Assessment of laboratory scale cylindrical sequencing batch reactor for the treatment of abattoir effluent

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Abstract
Meat factory effluent contains fat, protein, diluted blood, and suspended solids. As a result, nutrient and organic concentrations in this effluent are incredibly high, and residues are slightly solubilized, likely to impact environmental pollution on streams, rivers, and other watercourses if discharged untreated. The biodegradation of abattoir waste was studied using a laboratory-scale cylindrical sequencing batch reactor (SBR) in aerobic mode. The aerobic sludge was collected from the aeration compartment of a paper and pulp effluent treatment facility and cultivated in a 2.83-L Perspex-based laboratory SBR. The raw wastewater comprised 6494 ± 2144 mg/l chemical oxygen demand (COD), 1946 ± 607 mg/l biochemical oxygen demand (BOD), 1722 ± 159 mg/l total suspended solids (TSS), 3062 ± 592 mg/l CaCO₃ alkalinity, 7.00 ± 0.27 pH. The duration of a complete cycle was 24 h and comprised four phases: fill (5 min), react (23 h 10 min), settle (40 min) and draw (5 min). The whole experiment was divided into four phases and the dilution was done with the help of domestic sewage. In the first stage, the reactor was fed four times diluted slaughterhouse effluent on a 24-h cyclic operation for two weeks. After achieving a significant reduction in COD, the organic content of the input was raised by lowering the dilution factor. In the second and third phases, the reactor was fed three times and twice diluted samples for two weeks each operating at the same cyclic interval. In the final stage, raw effluent was fed to the reactor for two more weeks. The average COD value of diluted wastewater in the first, second, third and fourth phase was 1040 mg/l, 3168 mg/l, 4800 mg/l, and 5200 mg/l, respectively. The COD removal efficiency at the end of the first, second, third and fourth phase was 83%, 93%, 85% and 97%, respectively. The average BOD value of diluted wastewater at the end of the first, second, third and fourth phase was 1120 mg/l, 610 mg/l, 1502 mg/l, and 1350 mg/l, respectively. The BOD removal efficiency at the end of the first, second, third and fourth phase was 84%, 88%, 85% and 98%, respectively. After 8 weeks, at an organic loading rate of 3.06 kg/m³/d, the final phase has achieved BOD and COD removal efficiency of 98% and 97%, respectively. The pH and alkalinity levels were within acceptable ranges. After two months, the sludge’s settling characteristics have improved, and the nitrification efficiency of the reactor was roughly 60% at the time of deactivation of the reactor.

Keywords Abattoir effluent · Alkalinity · Biochemical oxygen demand · Chemical oxygen demand · pH · Sequencing batch reactor · Slaughterhouse wastewater (SWW)

Introduction
The slaughter of animals generates an enormous volume of meat, which meets the world’s growing protein requirement. Water quality has deteriorated in recent decades as a result of the growing population and industrialization. The meat processing industry consumes 29% of all freshwater globally consumed by the agricultural sector [1, 2]. Furthermore, global beef, swine, and chicken meat production has doubled in the last decade and is expected to grow until 2050 [3]. As a result, the number of slaughterhouses is expanding, leading to a large volume of slaughterhouse wastewater (SWW) must be treated [4]. The global meat production in 2020 reached almost 337.18 million tonnes in the case of bovine, poultry, pig, and ovine as per the meat statistics data of the Food and Agriculture Organization of the United Nations, 2021 [5]. The leading meat-producing countries in 2020 were China, USA, European Union, Brazil, Russia, Mexico, India, and Argentina. Poultry meat production (133.3 million tonnes)
was most significant compared to other meat productions in that particular year. Table 1 gives the world’s meat production and export in the year 2020 [5].

Meat production in India has expanded rapidly in recent years. In 2010, India exported approximately 1.45 million tonnes of beef abroad, generating around 1500 million US dollars in income [6]. In the present scenario, India’s meat production and exports have risen to 7.36 million tonnes and 1.23 million tonnes, respectively [5]. Due to Covid-19-related market disturbances, inadequate availability of animals for slaughter, and regulatory limits on purchasing and shipping animals, meat exports have decreased marginally. According to India’s Central Pollution Control Board (CPCB), the nation has approximately 1176 slaughterhouses and 75 modern abattoirs. The leading meat-producing states are Andhra Pradesh, Uttar Pradesh, Tamil Nadu, and Maharashtra [6].

The properties of slaughterhouse wastewater (SWW) are influenced by several factors, including the size of the slaughtering facility, the type of animals slaughtered, the style of slaughtering involved, the amount of water consumed per animal, and the washing of killing equipment. According to the World Bank Group (2007), for every tonne of cattle carcass, 1.62–9 m³ of water is utilized, and 1.6–8.3 m³ per tonne of pig carcass [7]. In slaughterhouses, large amounts of water are used for evisceration, cleaning, and washing activities [8]. Effluent is generated from all water used in slaughtering and manufacturing units [6]. The discharge of wastewater can make up a significant portion to 80% of total water usage [9]. Slaughterhouse effluent wastewater is high in pollutants and has the potential to harm the environment. Organic materials, suspended particles, oil and grease, and nutrients are higher in the slaughterhouse sector [2]. Blood, fat, dung, urine, and meat tissues are lost to wastewater streams during abattoir processing [10, 11]. One of the principal dissolved contaminants in abattoir wastewater is blood, with the highest COD of any abattoir effluent. The effluent load from a single cow carcass discharged straight into a sewer line would be equivalent to the total sewage discharged by 50 persons on a typical day [12]. Slaughterhouse effluent, along with different industrial effluents, is investigated to gain a better understanding of their characteristics (Table 2).

The United States Environmental Protection Agency (US EPA) has recognized SWWs as one of the most environmentally hazardous industrial wastewaters since improper management is one of the culprits of river deoxygenation and groundwater contamination [19]. The discharge of raw SWW into water bodies impacts water quality, notably, because it reduces dissolved oxygen (DO), which can lead to aquatic life mortality [20]. Furthermore, macronutrients such as nitrogen and phosphorus have the potential to produce eutrophication. The release of these nutrients causes an overabundance of algae growth and, as a result, deterioration. As a result of the mineralization of algae, aquatic life may deteriorate due to a decrease in DO levels [21]. If wastes from slaughterhouses are released without essential treatment, municipal sewers will become clogged or overburdened [8]. As a result, it is critical to use proper treatment to control the discharge of mixed organic carbon and nitrogen-laden wastewater. If effective process control can be ensured, biological treatment has been shown to be a relatively benign and energy efficient method of treating wastewater [11]. In terms of bulk parameters like BOD, COD, and TN, particular emphasis is paid to organic and nutrient removal. Table 3 displays the findings of prior studies on abattoir wastewater treatment by numerous researchers. SWW treatment efficiency varies widely and is dependent on SWW parameters, treatment time, influent concentration, and treatment type.

### Table 1 World’s meat production and export in 2020

|          | World | China | USA | EU | Brazil | Russia | Mexico | India | Argentina |
|----------|-------|-------|-----|----|--------|--------|--------|-------|-----------|
| Meat production | 337.18 | 77.91 | 48.68 | 48.60 | 28.83 | 11.17 | 7.52 | 7.36 | 6.30 |
| Meat export | 38.69 | 0.71 | 8.45 | 6.82 | 7.99 | 0.58 | 0.70 | 1.23 | 1.10 |

All values in million tonnes

### Table 2 Characteristics of different industrial wastewater

| Parameter          | pH   | COD (mg/l) | BOD (mg/l) | TN (mg/l) | TP (mg/l) | TSS (mg/l) | Alkalinity (mg/l) | References |
|--------------------|------|------------|------------|-----------|-----------|------------|-------------------|------------|
| Slaughterhouse wastewater | 5–7.8 | 1100–15,000 | 600–3900 | 50–840 | 15–200 | 220–6400 | 350–1340 | [13] |
| Pharmaceutical wastewater | 4.2–4.5 | 5000–80,000 | – | 135–1250 | 30–120 | 900–18,800 | – | [14] |
| Dairy wastewater | 6–11 | 1150–9200 | – | 8–68 | 340–1730 | 320–970 | – | [15] |
| Livestock wastewater | – | 6190–78,600 | 3940–34,600 | 1530–6500 | 116–1770 | 1850–29,000 | – | [16] |
| Textile wastewater | 7–7.2 | 773–1290 | 400–490 | – | 9.4–27.9 | – | – | [17] |
| Oil refinery wastewater | 6.9–10 | 125–1095 | – | – | 9–93 | – | – | [18] |
Aerobic wastewater treatment techniques have several advantages, including reduced odor emission, rapid biological growth rate, and quick temperature and loading rate adjustments. On the other hand, aerobic systems have higher operational costs than anaerobic systems due to the maintenance and energy required for artificial oxygenation. Aerobic activated sludge (AS), rotating biological contactors (RBCs), and sequencing batch reactors (SBRs) are examples of aerobic unit operations for SWW treatment [39]. The Sequencing Batch Reactor (SBR) is a more advanced variant of the activated sludge process that treats biological wastewater in a fill-and-draw mode. Fill-react-settle-draw-idle is a cyclic process that SBRs go through [40, 41]. An SBR reactor differs from a traditional activated sludge system. It accomplishes equalization, aeration, and sedimentation in a time sequence rather than the traditional space sequence used in continuous-flow systems. According to USEPA report (1983) “The SBR is nothing more than an activated sludge system that acts in time rather than space” [19].

SBRs are widely regarded as one of the most accessible methods for treating abattoir wastewater [42] due to their ability to extract organic carbon, suspended particles, and nutrients from wastewater in a single tank and their low operating and capital costs [43]. Several process modifications in the duration associated with each stage can be made to remove nitrogen and phosphorus from wastewater [44, 45]. With considerable success, SBRs have been used to treat landfill leachate [46, 47], tannery wastewater [48, 49], phenolic wastewater [50, 51], and a range of other industrial wastewaters. The cylindrical Sequencing batch reactor has begun to gain renown as a better biological treatment system [52–54] due to its low space and power needs, ability to break down harmful contaminants, and ability to withstand greater organic loads and shock loads. Despite the benefits of the aforementioned elements affecting SBR system performance, various aspects such as influent characteristics, organic loading rate, carbon source, pH, dissolved oxygen, hydraulic retention time, sludge retention time, feed pattern, cycle length, settleability, and temperature might affect its performance [55]. In simultaneous N and P removal systems, low temperature is a significant difficulty [56]. Furthermore, it necessitates expert labor, continuous power, and costly maintenance [57]. The purpose of this study is to evaluate the performance efficacy of a cylindrical Sequencing Batch reactor for the treatment of abattoir effluent.

### Materials and methods

In this experiment, industrial effluent was collected from a nearby slaughterhouse located in the district of Azamgarh, Uttar Pradesh, India. The Sequencing Batch Reactor System (SBR) was made up of Perspex material and had a total volume of 2.83 L. The cylindrical reactor had a diameter.

| Reactor                          | Influent COD (mg/l) | COD Removal (%) | Influent BOD (mg/l) | BOD Removal (%) | Influent TN (mg/l) | TN Removal (%) | HRT (h) | References |
|---------------------------------|---------------------|----------------|---------------------|-----------------|--------------------|----------------|--------|------------|
| Electrocoagulation              | 2171                | 85             | 1123                | –               | 148                | –             | 1      | [22]       |
| Sequencing batch reactor        | 6580                | 81             | –                   | –               | 3321               | 95            | 96     | [23]       |
| Anaerobic filter                | 15,800              | 60             | –                   | –               | –                  | –             | 46     | [24]       |
| Anaerobic lagoon                | 9216                | 59             | 5088                | 73              | 343                | –             | 48     | [25]       |
| Anaerobic filter—ultrafiltration| 1778                | 95             | –                   | –               | 374                | 78            | 48     | [26]       |
| Electrocoagulation              | 3337                | 78             | 1950                | –               | –                  | –             | 1      | [27]       |
| Sequencing batch reactor        | 6057                | 98             | 4240                | –               | 576                | 98            | 161    | [28]       |
| Anaerobic filter                | 88                  | 80             | –                   | –               | –                  | 90            | 24     | [29]       |
| Anaerobic digester              | 18,600              | –              | –                   | –               | 5200               | 66            | 2640   | [30]       |
| Microfiltration                 | 480                 | 91             | –                   | –               | 115                | 45            | 48     | [31]       |
| Constructed wetland             | 468                 | 60             | –                   | –               | 61                 | 46            | 28     | [32]       |
| Sequencing batch reactor        | 6057                | 93             | 4240                | –               | 576                | 93            | 12     | [33]       |
| Advanced oxidation process      | 406                 | 84             | –                   | –               | –                  | –             | 1      | [34]       |
| Sequencing batch reactor        | 8604                | 80             | –                   | –               | 1493               | 88            | 3      | [35]       |
| Sequencing batch reactor        | 356                 | –              | –                   | –               | 175                | 91            | 12     | [36]       |
| UST–AF–UF*                      | 5200                | 96             | –                   | –               | 74                 | –             | 343    | [37]       |
| Advanced oxidation process      | –                   | –              | 340                 | –               | 55                 | –             | 2      | [38]       |
| Cylindrical SBR                 | 4332                | 97             | 1350                | 98              | 23                 | 60            | 24     | Present study |

*Ultrasound technology-anaerobic filter-ultrafiltration
of 6 cm and a height of 100 cm. During the aerobic phase of the reaction period, a 5.0-W air pump was used to supply diffused air from the bottom of the reactor. Automatic on–off timers with various time-dependent cycles were used to automate the complete experimental setup. Throughout the investigation, raw effluent samples were collected five times in 20.0 L plastic containers from the equalization tank of the meat factory and stored in the laboratory refrigerator at 4 °C. The influent of the SBR was placed in a tank with a capacity of 12 L. Figure 1 shows the experimental laboratory setup used in the study. The reactor was cycled for 24 h, with 5 min of influent filing, 23 h 10 min of aeration, 40 min of settling, and 5 min of effluent withdrawal.

The reactor was seeded with aerobic sludge obtained from the aeration tank of the paper and pulp wastewater treatment plant and cultivated in the laboratory under ambient conditions. The reactor was left open to allow a diverse population of bacteria to grow. The effluent was collected from a sampling port located at 50 cm from the bottom of the reactor, with a volumetric exchange ratio of 50%, which was preferable as it would result in a higher volumetric turnover and allow the use of smaller reactors [58]. The sampling port at 30 cm height from the bottom of the reactor was used for MLSS collection and periodical sludge wasting. The sludge retention time (SRT) was manually managed by withdrawing excess volumes of mixed liquor from the reactor at an

Fig. 1 Cylindrical SBR
interval of one week. Table 4 shows the characteristics of
the raw wastewater collected from the industry.

The overall experiment was divided into four phases, and
the dilution was done with the help of domestic sewage.
The reactor was fed four times with diluted slaughterhouse
effluent on a 24-h cyclic operation for two weeks in the
first stage. After achieving a significant reduction in COD,
the organic content of the input was raised by lowering the
dilution factor. In the second and third phases, the reactor
was fed three times and two times diluted samples for two
weeks, each operating at the same cyclic interval. In the final
stage, raw effluent was provided to the reactor for two more
weeks. The reactor was continuously monitored for an over-
all period of two months. The duration and COD concentra-
tion of the influent feed to the reactor is shown in Table 5.

The procedures given in Standard Methods were
employed to carry out the analytical techniques used in
this investigation [59]. Chemical oxygen demand (COD)
(standard code: 5220), biochemical oxygen demand (BOD5)
(standard code: 5210B), total suspended solids (TSS) (stand-
ard code: 2540), and alkalinity (standard code: 2320). The
pH was monitored using a pH meter (HACK pH Meter HQ
90D) (standard code: 4500-H), Sludge volume index (SVI)
(standard code: 2710D), MLSS concentrations in the sam-
ples (standard code: 2540D).

### Results and discussion

This study aimed to assess the efficacy of a laboratory-scale
cylindrical sequencing batch reactor for the aerobic treat-
ment of Slaughterhouse wastewater. In order to start the
reactor, an active microbial seed was required. The active
bacteria will quickly adapt to the industrial wastewater
and the cylindrical SBR will start functioning. Therefore,
digested waste from the paper and pulp mill was used to
seed the reactor and operated at room temperature. Aerobic
bacteria degrade the organic matter into CO2, H2O and new
cells. The reactor was left open to release CO2, excess O2
and other dissolved gases into the atmosphere. Organic car-
bon, which is the energy source for heterogenic and denitri-
fying microorganisms, is known as chemical oxygen demand
(COD). Throughout the course of the study, the raw waste-
water sample was collected five times from the industry at
an interval of two weeks. The properties of the collected
samples vary depending on the time and operations taking
place in the industry. Wastewater sample was collected from
the equalization tank of the Effluent Treatment Plant (ETP)
of the abattoir industry.

As demonstrated in Fig. 2, the COD value of raw waste-
water at different time intervals varies between 4160 mg/l
and 9408 mg/l with an average COD value of 6494 ± 2144
(mg/l). Similar values have been reported in different stud-
ies [23, 25, 28, 33, 35, 37]. As demonstrated in Fig. 3, the
pH value of raw wastewater at different time intervals var-
ies between 6.98 and 7.70 with an average pH value of
7.00 ± 0.27. Similar values have been reported in different
studies [13].

The average COD value of collected raw wastewater was
in the range of 6494 ± 2144 (mg/l); therefore it was four
times diluted with the help of domestic sewage prior feeding
it to the reactor. The reactor was operated on a 24-h cyclic
operation. The influent COD was then increased by reducing
the dilution factor till optimum COD removal efficiency was
achieved. Later on, the raw effluent was fed to the reactor,
and the performance of the reactor was monitored in terms
of COD removal efficiency.

Figure 4 shows the variation of influent, effluent, and
removal efficiency of COD with time. The average value of
diluted wastewater in the first, second, third and fourth
phase was 1040 mg/l, 3168 mg/l, 4800 mg/l, and 5200 mg/l,
respectively. The COD removal efficiency at the end of the
first, second, third and fourth phase was 83%, 93%, 85% and

### Table 4 Characteristics of the
raw wastewater used in the
Study

| Wastewater characteristics | Average | Std deviation | Minimum | Maximum | N* = a×b |
|----------------------------|---------|---------------|---------|---------|----------|
| COD (mg/L)                 | 6494    | 2144          | 4160    | 9408    | 15       |
| BOD (mg/L)                 | 1946    | 607           | 1300    | 2808    | 15       |
| TSS (mg/L)                 | 1722    | 159           | 2250    | 1962    | 15       |
| Alkalinity as CaCO3 (mg/L) | 3062    | 592           | 2250    | 3900    | 15       |
| pH                         | 7.00    | 0.27          | 6.98    | 7.70    | 15       |

*aNumber of samples analyzed; a = 3 (samples of each parameter); b = 5 (frequency of industry visit for sample collection)*
Fig. 2 Variation of raw wastewater with time

Fig. 3 Variation of raw wastewater pH with time

Fig. 4 Performance of SBR during 62 days of operation for influent, effluent, and COD removal efficiency
97%, respectively. It is seen that in each dilution phase, COD removal efficiency is increasing with time, despite variations in the influent COD values. The reactor was operated at a 24-h cyclic operation for 62 days. The variation in influent COD does not affect the COD removal efficiency, which shows that the microorganisms have become acclimatized to the slaughterhouse industry wastewater. At the termination time of the reactor, i.e., on the 62nd day, the COD removal efficiency of the cylindrical SBR was 97% at an organic loading rate of 3.06 kg/m³/d. Similar COD removal efficiency values have been reported in different studies [28, 31, 33]. Therefore, we have decided to terminate the reactor [59–61].

Similar to the COD graph, Fig. 5 shows the variation of influent, effluent and removal efficiency of BOD with time. The BOD values of raw wastewater at different time intervals vary between 1300 mg/l and 2808 mg/l, with an average BOD value of 1946 ± 607 (mg/l). The average value of diluted wastewater at the end of the first, second, third and fourth phase was 1120 mg/l, 610 mg/l, 1502 mg/l, and 1350 mg/l, respectively. The BOD removal efficiency at the end of the first, second, third and fourth phase was 84%, 88%, 85% and 98%, respectively. It is seen that in each dilution phase, BOD removal efficiency is increasing with time, despite variations in the influent BOD values. The variation in influent BOD does not affect the BOD removal efficiency, which shows that the microorganisms have become acclimatized to the slaughterhouse industry wastewater. At the termination time of the reactor, i.e., on the 62nd day, the BOD removal efficiency of the cylindrical SBR was 98% at an organic loading rate of 3.06 kg/m³/d. Similar BOD removal efficiency values have been reported in different studies [62, 63].

Figure 6 shows a laboratory snapshot of the glass beaker containing a sample of influent feed and treated effluent at the termination time of the reactor. It shows 97% COD removal and 98% BOD removal efficiency.

In biological systems, pH and alkalinity concentrations are essential parameters for bacterial metabolism. The pH value has an impact on determining the activity of microorganisms. For many microorganisms, the ideal living conditions are at a relatively neutral pH value. Figure 7 shows the variation of influent and effluent pH with time. In the present study, the pH was mostly found to be between 7.0 and 8.0.
This is beneficial for the proper functioning of the reactor [64]. A similar pH range has been reported in previous studies [65]. For organic carbon oxidation and nitrification, the pH value decreases; for ammonification and denitrification, the pH value increases [11]. Moreover, to avoid damage to the sewage systems and the connected treatment plants, the pH value of the discharged effluent should be between 5.5 and 9 [6].

The alkalinity of a system is used to determine the stability of the reactor. Because different degrees of nitrification (alkalinity consumption) and denitrification (alkalinity production) contribute to the change of alkalinity in the system, it has a close relationship with SBR operating parameters [11]. The alkalinity content regulates the pH level in the reactors. Bacterial growth was ensured by high alkalinity and pH control [66]. The alkalinity value of raw wastewater at different time intervals varies between 2250 and 3900, with an average value of 3062 ± 592. Figure 8 shows the variation of influent and effluent alkalinity with time. The effluent alkalinity was above 1000 mg/L for most of the time.

Since enough alkalinity is required for effective nitrification, this concentration is close to the recommended value of 1,000 mg/L as CaCO₃ [9, 59]. The treated effluent contained a total alkalinity concentration in the narrow range of 500–600 mg/L as CaCO₃ (Fig. 8).

The sludge volume index (SVI) and mixed liquid suspended solids (MLSS) concentration in the reactor were used to track biomass growth. In a muffle furnace, mixed liquor suspended solids (MLSS) and volatile liquor suspended solids (MLVSS) were measured using a gravimetric method at 103–105 °C and 550 °C, respectively. In the present study, VSS was 6370 mg/l and 7000 mg/l on the 56th day and 62nd day, respectively. The increase in VSS in the reactor indicated that the microorganisms were sprouting in a favorable environment [11]. This shows growth in microorganisms. This is beneficial for the efficient functioning of the reactor. Microorganisms convert organic matter into gaseous end products and new cells.

The settling quality of sludge is described by the Sludge Volume Index (SVI). It determines the sludge
recycling rate, and too much or too little may affect the performance of the reactor. In the present investigation, SVI was found to be 125 ml/g at the closing time of the reactor. It depicts flocculent settling, in which the sludge settles slowly and traps more particle matter before settling into a uniform blanket. For good biomass settling, SVI should be less than 100 ml/g [58].

The reactor contains a mixed culture of microbes; therefore oxidation of ammonia occurred due to nitriifying autotrophic bacteria. During carbon oxidation, a fraction of ammonia was assimilated by cell mass to synthesize new cells, and in the subsequent phase, dissimilatory ammonia removal happened to convert NH$_4^+$–N into NO$_2^-$–N and NO$_3^-$–N under aerobic conditions. Excess sludge was used to maintain a microbial concentration inside the reactor. In this study, the sludge retention time (SRT) was manually controlled by withdrawing a volume of mixed liquor from the reactor every 7–8 days, resulting in 60 percent nitrification at the reactor’s termination time. SRT should be longer than ten days to remove nitrogen efficiently [9, 11, 58].

Table 6 shows current legislation and discharge limitations for organics and nutrients in SWW for proper environmental release in various jurisdictions across the globe, including the World Bank Group [7], the US EPA [19], the Council of the European Communities [67], the People’s Republic of China Ministry of Environmental Protection [68], the Environment Canada [69], the Colombian Ministry of Environment and Sustainable Development Colombia [70], the Australian and New Zealand Environment and Conservation Council [71], and the Indian Central Pollution Control Board [3, 6]. The BOD, COD, TN, TSS, and pH of the effluent from the SBR reactor on the 62nd day at the reactor’s termination time are found to be within the allowable limits set by the Central Pollution Control Board (CPCB) of India.

### Table 6  Global comparison of slaughterhouse wastewater discharge standards and effluent from the present study

| Parameter | BOD$_5$(mg/l) | COD (mg/l) | TN (mg/l) | TP (mg/l) | TSS (mg/l) | pH | References |
|-----------|---------------|------------|-----------|-----------|------------|----|------------|
| World Bank| 30            | 125        | 10        | 2         | 50         | 6–9| [7]        |
| US EPA    | 16–26         | n.a        | 4–8       | n.a       | 20–30      | 6–9| [19]       |
| EU        | 25            | 125        | 10–15     | 1–2       | 35–60      | n.a| [67]       |
| China     | 20–100        | 100–300    | 15–20     | 0.1–1.0   | 20–30      | 6–9| [68]       |
| Canada    | 5–30          | n.a        | 1.25      | 1.0       | 5–30       | 6–9| [69]       |
| Colombia  | 50            | 150        | 10        | n.a       | 50         | 6–9| [70]       |
| Australia | 5–20          | 40         | 10–20     | 2         | 5–20       | 6–9| [71]       |
| India     | 30–100        | 250        | 10–50     | 5         | 100        | 5.5–9.0| [3, 6]     |
| Effluent from the SBR reactor on the 62nd day | 35 | 70 | 8.9 | n.a | 94 | 7.64 | [Present study] |

### Conclusions

According to the findings of this study, at the time of the reactor’s decommissioning, the BOD and COD removal efficiency at an organic loading rate of 3.06 kg/m$^3$/d was 98 percent and 97 percent, respectively. The effluent pH and alkalinity were within acceptable limits, and the reactor’s nitrification efficiency was around 60%. The findings suggested that cylindrical SBR would be a preferable solution for slaughterhouse wastewater treatment. It has successfully extracted organic and nutrient components from wastewater without the use of chemicals or the addition of additional expenditures. Furthermore, because the microorganisms have become accustomed to the wastewater, the hydraulic retention period of a 24-h cycle can be shortened by up to 12 h. However, the results of laboratory experiments may not realistically reflect the performance at polluted sites. As a result, more large-scale field studies are needed to determine the performance of cylindrical SBR on a commercial scale. Its application would assist the industry since it consumes less space and power.

### Declarations

**Conflict of interest**  The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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