Technical paper

An SBR System With a High Flocculent Biomass Concentration

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Abstract

Nitrification/denitrification processes at high flocculent biomass concentrations (11.6–13.4 g L^{-1}) were studied in pilot Sequencing Batch Reactor (SBR). Optimal operating conditions for maximal nitrogen elimination efficiency were as follows: organic loading of 0.9 g COD L^{-1} d^{-1}, nitrogen loading of 0.11 gN L^{-1} d^{-1}, MLSS of 12 g L^{-1} and SRT of 52 days. Medium sized sludge flocs (0.1–0.4 mm) with excellent settle ability (SVI = 27 mL g^{-1}) were formed during the experiment. Volumetric nitrogen removal rate of 90 mg NL^{-1} d^{-1} was achieved, which is twice as much as in SBR operating at low MLSS of 3.5 gL^{-1} and low SRT of 21 days. This process offers an attractive option for the treatment of highly polluted wastewaters with lower investment and operating costs.

Keywords: High MLSS, denitrification, nitrification, SBR.

1. Introduction

The sequencing batch reactor (SBR) has been proven to be highly effective for biological wastewater treatment. It was reported that SBRs are useful for treating municipal, dairy, paper mill, tannery and piggery wastewater.[1,2,3,4,5] Improvements in equipment and technology, especially in aeration devices and computer control systems, have made SBRs a viable choice relative to conventional activated sludge system. High rates, good bulking control and nutrient removal have been reported as useful features of SBR processes.[6,7]

In the SBR system it is important to achieve a low biomass growth rate, which results in good settling ability of the sludge. The biomass growth can be accompanied by measurement of mixed liquid suspended solids (MLSS) and by a suitable food to microorganism (F/M ratio), solid retention time (SRT) and dissolved oxygen (DO). It is possible to reduce the relative amount of sludge produced by operating the plant at a low F/M ratio.[8,9,10] In a low ratio system, very little sludge will be produced, and is characterized by having good setting characteristics, i.e. a low sludge volume index (SVI). The downside of this mode of operation is that the overall treatment time is increased and so is the total amount of aeration required. A high F/M may encourage filamentous organisms to predominate, leading to poor settling ability.[11]

Slow growing bacteria such as nitrifiers in the activated sludge could be enriched at high SRT. A high SRT also enables better flocculating ability of sludge, leading to good settling of sludge flocs. Sludge flocs produced at a lower SRT are much more irregular and more variable in size with time than those at higher SRT, and the level of suspended solids in the effluent at lower SRT is higher than that at higher SRT.[12] A high sludge age (20 days) and a short filling period of the SBR were the most favourable conditions for efficient removal of COD and ammonium.[13]

For good operation of the SBR, the concentration of DO is important because of its influence on microbial growth and also on energy saving. A low DO can usually result in the growth of filamentous bacteria, leading to poor sludge settle ability and can reduce nitrifying activity. Normally DO should be maintained above 2 mg L^{-1} in the reactor. DO has an extremely strong effect on sludge settle ability[14] and exerts a significant selective pressure on ammonia-oxidizing bacteria communities.[15]

The purpose of the present work was intensification of the SBR process at a high flocculent biomass concentration. Under special condition (biomass concentration between 11.6 and 13.4 g L^{-1}, an organic loading rate between 0.9 and 1.5 g COD L^{-1} d^{-1} and a nitrogen loading rate between 0.11 and 0.19 g N L^{-1} d^{-1}) we investigated nitrification/denitrification processes and the efficiency of organic and nitrogen elimination in the SBR. Particular attention was paid to the influence of the SRT on the reactor performance. The operational parameters such as MLSS, SVI, concentration of COD, NH_4–N, NO_2–N and NO_3–N in influent and effluent were routinely assayed.

2. Experimental

2. 1. SBR reactor

A laboratory-scale SBR reactor with a total working volume (V_{tot}) of 34–50 L was used for investigation. The rectangular reactor was made of plexiglass and equipped with instruments to measure dissolved oxygen (DO), oxidation-reduction potential (ORP), temperature (T), pH and water level. A mechanical mixer was used to provide appropriate mixing during the anoxic and aerobic phases. Dissolved oxygen was supplied using a porous diffuser, placed at the bottom of the reactor. The flow rate of air was 380 Lh^{-1}. Fig. 1 shows the scheme of the laboratory-scale SBR reactor.

The operation of the SBR was automated and DO, ORP, T and pH values were measured on-line; operation was controlled by a PLC connected to a supervisory system. The SBR was operated sequentially with a cycle time of 6 h (four cycles per day). The duration of each phase in different stages is presented in Table 1.

Table 1: Duration of phases in SBR operation

Phase	Stage I and Stage II (min)	Stage III (min)
Fill + anoxic	5+55	5+55
Aerobic	274	284
Settling	20	10
Discharge	5	5
Idle	1	1
Total cycle time	**360**	**360**

In the fill period, 3 litres (stage II) and 5 litres (stage I, III) of synthetic wastewater were pumped into the SBR, and after a settling period, 3 litres or 5 litres of the clear supernatant liquid were withdrawn from the reactor. In stage I the volumetric exchange ratio in the reactor was 14.7%, in stage II 8.8%, and in stage III 10%. The SBR was operated ten months at different operational conditions, as shown in Table 2, where average values for individual stages are given. Over the entire working period of the reactor, three different sludge retention times (SRT) were tested. All experiments were carried out at room temperature of 20 ±1 °C.

2. 2. Activated Sludge and Wastewater

The pilot SBR was seeded with activated sludge from a nearby municipal wastewater treatment plant; the biomass concentration was 2.5 g L^{-1} after inoculation. Synthetic wastewater, used in the experiments, was composed of 2.5 g L^{-1} of meat peptone (Merck, Germany) dissolved in tap water and with the addition of 10 vol. % of municipal wastewater. Municipal wastewater served as a source of microelements and fresh microorganisms.

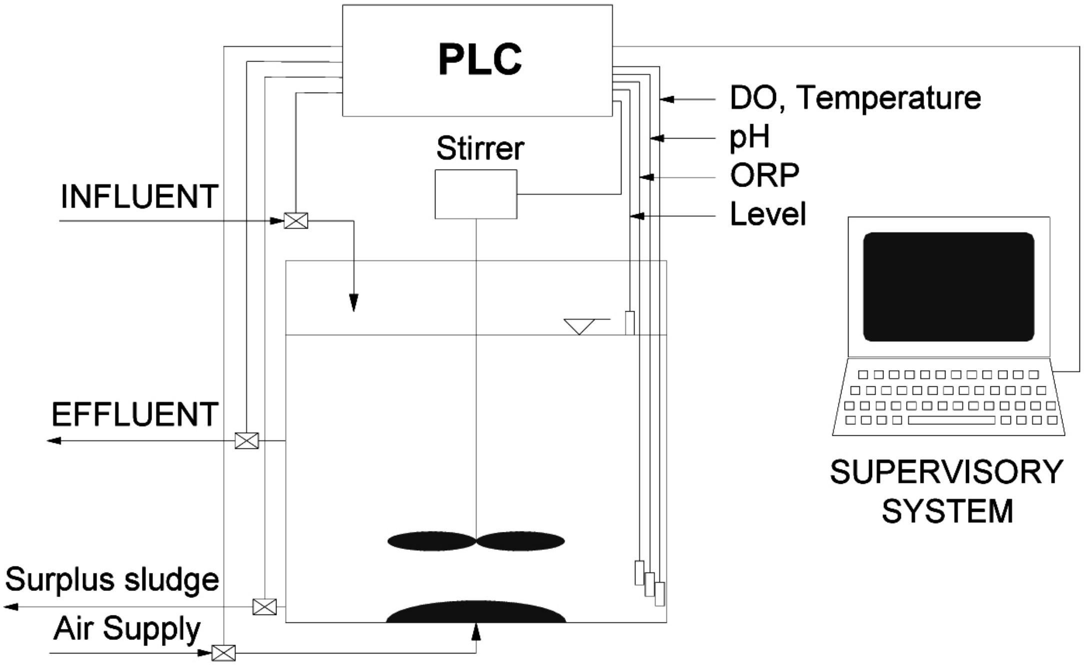

Figure 1: Scheme of laboratory – scale SBR reactor.

Table 2. The operational conditions in the SBR

Constituent	Stage I	Stage II	Stage III
V_T (L)	34	34	50
MLSS (g.L^{-1})	13.4	11.6	11.9
MLVSS/MLSS	0.87	0.85	0.85
F/M ratio	0.20	0.21	0.21
C/N ratio	8.2	8.1	8.0
SRT (day)	31	52	21
HRT (day)	2.5	4.2	2.5
SVI (mL.g^{-1})	33	27	50
Organic loading rate (g COD.L^{-1}.d^{-1})	1.5	0.9	1.04
Nitrogen loading rate (g N.L^{-1}.d^{-1})	0.19	0.11	0.19
COD$_{\text{influent}}$ (mg.L^{-1})	2624	2554	2606
TN$_{\text{influent}}$ (mg.L^{-1})	318.7	313.7	324.6

2. 3. Analytical Methods

Mixed liquid suspended solid (MLSS) and sludge volume index (SVI) were routinely assayed. SBR performance was controlled daily by analyses of COD, NH_4–N, NO_2–N and NO_3–N in the influent and effluent samples. All samples were filtered through a 0.45 µm filter paper and analysed according to Standard Methods.[16] Temperature, pH, ORP and DO concentration were recorded on-line. Electrodes (WTW, Germany) were calibrated and maintained according to the manufacturer's operating instructions. Methods for determination of COD and nitrogen formed part of the accreditation of the laboratory.

2. 4. Microscopic Observation

The sizes of flocs were determined by a confocal microscope (Leica TCS SP2 RS) using a x 10 objective lens with a format of 512 × 512 pixels.

3. Results and Discussion

The pilot SBR system was operated for ten months under alternating anoxic/aerobic conditions. The influence of SRT on the formation of flocs and their settling ability and the efficiency of carbon and nitrogen elimination was determined throughout the operational period. Figure 2 shows the time course of MLSS, SVI and SRT during the operational period; an adaptation stage and three operational stages are evident from the graph. The adaptation stage lasted for 56 days; in this period the organic loading rate was gradually increased from 1.5 g COD L^{-1} d^{-1} to 1.8 g COD L^{-1} d^{-1}, MLSS increased from 2.5 to 12 g L^{-1} and SVI decreased from 160 mL g^{-1} to 60 mL g^{-1}. In seeded activated sludge the flocs were small and irregular in shape (Fig. 4a).

Fig. 3 shows the concentration of COD and nitrogen compounds in the effluent in the operational stages I, II and III.

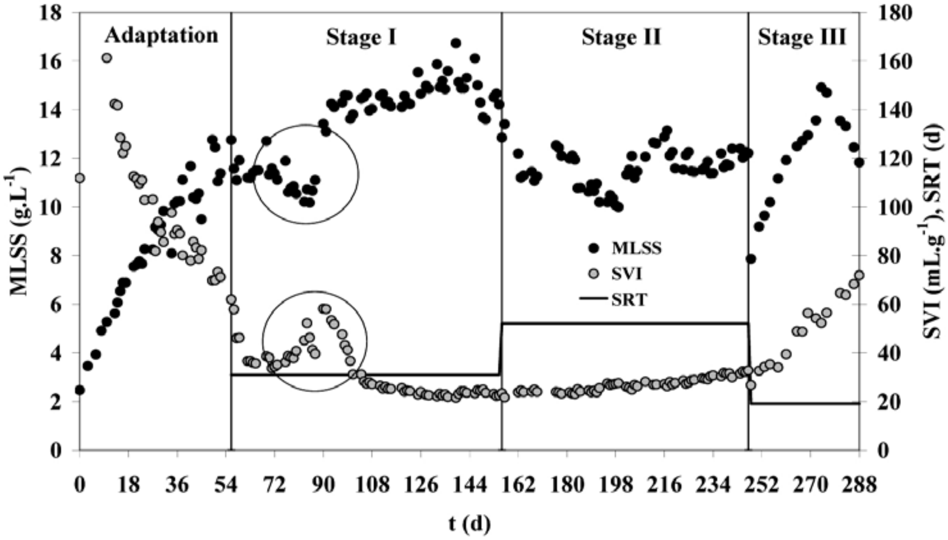

Figure 2: Time courses of MLSS, SVI and SRT.

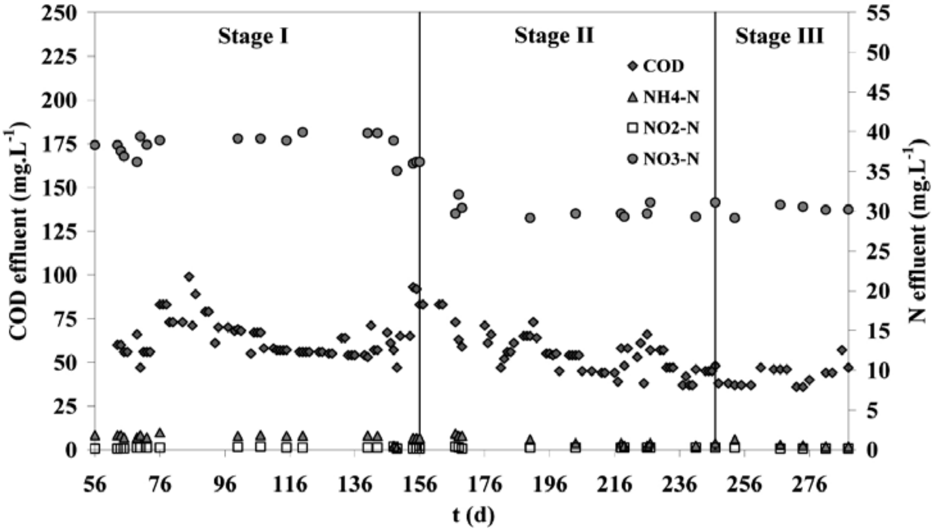

Figure 3: COD and nitrogen concentration in the effluent.

The average organic loading rate at the beginning of Stage I (from day 56 to day 90) was 1.8 g COD L^{-1} d^{-1} and the average nitrogen loading rate was 0.19 g N L^{-1} d^{-1}. The high organic loading rate at the beginning of Stage I had a negative influence on MLSS characteristics and effluent quality. Flocs started to break up, MLSS in the reactor decreased (which is marked with circles in Fig. 2) and SVI increased. MLSS, COD and NO_3–N in the effluent increased (Fig. 3). At a lower organic loading rate (1.5 g COD L^{-1} d^{-1}) an optimal F/M and C/N ratio was established. The average SRT was 31 days. Large and stable flocs were formed (Fig. 4b), MLSS increased and SVI decreased in the reactor (Fig. 2), and MLSS, COD and NO_3–N in the effluent decreased (Fig. 3). Average COD elimination efficiency in Stage I was 97% and the average nitrogen elimination efficiency was 86%.

The influence of a very high SRT (52 days) on the MLSS characteristics and effluent quality was studied in Stage II. The organic loading rate was decreased (0.9 g COD L^{-1} d^{-1}) in order to maintain a constant F/M and C/N ratio (Table 2). The average floc size decreased from 0.4 mm – 1.1 mm (Stage I) to 0.3 mm – 0.6 mm (Fig. 4c). At a higher SRT flocs were smaller but the stability of floc size distribution was better. The average COD elimination efficiency in Stage II was 98% and the average nitrogen elimination efficiency was 87%.

In Stage III we studied the influence of a short settling time and high organic and nitrogen loading rate on MLSS properties. The settling phase was shortened from 20 min (Stage II) to 10 min. According to literature data[17] a short settling time and a high organic and nitrogen loading rate have a beneficial effect on MLSS properties in granulated systems. In our case SVI started to increase (Fig. 2) and from day 274 onward filamentous bacteria appeared in the reactor (Fig. 4d). The organic and nitrogen elimination efficiency was similar to that in Stage II, despite the higher value of SVI and lowering of MLSS. The average COD elimination efficiency was 98% and average nitrogen elimination efficiency was 87%. Due to the presence of filamentous bacteria which cause wash out of activated sludge from the reactor, the experiment was terminated at day 288.

The pilot SBR was restarted with the optimal operational conditions (Table 1/Stage II). In this experiment we accompany the kinetics of denitrification and nitrification processes at SRT of 52 days.

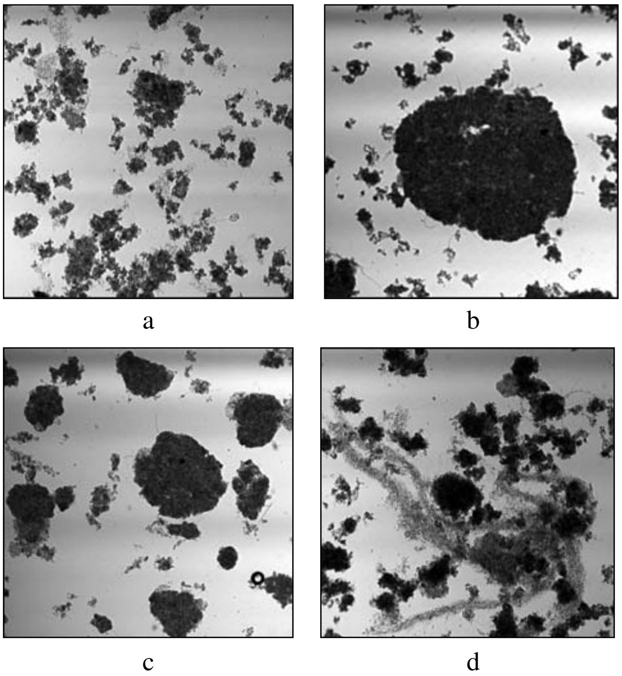

Figure 4: The size and form of flocs in seeded sludge (a) and activated sludge at SRT 31 days (b), SRT 52 days (c) and SRT 21 days (d), scanned with a x 10 objective lens.

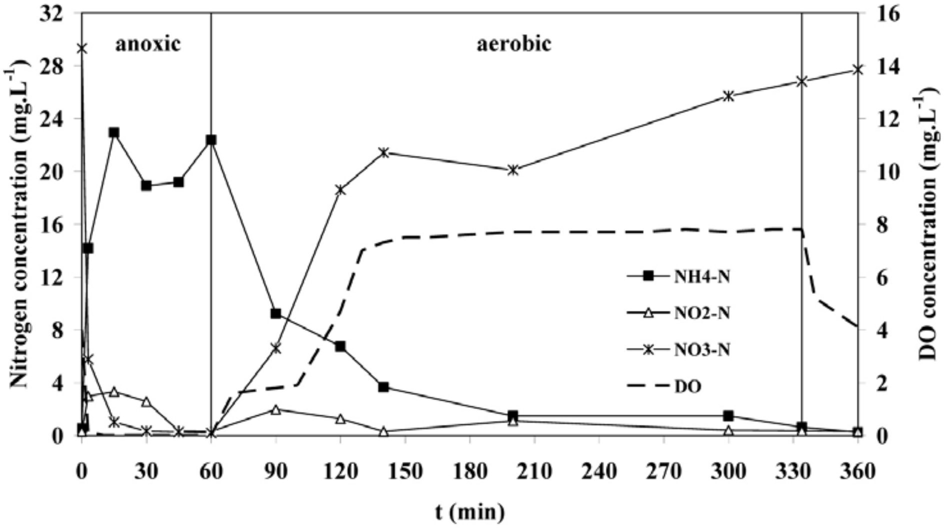

Figure 5: Time courses of nitrogen compounds and DO

Figure 5 shows the time courses of NH_4–N, NO_2–N, NO_3–N and DO during one cycle. At the beginning of the anoxic phase, NO_3–N is reduced into nitrogen gas; the COD from the incoming wastewater is used in this process. Nitrification occurred in the aerobic phase; concentration of NH_4–N decreased because of oxidation to NO_2–N and forward to NO_3–N. Nitrification was generally complete, with full conversion of the ammonia to nitrate.

Due to the excellent sludge settle ability (SVI = 27 mL g^{-1}) it was possible to operate the SBR at the MLSS of 12 g L^{-1}. The volumetric nitrogen removal capacity of 90 mg N L^{-1} d^{-1} was achieved in the single sludge nitrification/denitrification system without external carbon addition. In comparison, the value of 56 mg N L^{-1} d^{-1} was obtained in the SBR operated at MLSS of 3,5 g L^{-1} and optimal influent nutrient composition.[18]

4. Conclusions

The present work shows that enhanced nitrification/denitrification processes can be achieved in the SBR at high MLSS and high SRT. Optimal operating conditions were as follows: organic loading of 0.9 g COD L^{-1} d^{-1}, nitrogen loading of 0.11 g N L^{-1} d^{-1}, MLSS of 12 g L^{-1} and SRT of 52 days. Medium sized sludge flocs (0.1–0.4 mm) with excellent settle ability (SVI = 27 mL g^{-1}) were formed; flocs characteristics remained stable over long period of the SBR operation.

High MLSS enable high volumetric nitrogen removal rate of 90 mg N L^{-1} d^{-1} which is twice as much as in SBR operating at low MLSS of 3.5 g L^{-1} and low SRT of 21 days. This process offers an attractive option for the treatment of highly polluted wastewaters with lower investment and operating costs.

5. Acknowledgements

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6. References

1. J. Y. Hu, S. L. Ong, W. J. Ng, W. Liu, J. Environ. Eng. -ASCE. **2005**, 131, 734–744.
2. X. Li, R. Zhang, Bioprocess Biosyst Eng. **2002**, 25, 103 –109.
3. J. R. Franta, P. A. Wilderer, Water Sci. Technol. **1997**, 35, 129–136.
4. A. Carucci, A. Chiavola, M. Majone, E. Rolle, Water Sci. Technol. **1999**, 40, 253–259.
5. D. Obaja, S. Mace, J. Mata-Alvarez, Biorecource Technol. **2005**, 96, 7–14.
6. L. H. Ketchum, Water Sci. Technol. **1997**, 35, 11–18.
7. N. Artan, P. Wilderer, D. Orhon, E. Morgenroth, N. Özgür, Water Sci. Technol. **2001**, 43, 53–60.
8. Metcalf and Eddy, Inc., *Wastewater Engineering: Treatment and Reuse*, 4th Edition, McGraw-Hill, Inc., New York, **2003**, pp. 677–683.
9. R. Y. Surampalli, R. D. Tyagi, O. K. Scheible, J. Environ. Syst. **2001**, 28, 25–42.
10. G. L. Mishoe, Florida Water Resour. J. **1999**, 20–27.
11. M. Richard, S. Brown, F. Collins, *Activated sludge microbiology problems and their control*. 20th Annual USEPA National Operator Trainers Conference, New York, **2003**, pp. 1–21.
12. B. Q. Liao, I. G. Droppo, G. G. Leppard, S. N. Liss, Water Res. **2006**, 40, 2583–2591.
13. E. Klimiuk, D. Kulikowska, Waste Manage. Res. **2005**, 23, 429– 438.

14. A. M. P. Martins, J. J. Heijnen, M. C. M. Von Loosdrecht, Appl. Microbiol. Biotechnol. **2003**, 62, 586–593.
15. H. D. Park, D. R. Noguera, Water Res. **2004**, 38, 3275–3286.
16. APHA, *Standard Methods for the Examination of Water and Wastewater Analysis*, 20th Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington D. C., 1998.
17. T. Etterer, P. A. Wilderer, Water Sci. Technol. **2001**, 43, 19–26.
18. M. Roš, J. Vrtovšek, Acta Chim. Slov. **2004**, 51, 779–785.

Povzetek

V šaržnem biološkem reaktorju (SBR) smo preučevali kinetiko razgradnje organskih in dušikovih spojin pri visoki koncentraciji biomase (11,6–13,4 g L^{-1}). Optimalni pogoji delovanja SBR so bili doseženi pri organski obremenitvi 0,9 g KPK L^{-1} d^{-1}, celokupni dušikovi obremenitvi 0,11 g N L^{-1} d^{-1}, koncentraciji aktivnega blata 12 g L^{-1} in starosti aktivnega blata 52 dni. Pri danih pogojih so se razvili kosmi blata velikosti 0,1 mm – 0,4 mm z zelo dobro sposobnostjo usedanja (VIB = 27 mL g^{-1}). Visoka koncentracija aktivnega blata je omogočala intenzivnejše procese nitrifikacije in denitrifikacije; dosegli smo volumsko hitrost odstranjevanja dušika 90 mg N L^{-1} dan^{-1}, kar je skoraj dvakrat več kot v SBR, ki deluje pri nižji koncentraciji aktivnega blata (3,5 g L^{-1}). Tehnologija SBR z visoko koncentracijo aktivnega blata omogoča, da čiščenje močno obremenjenih odpadnih voda poteka v manjših reaktorjih.