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Separation of Solids from Washing Machine Waste Water using a Hydrocyclone

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Abstract

In mineral processing and chemical industry, hydrocyclones are widely used for solid/liquid separation [1]. The present work shows investigations whether a hydrocyclone can also be used to separate impurities from waste water, focusing on waste water from washing machine drains. In this respect, two different samples of waste water, the "washing water" and the "synthetic water" are used. Here, a separation was achieved by using the "washing water" containing cotton fibres, PES fibres, hair, detergent and grease residues. However, by using the "synthetic water" no separation could be achieved due to the small microplastic particles.

Introduction

The aim of this investigation is to verify whether a hydrocyclone can be used to separate impurities from washing machine waste water. Depending on the application, the waste water can be contaminated with cotton fibres, polyester (PES) fibres, hair and many other impurities [2]. Just for reference, a single garment can lose more than 1,900 PES fibres per washing cycle [3], which then, can hardly be separated in waste water treatment plants. Ideally, these impurities could be separated by a hydrocyclone in washing machines so that these impurities do not enter the wastewater in the first place.
In general, the physical principles for the separation of solids from liquids range from sedimentation in a gravitational or centrifugal field to the retention of solids in porous material (filtration) [4]. Fig. 1 shows a simplified representation of the apparatus and its functionality. The material flows are the contaminated raw liquid (RAW), the separated particles (PART) and the purified liquid (CLEAN) entering the apparatus.

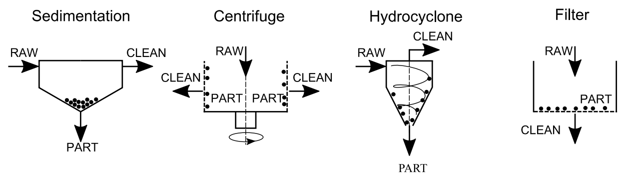

Fig. 1: Different principles for solid-liquid separation [4]

During sedimentation, the particles are separated by settling down by gravity. The most common sedimentation apparatuses are sedimentation tanks. Centrifuges and hydrocyclones are also assigned to sedimentation apparatus, whereby particles are separated by centrifugal forces. Due to higher centrifugal forces compared to gravitational force, the settling velocity can be increased [4]. During filtration, the particles are separated on a filter medium, while the cleaned liquid can pass through the filter medium. The effect is based on diffusion, electrostatic, inertial and barrier effects [5].

According to the task and technical requirements following boundary conditions [6] could be defined:

- Selectivity: The impurities should be separated in the best possible way.
- Low maintenance requirements: The separating equip-ment should have hardly any wearing parts.
- Simple construction: Complex installations increase the risk of blockages during operation of the apparatus.
- Low operating costs: Operating costs for the apparatus must be kept low. Apparatuses that require consumables (e.g. filter media, lubricants) in addition to energy are only suitable to a limited extent.
- Little space demand: The installation of the device must not be complex and should take up little space. A compact design is required.
- Simple integration: A simple integration results mainly from little space demand.

Based on the boundary conditions described above, the different separation principles can be qualitatively evaluated. Sedimentation tanks are not suitable for the given application due to the large space requirement resulting in difficult integration. Centrifuges are widely used at low flow rates, but have a complex geometry and moving parts, which makes centrifuges not suitable [5]. Filter devices (hydrostatically operated, suction and pressure filters) can be easily integrated, but have higher operating or maintenance costs, e. g. due to replacement of the filter medium [5].
After the qualitative evaluation, the use of a hydrocyclone appears to be the most promising. This apparatus has a compact design and the selectivity can be adjusted by adapting the geometry accordingly. In addition, the operating costs result mainly because of the power needed to operate the hydrocyclone. However, increased wear could be a disadvantage due to the high velocities inside the separation chamber [7]. Furthermore, the hydrocyclone is only suitable to a limited extent for medium and high viscosity media, since particle movement in the centrifugal field is inhibited by the viscosity of the medium [1].
However, since the present problem refers to contaminated waste water from washing machine drains, the limitation in terms of viscosity and wear and tear does not cause any problems. This study will also show whether the hydrocyclone provides the appropriate selectivity to separate even small microplastic particles.

Method

Two different samples of washing machine waste water are used for the experiments:

- "Washing water": Water from a washing process containing cotton fibres, PES fibres, hair, detergent and grease residues.
- "Synthetic water": Water which is derived from the washing cycles of pure synthetic garments without detergents or other additives and thus contains PES fibres only.

Fig. 2 and Fig. 3 show the two different samples of washing machine waste water. Whereas sedimented fibres can be qualitatively observed in the "washing water", no visible solids can be identified in "synthetic water".

Fig. 2: “washing water” – sample with sedimented fibres

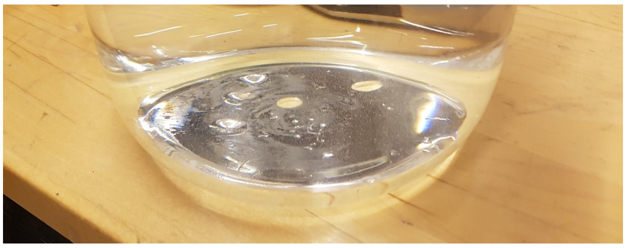

Fig. 3: “synthetic water” – sample without any visible impurities

The test rig (see Fig. 4) was developed particularly for tasks in the field of solid-liquid separation. The operating parameters are in the following ranges:

- Flow rate: 0.2 to 40 m³/h
- Pressure: up to 4 bar
- Solid mass flow of dosing unit: 10 g/h to several kg/h
- Operating mode: circulation or final separator operation
- Smallest separable particle size: 0.75 µm (bag filter)

Depending on the task, model hydrocyclones are manufactured individually using rapid prototyping or other manufacturing processes.

Fig. 4: test rig for solid-liquid separation

For the present task, the hydrocyclone was designed for a flow rate of 1 m³/h according to the principles of [6] and was manufactured by using rapid prototyping. The manufactured hydrocyclone can be seen in Fig. 5.

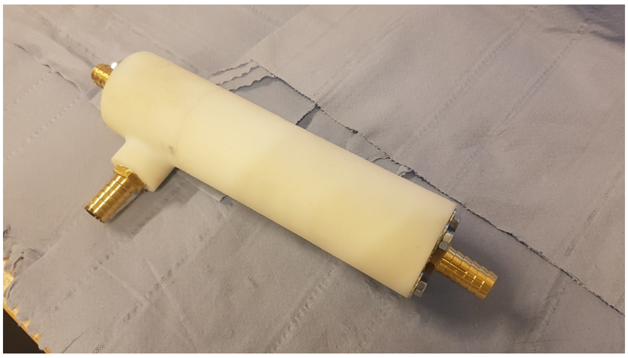

Fig. 5: Manufactured hydrocyclone using rapid prototyping

A simplified flow chart of the test rig is shown in Fig. 6. The waste water is conveyed to the hydrocyclone by a circulation pump from a reservoir, containing the respective water sample. The highly contaminated underflow as well as the cleaned overflow are then recirculated into the reservoir. The main fluid flow is controlled by a magnetic-inductive sensor and the respective circulation pump. The actual setup can be seen in Fig. 7.

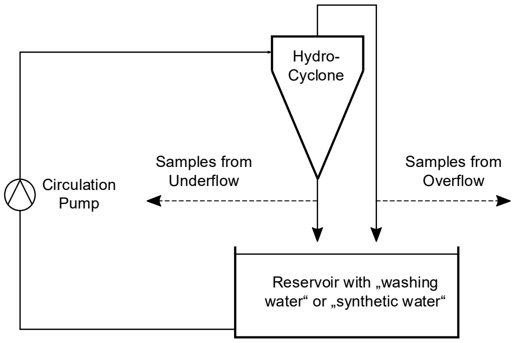

Fig. 6: Schematic representation of the test rig for the experiments

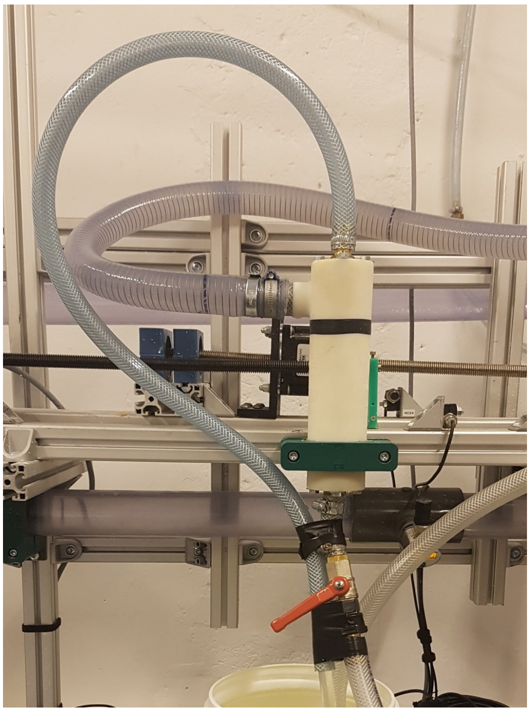

Fig. 7: Setup for the experiments

To evaluate the separation performance of the hydrocyclone, samples are taken from the underflow and overflow. After drying the samples in a drying cabinet, the concentration or specific dry matter of impurities is determined in the respective partial flow. If the specific dry matter in the underflow is greater than that in the overflow, the hydrocyclone can be classified as suitable.
The underflow is considered as particularly significant regarding separation performance [4]. The setting of the underflow, typically in the range of 2 to 10 % of the main fluid flow [6], is adjusted by a valve in the underflow downstream the hydrocyclone. For the present investigations, an underflow of 3 % of the main fluid flow (0.03 m³/h) was defined. In case of a successful separation, the underflow should contain the separated impurities, while the overflow should be almost free of them.
For the "washing water" as well as for the "synthetic water" three equivalent experiments are carried out in order to determine an average of the samples from the underflow and overflow.

Results and Discussion

In the following section the results for the "washing water" on the one hand as well as the results for the "synthetic water" on the other hand are presented. The test procedure was the same for both water samples.
Fig. 8 and Fig. 9 show illuminated pictures of the samples from the underflow and overflow after separation, which enable a qualitative evaluation of the separation performance of the hydrocyclone in the first place. It can be observed that visible fibers have accumulated in the underflow, whereas the overflow contains hardly any visible fibers.

Fig. 8: Illuminated sample from the underflow with clearly visible fiber content

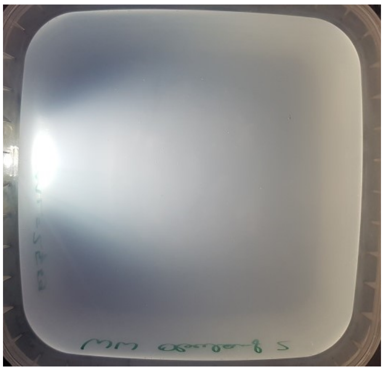

Fig. 9: Illuminated sample from the overflow without any visible fiber content

It can be concluded that a centrifugal separator of the present design and operating mode is suitable for this separation task.
In addition, Tab. 1 and Tab. 2 show the measurement results after drying the individual samples.

Here, too, increased dry residue or specific dry matter of impurities in the underflow have been verified. The abbreviation "MV" describes the mean value of the repeated experiments.

Tab. 1: Specific dry matter in the underflow after tests with the “washing water”

Samples	Partial flow	#	Spec. dry matter
Washing water	Underflow	1	1.980 mg/ml
		2	2.332 mg/ml
		3	1.598 mg/ml
		MV	**1.970 mg/ml**

Tab. 2: Specific dry matter in the overflow after tests with the “washing water”

Samples	Partial flow	#	Spec. dry matter
Washing water	Overflow	1	1.072 mg/ml
		2	1.023 mg/ml
		3	1.046 mg/ml
		MV	**1.047 mg/ml**

Fig. 10 and Fig. 11 show pictures of the samples from the underflow and overflow, however, here with regard to the experiments with the "synthetic water". Since no visible solids (sedimented fibers) were identified in the sample of "synthetic water" in Fig. 3, no visible separated solids could be detected qualitatively after the separation by the hydrocyclone.

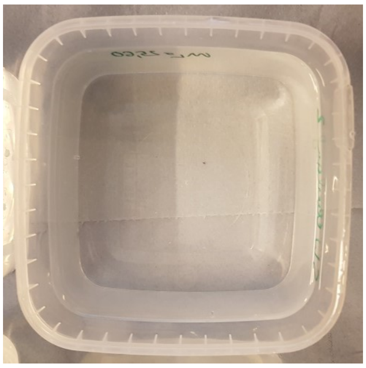

Fig. 10: Sample from the underflow without any visible solids

Fig. 11: Sample from the overflow without any visible solids

In addition, Tab. 3 and Tab. 4 show the quantitative results after drying the individual samples. Both the qualitative and quantitative analysis of the samples from the underflow and overflow show that no separation of solid matter was achieved regarding the ”synthetic water”.

Tab. 3: Specific dry matter in the underflow after tests with the “synthetic water”

Samples	Partial flow	#	Spec. dry matter
Synthetic water	Underflow	1	0.290 mg/ml
		2	0.289 mg/ml
		3	0.294 mg/ml
		MV	**0.291 mg/ml**

Tab. 4: Specific dry matter in the overflow after tests with the “synthetic water”

Samples	Partial flow	#	Spec. dry matter
Synthetic water	Overflow	1	0.289 mg/ml
		2	0.293 mg/ml
		3	0.285 mg/ml
		MV	**0.289 mg/ml**

When using the “synthetic water”, hardly any differences in the specific dry matter of impurities in the underflow and overflow could be detected. Thus, the hydrocyclone is classified as not effective for this application. This is mainly due to the microplastic particles, which cannot be separated by the present hydrocyclone due to the small particle size and low difference between particle and fluid density [8, 9]. Laser diffraction measurements (Mastersizer 2000E, Malvern) also proved that the particle size of the microplastic particles was smaller than 5 µm.

Conclusion

The findings only indicate a separation when using the “washing water” with the visible impurities. The specific dry matter in the underflow was 1.970 mg/l, while in the overflow it was 1.047 mg/l. Thus, the hydrocyclone can be considered as a suitable device for the separation of visible fibres from the "washing water". However, using the “synthetic water” no separation could be achieved due to the size and low density of the microplastic particles. Here, the specific dry matter in the underflow was 0.291 mg/l, while it was 0.289 mg/l in the overflow. Thus, the hydrocyclone can be considered as unsuitable for separation regarding the "synthetic water", as the hydrocyclone does not meet the requirements for sufficient selectivity

In this case, other separation methods, e. g. membrane technology or filtration could be used [10, 11].

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