

# Spinning Disc Technology – Residence Time Distribution and Efficiency in Textile Wastewater Treatment Application

E T Iacob Tudose<sup>1</sup> and C Zaharia<sup>1,\*</sup>

<sup>1</sup> “Gheorghe Asachi” Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection, 73 Prof.Dr.Docent D.Mangeron Blvd, 700050, Iasi, Romania

E-mail: czah@ch.tuiasi.ro

**Abstract.** The spinning disc (SD) technology has received increased attention in the last years due to its enhanced fluid flow features resulting in improved property transfers. The actual study focuses on characterization of the flow within a spinning disc system based on experimental data used to establish the residence time distribution (RTD) and its dependence on the feeding liquid flowrate and the disc rotational speed. To obtain these data, an inert tracer (sodium chloride) was injected as a pulse input in the liquid stream entering the disc and the salt concentration of the liquid leaving the disc was continuously recorded. The obtained data indicate that an increase in the liquid flowrate from 10 L/h to 30 L/h determines a narrower RTD function. Also, at rotational speed of 200 rpm, the residence time distribution is broader than that for 500 rpm and 800 rpm. The RTD data suggest that depending on the needed flow characteristics, one can choose a certain flowrate and rotational speed domain for its application. Also, the SD technology was used to process textile wastewater treated with bentonite (as both coagulation and discoloration agent) in order to investigate whether the quality indicators such as the total suspended solid content, turbidity and discoloration, can be improved. The experimental results are promising since the discoloration and the removals of suspended solids attained values of over 40%, and respectively, 50 %, depending on the effluent flowrate (10 l/h and 30 L/h), and the disc rotational speed (200 rpm, 550 rpm and 850 rpm) without any other addition of chemicals, or initiation of other simultaneous treatment processes (e.g., advanced oxidative, or reductive, or biochemical processes). This recommends spinning disc technology as a suitable and promising tool to improve different wastewater characteristics.

## 1. Introduction

Spinning disc (SD) technology involves the use of centrifugal force created by the rotation of the surface of a disc on which shaft a fluid is fed, and the formation on its surface of a thin film that travels predominantly radially to the edge of the disc.

Spinning disc (SD) or Spinning Disc Reactor (SDR) technology has received a lot of attention over the past few years due to the net superiority compared to conventional technologies [1-4].

Although SD technology has been studied for a long time, there are a number of issues that have not been sufficiently investigated and some new areas in which SD can be extremely efficient [5-6]. For example, the hydrodynamics of the film on the disc and, in particular, the achievement of a more uniform flow, close to the plug flow, but also some parameters that cause or, on the contrary, disrupt such an ideal flow, were not enough explored. Knowing such parameters can cause the reactor to operate at optimal parameters so as to obtain a higher final product quality.

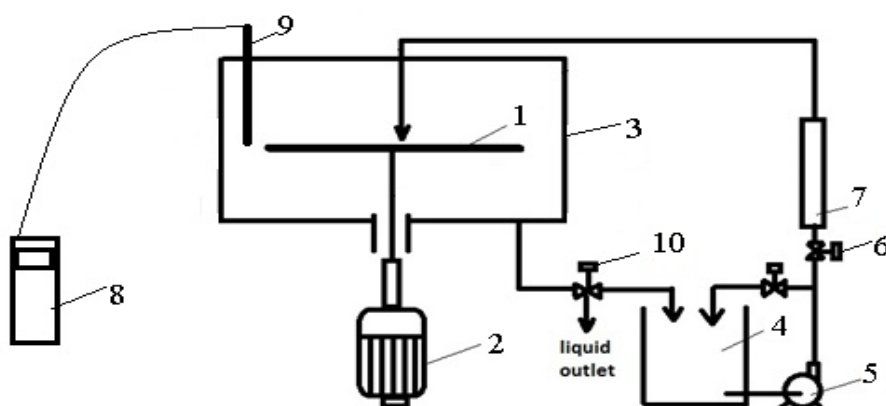


In this study, it was sought to gather information on the distribution of residence times in such a rotating disc (RD) system and the influence of some factors such as the liquid supply rate on the disc as well as the rotational speed. These data were used as a starting basis to investigate the SD technology efficiency on treatment of a textile effluent without initiation of any other process (mechanical-physical, chemical, or biochemical), or operation.

## 2. Experimental installation and measurement procedure. Data analysis and preliminary performance estimation methodology

### 2.1. Experimental installation laboratory setup

The set-up used to perform all experiments is presented in Figure 1. A rotating disc 1 of 20 cm diameter, connected to a variable speed, adjustable electric motor 2, encapsulated in an acrylic housing 3, was fed with water/wastewater from a tank 4, using a pump 5, passing a flow meter 5, with a preset flow rate from tap 6. The rotational disc speed was measured using a laser tachometer with an accuracy of  $\pm 0.1$  rpm. For the residence time distribution, a pre-calibrated WTW 315i Conductometer 8 with a probe 9 has been used to measure the water conductivity. The outlet liquid was collected for spectral measurements by means of tap 10.



**Figure 1.** Experimental set-up for RTD and wastewater quality measurements.

The working liquid was tap water for the residence time distribution and textile wastewater for the effluent quality indicators investigation, and also performance estimation of the SD experimental installation in textile effluent treatment.

The temperature was measured using a calibrated thermometer and was found to be practically constant, with a value of  $20\text{ }^{\circ}\text{C} \pm 0.1\text{ }^{\circ}\text{C}$  during each test run.

The measured conductivity was recorded and rendered the solution salt concentration at the disc outlet, while for the wastewater data, samples from the liquid outlet were collected and analyzed using a DR/2000 UV-VIS spectrophotometer (HACH Company).

### 2.2. Studied wastewater characterization

It has been worked with real industrial effluents, i.e. textile wastewaters, produced in a private NE Romanian company due to the chemical finishing stage of textile fabrics (cotton) after dyeing, and also 1st and 2nd rinsing steps [7, 8].

**2.2.1. Wastewater analytical analysis.** It depends firstly on the initial and after a few specific times ( $t_i$ ) supervision and sampling of untreated and/or treated textile wastewater from SDR outlet (exit of the experimental installation) and secondly on the analysis methods applied for characterization of wastewater samples, especially consisting in some specific quality indications such as pH, suspended

solids content, turbidity, colour, organic matter expressed as chemical oxygen demand (COD) and biochemical oxygen demand (BOD), etc.

All analyses were performed according with recognized standard methods, internationally approved, as well as specific reference materials and kits of analytical purity. In this work, it was used as coagulation agent only local indigen bentonite powder, that can be considered also a potential discoloration agent for the studied textile wastewater [9].

**2.2.2. PH determination.** It was measured directly at HACH One Laboratory pH meter (HACH Co.).

**Colour determination.** It was measured the absorbance related to a blank with distilled water, measured at three different standard characteristic wavelengths (SR ISO 7887-97) meaning 436, 525, and 620 nm, especially at 436 nm for industrial wastewaters (*apparent colour* in supernatant, or *real colour* in filtrate), or Hazen colour index (Hazen units – HU, i.e. an absorbance of 0.069 at 456 nm corresponds to 50 HU).

**2.2.3. Suspended solids determination.** It was measured directly at 630 nm (in mg/L) using a DR/2000 spectrophotometer-based methodology (test program #630) under a blank with distilled water.

**2.2.4. Turbidity determination.** It was measured directly at 450 nm (in FTU) using the DR/2000 spectrophotometer-based methodology (test program #750) under a blank with distilled water.

**2.2.5. COD<sub>Cr</sub> determination.** It was used the COD reactor' methodology, based on a 2h-oxidation at 150°C in the presence of a strong oxidation agent (H<sub>2</sub>SO<sub>4</sub> conc. and K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> 0.25 N) and catalyst (HgSO<sub>4</sub>) and chloride inhibitory agent (Ag<sub>2</sub>SO<sub>4</sub>). The calibration of test program was performed with potassium acid phthalate as COD-Cr calibration reagent solution.

The performed experimental results will permit the estimation of SDR technology performance in terms of suspended solids and turbidity removals, and also of colour removal, or textile wastewater discoloration.

The higher the value of studied species removal the better the performance of SD technology is. It can be determined the minimal and maximal removal efficiency of wastewater treatment based on SDR technology without any other chemical adding, or can be initiated supplementary operations or processes for SD technology performance improvement. That is why, these basic results are significant for the further treatment optimization possibilities.

### 2.3. Data analysis methodology

The data has been processed in Excel files using the following equations for calculating the RTD values:

- the residence time distribution indicating the variation of tracer concentration at the disc exit:

$$E(t) = \frac{C(t)}{\int_0^\infty C(t)dt} \quad (1)$$

- the dimensionless residence time distribution:

$$E(\theta) = \tau E(t) \quad (2)$$

with  $\tau$  - the mean residence time:

$$\tau = \frac{\sum t_i C_i \Delta t_i}{\sum C_i \Delta t_i} \quad (3)$$

where  $C_i$  is the measured salt concentration at the time  $t_i$ .

The variance  $\sigma^2$  and the normalized variance  $\sigma_\theta^2$  are determined as

$$\sigma^2 = \frac{\int_0^\infty t^2 C dt}{\int_0^\infty C dt} - \tau^2 \quad (4)$$

$$\sigma_\theta^2 = \frac{\sigma^2}{\tau^2} \quad (5)$$

and the dispersion number, defined by  $D/u_m R$ , is calculated from the normalized variance [10], for open-open boundary conditions with the equation:

$$\sigma_\theta^2 = 2 \frac{D}{u_m R} + 8 \left[ \frac{D}{u_m R} \right]^2 \quad (6)$$

where  $D$  is the dispersion coefficient ( $\text{m}^2\text{s}^{-1}$ ),  $u_m$  is the radial mean velocity across the disc ( $\text{ms}^{-1}$ ),  $R$  is the disc radius (m).

The dispersion number is a measure of the ratio of the rate of transport by diffusion and the rate of transport by convection, thus if the dispersion number is very small, the dispersion is negligible, hence the flow attains plug hydrodynamics.

The efficiency of SD technology applied in the case of the studied textile wastewaters was established based on the calculation of the removal efficiency (%),  $R$ , using the well known relation:

$$R (\%) = \frac{C_i - C_f}{C_i} * 100 \quad (7)$$

where,  $C_i$  is the initial value of studied quality indicator (mg/L, or FTU, or HU) and  $C_f$  is the final (after  $t$  time) value of studied quality indicator (mg/L, or FTU, or HU).

### 3. Results and discussions

#### 3.1. Liquid flowrate and disc rotational speed influence on the residence time distribution

**3.1.1. Feeding flow rate influence on the residence time distribution.** Figure 2 a, b, c shows the normalized distribution functions of the non-dimensional residence times  $E(\theta)$  calculated with the formulas presented above, at two different flow rates of 10 and 30 L / h, at a constant rotational speed, with values of 200, 500 and 800 rpm, respectively.

Absolutely all distributions have a characteristic, relatively symmetrical shape, however the presented experimental data show that an increase in the liquid flow rate for a constant disc speed generally results in a narrower distribution of the residence times and a higher maximum value  $E(\theta)$  for the higher liquid flowrate, indicating closer hydrodynamics to plug flow.

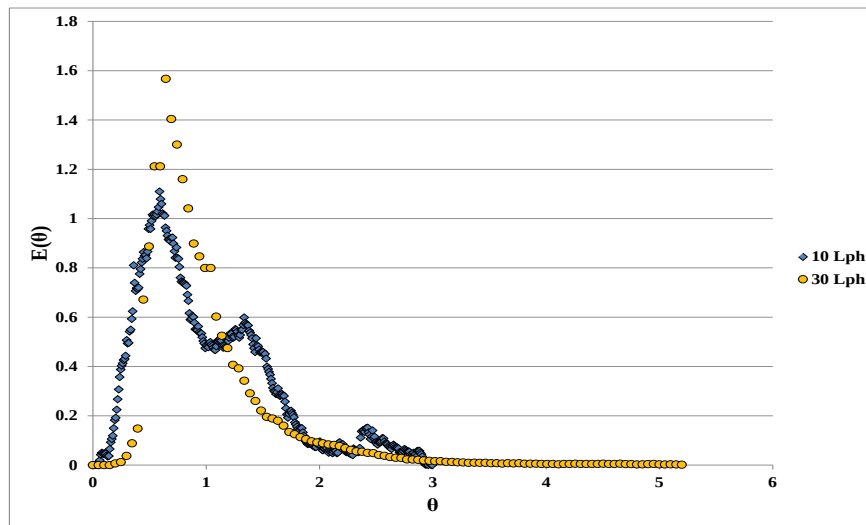
One can observe that, at the lowest liquid flowrate of 10 L/h, the  $E(\theta)$  function presents some two other smaller peaks indicating some less active areas on the disc.

Comparison to some other literature data <sup>[11]</sup>, even though performed for some different flowrates and rotational speeds, indicate similar trends in RTD curves.

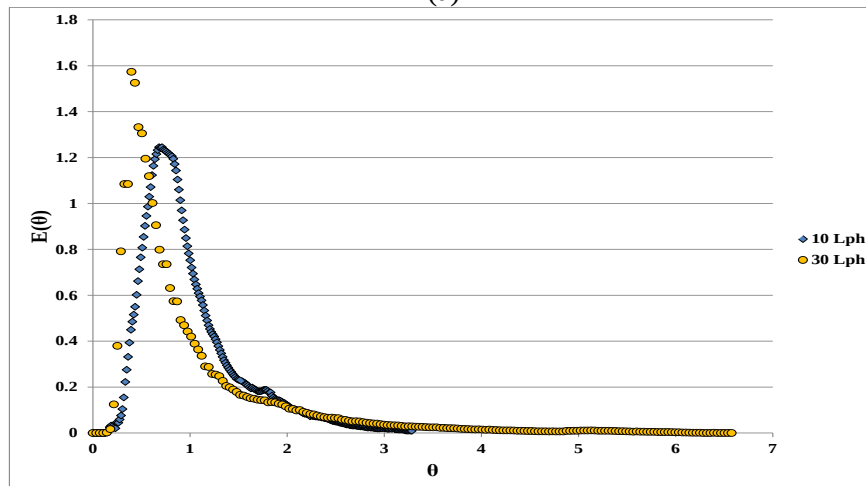
**3.1.2 Rotational speed influence on the residence time distribution.** Figure 3 a and b indicates the influence of the disc rotational speed on the residence time distribution at 10 l/h and respectively, 30 l/h. One can observe that an increase in the rotational speed renders a narrower distribution of  $E(\theta)$  function, suggesting a disc flow hydrodynamics closer to the ideal plug flow.

However, the experimental data obtained at a rotational speed of 800 rpm were not included, since, especially at the larger flowrate of 30 L/h, a slight liquid atomization occurred, so the measured liquid salt content at 800 rpm was smaller and the rendered conductivity signal was slightly less than the 500 rpm conductivity signal.

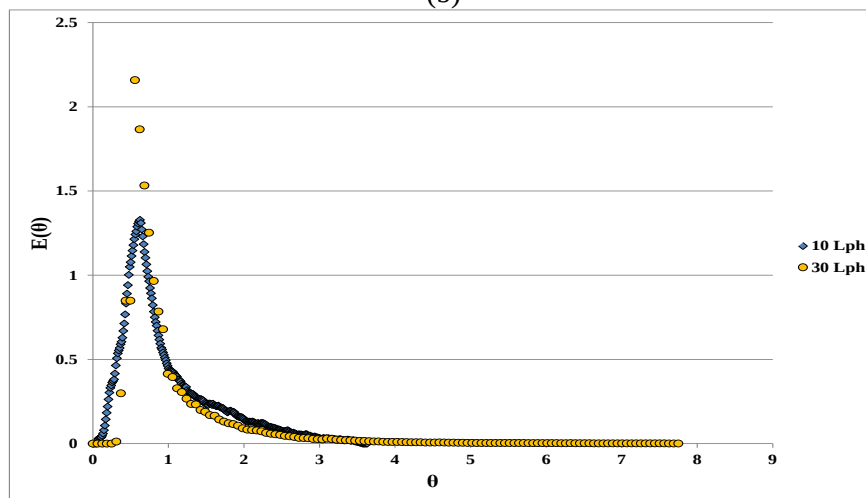
Estimations of the dispersion number, using the equation (6), are presented in Table 1 and indicate furthermore that at low flowrates such as 10 Lph, the dispersion number decreases with the increase in the disc rotational speed. The trend is followed also at 30 Lph, for a disc rotational speed increase from 200 rpm to 500 rpm, however an increase at 800 rpm renders a lower dispersion, possibly due to the already mentioned slight liquid atomization.



(a)

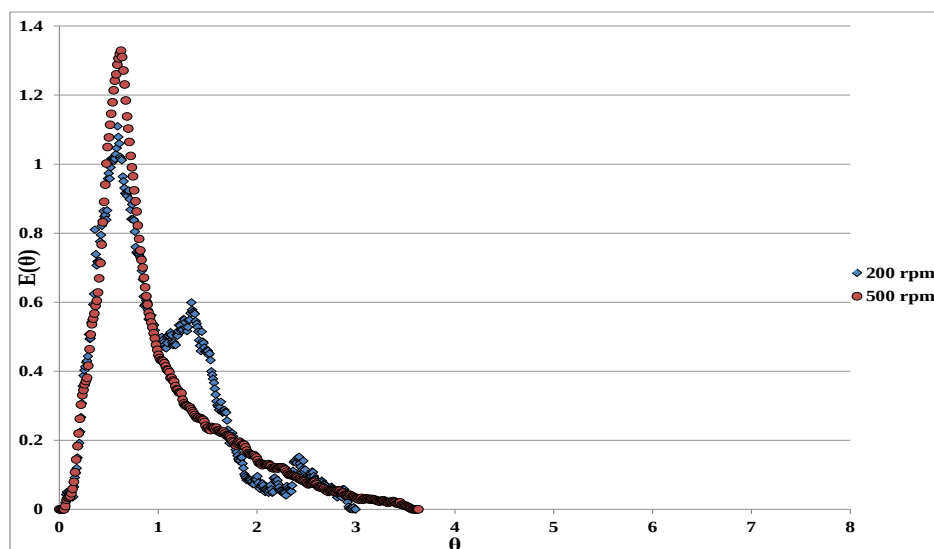


(b)

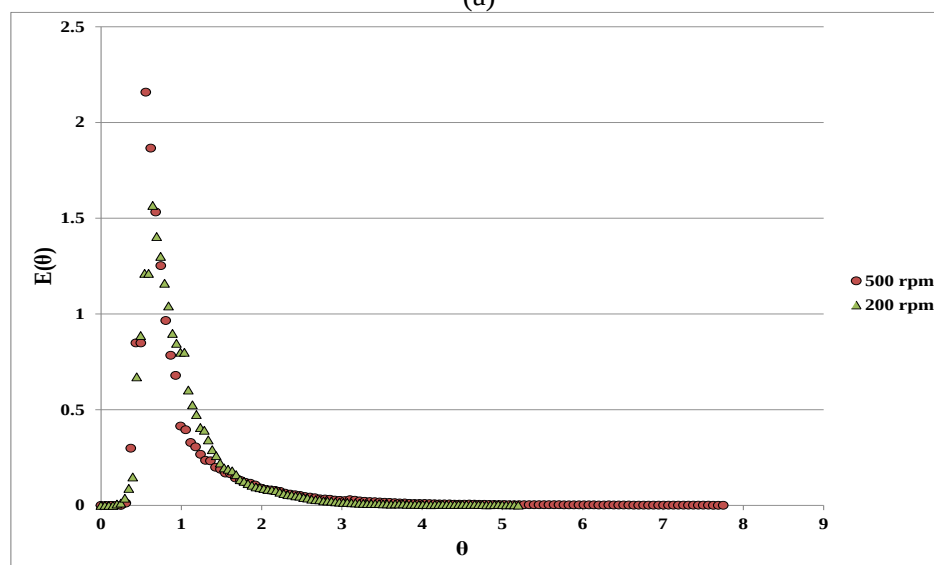


(c)

**Figure 2 (a-c).** Water flow rate influence on residence time distribution for different disc rotational speeds (a) 200 rpm, (b) 500 rpm, (c) 800 rpm.



(a)



(b)

**Figure 3 (a-b).** Disc rotational speed influence on residence time distribution for different water flowrate values (a) 10 L/h, (b) 30 L/h.

**Table 1.** Dispersion number for different water flow rates and disc rotational speeds.

| Liquid flow rate<br>[L/h] | Disc rotational speed [rpm] |          |          |
|---------------------------|-----------------------------|----------|----------|
|                           | 200                         | 500      | 800      |
| 10                        | 0.430811                    | 0.417594 | 0.261875 |
| 30                        | 0.323889                    | 0.569083 | 0.168079 |

### 3.2. Textile wastewater treatment performance using SD technology laboratory setup

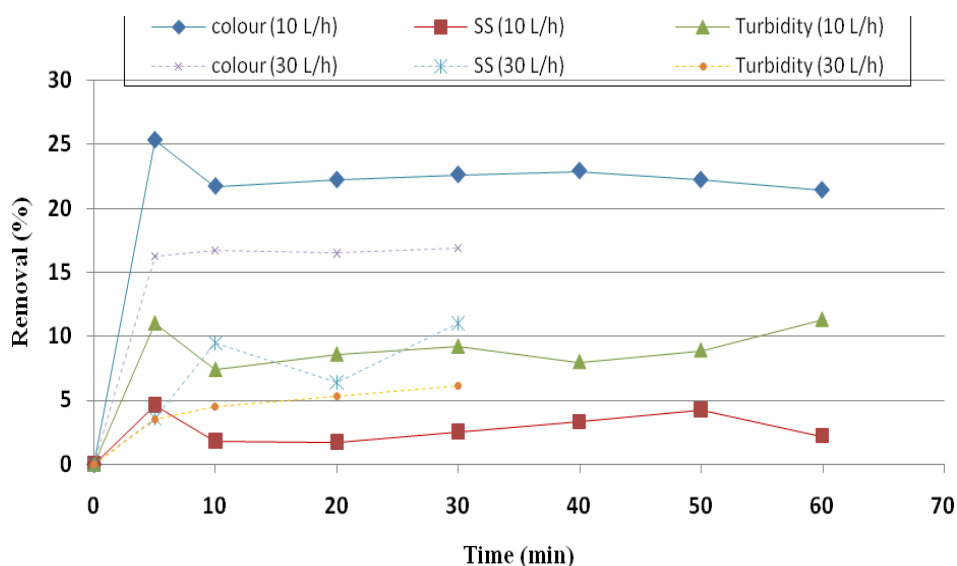
The main characteristics of the textile wastewater analyzed in the SD system and the maximum admissible concentrations are presented in Table 2 [7-8]. The NE Romanian textile company is manufacturing cotton fabrics and the studied wastewaters are being generated from fabrics coloured from yellow to red.

**Table 2.** The main characteristics of the studied textile wastewater and the maximum admissible concentrations.

| Quality indicators                      | Measured value<br>[mg/L] | M.A.C.*<br>[mg/L] | Quality indicators        | Measured<br>value<br>[mg/L] | M.A.C.*<br>[mg/L] |
|-----------------------------------------|--------------------------|-------------------|---------------------------|-----------------------------|-------------------|
| pH                                      | 7.49-7.75                | 6.50-8.50         | Total P                   | 5.72-6.39                   | 1                 |
| Colour, HU<br>(A <sub>436</sub> )       | 871-4447<br>(1.203-2.57) | 50                | Extractible<br>substances | 25.44-31.67                 | 20                |
| Suspended solids                        | 386-900                  | 35 (60)           | Total N                   | 8.34-9.80                   | 10                |
| Turbidity, FTU                          | 185-808                  | -                 | Ammonia                   | 2.10-2.45                   | 2                 |
| Fixed residues                          | 3600-4000                | 1000              | Sulfates                  | 782.34-810                  | 600               |
| COD, mg O <sub>2</sub> /L               | 564.12-650.24            | 125               | Chlorides                 | 98.56-138.23                | 70                |
| CBO <sub>5</sub> , mg O <sub>2</sub> /L | 322.10                   | 25                | Phenol index              | 2.63-3.26                   | 0.30              |
| Synthetic<br>detergents                 | 1.78-2.10                | 0.50              | Total heavy metal<br>ions | < 4                         | < 2 (max 5)       |

\* M.A.C.- maximum admissible concentration, according with Romanian Government Decision No. 352/2005-Technical Norms for Treated Wastewater Discharged in Natural Water Resources (NTPA 001)

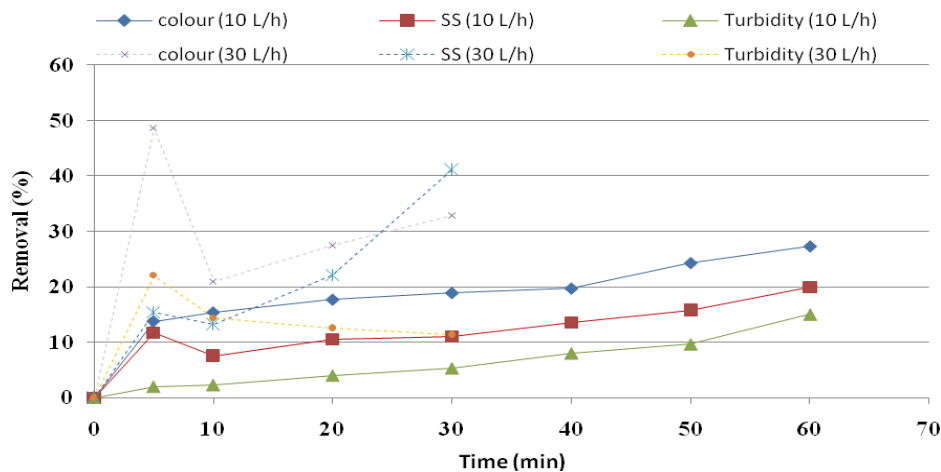
**3.2.1. Flowrate influence on the effluent treatment efficiency using SD technology setup.** Considering the obtained values of all studied quality indicators measured at a rotation speed of 550 rpm, when SD technology was applied to textile effluents, the highest removals of colour, suspended solids and turbidity were, respectively, of 21.449 % (10 L/h), 13.004 % (30 L/h) and 11.30 % (10 L/h), as it is illustrated in Figure 4.

**Figure 4.** Variation in time of studied removal efficiencies at 550 rpm for two flowrates (10, 30 L/h).

The 10 l/h flowrate value was the most indicated to perform the highest removal in terms of colour, however, for the suspended solids and turbidity the highest removals were obtained for the higher flowrate of 30 L/h. Thus, at a rotational speed of 550 rpm a clear influence of flowrate cannot be stated at this point. At a rotation speed of 850 rpm, the experimental results presented in figure 6 indicated that

the highest removals were performed at the high flowrate (30 l/h) for all studied quality indicators, i.e. colour (48.6%, after 5 min), suspended solids (22.1%, after 5 min) and turbidity (22.02%, after 5 min).

**3.2.2. Rotation speed influence on the treatment efficiency using SD laboratory setup.** At a low flow rate of 10 l/h and 500 rpm, a relatively constant efficiency in colour removal (between 20.229 - 22.988 %) was found during the first tested 40 minutes, afterwards, a slight decrease was registered, as presented in figure 6a.



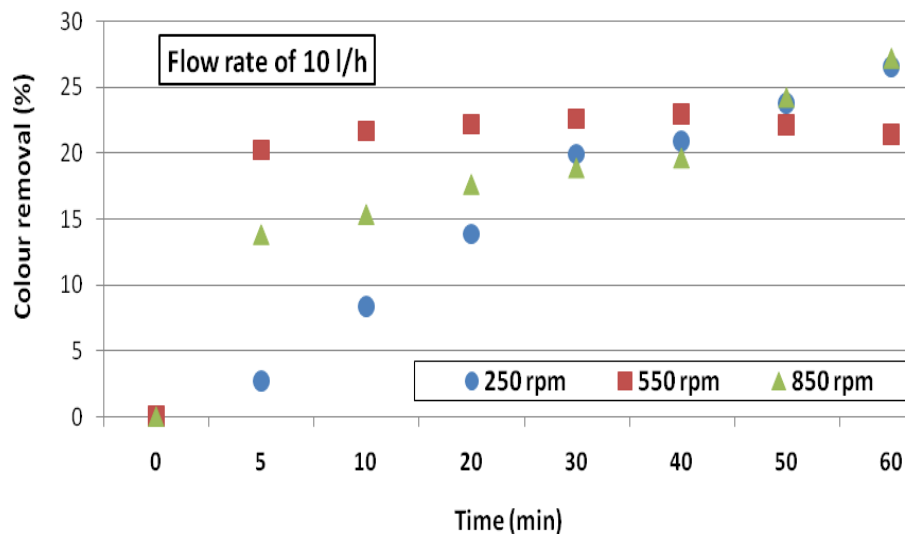
**Figure 5.** Variation in time of studied removal efficiencies at 850 rpm for two flowrates (10, 30 L/h).

At the same flow rate of 10 l/h and a rotational disc speed of 250 rpm and respectively, of 850 rpm, lower values for colour removal, namely 2.725 - 19.967 % and, respectively, 13.84 - 18.919 %, were obtained, during the first 30 minutes measuring time interval. However, after 50 min, the discoloration degree increased up to 27.260 % for a flow rate of 10 l/h (Figure 6a) and up to 32.93 % for a flow rate of 30 l/h (Figure 6b). All experimental results concerning the maximal efficiency in suspended solids and turbidity removal are summarized in Table 3. One can observe that the highest removal for suspended solids (54.29 %) and turbidity (49.07 %) are obtained at a flow rate of 10 L/h and a rotational speed of 250 rpm, after 60 min.

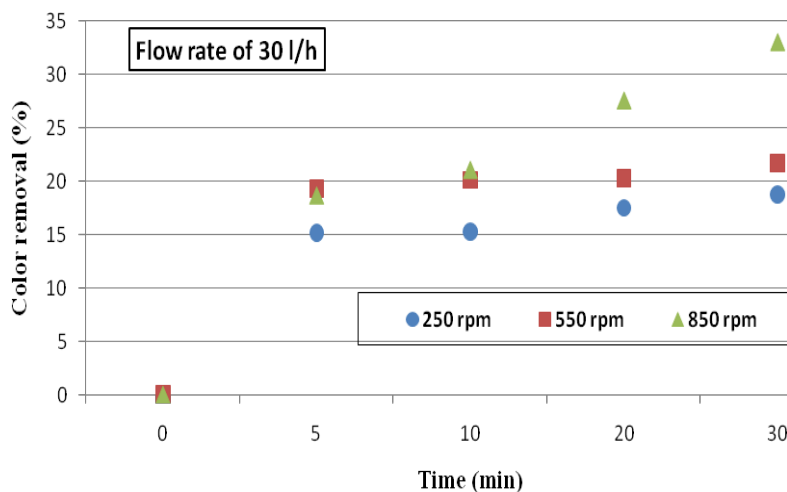
The effluent treatment efficiency by SD technology in the laboratory setup is relatively good considering that no other chemical, mechanical-physical, or biological treatment processes or operations were applied, and, thus, this can be used to minimize the suspended solids and turbidity loads within a relatively short period of time (no more than 30 min for a flow rate of 30 L/h, or 60 min for a flow rate of 10 l/h, as seen in Table 3).

**Table 3.** Maximal values of suspended solids (SS) and turbidity removal for SD technology setup.

| Rotation speed<br>[rpm] | Flow rate<br>[L/h] | SS removal<br>[%] | Operating time<br>[min] | Turbidity removal<br>[FTU] | Operating time<br>[min] |
|-------------------------|--------------------|-------------------|-------------------------|----------------------------|-------------------------|
| 250                     | 10                 | 54.29             | 60                      | 49.07                      | 60                      |
|                         | 30                 | 1.52              | 30                      | 2.36                       | 30                      |
| 550                     | 10                 | 4.23              | 50                      | 11.32                      | 60                      |
|                         | 30                 | 13.03             | 30                      | 6.12                       | 30                      |
| 850                     | 10                 | 19.93             | 60                      | 14.95                      | 60                      |
|                         | 30                 | 41.15             | 30                      | 22.02                      | 5                       |



(a)



(b)

**Figure 6 (a-b).** Variation in time of colour removal efficiencies at three different rotational speeds.

These results provide significant reference data to initiate a few new technological improvements of textile wastewater treatment based on SD technology and also, process optimization.

#### 4. Conclusions

The experiments performed to obtain the residence time distribution in order to characterize the flow on a spinning disc indicated that an increase in the liquid flowrate from 10 L/h to 30 L/h determines a narrower RTD function and, also, at a rotational speed of 200 rpm, the residence time distribution is broader than that for 500 rpm. The RTD data suggest that depending on the needed flow characteristics, either plug or stirred flow, one can choose a certain flowrate and rotational speed domain for its application.

The maximal obtained efficiency of SD technology applied for textile wastewater treatment without any supplementary process or operation is very good for the flowrate of 10 L/h and rotational speed of 250 rpm, after 60 min of application (22.99 % for colour, 54.29 % for SS, and 49.07 % for turbidity),

and also for the flowrate of 30 L/h working, at a rotational speed of 850 rpm, for 30 min of application (48.06 % for colour after only 5 min, 41.15 % for SS, and 22.02 % for turbidity after 5 min).

These experimental results determined on textile wastewaters demonstrate the feasibility of SD technology application for removal of some polluting species from different systems.

## 5. References

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