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Short communication

Energy utilization and recirculation of currant-finishing wastewater

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Abstract

In this study, a new method for the treatment of currant-finishing wastewater was proposed in the context of the "clean technology" concept. This method consisted of two stages. In the first stage, the currant-finishing wastewater was recirculated in the currant-wash process and in the second stage this wastewater was utilized for the production of energy through anaerobic digestion. Recycling ratios from 0 to 95% were examined. By increasing the recycling ratio, effluent's COD increased from 3808 to 43,722 mg/l, effluent's BOD from 681 to 5378 mg/l, total sugars from 2.57 to 42.13 g/l, total phosphorous from 0.79 to 5.14 mg/l and total Kjeldahl nitrogen from 7.36 to 51.9 mg/l while fresh water addition decreased from 6 to 0.3 kg per kg of currants processed. The optimum recycling ratio range for the wastewater energy utilization proved to be 30–40%. In this range, the mass of COD and sugars digested was maximized resulting in the highest biogas production. Thus, the proposed system could be promising since water consumption is minimized and wastewater energy utilization is achieved rendering the process almost energetically self-sufficient.

Keywords: Currant; Currant-finishing wastewater; Wastewater reuse; Anaerobic digestion; Energy recovery

1. Introduction

The volume of currant-finishing wastewater (CFW) produced in Greece is estimated to be 4–6 m^3 per tonne of currants processed. The annual production of currants in Greece is about 80,000 tonnes for Sultana type currants and 87,000 tonnes for Corinthian type currants. Thus the corresponding CFW are of the order of 400,000 and 500,000 m^3, respectively, per year. These are disposed in the sea causing environmental pollution equivalent to a total population of 130,000 people [1].

The CFW are produced during currant washing. This is usually done by spraying fresh and recycled water in a primary washing unit followed by a SO_2 treatment unit for sterilization and decolourisation of currants. After this, there is a second washing unit where the currants are finally washed using just fresh water. The spent water goes through a fine rotating screen for suspended solids removal. Some of this screening wastewater is reused for washing while the remainder is rejected as CFW. The recycled wastewater is usually about 20–30% of the fresh water flow. At any time, the ratio of washing water to raw currants input in the primary washing unit is about 10/1 to 15/1 (weight per weight) [2].

CFW contains mainly sugars, tannins and colloidal suspended solids [3]. The concentration of sugars, mainly glucose and fructose, ranges between 10 and 30 g/l, while average COD values have been reported as 20,000–30,000 mg/l with a COD/BOD_5 ratio of around 10 [3]. A high COD/BOD_5 ratio indicates high toxicity of CFW, probably due to the presence of tannins extracted from the grape skin and from the use of SO_2 during processing.

A small amount of lipids is present in CFW. The level of total Kjeldahl nitrogen (TKN) varies from 50 to 100 mg/l and tends to follow the trend of COD. The pH of CFW is slightly acidic (∼6.3).

Among the common types of CFW treatment, aerobic biological oxidation (biofiltration/activated sludge) is considered to be an expensive option in terms of both capital and operational cost [4]. Alternatively, anaerobic digestion of CFW seems to be more advantageous than aerobic treatment due to the fact that it requires lower energy [3,5].

This paper reports on the possibility of recirculation of CFW in an effort to remove suspended and colloidal particles, minimizing water volume and energy under the philosophy of "clean

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technologies concept", while achieving the energy utilization of the wastewater through anaerobic digestion.

2. Materials and methods

2.1. Methodology

Fig. 1 is a block diagram illustrating the steps of the currant-wash process that were followed in the laboratory scale plant. The 0.5 kg of currants were washed using 3 kg of water for 10 min in the primary washing unit. The mixture was drained on a sieve and the drains were collected and filtered for the removal of solid wastes. The currants were led to a SO_2 treatment unit for sterilization and decolourisation. Then the currants were rewashed in the final washing unit with a mixture of fresh and recycled water. The drains of this unit were led to the primary washing unit.

The drains collected from the primary washing unit, after the solid wastes' removal, were treated with aluminium (1% w Al/w suspended solids) followed by lime for pH adjustment at 8.5 and by Praestol-2540 (0.05%, w/w). Praestol-2540 is a mildly anionic polyelectrolyte of the polyacrylamide type. The chemically treated effluent was transferred to a settling tank for sedimentation. After one hour, the separated sludge was removed by pumping it from the bottom of the settling tank and the supernatant liquid was divided into two portions: one portion was removed (in order to adjust the recycling ratio and to make the necessary chemical determinations) and the other was recycled.

The 0.5 kg of new currants were added to the primary washing unit and the process described above was repeated. Every sequence of trials was continued until there was no change of the effluent soluble characteristics; that is until steady state conditions were achieved.

The recycling ratio of the effluent was defined as follows:

$$r = \frac{Q_r}{Q_r + Q_{in}} \times 100\%$$

where r is the recycling ratio, Q_r the volume of effluent recycled per each trial, and Q_{in} is the volume of fresh water added per each trial.

The aim of each experiment was to determine the influence of the applied effluent recycling ratio on the characteristics of the discharged effluent.

Experiments were run under recycling ratios of 0–95% with a step of 5%. For each trial the following parameters of the discharged effluent were measured: BOD_5, COD, total phosphorous (TP), total Kjeldahl nitrogen (TKN) and total sugars (TS).

The discharged effluent was collected and was led to a UASB reactor (Fig. 2) with a volume of 20 l and operating temperature of 35 °C. The organic loading rate (OLR) was kept constant for all recycling ratios and equal to 5 g COD l^{-1} day^{-1}. In order to achieve this, the hydraulic retention time (HRT) varied from

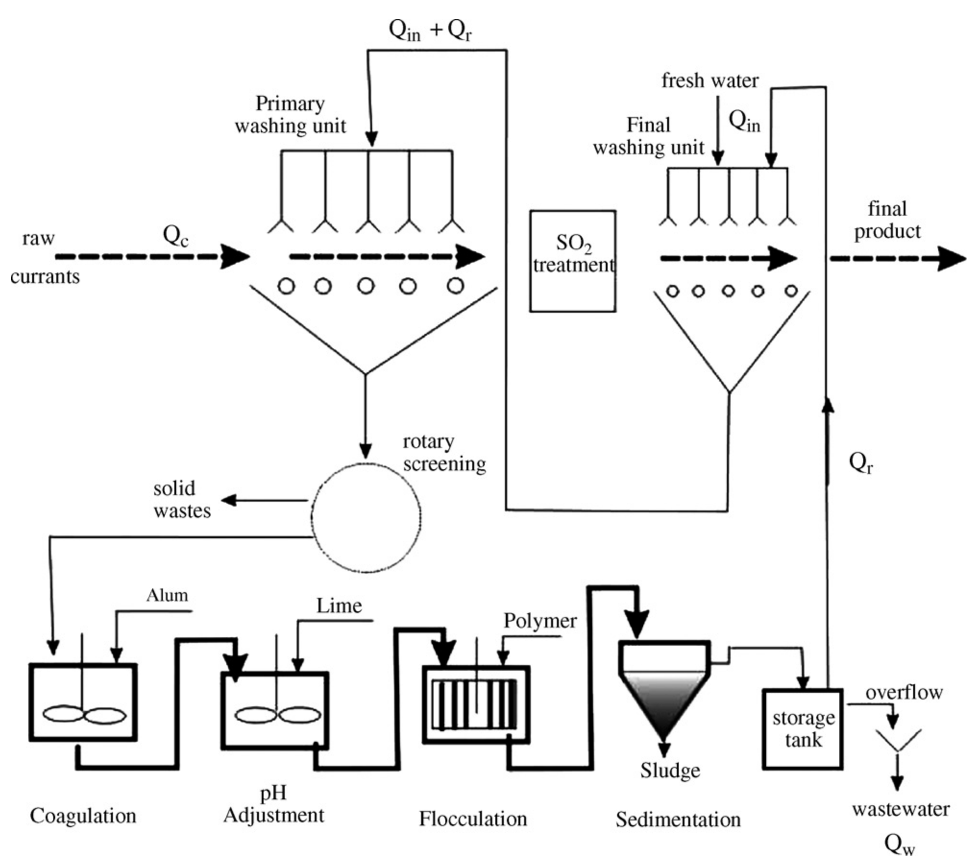

Fig. 1. Block diagram of laboratory pilot plant (currant-wash process–wastewater treatment).

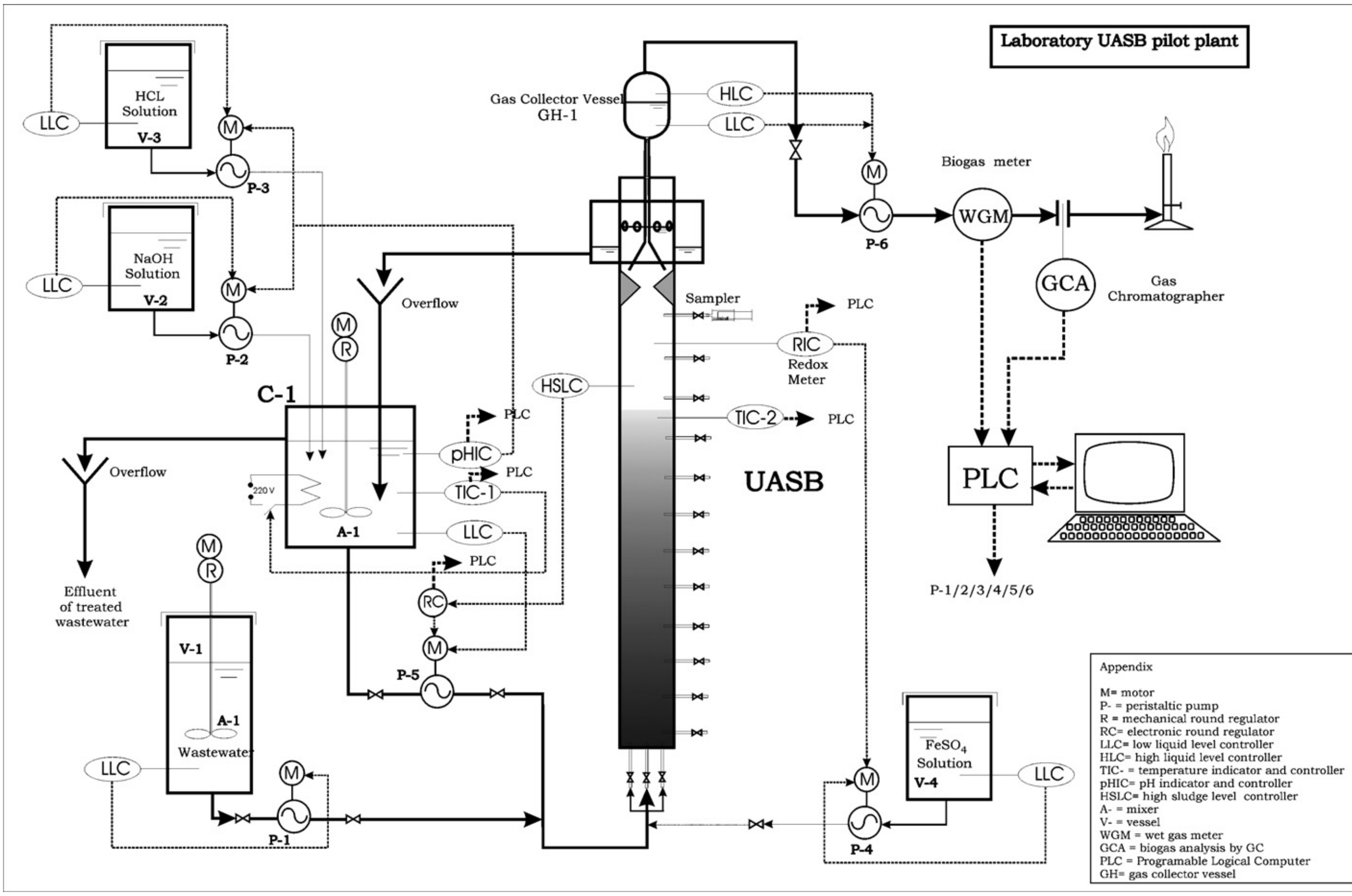

Fig. 2. Laboratory scale UASB reactor.

0.89 to 9.00 days. The choice of this loading rate was made in accordance with the experimental data of Athanasopoulos et al. [6]. They supported that the UASB reactor is the most favourable anaerobic reactor for the treatment of CFW and a high COD removal (85%) can be achieved for COD loading 15.7 kg m^{-3} day^{-1} [6].

During the reactor's operation, COD concentrations in the influent and effluent, gas production and composition were measured daily. The microbial communities of the UASB reactor were acclimated to currant-finishing wastewater. The main aim of this study was to examine the effect of recirculation ratio on the biogas production in a UASB reactor and not to examine the feasibility of anaerobic treatment of CFW.

2.2. Methods of analysis

COD, BOD_5, TKN and total phosphorous measurements were carried out according to Standard Methods [7]. Total phenolic compounds were measured with the Folin–Ciocalteu method [8]. Total sugars were determined according the official methods of analysis [9]. The produced gas was recorded by a wet gas meter (Ritter Gas meter Drum type TG01) and the gas composition was analysed by gas chromatography (HP Agilent 5890) using a thermal conductivity detector (TCD) and a packed column suitable for biogas. Argon was used as the carrier gas with flow rate of 30 ml min^{-1}. Statistical analysis of the results was carried out utilizing the techniques given by Taylor [10].

3. Results and discussion

3.1. Wastewater recirculation

An experiment scheduled for a given recycling ratio consisted of a sequence of trials which always attained steady state conditions at the end. So, for every experiment, each measured parameter was identified by a limiting value, which was attained under steady state conditions. For example, Fig. 3 presents the number of trials needed in order to reach steady state conditions in terms of BOD_5 concentration for a given recycling ratio. For $r = 0\%$, the limiting BOD_5 value was 681 mg/l. In order to draw conclusions on the influence of recycling ratio on the effluent's composition, the limiting values of the examined parameters were compared. In general, for all recycling ratios, 10 trials were enough in order to reach steady state.

The BOD_5 of the effluent was an exponential function of the recycling ratio (Fig. 4). Its lower value was about 681 mg/l at $r = 0\%$, while its highest value was about 5378 mg/l at $r = 95\%$.

As shown in Fig. 5, the estimated COD limiting value in relation to recycle ratio followed an exponential function (for $r = 0$ and 95% the COD limiting values were 3808 and 43,722 mg/l, respectively).

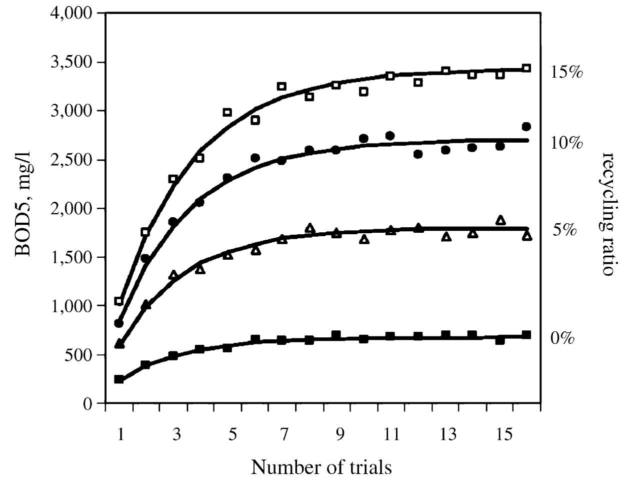

Fig. 3. Fluctuation of BOD_5 concentration for recycling ratios 0, 5, 10 and 15%.

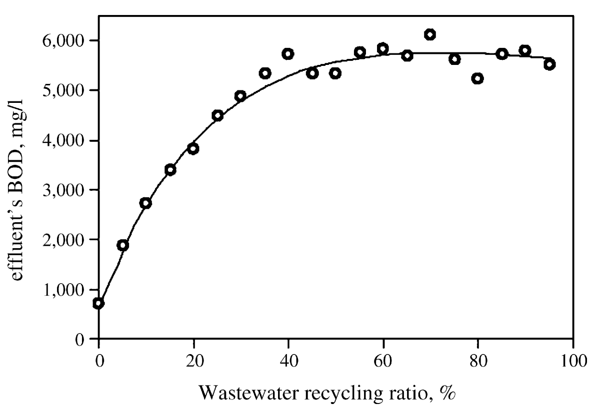

Fig. 4. Influence of the recycling ratio on the limiting BOD_5 value of the effluent.

The total sugars concentration limiting value was related to the recycle ratio by an exponential function (Fig. 6), starting from a concentration of 2.57 g/l at $r = 0\%$, while at $r = 95\%$ the limiting value of this parameter increased to 43.2 g/l.

The total phosphorous concentration limiting value increased as the recycle ratio was increased, from 0.73 mg/l at $r = 0\%$ to 5.14 at $r = 95\%$ (Fig. 7). As far as nitrogen is concerned, the TKN concentration limiting value increased as the recycle ratio was increased, from 7.6 mg/l at $r = 0\%$ to 51.9 mg/l at $r = 95\%$ (Fig. 8).

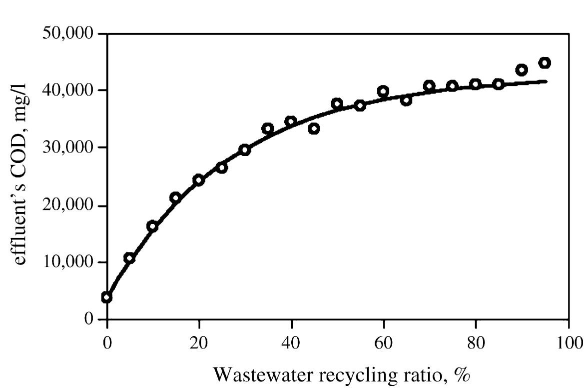

Fig. 5. Influence of the recycling ratio on the limiting COD value of the effluent.

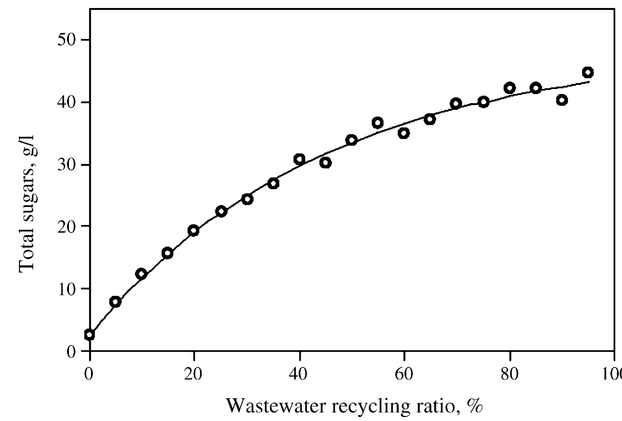

Fig. 6. Influence of the recycling ratio on the limiting value of total sugars of the effluent.

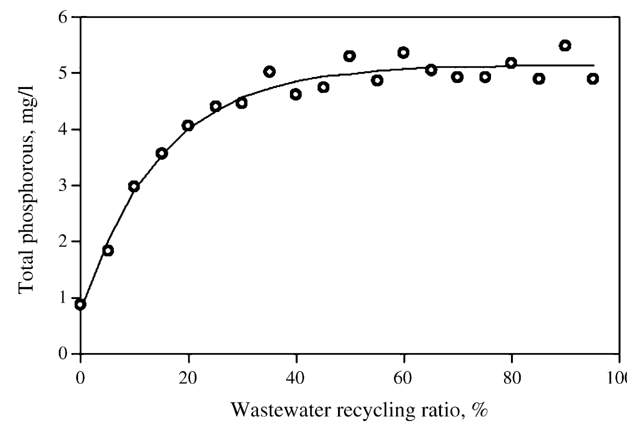

Fig. 7. Influence of the recycling ratio on the limiting value of total phosphorous of the effluent.

3.2. UASB reactor's performance

The influent COD of the UASB reactor varied from 4453 to 43895 mg/l (Fig. 5). Due to the constant organic loading rate, the operation of the UASB reactor was stable for all the recycling ratios, achieving a nearly constant COD removal of 85% for all cases. In Fig. 9 the produced biogas per kilogram of processed currants in relation to the recycling ratio is presented. It

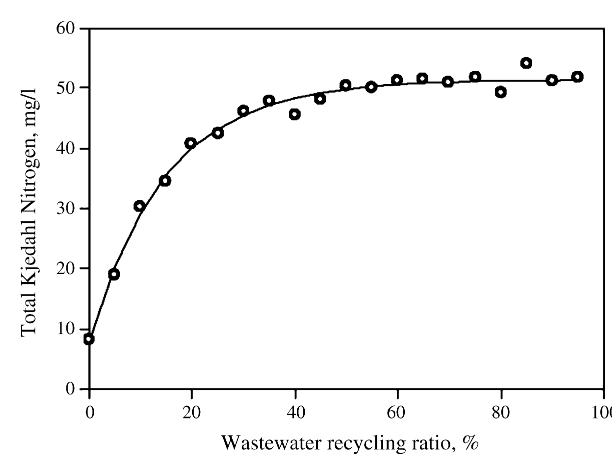

Fig. 8. Influence of the recycling ratio on the limiting TKN value of the effluent.

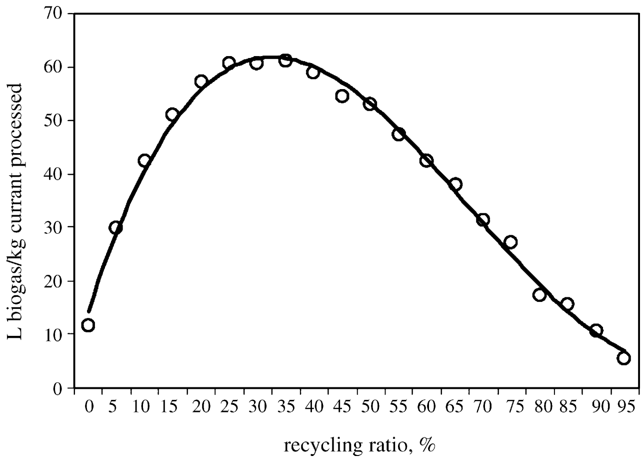

Fig. 9. Influence of the recycling ratio on the produced biogas per kilogram of processed currants.

is obvious that at a recycling ratio of 35% the produced biogas per kg of processed currants is maximized (61 l biogas/kg processed currant); in other worlds, at this recycling ratio, the best wastewater energy utilization is achieved. For the optimum recycling ratio ($r = 35\%$), the UASB reactor operated under the following conditions: HRT 7 days, influent COD 35,220 mg/l, effluent COD 4516 mg/l, COD removal 87%. As far as the biogas composition is concerned, it was also nearly constant, containing 85% methane. The high methane percentage can be attributed to the high concentration of sugars in the digested wastewater.

4. Conclusions

Currant-finishing wastewater is a typical Greek wastewater and that is the reason why just few researchers have dealt with this issue. Anaerobic treatment and especially UASB reactors have been proved favourable for the treatment of such wastewater. Given the strict environmental European policy and the concern about water consumption and energy recovery, integrated wastewater treatment methods should be implemented. In the present study, the feasibility of recirculation of currant-finishing wastewater in currant-wash process and of wastewater energy utilisation was investigated. It was proved that by recirculating CFW even in high recycling ratios, up to 95%, the currant-wash process took place smoothly and at the same time a number of profits derived.

- The water consumption was significantly reduced.
- The discharged effluents were proved to be susceptible to anaerobic digestion.
- For a recycling ratio of 35%, 61 l biogas were produced per kilogram of processed currants, which reflects the maximum energy recovery.

Conclusively, the proposed system could be promising since water consumption is limited and wastewater energy utilization is achieved rendering the process almost energetically self-sufficient.

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