# LOW STRENGTH EFFLUENT TREATMENT WITH CYCLIC TECHNOLOGIES IN VIETNAM

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**Abstract:** *Wastewater with low pollution concentrations are common in cities of the developing countries also in Vietnam because sewer network for wastewater is not yet construction that rely on combined sewer network. The results of the decomposition of organic matter partly in combined sewer network significantly reduced levels of BOD, while reducing nitrogen only a small part. The imbalance of BOD, nitrogen ratio is a challenge for treatment of wastewater - especially to ensure the nitrogen meets requirements. Results of the analysis of influent and effluent concentrations in Yen So (Hanoi), Vinh (Nghe An) wastewater treatment plants where applied cyclic activated sludge technologies base on sequencing batch reactors, with good control of operation to show that the effluent quality is stability and meet Vietnamese standard.*

**Keywords:** Nitrogen removal, nitrification / denitrification, cyclic activated sludge technology, modified SBR / SBR.

## BACKGROUND

In 1995, Vietnam had issued the Environmental Protection Law, but until 2002 the criteria for municipal wastewater treatment TCVN 7222:2002 was issued with requirements for some parameters. The regulations for wastewater treatment plant that contained "secondary treatment" stage are: BOD ≤ 30mg/l; TSS ≤ 30mg/l; Total N ≤ 30mg/l; Total P ≤ 12mg/l. $NH_4$-N had not been regulated.

In 2008 Ministry of Natural Resources and Environment issued QCVN 14: 2008/BTNMT [11] regulations for municipal wastewater which was applied in parallel with TCVN 7222: 2002. QCVN 14: 2008/BTNMT contains two limits- specified in column A (in case the effluent discharge to the basin that used for domestic water supply) and column B (others) as given in Table 1.

Generally in Vietnam's the industrial factories often in the city but the industrial wastewater is not good control, so the wastewater from cities are often mixture of domestic and industrial compounds.

Earlier, in 1995 standards for industrial wastewater (TCVN 5945: 1995) contains provisions corresponding to column A and column B as mentioned above, the NH4-N targets to achieve the highest level of 0.1mg/l (column A) / 1mg/l (column B), total N was 30mg/l (column A) / 60mg/l (column B). In 2005 the Ministry of Science and Technology issued TCVN 5945:2005 standard (replaced TCVN 5945:1995) which increased the limit for ammonia to NH4-N ≤ 5 mg/l (column A) / 10mg/l (Column B) but reduced the limit for Total N ≤ 15mg/l (column A) / 30mg/l (column B). In 2009, the Ministry of Natural Resources and Environment issued QCVN 24:2009/BTNMT which replaced TCVN 5945:2005, without changes for Total N and N-NH3. In 2011, the Ministry of Natural Resources and Environment issued QCVN 40:2011/BTNMT [11] replacing QCVN 24:2009/BTNMT which increased the allowed limits to total N ≤ 20 mg/l (column A) / 40mg/l (Column B).

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**Table 1: Changing of Effluent Limits for Total N and NH4-N over time.**

| Regulation | | TCVN 5945:1995 | TCVN 5945:1995 & TCVN 7222: 2002 | TCVN 7222: 2002 & TCVN 5945:2005 | TCVN 7222: 2002, TCVN 5945:2005 & QCVN 14: 2008/BTNMT | TCVN 7222: 2002, QCVN 14: 2008/BTNMT & QCVN 40:2011/BTNMT |
|---|---|---|---|---|---|---|
| Parameter | Column | 1995 | 2002 | 2005 | 2008 | 2011 |
| Total N, mg/l | A | 30 | 30 | 15 | 15 | 20 |
| | B | 60 | 30 | 30 | 30 | 40 |
| NH4-N, mg/l | A | 0.1 | 0.1 | 5 | 5 | 5 |
| | B | 1 | 1 | 10 | 10 | 10 |

Above values are to be understood as maximum - which means that 100% of the collected samples have to comply with the given limits.

Samples are generally composite samples made up from 3 individual spot samples at the beginning, the middle and end the end of the sample period (day). Hence samples are time proportionate and not flow proportionate samples as for example in many western states.

Most of the current cities in Vietnam, included Hanoi, Vinh,... lack the existence of a constructed sewer system [9]. Most widely used are surface run-offs which have been converted into open sewer systems over the time without a proper slope or hydraulic engineering. Long retention times do lead to sedimentation and aerobic/anaerobic degradation of carbonaceous compounds and hydrolyses of organic nitrogen and phosphors compounds during dry season- but may cause severe concentration peaks during heavy rainfalls. Average BOD concentrations may typically go as low as 80mg/l – much lower than in European or other developed countries networks, peaks may reach 300mg/l easily whereas the ratio of BOD/TN is typically very low and may average at around a factor of 2 only [9],[10]. Western countries show typically a ratio of 4-5 and sometimes even higher than that - up to 6 [1]. Inlet sewage color typically shows a low strength blackish color with little suspended solids but significant smell and is transported by open channels to the point of treatment. Such channels may partially also be abused for solid waste disposal- picture 1 shows such a typical relatively clean channel close to the WWTP of Yen So Park in Hanoi City.


*Figure 1: Typical open channel sewer system in Hanoi City close to Yen So Park WWTP*

The achievement of the Nitrogen limits as shown in column A of Table 1 hence is a technological challenge which requires technological solutions which give the required flexible operation without extra costs and without the requirement of adding expensive external carbon sources for enhanced denitrification.

Low cost technologies like trickling filters would not allow complying to the effluent standards, conventional activated sludge systems may - but under the given circumstances do not provide the required flexibility of operation and consume significantly more land than rectangular shaped cyclic technologies.

**CYCLIC TECHNOLOGIES**

Modified sequencing batch reactors (SBR) [3],[4],[7] referred to as Cyclic Technologies [2] do have the potential – when properly designed- to provide for the required flexibility and the principal capability of low strength nitrogen oxidation and denitrification (N/DN) and have already demonstrated its suitability to achieve the effluent requirements as per Table 1 Column A.

During the last few decades various process configurations cyclic processes have been tested in the waste water industry successfully.

A cyclic technology is typically a process without dedicated sedimentation tanks and recirculation which would additionally also not use dedicated anoxic or anaerobic mixing sequences or mixing devices and would not use inlet or outlet equalization or flash filling. Cyclic Technologies are again distinguishing between processes for example with continuous, uninterrupted influent which accomplish the tasks of N/DN in a co-current mode during the aeration sequence by keeping the equilibrium of oxygen penetration and nitrogen diffusion at a level where the internal parts of the flocks are still maintained anoxic while the periphery parts are kept oxic. (Continuous sequencing type of operation). Such equilibrium requires usually a proper front end contactor chamber with recirculation and a proper DO management in the reactor which usually exceeds the simple set point DO regime of conventional systems. Previously used full scale respirometric methods involving initial high rate aeration at the beginning of the cycle, followed by DO-drop measurements for respiration rate estimations [2] have been replaced by methods that are simpler and more precise and use the technology of reciprocal linearization of dynamic DO profiles for proper estimations of the substrate proportionate aeration control- which resulted in better settling properties of the activated sludge.

The main part of the denitrification- estimated roughly 70% - occurs simultaneously during the aeration in the main reactor while about 20 % occur in the front end contactor and 10% during sedimentation only.

The denitrification inside the sludge flock would be – supported by the high-F/M contactor - carefully regulated by the oxygenation regime and allow the interior parts to remain anoxic while the outer zones do remain oxic throughout the aeration sequence ( Figure 2).

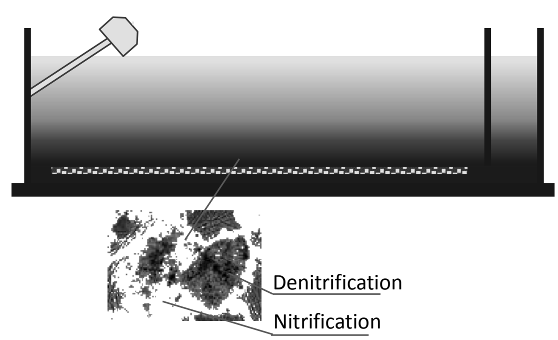


*Figure 2: Sludge flock schematic with co-current N/DN*

Such designed Cyclic Technologies have proven to operate well under very dilute wastewater concentrations as well as a very low ratio of $BOD_{in}$/ $TN_{in}$ as shown in Figure 3 below.

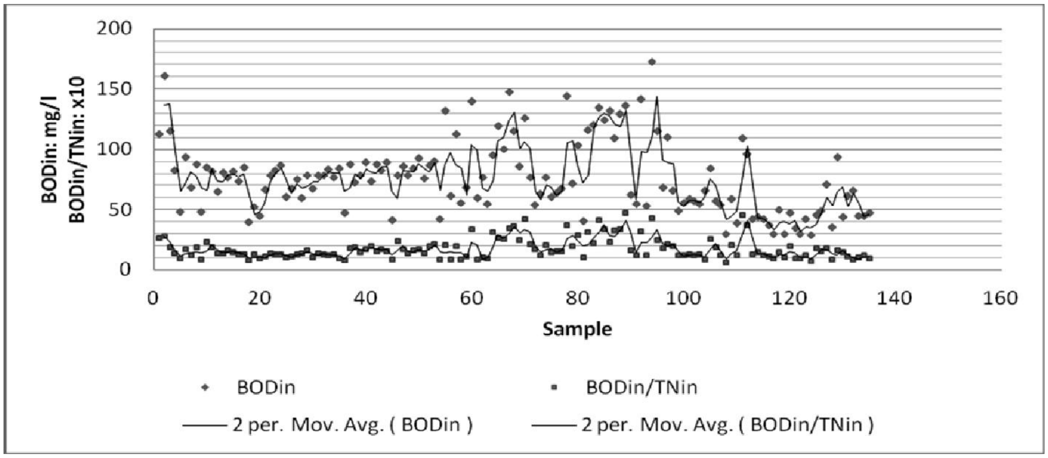


*Figure 3: Variation of inlet BOD concentration as well as 10 x the variation of the ratio between BOD/TN at the inlet sampling point of Yen So WWTP, Hanoi City.*

The applied cycle time is usually shorter than in generic SBRS and ranges from 3 to 4 hrs typically but may also be lower than that.

Aeration, sedimentation and decanting are the phases of a repeated cycle which is usually time shifted between parallel tanks.

Known positive side effects of the contactor are the suppression of bulking and foaming organisms through the so called selector effect [2] and the possibility of achieving P- release as part of the luxury uptake mechanism known as "bio-P" removal, as well as the storage effect during the not aerated fill sequences if applied.

**EXPERIENCE IN VIETNAM**

In Vietnam 2 big municipal wastewater treatment plants have recently been put into operation using Cyclic Technologies: Vinh City – Nghe An province (12.000 m3/d) in the year 2012 and the Yen So - Ha Noi ( 200.000 m3/d) in the year 2013 – 2014.

Both plants consist of a screening station, sand and grit removal, cyclic technology biological treatment tanks, disinfection, sludge thickener and centrifugal sludge dewatering whereas in the Yen So plant additionally the steps of anaerobic sludge digester is employed.

Wastewater is collected in the case of Vinh City from a constructed underground sewage collection system and in the case of Yen So Park from the combined surface water and sewage collection channel. In both cases most homes are forced to operate septic tanks which significantly reduce the discharged BOD concentration prior to the sewer system already but do hardly reduce Nitrogen. Therefore, the incoming BOD concentrations are very low but inlet TN concentrations are relatively high. The design parameters for the Vinh WWTP in comparison to the actual measured inlet parameters are shown in below Table 2.

**Table 2. Vinh treatment plant influent/effluent data**

| **Influent** | Design [6] | Actual |
|---|---|---|
| - Average flow, dry weather, m3/day | 25.100 | 12.000 |
| - Peak flow, dry weather, m3/h | 1.330 | 1.330 |
| - Peak flow, wet weather, m3/h | 2.080 | 2.080 |
| - $BOD_5$, mg/l | 110 | 83 (±222) |
| - $BOD_5$, kg/day | 2.760 | |
| - TN, mg/l | 20 | 48 (±67) |
| - TN, kg/day | 502 | |

| | | | |
|---|---|---|---|
| - N-NH3, mg/l | None | | 36 (±56) |
| **Effluent** | | | |
| | A | B | Effluent |
| - BOD5, mg/l | 30 | 60 | 5.6 (max 9) |
| - TN, mg/l | 20 | 40 | 12.2 (max 25) |
| - N-NH3, mg/l | 5 | 10 | 2.2 (max 6.4) |

Vinh Cyclic Technology includes 4 SBR tanks size of 21 x 43 m and is currently receiving about 12.000 m3/day, currently the plant operates only with 2 tanks. Yen So wastewater treatment plant receives the raw sewage from the open Kim Nguu and Set channels which collect both-surface water and sewage of the city. The mixtures are pumped from a collection point and after coarse screening to the plants headworks. The described situation is leading to a very dilute inlet concentration which is in comparison to the selected design parameters significantly lower than expected. The comparison of both is shown in Table 3

**Table 3. Yen So treatment plant influent/effluent data**

| **Influent** | Design [5] | | Actual |
|---|---|---|---|
| - Maximum flow, dry weather, m3/day | 200.000 | | 200.000 |
| - $BOD_5$, mg/l | 250 | | 76 (±144) |
| - TN, mg/l | 40 | | 47 (±61) |
| - N-NH3, mg/l | 30 | | 41 (±55) |
| **Effluent** | | | |
| | A | B | Effluent |
| - BOD5, mg/l | 30 | 50 | 6 (max 18) |
| - TN, mg/l | 20 | 40 | 14 (max 28) |
| - N-NH3, mg/l | 5 | 10 | 2.7 (max 9) |

The Yen So Cyclic Technology Plant includes 8 SBR tanks with dimensions of 21 x 43 m and is currently receiving wastewater flows well at the design limits.

Total N effluent concentrations of Yen So WWTP are shown in Figure 4

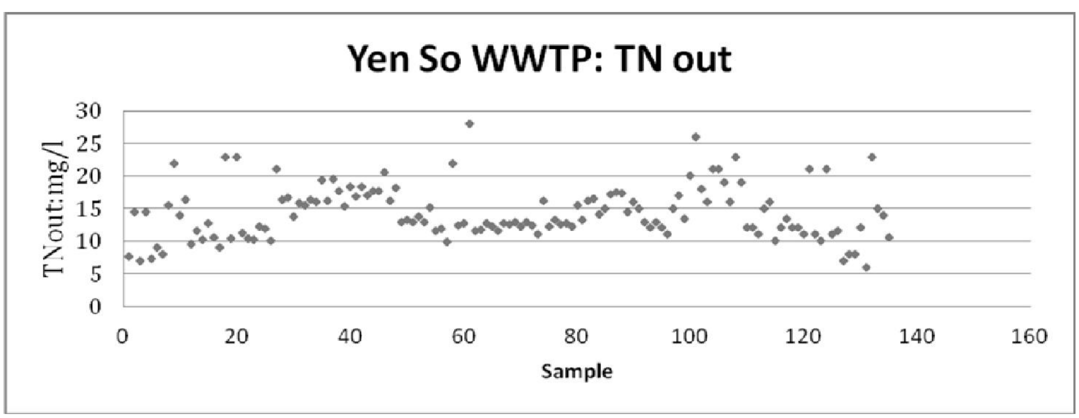


*Figure 4: Variations of Effluent TN concentration during the year 2013 of the Yen So WWTP*

The sample numbers as per figures presented herein above and after represent one batch of treatment whereas one effluent sample point is made up from 3 individual samples taken during the decanting of each individual reactor. The influent samples are taken at the same time as the effluent samples at a point upstream the distribution chamber to the individual tanks. The analysic method base on Standard Method for the Examination of Water and Wastewater (22nd Edition) [8].

**RESULTS AND DISCUSSION**

As shown in Table 1 the permissible effluent concentrations for TN in 1995 have been quite high and have been later on dropped and then increased again in 2011 being still lower than the once imposed in 1995. The limits for N-NH4 early 1995 have been way to low and have been increased significantly in 2005 to realistically and economically viable values and have been kept up to date. With the current limit corresponds to column A/B, the TN: 20/40; N-NH3: 5/10 is not too strict to be achieved for real wastewater, but the real challenge for mixed waste in Vietnam when the incoming BOD concentration is very low. On the other hand to determine the treated waste water to achieve column A and column B is also an issue for the purpose of water - which receives body for treated wastewater often change with no real planning stability in developing country such as Vietnam. Along with the frequent changes in the limits of the above criteria, it is clear that an wastewater treatment plant can operate to achieve as high as possible to the parameters TN, NH4-N is encouraging.

With datas of Vinh and Yen So showed very low input BOD5: respectively 83/76mg/l but very large fluctuations: the maximum value and the minimum difference 222/144mg/l; during which the value of TN/NH4-N is very high compared with BOD5 and also large fluctuations - especially the NH4-N - corresponding TN: 48 (± 67) / 47 (± 61); N-NH3: 36 (± 56) / 41 (± 55). Very low ratio BOD5in/TNin and large fluctuations: 0.70÷4,47 / 0.65÷4.77 and the corresponding average is only 1.82/1.75. BOD5 in treated wastewater achieved an average of 5.6/6.0mg/l and maximum value of 9/18mg/l - means that achieve standard column A. The average concentration TNout meets column B but only 8%/10% sample meets column B. Similarly N-NH3out average meets column B but only 5%/8% of the samples meet column A, which under the provisions of Vietnamese standard, the plants only meet column B. *Figure 4* show that the reduction of the N is quite stable.

The real challenge for nutrient removal from the typically low strength combined sewage results from the very low BOD concentrations arriving at the headworks which are typically below or around 100mg/l BOD and TN concentrations of somewhere between 40-50mg/l which would require a specific TN reduction according to column A Table 1 of roughly 60% or 30-40% of TN elimination coefficient per $kgBOD_{inlet}$ ( $TN_{el}/kgBOD_{in}$).

The TN elimination coefficient is shown in below *Figure 5* for the Yen So WWTP and plotted versus the inlet ratio of $BOD_{influent}/TN_{influent}$ ($BOD_{in}/TN_{in}$). It clearly shows that the effluent concentration of TN is practically reached independently of the influent concentration ratio and actually a higher inlet ratio results in a lower elimination coefficient. The average inlet ratio of BOD/TN is 1,75 with a standard deviation of 0,87. Hence 85% of the observed values show an inlet ration of BOD/TN of less than 2,55 and average inlet concentrations of BOD and TN of 76mg/l and 47mg/l respectively (Table 3). Typical industrialized countries' ratios of influent concentrations are typically around 5-6 in comparison which in Vietnam cannot be reached. The achieved effluent concentrations of TN reach an average of 14mg/l and a 85%-ile of 18mg/l which are well within the given limits of *Table 1*.

The elimination coefficient as shown in *Figure 5* is the sum of the incorporated Nitrogen and the denitrified Nitrogen together. As there is no simple methodology to measure the incorporated Nitrogen in the excess biomass both- incorporated and denitrified Nitrogen- are included in the amount of Nitrogen which is eliminated and hence included in the elimination coefficient of *Figure 5*. International standards such as ATV [1] suggest that the incorporated Nitrogen under normal operating circumstances may be 4-5% of the inlet BOD and also limit the amount of maximum denitrification ratio to 15% of the inlet BOD. Under such considerations the comparable number for the elimination coefficient following international literature [1] should not exceed 20% of the inlet BOD for design purpose. The actual data of the treatment plant in Vinh City and Yen So show in contrary to this elimination coefficients of roughly 43% and 52% respectively. Especially for Yen So the coefficient is on 85% of the observed days under 80% and on 85% of the observed days over 24%.

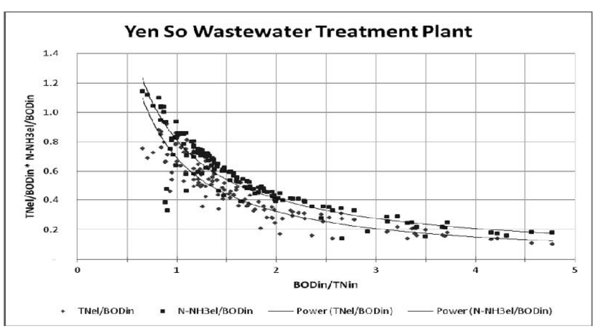


*Figure 5: Yen So WWTP ratio of influent BODin/TNin versus TNeliminated/BODinfluent and NH4-N eliminated/BODinfluent*

The effluent concentrations of COD from the Yen So WWTP which is shown in below Figure 6 averages at 18 mg/l show good degradability but about 4 individual samples exceeding 40 mg/l which had been caused by impurities during the sampling procedure.

The average elimination of COD is 88 % and hence comparable to higher strength domestic sewage works in western cities with higher strength effluents.

Included in the sampling are eventual backloads coming from sludge dewatering which do return significant amounts of loads during start up of the mechanical dewatering machines specifically during the morning hours.

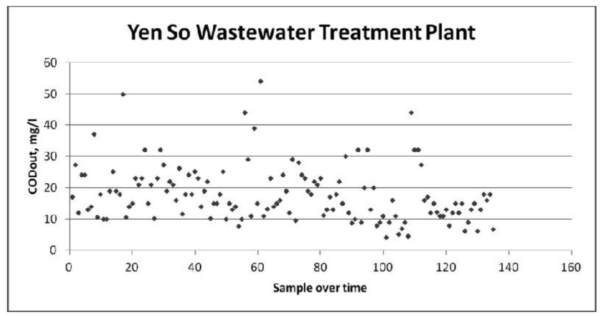


*Figure 6: Effluent concentration of COD in mg/l from individual batches from the Yen So WWTP*

**SUMMARY**

Low strength effluent treatment is per se an issue which challenges treatment process generally and when it comes unpredicted particular challenges are the required process adjustments to finally meet the given limits. For carbon removal such adjustments are typically a reduction of the aeration cycling with reduced aeration time and intensity. In respect to the nitrogen removal - which is not only an issue of meeting the limits or not - but also an economical issue of operation cost reduction- the possibilities of a cyclic technology offer a wide range of operational regimes allowing to remove about 50% of the BOD as TN through incorporation and denitrification. The operation of the front end contactor enhanced the settling properties and the anoxic/anaerobic conditions favoring denitrification during the aeration sequence in the main reactor.

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**Tóm tắt**

**HIỆU QUẢ XỬ LÝ CỦA CÔNG NGHỆ BÙN HOẠT TÍNH DẠNG MẺ TUẦN HOÀN TRONG XỬ LÝ NƯỚC THẢI NỒNG ĐỘ Ô NHIỄM THẤP Ở VIỆT NAM**

*Nước thải có nồng độ ô nhiễm thấp là phổ biến ở các thành phố của các nước đang phát triển nói chung, Việt Nam nói riêng do mạng lưới thu gom nước thải riêng vẫn chưa được xây dựng hoàn chỉnh mà phải dựa vào hệ thống cống thu gom chung. Kết quả của quá trình phân hủy một phần chất hữu cơ trong hệ thống thoát nước chung của các thành phố này làm giảm đáng kể nồng độ BOD, trong khi nitơ chỉ được giảm một phần nhỏ. Sự mất cân đối tỷ lệ các thông số BOD, nitơ là một thách thức trong việc xử lý – đặc biệt là đảm bảo các chỉ tiêu nitơ đạt yêu cầu. Kết quả phân tích nồng độ đầu vào và sau xử lý tại Nhà máy xử lý nước thải Yên Sở (Hà Nội), Vinh (Nghệ An) áp dụng công nghệ bùn hoạt tính dạng mẻ tuần hoàn, bằng việc điều khiển vận hành hợp lý đã cho kết quả xử lý là tương đối ổn định và đạt tiêu chuẩn Việt Nam theo quy định.*

**Từ khóa:** Loại bỏ Nitơ, Nitrate hóa / Đề nitrate hóa, Công nghệ bùn hoạt tính dạng mẻ tuần hoàn, SBR cải tiến / SBR.

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