrane modules are available on the market from various suppliers. In Figure 2.1 the MEGAMODUL with six installed hollow fiber modules can be seen. These six modules are cast into the head and foot plate of the MEGAMODUL. A permeate extraction pipe is installed in the center of the circular modules. This pipe provides additional static support for the MEGAMODUL construction.

The separation of the activated sludge and the rinsing air, which is released into the atmosphere, takes place in the head of the MEGAMODUL. The retentate (activated sludge) is led back to the activated sludge tank. The permeate is pumped out of the module, which is unusual for pressure-driven systems, but provides flow limitation and is necessary in order to control the permeate flow. The air rinsing principle is shown in Figure 3.1. (see also Taitel, 1980).

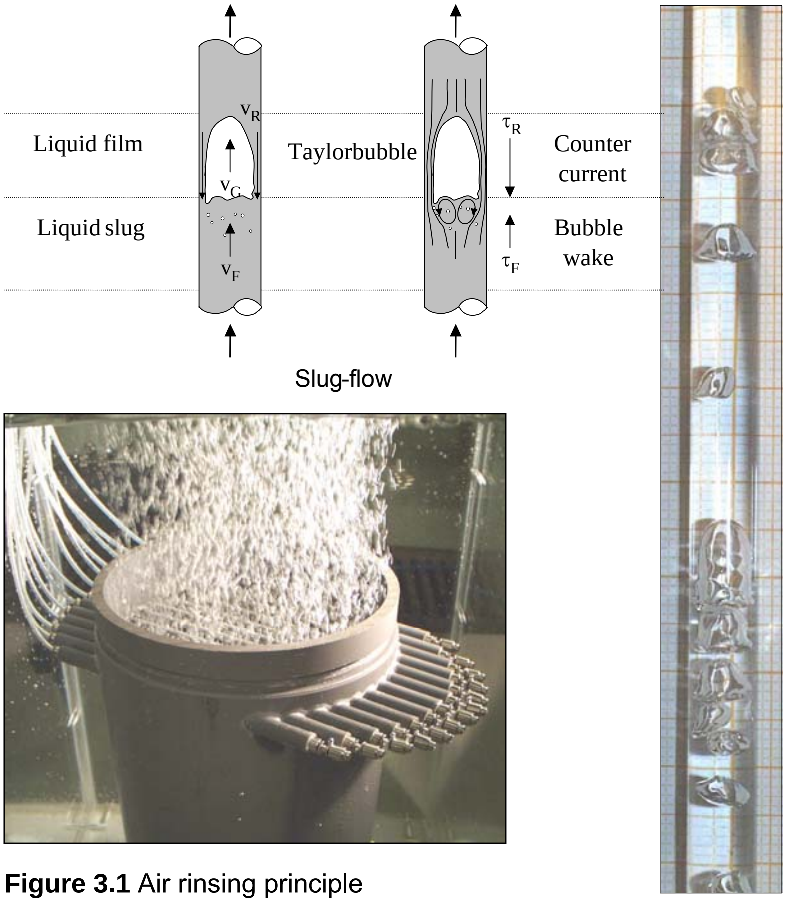


Figure 3.1 Air rinsing principle

The rinsing air, which rises more quickly than the activated sludge suspension, produces both a thin film in the hollow fiber and turbulences in the air bubble wake. Both effects provide effective cake layer control for the avoidance of membrane fouling. This biofilm control instrument acts specifically and as compared to submerged MBR systems, the rinsing air demand is much lower.

Moreover, by contrast with the Air Lift process (Futselaar, 2006), which exclusively uses rinsing air, the MEGAMODUL additionally requires a cross-flow. Both instruments, i.e. fine bubble aeration and cross-flow secure the function of the MEGAMODUL and increase the performance of the ultrafiltration process and operational stability. The MARAPUR process with the MEGAMODUL is shown in Figure 4.1.

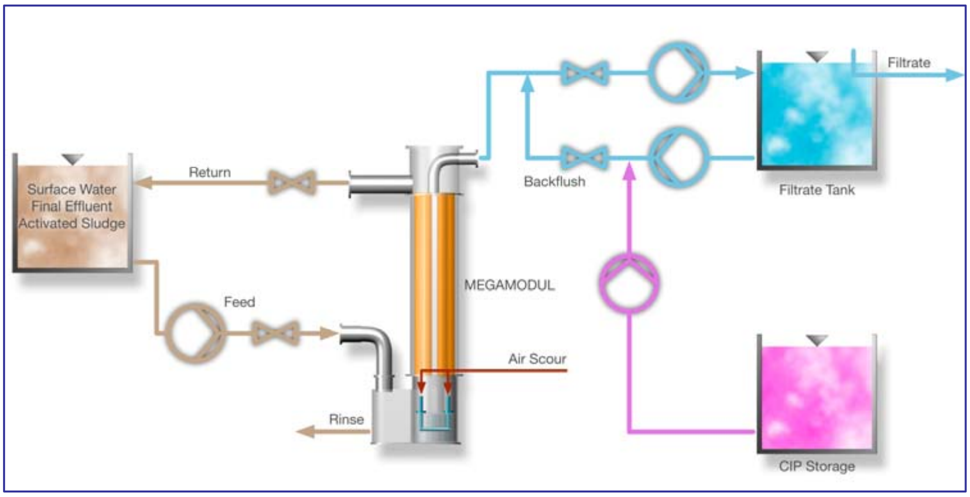


Figure 4.1 MARAPUR process with the MEGAMODUL

In order to guarantee stable filtration performance, measures for cake layer control are required, which apart from air rinsing, additionally include regular permeate backflush and chemical cleaning at longer intervals.

All processes for the operation of the MEGAMODUL are automated. In the filtration mode the inlet and outlet values of the activated sludge pipes are open and both the inlet pump and the rinsing air blower are in continuous operation. The permeate extraction pump works intermittently. After a longer filtrate extraction phase, a short high-flow back pulse with permeate is applied. For this purpose a reversible permeate pump or a separate back pulse pump can be employed. The permeate required for the back pulse is withdrawn from the permeate tank, which has to be designed for the specific backflush requirements. Where separate back pulse pumps are used, adequate valves, which can be operated by remote control, have to be installed. The back pulse can be supported after longer intervals by chemicals. For this purpose, chemicals are dosed into the permeate from the CIP storage tank (see Figure 4.1).

However, chemical cleaning is normally conducted as cleaning in place (CIP), which is necessary only after longer intervals of several months. The filtration process is interrupted for CIP and the inlet and outlet valves are closed. The MEGAMODUL is drained and the membranes are rinsed (reverse to filtration direction) with permeate. Subsequently, the MEGAMODUL is filled with warm chemical solution in a backflow over the membranes. The fine bubble aeration stays in operation. Depending on the cleaning requirement, sodium hypochlorite, citric acid and ultrasil, an industrial cleaning agent containing detergents, are used as cleaning chemicals and in line with the cleaning aim, the chemicals are allowed to react for four to twelve hours. If necessary, consecutive cleaning with two, or all three cleaning agents, can be completed. The chemical solution is drained after cleaning has been concluded and the MEGAMODUL is rinsed in a backflow. Renewed operational readiness is obtained after a few hours.

The high packing density of the membranes in the MEGAMODUL provides a selective and conservative use of the cleaning chemicals. CIP cleaning is required at intervals of three to six months for municipal wastewater and of one to three months for industrial wastewater.

Currently, three sizes of the MEGAMODUL with installed membrane areas of approx. 200, 500 and 1,000 m^2 are available.

The wastewater fine sieving process concept

The adequate pretreatment, i.e. the elimination of fibers and hair, is an essential requirement for the employment of the MEGAMODUL in the municipal MBR process. Conventional primary clarification cannot be considered, as MBR plants are only realized with simultaneous sludge stabilization. Thus wastewater sieving is the most appropriate process for wastewater pretreatment.

Slot sieves with gap widths of 0.5 mm and mesh sieves with mesh sizes of 1 mm have already been employed (Frechen, 2006). However, the filter elimination performance of these sieves is insufficient for MEGAMODUL pretreatment, which uses hollow fiber membranes with a 5 mm inner diameter. The ability of short cellulose fibers to crosslink and form larger aggregates can be a special problem for the MARAPUR process. For the solution of this problem, together with Passavant Geiger, VA TECH WABAG has developed a fine sieving process (Figure 5.1), which employs a drum sieve with a mesh size of 0.25 mm.

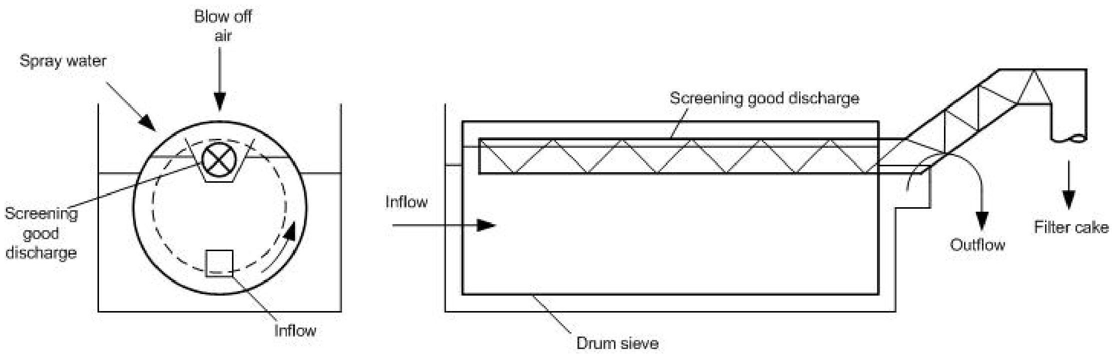


Figure 5.1 Fine sieve for MEGAMODUL pretreatment

This process was developed basically for fine sieving in cooling and drinking water treatment and has been adapted for the more robust wastewater application.

The circular sieve drum, which is covered with a fabric, is installed in a tank and is flown through from inside to outside. Separated retainings accumulate on the inner side of the fabric and produce back pressure. Once a set pressure difference has been exceeded, the sieving drum automatically starts to rotate in order to clean the fabric. In a first step, sieve cleaning is accomplished by blowing air onto the outside of the fabric and in a second step, by washing down with water. The retainings fall into a container installed under the air-blowing pipe. From this container the retainings are conveyed out of the sieve drum by a screw and at the same time are pressed and dewatered. The sieved wastewater is pumped directly into the MBR process.

RESULTS

The MARAPUR process has been operated on a technical scale at the Vienna Main Sewage Treatment Plant since 2003. The fine sieving treatment step was integrated into the process in 2005. The technical sieving pilot plant (Figure 6.1) features a drum with a sieving area of 9.5 m^2. 50% of the drum is submerged in the wastewater. The capacity of the plant is 100 m^3/h with a mesh size of 250 µm. The inlet consists of raw wastewater from the Vienna Main Sewage Treatment Plant, which has been pretreated by a fine screen (5 mm) and a non-aerated sand trap.

Figure 6.1 Fine sieving pilot plant

The hydraulic load of the sieve was varied according to the Viennese wastewater flow characteristics. The major sieving results are summarized in Table 1.1. This is the first performance data relating to a mesh size of 250 µm. The performance accomplished guarantees the safe and reliable operation of the MARAPUR process. However, the fine sieving process still has some optimization potential. Therefore, in the upcoming testing phase, parameters such as mesh size (0.1 - 1 mm) and sieve machine specific settings (circumferential, etc.) will be examined.

Table 1.1: Sieving results

Fiber elimination	
> 1 mm length	100 %
0.2 - 0.5 mm	95 %
< 0.2 mm	90 %
Solids elimination	300 mg/l
Retaining concentration	25 %
Specific sieve performance	20 m^3/ m^2·h

Figure 7.1 shows the technical scale MEGAMODUL during installation into the MARAPUR pilot plant. The MEGAMODUL consists of six single membrane modules with a total membrane area of 180 m^2. The pilot plant is designed for 130 m^3/d dry weather flow and 11 m^3/h storm weather flow.

Figure 7.1 MEGAMODUL in installation phase

The major membrane filtration performance results are shown in Figure 8.1. Pilot plant loading and the membrane flux were adjusted to the actual wastewater flow (see 24 h chart in Figure 8.1). During the low-flow morning hours, the flux was approx. 20 l/m^2 ·h (net) whereas during the high- flow midday and evening hours the flux increased to 50 l/m^2·h (net). The transmembrane pressure and the permeability show stable behavior (see monthly chart in Figure 8.1). Depending on the hydraulic load, the transmembrane pressure was in the range of 50 - 175 mbar. Temperature corrected permeability has been calculated as 400 l/m^2·h·bar with short-term peaks up to 500 l/m^2·h·bar. Only at the end of the testing period, when the flux is adjusted continuously at 60 l/m^2·h (net), do the transmembrane pressure increase and permeability decrease correspondingly. Under this continuous loading (60 l/m^2·h) the MARAPUR membrane filtration process reaches its limits, whereby such loading over a few days can be tolerated. On the basis of these results, it was concluded and proven in further pilot tests that a flux performance of 50 l/m^2·h can be used for the storm weather flow design.

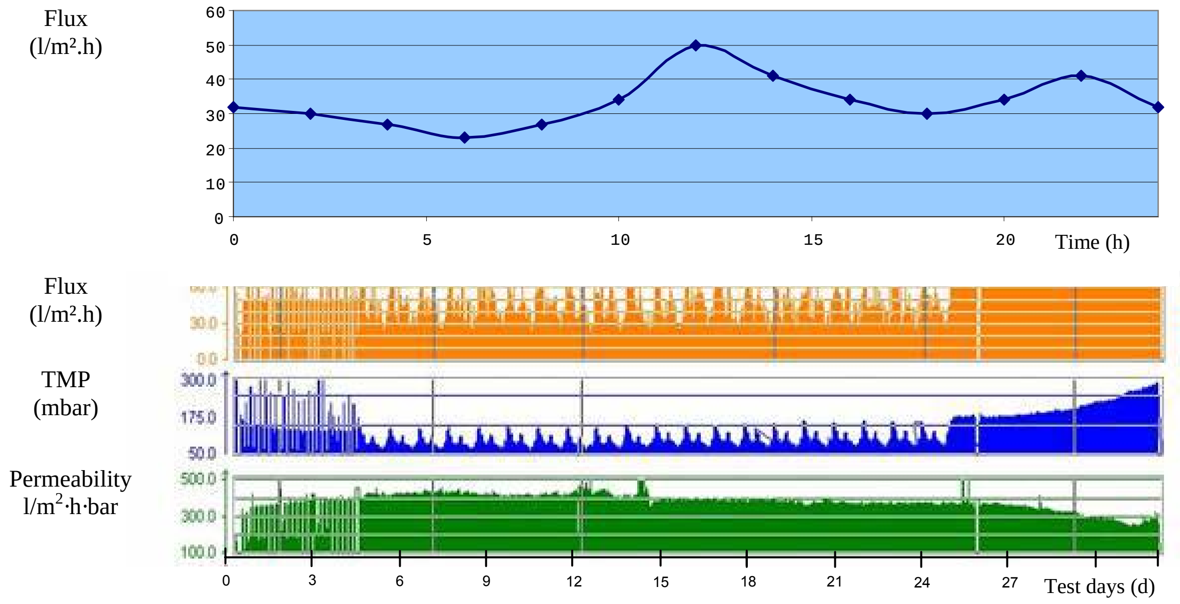


Figure 8.1 Membrane filtration performance results

The Viennese wastewater is basically relatively cool and the temperature can fall to below 5 °C. Under these conditions filtration performance of 50 l/m^2·h at acceptable permeability values of > 300 l/m^2·h·bar was accomplished. The sludge concentration in the aforementioned testing period was in the range of 10 - 12 g/l. The wastewater treatment results, which were achieved over a longer period of continuous operation, are comparable with those from other MBR plants (Table 2.1).

Table 2.1: Wastewater treatment results

Parameter	Dimension	Inlet MARAPUR	Outlet MARAPUR
Suspended solids	mg/l	125	
Chemical oxygen demand	mg/l	400	20
Total nitrogen	mg/l	60	10
Ammonium nitrogen	mg/l NH_4-N	50	1
Nitrate nitrogen	mg/l NN_3-N		8
Total phosphorous	mg/l PO_4-P	8	1
Turbidity	NTU		0.3

The quality of the treated wastewater is stable and does not deteriorate under hydraulic load changes. Thus all the relevant international standards for municipal wastewater can be safely met. Furthermore, the reclaimed permeate is an excellent source of various water reuse applications in urban and industrial water management.

The intention is to firstly employ the MARAPUR process for smaller wastewater treatment applications. A case study for a small municipal WWTP with a capacity of 700 m^3/d showed that the total costs for the MARAPUR/MEGAMODUL process are approx. 5% lower than those of an MBR process utilising submerged hollow fiber membranes. Table 3.1 shows the cost comparison.

Table 3.1 Cost comparison

Costs [EUR/m^3]	MARAPUR Process (external with MEGAMODUL)	MBR with submerged hollow fiber system
Operating costs	0.77	0.85
Capital costs	0.42	0.40
Total costs	1.19	1.25

Fine sieving not only removes fibers, but also suspended solids, which also contribute to COD and BOD. The actual BOD load, which flows to the MBR is reduced considerably and significantly influences the MBR design. Table 4.1 shows the influence of wastewater sieving on the performance of the MARAPUR process. Based on the generally applied MBR design guidelines and e.g. the German standard guideline A 131, an increased hydraulic load of 35 % can be used for the design. However, membrane filtration performance remains unaffected.

Table 4.1 Influence of wastewater fine sieving on MBR design

Parameter	Dimension	MARAPUR with fine sieving	MARAPUR without fine sieving
Mesh size /Fine sieving	mm	0.25	
Volume/ Activated sludge tank	m^3	32	32
Activated sludge concentration	g/l	12	12
Sludge load	kg CSB/kg DS·d	0.1	0.1
Sludge age	d	25	25
COD concentration	mg/l	400	600
Inlet activated sludge	m^3/d	10	6.5

CONCLUSIONS

The main advantages of the MARAPUR process, using the newly developed MEGAMODUL and wastewater fine sieving, are the relatively high filtration performance (50 l/m2·h net), the high operation reliability provided by wastewater fine sieving, and the reduction in cleaning chemicals demand derived mainly from the compact design of the MEGAMODUL. The MARAPUR process still has substantial development potential. In particular, the wastewater fine sieving process, which influences the MBR design, has to be further investigated. During these investigations, the effects of both sieve parameters (mesh sizes of 0.1 - 1.0 mm and sieve machine settings) and MBR parameters (shorter retention times in the activated sludge tank and dewater ability of the excess sludge) will be of interest.

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