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Development of a classifier system for the treatment of process and effluent streams

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SYNOPSIS

The paper describes the development of a flexible system for the pre-treatment of process and effluent streams. Incorporating both a cyclone separator stage, and a recovered product de-watering stage, the system has a number of possible modes of operation. Depending on the requirements of individual applications, it could be regarded as a solids recovery system, a fluid recovery system, or as a solid-solid separator/concentrator system. The implications of each of these potential applications are addressed.

The results of a series of preliminary trial studies, focusing on the characterisation of the cyclone separator stage are presented. By means of adjusting various parameters, it is demonstrated how the output of the unit can be varied and controlled, indicating its potential scope for application in the industrial effluent and processing scene.

1 INTRODUCTION

1.1 General

Municipal and industrial activity results in the generation of wastewater which can be highly polluting requiring some form of treatment prior to discharge. In the case of industrial effluents, the discharge to either a sewer or receiving watercourse may contain considerable quantities of valuable materials or by-products [(1)]. Changes in legislation and the threat of prosecution from regulatory bodies, has focused attention on the need for cost-effective industrial wastewater treatment. In the UK only 1 in 5 industrial effluents are discharged into receiving waters. The majority discharge into public sewers and are subject to sewer charges relating to the strength and volumes of wastewater discharged. The lower the strength and volume of wastewater discharged by an industry to the public sewer, the lower the costs of its sewer charges.

The current legislative and regulatory framework provides an impetus for industry to adopt waste minimisation, recycling and re-use initiatives to reduce liabilities or costs of discharging wastes resulting from industrial activity.

The paper describes the development of a flexible system for the pre-treatment of effluent streams focussing on the removal of grits or recovery of sands and grits from effluent streams.

1.2 Grit removal from effluent streams

The replacement of worn pumps, valves and other ancillary equipment within process and effluent treatment plants can cause a considerable maintenance commitment. Downstream processes, particularly channels and sumps, which become laden with heavy silts and grits, often require manual labour to physically dig them out, representing a somewhat inefficient way of operating a treatment or material recovery process.

Certainly, the need for preliminary solids separation, in particular the removal of grit and sand particles, has been a widely accepted process requirement within the municipal sewage treatment industry. Further to this, it is considered that in certain process industries, the adoption of an effluent grit removal process might well be justified. As well as providing grit removal as a means of avoiding its 'negative' effects, described above, it is envisaged that, in some cases, the recovery of valuable by-products might be a motivating factor.

In addition to considering the implications of effluent stream grit removal, as addressed above, it should be borne in mind that water itself is becoming an increasingly valuable commodity. Any 'grit removal' process is likely to involve a de-watering stage, and one should ask the question whether the primary objective is to de-water the grit, or to de-grit the water. Indeed, one of the key purposes of effluent treatment is to enable the recovery and reuse of water, where appropriate. In addition to reducing the cost of water intake, such schemes are likely to lead to a reduction in the cost of dumping effluents to drain.

1.3 Separation of effluent components

When solid matter is removed from an effluent stream, it is normally produced in the form of a slurry. Prior to further treatment and dewatering, the use of a small proportion of the original carrier fluid facilitates ease of handling and transportation. In many cases, such a slurry will contain multiple components. For example, in a vegetable washing process, there are likely to be quantities of both grit, and organic matter within the stream. This has implications with regard to the disposal of the final, dewatered product.

In the case in which grits are removed for the purpose of protecting downstream treatment stages, the recovered product is normally sent to landfill. This incurs costs, not only for transportation, but also for the actual transfer of waste into the hands of the landfill operator. The proposed EC Landfill Directive [2] calls for staged reductions in biodegradable wastes going to landfill. Consequently, legislative requirements are likely to force the landfill operator to implement acceptance criteria, relating to the quality of waste arriving at the landfill site. Certainly, in the case of the disposal of municipal sewage treatment grits, it is becoming more and more common for specifications to call for less than 5 % organic content by weight, whereas up until recently an acceptable figure has been more like 15 % to 25 % organic content.

Dictated by the above, along with environmental factors, the need to classify the components of an effluent is likely to be a relevant consideration in many industrial effluent treatment cases.

1.4 Systems for the preliminary treatment of effluent streams

A system that might be used for effluent grit removal, organics separation (where appropriate), and subsequent dewatering would typically consist of two treatment stages; a primary stage to effect the separation requirements, and a secondary stage to provide further washing and dewatering of recovered grits. In the case of conventionally designed systems operating the two-stage approach, a system of automatic control is necessary to provide a controlled cycle of degritting and dewatering.

A process has been developed that is able to provide a single stage operating system for the low flow end of the market (typically up to 72 m^3/hour). The process adopts the principle of the two-stage approach, but combines them into a single, self-contained unit. Already applied in the municipal sewage treatment industry, it is envisaged that the process has a number of potential applications, particularly in instances where water recovery and reuse is an issue. Example applications might be for vegetable wash water recycling, mineral slurry recovery and de-watering, wool scouring plant effluent treatment. Further details of the system are presented in the following sections.

2 THE HYDRO CLASSIFIER SYSTEM

2.1 Background

In its role as a sub-stage in a large scale treatment process, the Hydro classifier system forms a part of the Grit-Pac® or Eff-Pac™ Process [3][4]. Figure 1 shows a schematic of this. In this case, the prime function of the classifier is that of dewatering slurries from the underflow of the primary separator. The underflow from the Grit King® Separator, for example, is typically a very wet slurry with a dry solids content of usually less than 2½ %. For effective disposal, this slurry has to be dewatered to produce a relatively dry stable product with typically less than 50 % free water.

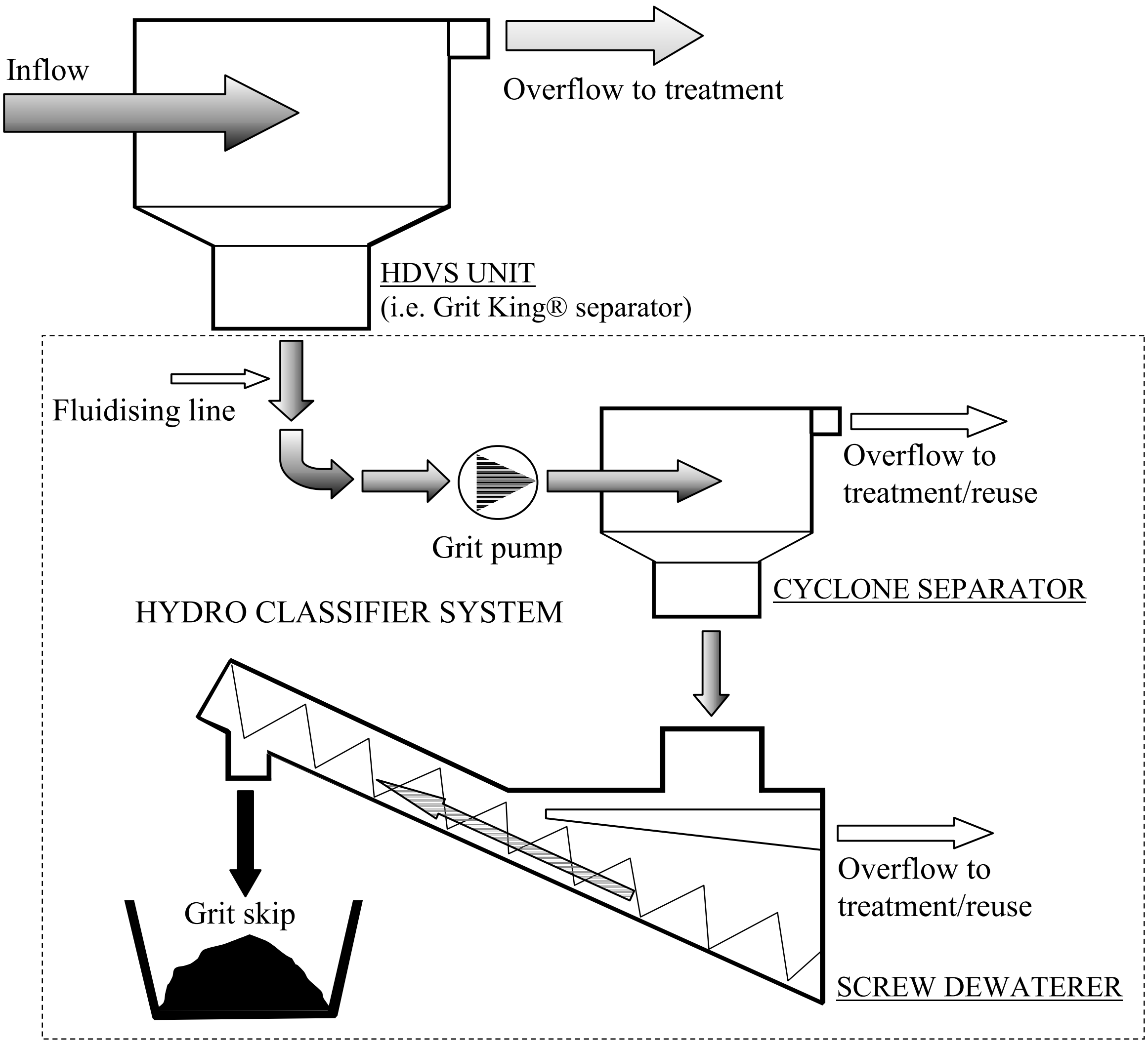

Figure 1 - Schematic of a typical process incorporating the Hydro classifier system

The Grit King® Separator, operating on the hydrodynamic separation principle, produces a relatively organics free slurry when subjected to influent feed flows within a hydraulic turn down ratio of less than 6:1 (i.e. ratio of peak flow to minimum flow). If a Grit King® Separator designed for a peak flow of, say, 300 l/s is subjected to a persistent low flow in the region of, say 30 l/s, the recovered product in the slurry stream will contain an increased proportion of organic solids which have settling velocities similar to very fine grit. The nature of the slurry in the underflow no doubt depends on the characteristics of the sewer solids arriving at the wastewater treatment works, in terms of the grit/organic ratio. However, supplementary processing to effect additional classification would be required to ensure that the recovered material is in a sufficiently clean and dry state to be disposed of to, for example, a landfill site. This ancillary equipment may include components to effect fluidisation and further classification prior to dewatering of the recovered solid material.

Hydrodynamic vortex separators (HDVS), including the Grit King® Separator, have been found to be effective solid-liquid separators which operate on the accelerated boundary layer principle [5]. The Grit King® has a configuration of internal static hydraulic flow modifying components which result in the formation of a stable flow regime over a wide range of flows [6]. HDVS have also been found to have remarkable ability to withstand shock hydraulic and solids loading. In comparison with hydrocyclones, the head loss across a HDVS is relatively low which makes them ideally suited to performing a solid-from-liquid removal function in sewerage systems and at wastewater treatment works sites.

2.2 The Hydro classifier system

The dewatering component of the Hydro classifier takes the form of an archimedean screw with a reception well and an inclined trough. Solids in the slurry to be dewatered settle in the well and are propelled upwards along the inclined trough and discharged through a chute into a collection receptacle for the dewatered product usually in the form of a skip. The hydraulic capacity of the screw classifier is dependent on the nature of the solids in the slurry to be dewatered in particular the settling velocity of the minimum size fraction to be removed. To be removed effectively, the solids in the slurry have to settle to the bottom of the reception well such that they can be raked up by the screw. If the classifier receives too high a hydraulic loading, this results in carry-over of solids in the overflow weir, leading to a reduction in the effectiveness of material recovery.

In its prime duty as a dewatering device, the classifier does not differentiate between different types of material or solids once they settle to the bottom of the reception well. These solids all become raked up and discharged with the dewatered product. Where the slurry contains a high content of undesirable contaminant solids (e.g. faecal organic solids for grit removal at a wastewater treatment plant), this can present a problem.

This paper describes work on the development of an integral classification unit built around the traditional screw classifier/dewaterer component. The additional classification unit can be described as a "cyclonic type" separator with characteristics which are a hybrid between those of traditional hydrocyclones and HDVS. Rotary flow separators including hydrocyclones and HDVS have differing classification characteristics depending on their geometry and the configuration of internal flow modifying members. Hydrocyclones in general operate at relatively high pressure drops (several metres) and are sensitive to variations in flow compared with HDVS. Providing an integral "rotary flow" separation unit with known hydraulic and classification characteristics provides the flexibility of tailoring the Hydro classifier for a given classification and dewatering duty.

3 PRELIMINARY CHARACTERISATION OF THE CLASSIFIER

3.1 Introduction

In the system described in the paper, the emphasis of the screw unit as a 'classifier' is reduced by the fact that cyclonic classification is provided before any flow enters this part of the process. Given that the combined effect of both the cyclone and screw classifier units is somewhat dependent on the effectiveness of the former stage, the emphasis of preliminary assessments of the hybrid system has been on the characterisation of the cyclone unit.

The performance of a cyclone is somewhat dependent on the strength of the vortex (determining the radially outward acting centrifugal forces), the relative rates of overflow and underflow (determining the fluid drag forces in each direction) and the overall flow structure within the system. For a particular classification size requirement, the effective particle ‘cut’ size is dependent on the resultant of these forces. Since the classification cut requirement may vary from application to application, preliminary studies have focused on determining the overflow/underflow split ratio for a series of design configurations, and the system head loss in each case. This data is presented. Further to this, for a selection of arrangements, the resulting classification performance has been investigated for a particular grit material. The results of these trials are also presented.

3.2 Cyclone unit configurations

A full scale, 0.75 m diameter cyclone unit was used for the trials. This was constructed so as to enable flexibility in terms of both the overflow and underflow configuration.

The main body of this, consisting of a cylindrical section, had a mid-positioned tangential inlet with an internal diameter of around 100 mm. The top end of the cylinder was flanged such that alternative overflow components could be fitted. In order to contain flows exiting from this region, a key-hole shaped section was fitted, directing the flows towards a 150 mm diameter gravity drain pipe. The lower end of the unit was fitted with a conical section, tapering at an angle of 30°, and terminating with a flanged 300 mm diameter orifice.

The underflow configurations considered included a cylindrical 'grit pot' with a 100 mm diameter tangential off-take, a conical base terminating with a central 100 mm diameter orifice (flanged), and orifice plates with diameters of 150 and 170 mm that fitted directly to the flanged base of the body section. In order to regulate the underflow flow rates, an appropriately sized Hydro-Brake® vortex flow control [7] was produced that fitted to both the tangential and central, 100 mm diameter underflow sections (in the latter case, via a 90° bend). Figure 2 illustrates these components, along with the main body section.

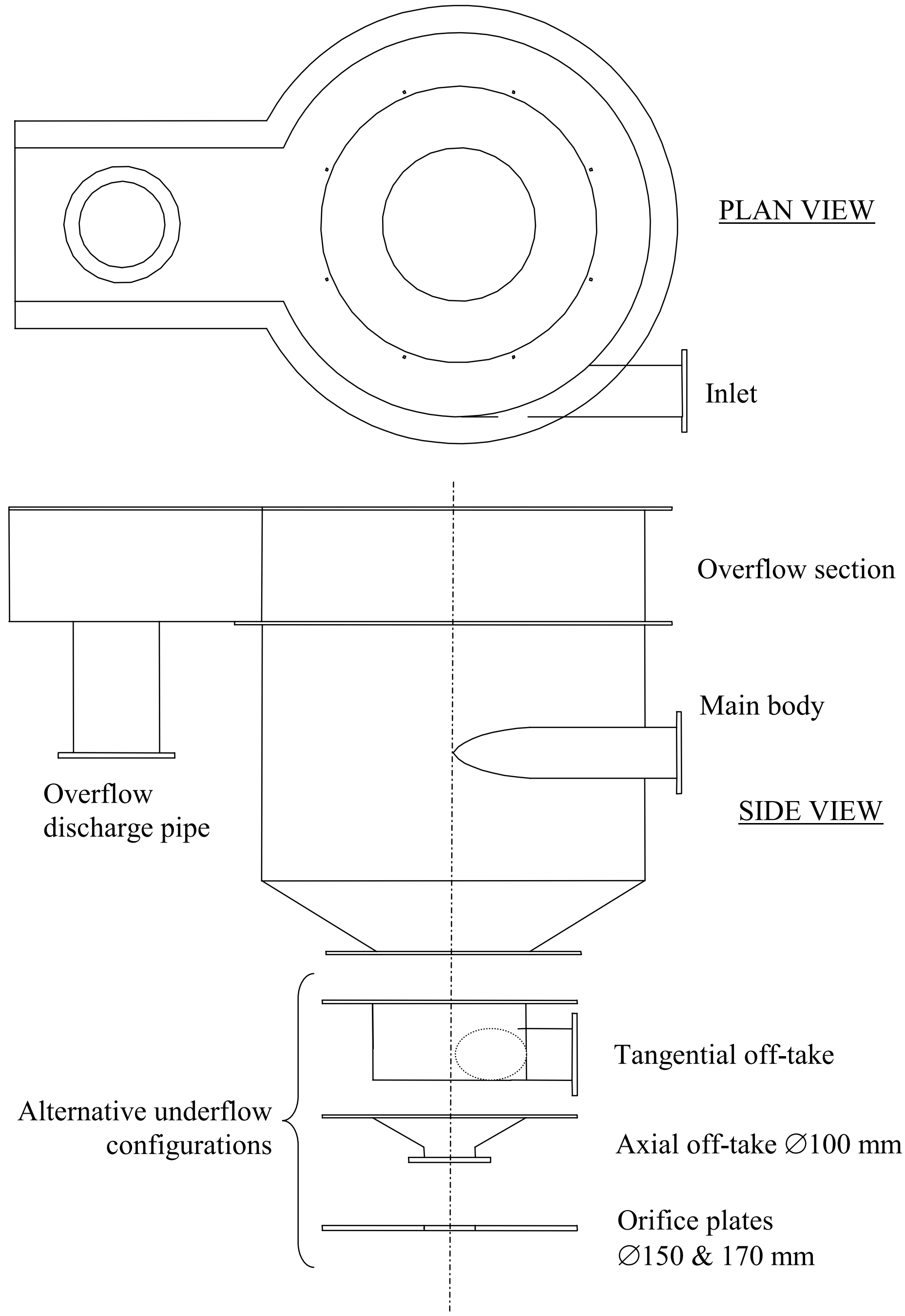

Figure 2 - Main body and underflow sections of the cyclone unit

Two overflow configurations were considered, both of which located directly onto the top of the main body section. One of these incorporated a central, 225 mm diameter orifice. This was fitted with a cylindrical vortex finder, that extended upwards, forming a weir ring, as well as downwards into the body of the cyclone. At a larger diameter, an additional cylindrical section also protruded downwards into the cyclone (referred to as a 'dip plate'). A second overflow configuration consisted of a plate with a 340 mm diameter orifice in its center. This was not accompanied with a cylindrical sleeve, as previously described, but simply had a dip plate attached at a larger radial location. During the trials, this was always used in conjunction with a central tube and cone section that protruded deep into the body of the unit. With a 100 mm diameter cylindrical section fitted with a conical attachment on its base, this terminated such that sufficient clearance was maintained between its edge and the closest internal wall of the main body section. The two configurations described are illustrated in Figure 3.

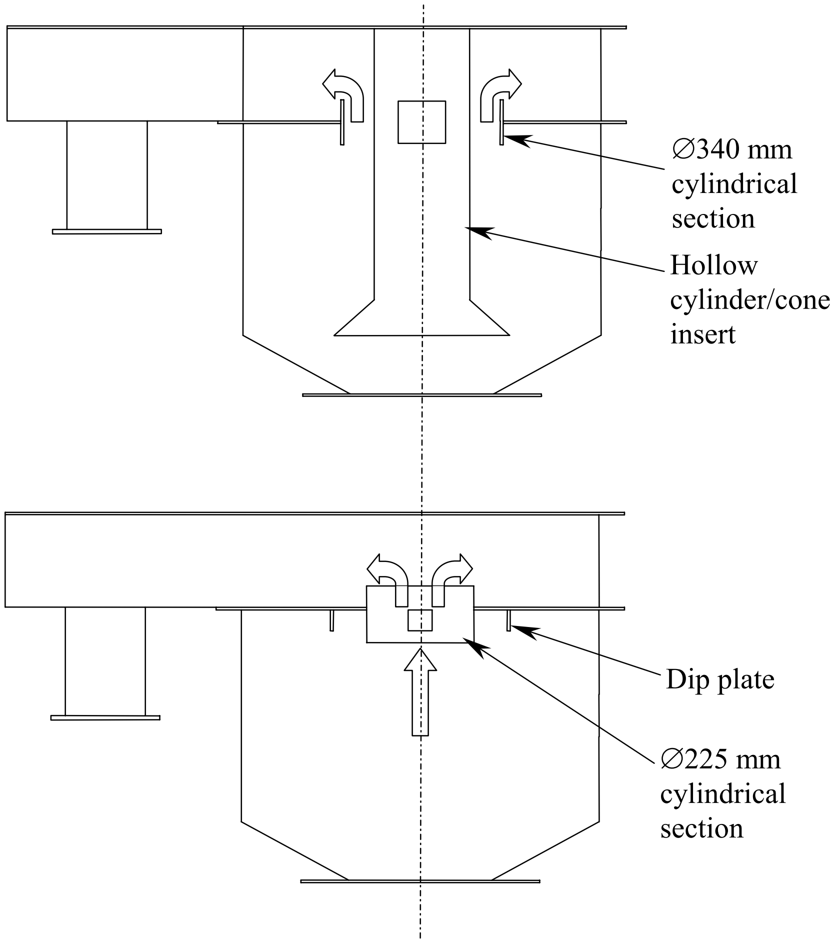

Figure 3 - Alternative internal/overflow configurations

During the trials, the cyclone was mounted above a flow collection channel. At one end of this was a drain, diverting flows back to the main pump reservoir. With a flexible pipe attached to the overflow discharge, it was possible to divert the flows into a 200 litre sample tank, enabling flow rates to be measured. The inlet flow rate was measured by means of a Detec 3033 ultrasonic flowmeter, appropriately mounted in the middle of a 1.2 m long section of straight pipe. A 1.5 m tall head column was fitted a short distance upstream of the inlet to the cyclone, enabling the assessment of system losses, and also to allow solid material to be introduced directly into the flows.

3.3 Hydraulic characterisation

Table 1 summarises the various combinations of configurations that were considered during hydraulic studies of the system. The results of the flow split investigations, for which inlet flow rates ranging between 10 and 20 l/s were used, are presented in Table 2. Each value is based on the averaging of 3 samples. The system inlet head, in each case, is also shown.

Table 1 - Cyclone unit configurations tested

Configuration	Overflow	Underflow
'A'	∅340 mm orifice & cone insert	Tang. off-take & flow control
'B'	∅225 mm orifice & dip plates	Tang. off-take & flow control
'C'	∅225 mm orifice & dip plates	∅100 mm central orifice
'D'	∅225 mm orifice & dip plates	∅150 mm central orifice
'E'	∅225 mm orifice & dip plates	∅170 mm central orifice

Table 2 - Flow split and inlet head data for each configuration

Configuration	Inflow (l/s)	Inlet head (m)	Overflow (l/s)	Underflow (l/s)	% Overflow	% Underflow
'A'	10	0.42	4.2	5.8	42.3	57.7
	12.5	0.52	7.2	5.3	57.3	42.7
	15	0.64	9.8	5.2	65.1	34.9
	17.5	0.78	12.3	5.2	70.1	29.9
	20	0.95	13.9	6.1	69.3	30.7
'B'	10	0.58	3.4	6.6	34.1	65.9
	12.5	0.73	5.6	6.9	45.1	54.9
	15	0.92	7.7	7.3	51.0	49.0
	17.5	1.2	10.2	7.3	58.2	41.8
	20	1.5	11.9	8.1	59.6	40.4
'C'	10	0.75	9.7	0.3	97.2	2.8
	12.5	0.92	12.3	0.2	98.8	1.2
	15	1.2	13.8	1.2	91.7	8.3
	17.5	1.63	15.9	1.6	90.8	9.2
	20	2.15	17.5	2.5	87.6	12.4
'D'	10	0.49	0.1	9.9	1.2	98.8
	12.5	0.92	4.8	7.7	38.5	61.5
	15	1.17	10.9	4.1	72.5	27.5
	17.5	1.52	12.7	4.8	72.5	27.5
	20	1.94	13.4	6.6	67.2	32.8
'E'	10	0.38	0.1	9.9	0.8	99.2
	12.5	0.72	0.3	12.2	2.1	97.9
	15	1.15	4.2	10.8	28.2	71.8
	17.5	1.47	10.7	6.8	61.0	39.0
	20	1.89	11.7	8.3	58.6	41.4

As expected, the system head loss is seen to increase with both increasing inlet flow rate, and also with either overflow/underflow orifice size reduction, and also underflow centralisation. In fact, in those cases where a central underflow off-take was fitted to the unit, the pressure gradients, and resulting air core formation had the effect of regulating the flows to the extent that the vortex flow control became air-choked and thus redundant. Extremes of system inlet pressure are seen for configurations A and C, with respective inlet heads of 0.95 and 2.15 m at an inlet flow rate of 20 l/s.

Of note is the general consistency of underflow rate for configurations A and B, provided by the use of a vortex flow control. This contrasts greatly with the variability illustrated for those tests in which a central off-take section was used. In these cases, the sensitivity to both inlet flow rate, and also orifice diameter, is clearly illustrated.

On the whole, the hydraulic characterisation data indicates the potential scope to vary and control the operating characteristics of the cyclone unit. This is demonstrated in the following section.

3.4 Grit classification studies

Based on the considerations of stability and flow split ratio, configurations A and B were selected for trials in which a quantity of grit material was added to the system inlet flows.

Adding a quantity of approximately 2.4 kg of grit to the stand pipe upstream of the cyclone unit, the separation characteristics of each configuration were investigated. This was carried out at inlet flow rates of 15, 17.5 and 20 l/s. Collection of overflow solids was enabled by means of a geotextile filter, in each case, positioned below the discharge of the gravity drain pipe. The collected samples for each run were dried, weighed, and subsequently sieve sized. For reference, Figure 4 presents a size analysis of the raw material added.

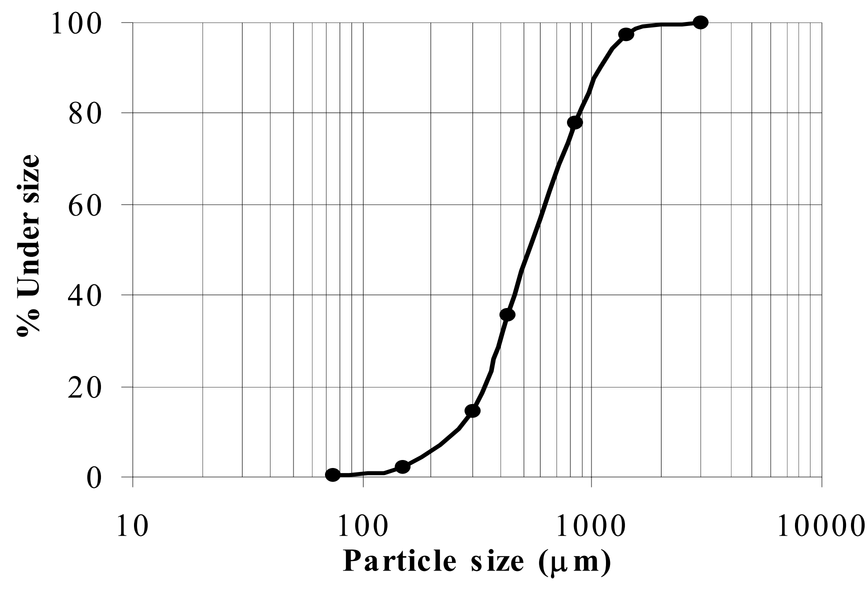

Figure 4 - Size analysis of material added to cyclone

Based on a knowledge of primary grit gradings, it is possible to present the approximate efficiency of a cyclone unit in terms of its ability to recover particular gradings of entrained material. This form of analysis has been adopted, as it can enable estimates to be made for the likely efficiency outcome, when used with other grit materials (assuming similar density; predominantly around 2650 kg/m^3 in this case).

Figure 5 presents the results of this analysis. It should be noted that the degree of accuracy is somewhat dependent on; similarity between the raw sample analysis and the actual sample added; the extent of losses of matter within the system; the physical quantity of material within each size band. Clearly, extremely fine particles, whilst being difficult to separate, are also prone to being 'lost'. Additionally, in the current work, the actual quantities of the finer grades of material (i.e. sub-150μm) were extremely small, thus magnifying this effect. However, it should be noted that in most grit removal cases, for example, in the municipal sewage treatment industry, it is acknowledged that particles finer than 200 μm are generally of little concern and in fact may even assist in downstream processes. The overall recovery efficiency of the unit for the grit considered, for all particles larger than 150 μm is shown in Table 3.

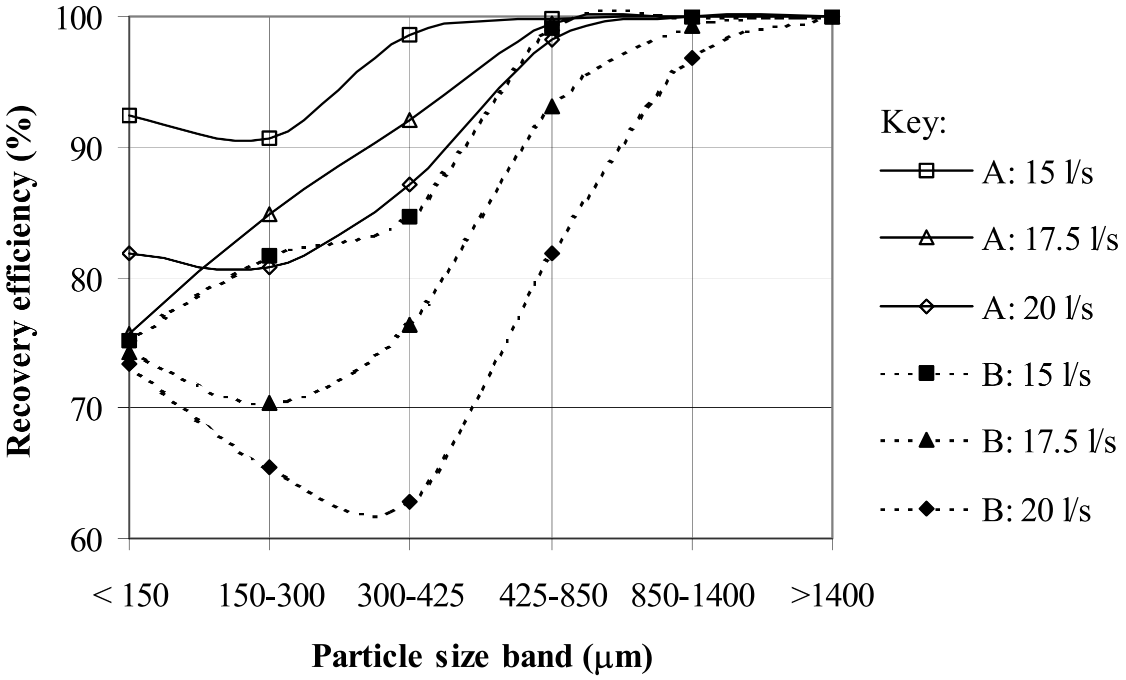

Figure 5 - Derived grade recovery efficiency of the cyclone unit

Table 3 - Overall recovery efficiency of the cyclone unit down to 150μm

Configuration	'A'			'B'		
Inlet flow rate	15 l/s	17.5 l/s	20 l/s	15 l/s	17.5 l/s	20 l/s
Recovery efficiency (%)	98.3	95.6	93.6	93.5	87.5	78.5

Immediately evident is the fall in recovery efficiency as the inlet flow rate is increased for each configuration (Figure 5), with values in the range > 150 μm falling from 98.3 to 93.6 % for configuration 'A', and from 93.5 to 78.5 % for configuration 'B' (Table 3). From this, it is also seen that configuration 'B' consistently gives lower efficiency values than configuration 'A'. This is interesting since, for this configuration, the underflow rate has actually been assessed as being consistently greater than for configuration 'A'. This can only be attributed to the alternative internal flow characteristics that will be dictated by the design.

Ultimately, the optimum configuration and operating regime selected will depend on the requirements of the user. For the purposes of grit removal, the optimum would simply be that at which most grit is recovered (subject to defining an 'acceptance' band). However, in situations in which two components are to be separated (for example, grit from organic matter), it stands to reason that an over effective grit remover is also likely to remove a portion of the secondary component. Of course, in practice, whether a component passes to the underflow or to the overflow will depend, to a large part, on the particular substances characteristics.

4 CONCLUSIONS

The results of the investigations described in the paper illustrate the effectiveness of a cyclone unit, forming part of the Hydro classifier system, for the removal of grits from effluent streams. Efficiency values of up to 98 % are shown to be achievable. With a well positioned cut-size band, the unit additionally exhibits great potential to be able to perform a grit washing function. By adjusting various operating and design parameters, the ability to vary and control the operation of the unit is demonstrated, illustrating the scope of potential use.

The system described has potential applications wherever there is the requirement to separate solids/grit or isolate components from process/effluent streams, whether the objectives are to enable either water reclamation and reuse (subject to further processing in some cases), or to reduce the burden of physical disposal costs.

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