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Feasibility Study for the Separation of Solid Particles from High-Pressure Water Jet Process Water with a Hydrocyclone

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Abstract

Hydrocyclone design and application is still a research item, although the first patent on hydrocyclones was already published in 1891. Now, 130 years later, there are still no general design criteria and calculation models for all applications available. The present paper shows a direct approach for hydrocyclone evaluation for a new application, a mixture consisting of water and concrete, produced by a water jet cutting process at a tunneling site. By the use of a mobile hydrocyclone test plant, the particle concentration in the underflow was 32% (average) higher than the feed particle concentration.

Introduction

On the tunneling site Perjen (Tyrol, Austria) the 40 years old existing structure is renovated. Therefore, thin concrete layers are removed by water jet cutting from the wall inside the tunnel. In this process, a volume of 5-10 m³ wastewater per day is produced. The wastewater is stored temporarily on-site and periodically taken away by a waste disposal company. In order to reduce disposal costs the reduction of the wastewater volume by mechanical treatment is required.

One possible option for separating the solid particles from liquids is the use of a hydrocyclone (Fig. 1). In a hydrocyclone, the feed (pumped into the device at the inlet) is split up in a particle-rich underflow and an overflow with low particle concentration.

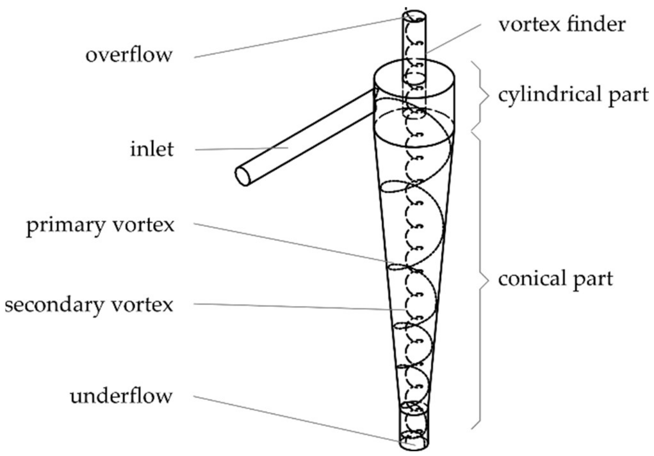


Fig. 1: General design and functioning principle (primary and secondary vortex) of a hydrocyclone [1,2]

Bretney [1] published the first patent on hydrocyclones 130 years ago, but there are still no generally valid universally accepted design criteria available. *Svarovsky* and *Svarovsky* highlight the problem at the first pages of their latest book with the following statement:

„If the equations and graphics […] are to be used for actual problem-solving it must be borne in mind that there are some assumptions involved and that the results are only as good as these assumptions and the given data [3].*"*

Even more striking is the summary of *Bergström* and *Vomhoff*, saying that the dissimilarities in measurement results between the studies are often greater than the similarities [4]. This is in accordance to the results of *Chen* et al. [5], who compared 6 established calculation models for hydrocyclones (*Braun* [6], *Plitt* [7], *Svarovsky* [8], *Schubert*/*Neesse* [9], *Müller/Bohnet* [10] and *Krebs Engineers*). One of the results is given in Fig. 2, showing the calculated and experimental results for the fractional efficiency for a selected test case.

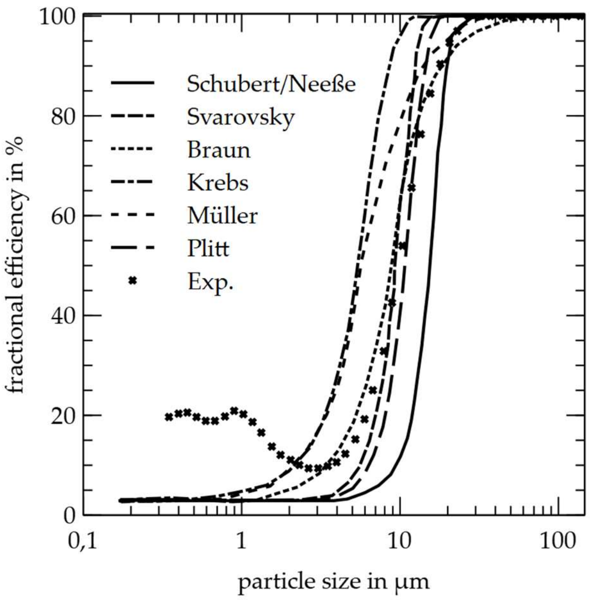


Fig. 2: Fractional efficiency for a selected test setup (vortex finder diameter 14 mm, underflow diameter 3.2 mm, feed rate 3.16 m³/h, overflow rate 3.08 m³/h, underflow rate 0.08 m³/h, feed concentration 0.5 vol.%, overflow concentration 0.23 vol.%, underflow concentration 9.3 vol.% [5]

In their discussion, *Chen* et al. [5] state that none of the models made good predictions for every set of data. Furthermore, they conclude that a calculation model may have a good prediction for the separation efficiency, but can perform poorly on predicting the pressure drop.

The comparability between the individual calculation models is limited by various reasons. The cyclones used by the individual authors have different geometries and the parameters used in the calculation are different. In addition, the individual approaches do not provide the same output parameters: while one model only provides the cut size diameter, another model can only calculate the pressure drop. In addition, empirically determined coefficients are used in the models (e.g. describing the hydrocyclone geometry), which cannot be easily transferred to another calculation configuration.

This results in the problem, that the separation characteristics of a hydrocyclone in a given practical application cannot be calculated reliable and therefore cannot be guaranteed. Consequently, on-site tests, with a mobile test plant, can be a possible solution. In previous studies, a mobile hydrocyclone test plant was developed and first presented in [2], followed by different experimental studies in the municipal waste sector [11] and for biological waste pre-treatment [12, 13].

This paper presents investigations on the separation of solid particles from water jet cutting wastewater (see Fig. 3) at a tunneling construction site.

Fig. 3: Water jet cutting wastewater container

Optical observation of the particle behaviour in the water is the first step for a rough assessment, if a hydrocyclone can be an appropriate separator (see Fig. 4-7).

Fig. 4: Sedimentation after 5 minutes time

Fig. 5: Sedimentation after 15 minutes time

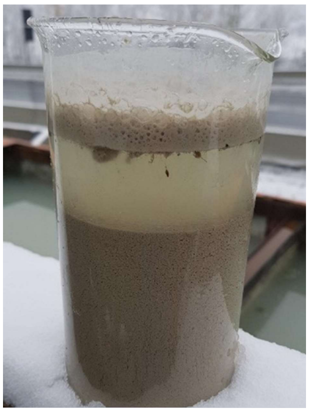


Fig. 6: Sedimentation after 45 minutes time

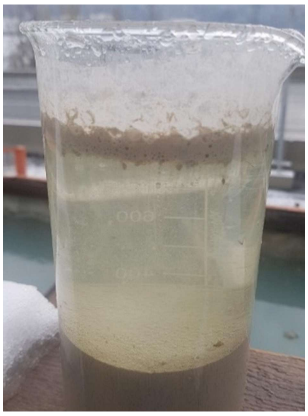


Fig. 7: Sedimentation after 120 minutes time

According to the particle sedimentation (qualitative sedimentation time) shown in Figs. 4-7, hydrocyclone testing was classified as promising, so the field tests on-site were implemented.

Methods

Environmental analytics always include errors caused by the sampling itself and by the measurement process [14, 15]. This leads commonly to high efforts in analytics (e.g. validation, isokinetic sampling, sample splitting, …) in order to get a precise result.

In contrast to the common way of analytics, on-site testing in industrial scale can be a more direct solution approach [2]. Therefore, a portable solid-liquid-separation test plant (see Figs. 8-10) was used for avoiding errors based on sampling and measurements.

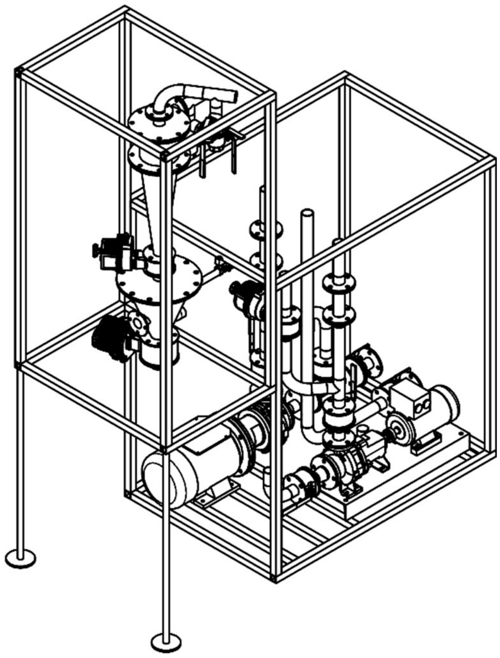


Fig. 8: Mobile test plant for on-site tests including the hydrocyclone unit (left) and pump units (right) [2]

Fig. 9: Mobile test plant for on-site tests [2]

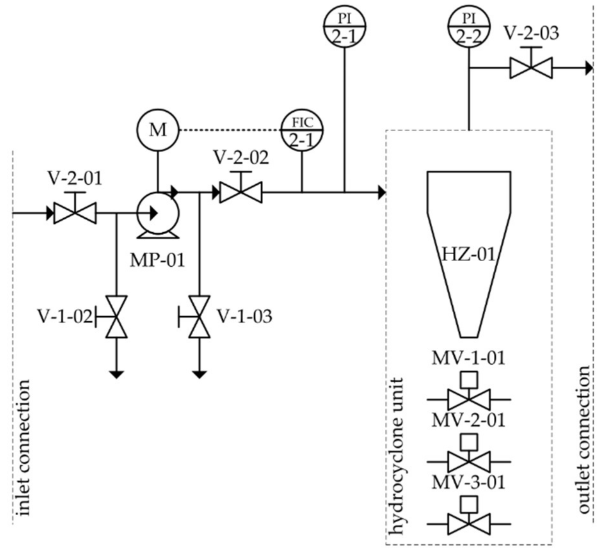


Fig. 10: Simplified P&I-diagram of the portable test rig with inlet connection, circulation pump MP-01, flowmeter FIC2-1, pressure sensors PI2-1and PI2-2, manually and electrically operated valves

The wastewater was pumped from the wastewater container to the hydrocyclone, where the feed is split up into overflow and underflow (separated particles), see. Figs. 11-12. The overflow was transferred back to the wastewater container, while the underflow was operated in patch mode. Samples of the feed (F), underflow (U) and overflow (O) were taken.

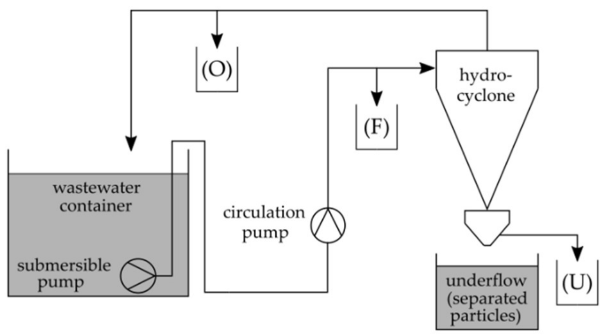


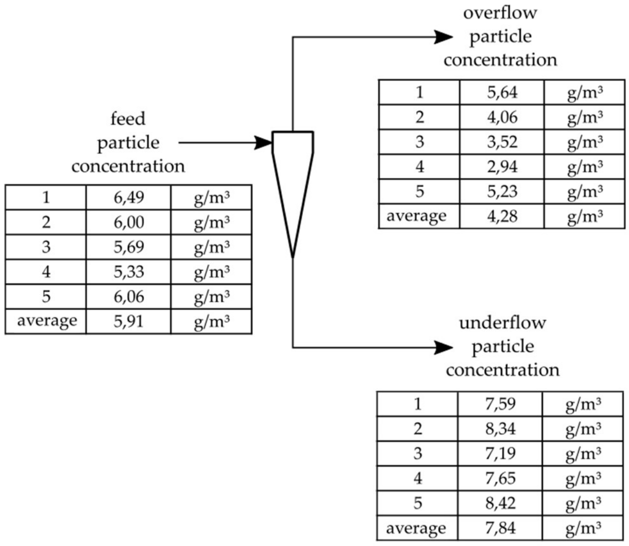
Fig. 11: Test setup and sampling positions for the feed (F), overflow (O) and underflow (U) of the hydrocyclone

Fig. 12: On-site testing with the mobile test plant

The inlet flow rate of the experiments was set to 20 m³/h. The separation performance of the hydrocylone is defined by the separation efficiency ε (gravimetrical determination) and the pressure drop Δ*p*. Repetitive sampling (n = 5) was implemented for determination of the feed (F), overflow (O) and underflow (U) particle concentration. The liquid fraction of the samples was removed by drying at 95°C for 7 days.

Results and Discussion

Fig. 13 shows the sample particle concentration of the inlet, underflow and overflow. The particle concentration in the underflow is 32% (average) higher than the inlet particle concentration, whereas the overflow concentration is 28% (average) smaller than the inlet particle concentration. In conclusion, particle separation by a hydrocyclone is partly possible for the present wastewater.



Feed particle concentration:

1	6,49	g/m³
2	6,00	g/m³
3	5,69	g/m³
4	5,33	g/m³
5	6,06	g/m³
average	5,91	g/m³

Overflow particle concentration:

1	5,64	g/m³
2	4,06	g/m³
3	3,52	g/m³
4	2,94	g/m³
5	5,23	g/m³
average	4,28	g/m³

Underflow particle concentration:

1	7,59	g/m³
2	8,34	g/m³
3	7,19	g/m³
4	7,65	g/m³
5	8,42	g/m³
average	7,84	g/m³

Fig. 13: Gravimetrically determined particle concentrations in the inlet, overflow and underflow of the hydrocyclone and average values.

Transferring the results of the hydrocyclone evaluation to the objective of the tunneling company (reducing the amount of wastewater) the purified water in the overflow of the hydrocyclone (average 4,28 g/m³) is still not clean enough for avoiding disposal of the wastewater by a disposal company. Nevertheless, on-site testing was the direct way to this result.

Outlook

The present study does not deal with the particle size distribution in the feed, overflow and underflow because of the extensive time and resource consumption of the necessary sampling and measurement process. In the next studies, this can be considered as an additional indicator for hydrocyclone performance, depending on the application.

The mobile test plant proofed that it is a good option for getting reliable results in a short time. Based on the results of this direct field tests it is possible for the producer of the wastewater to decide if a hydrocyclone is a solution for their problem or not. The current test plant will be continuously optimized (e.g. increased grade of automation) and the field of application will be extended to other fields in the coming years.

Acknowledgement

BeMo Tunneling GmbH, who wants to reduce their disposal costs for water jet cutting wastewater on their construction sites, initiated this study. The support of BeMo Tunneling GmbH, ATM Abfallwirtschaft Tirol Mitte GmbH and MCI – The Entrepreneurial School® is gratefully acknowledged.

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