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RESEARCH ARTICLE

A new calculation method of efficiency for gypsum and wastewater hydrocyclones in FGD unit in a power plant

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ABSTRACT

This study was carried on hydrocyclones in the Wet Flue Gas Desulfurization (WFGD) system of a local thermal power plant. In WFGD systems, hydrocyclones are used for classification in terms of PSD of limestone, dewatering the gypsum slurry and recycling the wastewater. Seperation efficiencies of hydrocyclones (waste water and gypsum) in power plant were calculated referring to each hydrocyclones' inlet size of D_{25}. Results obtained with Malvern Mastersizer for the samples from each exits of hydroclones were taken into consideration. Separation efficiency for waste water hydrocyclone was calculated as 4.0 % while it was calculated 77.5 % for gypsum hydrocyclone.

Keywords: Wastewater, thermal power plant, particle size distribution, hydrocyclone

1. INTRODUCTION

Power plants are equipped with several sub systems and coal entering to power plant is processed to the final products (ash, byproducts, wastewater and flue gas). In order to decrease the level of SO_2 emission and to purify the wastewater, a technology called Wet Flue Gas Desulphurization (WFGD) is employed. WFGD, due to abovementioned purposes, is one of the most important technology in a power plant in terms of environment. Because of its high efficiency and reliability, WFGD system in the power plants is the most commonly used technology for controlling the emission of SO_2 in the world [1- 4]. Sketch of WFGD system in power plant is provided in Fig 1 [5].

Having more than 100 years history hydrocylones, mostly employed in WFGD systems of power plants in terms of removing or classifying particles [6], belong to a class of fluid-solid classifying devices that separate dispersed material from a fluid stream. The structure of a hydrocyclone is presented in Fig 2. (Diameter of the hydrocyclone (D), height (H), diameter of the overflow (Do), thickness of the overflow (d), diameter of the underflow (Du), diameter of the inlet (Di), height of the overflow in cyclone chamber (h), cone angle (θ)) [7].

Separation efficiency or in other words hydrocyclone performance is significantly questioned by many recent researches which includes mostly CFD model approaches recently. Hwang and Chou [8] have employed CFD (computational fluid dynamics) in terms of understanding the separation efficiency differentiation of the designed hydrocyclones. Hwang and Chou [8] have summarized the fact that "design of highly efficient hydrocyclone with CFD is an effective, economical, and timesaving approach". Zhu et al. [9] have conducted a computational study of the flow characteristics and separation efficiency of a mini-hydrocyclone. Cullivan et al. [10, 11] have also employed CFD to simulate fluid velocity, pressure distributions, particle trajectories. Although this wide employment of CFD, there is still this complexity for the performance of a hydrocyclone since it depends on the numerous parameters such as particle size, operating conditions, and geometric structures [8].

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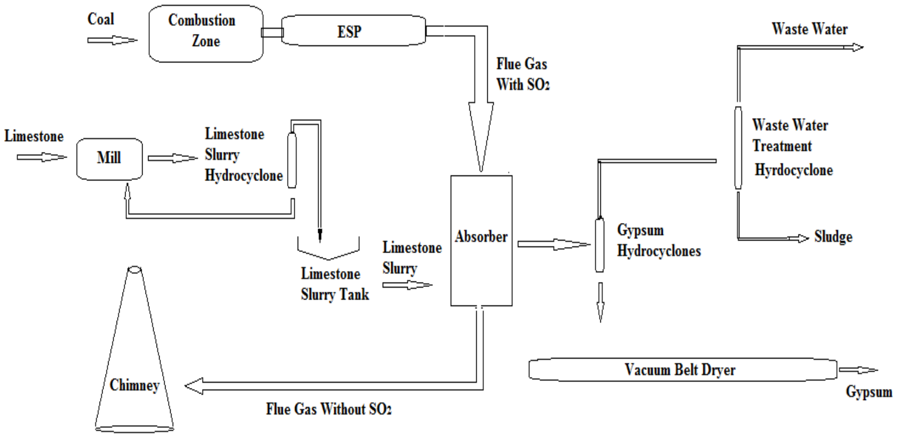


Fig 1. Schematic representation of coal utilizing power plant and final products [5] (Bilen et al.2016)

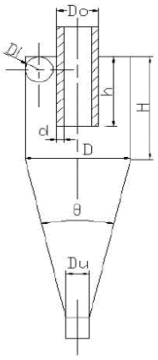


Fig 2. Sketch of hydrocyclone's structure [7]. (Jun et al, 2009)

Separation efficiency is off interest by many researchers [8-15]. In this context, Rocha et al. [12] (2020) have tried to evaluate the role of feed duct changes on hydrocyclone performance, Mousavian and Najafi [13] have investigated the role of geometry. Likewise, Chu et al. [14] have investigated the effect of structural modification on hydrocyclone performance. Boylu et al. [15] have investigated the separation efficiency of Na-bentonite by hydrocyclone. Although CFD approach is useful and reliable method [16] for designing of hydrocyclone, separation efficiency calculation should be based on the real life experimental data evaluation.

In this study, a new calculation method for separation efficiency was proposed. Samples were collected from inlet, upstream and downstream of gypsum and waste water hydrocyclones of a power plant. Collected samples were analyzed in terms of their PSD and a new size parameter of D_{25} was taken into consideration in the order of efficiency calculation.

2. EXPERIMENTAL METHOD

Sieve analysis of the samples from upstreams and downstreams of hydrocyclones in power plant (gypsum and waste water hydrocyclones) a total of 5 samples was done by using Malvern Mastersizer S 2000 with the employment of wet method and PSD of waste water samples was obtained over a range of 0.05 µm – 878.67 µm. Obscuration of the Mastersizer experiments was kept between 12% and 18%, mostly about 15%. Prepared waste water samples of lower and upper exits of hydrocyclone of power plant were analyzed and size distribution parameters (D_{10}, D_{25}, D_{50}, D_{90}, D_{32}, D_{43}) for each were obtained. Size parameters and their descriptions are as the following.

D_{10} (µm): sieve opening which 10 % of particles passing through

D_{25} (µm): sieve opening which 25 % of particles passing through

D_{50} (µm): sieve opening which 50 % of particles passing through

D_{90} (µm): sieve opening which 90 % of particles passing through

D_{32} (µm): volume / surface mean (Sauter Mean)

Sauter mean is defined as the diameter of a sphere that has the same volume/surface ratio as a particle of interest.

$$D_{32} = \frac{\sum_1^n D_i{}^3 v_i}{\sum_1^n D_i{}^2 v_i} \qquad (1)$$

D_{43} (µm): the mean diameter over volume (DeBrouckere Mean)

$$D_{43} = \frac{\sum_1^n D_i{}^4 v_i}{\sum_1^n D_i{}^3 v_i} \qquad (2)$$

If we assign 3 spheres with diameters 1, 2, 3 units, the calculation of Sauter and De-Brouckere means of these spheres is examplified as in the following equations (Eq. (3) and Eq. (4)).

$$D_{32} = \frac{1+8+27}{1+2+3} = 2.57\ \mu m \qquad (3)$$

$$D_{43} = \frac{1+16+81}{1+8+27} = 2.72\ \mu m \qquad (4)$$

2.1 Separation efficiency of hydrocyclones

The particle size distribution of the samples from 3 hydrocyclones in the power plant was measured by Malvern Mastersizer. In this context, a typical plot of particle size distribution of sand particles from the study of Dwari et al. [17] is provided in Fig 3.

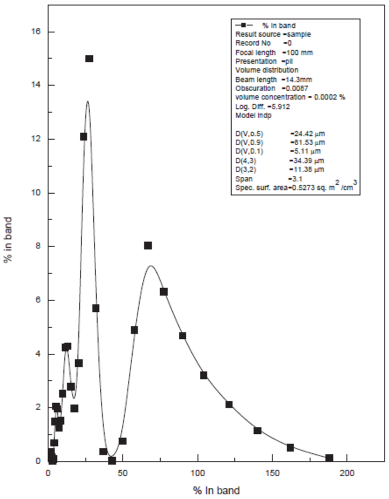


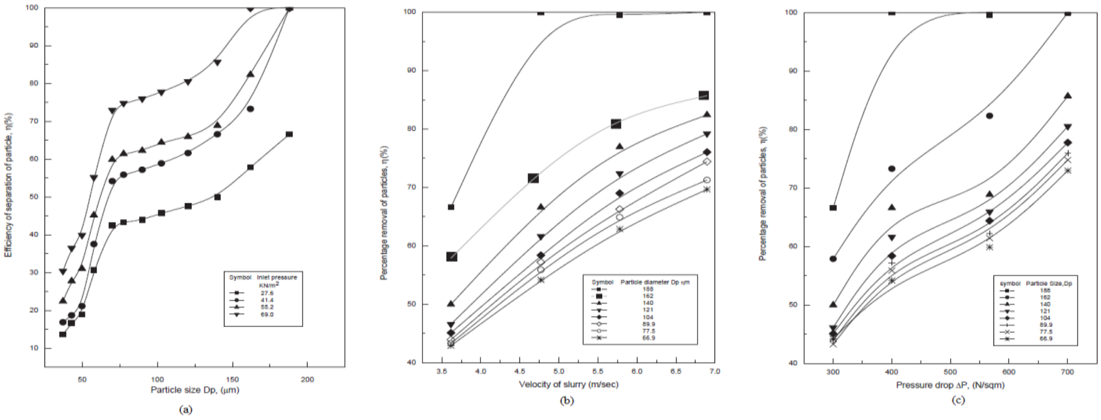
Fig 3. A typical plot of particle size distribution (Malvern particle size analysis for sand inlet sample at 27.6 kN/m^2 inlet slurry pressure) [17].

Knowing the particle size inlet and overflow, the efficiency of separation can be calculated by Eq. (5).

$$\eta = \frac{\text{Wt \% of particle at inlet} - \text{Wt \% of particle at overflow}}{\text{Wt \% of particle at inlet}} x100 \tag{5}$$

Dwari et al. [17] summarized the effect of particle size, velocity of flow, pressure drop on separation efficiency and their finding are represented in Fig 4.

Hydrocyclone studied by Dwari et al. [17] gave very little separation efficiency for the particles below 60 µm. It should be modified to increase the separation efficiency for the particles in range 10-50 µm. In terms of installation angle, Jun et al [7] claimed that it has little effect on classification performance in power plants. Accordingly, changing the installation angle and reducing the installation height is a good way to enhance the production capacity of hydrocyclones. Other than installation angle, particle size there are more parameters affecting hydrocyclone performance as pointed out in the study of Jun et al [7]. For example size of the hydrocyclone is also important and larger the size of hydrocyclone is the lower the separation performance. Regarding to cone angle, total separation efficiency decreases with the cone angle increasing. Last but not the least, increasing the underflow tube length will enhance production capacity at the same time reduce the cut size and increase the seperation efficiency [7].



(a) (b) (c)

Fig 4. Observations of Dwari et al [17] on parameters affecting the efficiency of separation of particles for sand and fly ash (a) effect of particle size (b) effect of velocity of flow (c) effect of pressure drop

3. RESULTS & DISCUSSION

Seperation efficiency of gypsum and waste water hydrocyclone was calculated in terms of Eq. (5). In order to do this calculation, inlet and overflow weight percentages at specific size should be known. For gypsum and waste water hydrocyclone Wt% are provided in Table 1. Malvern Mastersizer analysis results are presented in Fig 5-7 and tabulated in Table 3 for waste water hydrocyclone. For gypsum hydrocyclone, results are presented in Fig 8-10 and tabulated in Table 4, respectively.

The values in Table 1 are raw data of Malvern Mastersizer analysis result. Referring to the values in Table 1, overflow and downstream percentages can be calculated. This calculation is carried out with the basis of x (%) is overflow and y (%) is downstream for gypsum hydrocyclone and k (%) is overflow and z (%) is downstream for waste water hydrocyclone. That is why;

x+y=100(%) for gypsum hydrocyclone (6)

k+z=100(%) for waste water hydrocyclone. (7)

Mass balance equations at inlet size of D_{25} can be written as;

26.50*x (%)+16.41*y (%)=25.86*100 (%) for gypsum hydrocyclone, (8)

92.61*k (%)+20.17*z (%)=24.47*100 (%) for waste water hydrocyclone. (9)

From Eq. (6)-(9), x is 93.65 (%), y is 6.35 (%), k is 5.94 (%) and z is 94.06 (%), respectively. Having calculated the overflow and downstream ratios for each hydrocyclone, real cumulative undersize percentages at inlet D_{25} size are provided in Table 2.

Table 1. Wt% (for the inlet D25 size) for gypsum and waste water hydrocyclones without considering overflow and downstream ratios (Refer to Table 3 and Table 4)

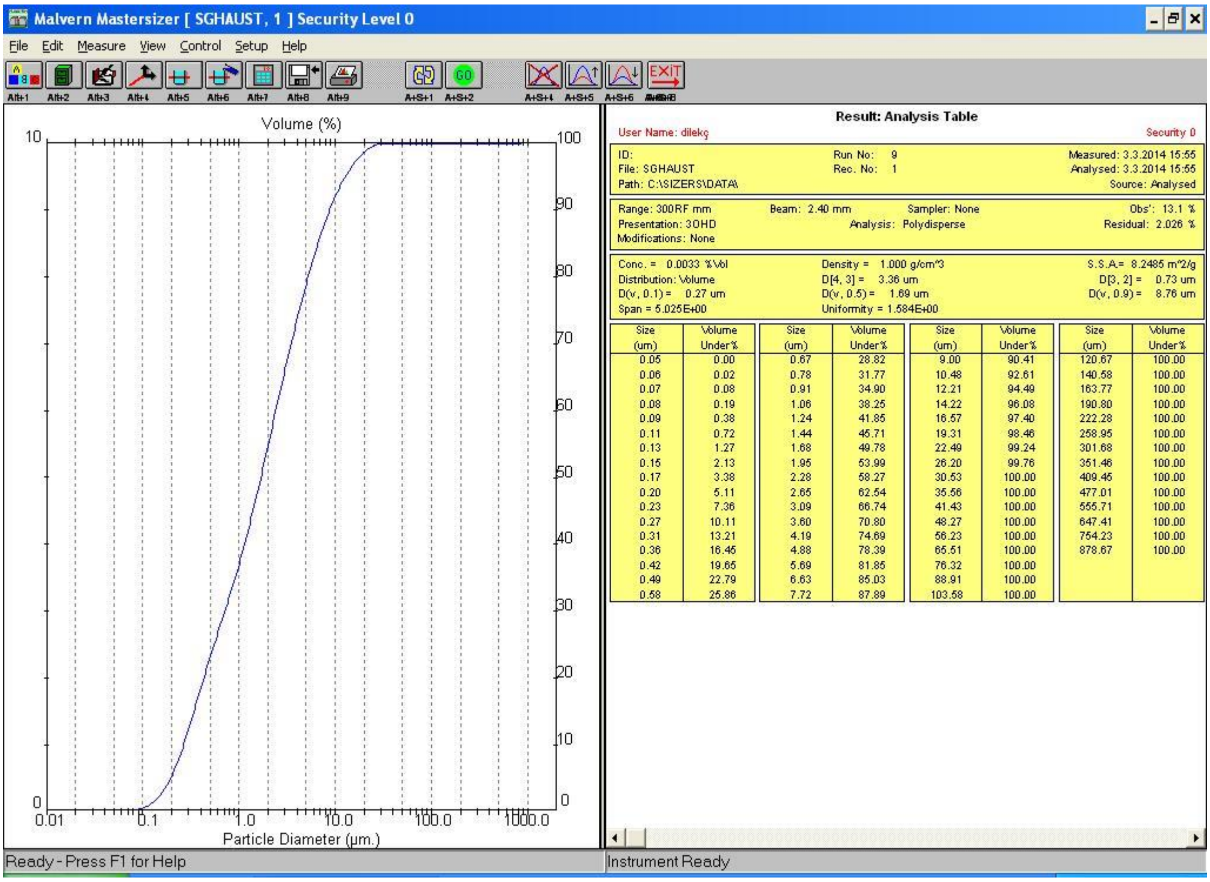
Hydrocyclone	**Wt% (for the inlet D25 size)**		
	Inlet	**Overflow**	**Downstream**
Gypsum Hydrocyclone	24.47	92.61	20.17
Wastewater hydrocyclone	25.86	26.50	16.41

Table 2. Wt% (for the inlet D25 size) for gypsum and waste water hydrocyclones with considering overflow and downstream ratios.

Hydrocyclone	**Wt% (for the inlet D25 size)**		
	Inlet	**Overflow**	**Downstream**
Gypsum Hydrocyclone	24.47	5.50	18.97
Waste water hydrocyclone	25.86	24.82	1.04

Replacing the values of inlet and overflow in the Eq. (5) seperation efficiencies were calculated as 77.5 % for gypsum hydrocyclone and 4.0 % for waste water hydrocyclone respectively.

Obtained D_{25} sizes (inlet) are 0.6707 µm (See Table 3) for waste water hydrocyclone and 12.2096 µm (See Table 4) for gypsum hydrocyclone, respectively. Waste water hydrocyclone has low separation efficiency. This is because coarser particles are fed to gypsum hydrocyclone and finer purification is done with waste water hydrocyclone. This is also supported in the study of Dwari et al. [17] claiming that separation efficiency is very little for fine particles. Separation efficiency of a hydrocyclone is one of the most crucial issue in terms of its design and operation. Yu and Fu [18] have investigated the separation performance of an 8 mm mini hydrocyclone and its application for the treatment of rice starch wastewater. Yu and Fu [18] have summarized the attempts to enhance the separation performance of hydrcyclones. For example, Fu et al. [19] have tried to optimize structural parameters such as cylinder diameter [18]. In addition, researchers have investigated vortex finder structure and size [20,21], inlet dimensions [22], cyclone height [23], underflow pipe diameter [24], and cut size [25] proportional to cylinder diameter roles on separation efficiency [18]. Although these abovementioned researchers have contributed significantly, a correct calculation of separation efficiency is most of the time is unheeded. Each research should initially focus on the correct calculation of the separation efficiency since any efficiency improvement can better be observed later on. Findings of this study would be significant in terms of correct calculation methodology of a hydrocyclone separation efficiencies.



Result: Analysis Table

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Security 0

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Analysed: 3.3.2014 15:55
Source: Analysed

Range: 300RF mm
Beam: 2.40 mm
Sampler: None
Obs': 13.1 %
Presentation: 3OHD
Analysis: Polydisperse
Residual: 2.026 %
Modifications: None

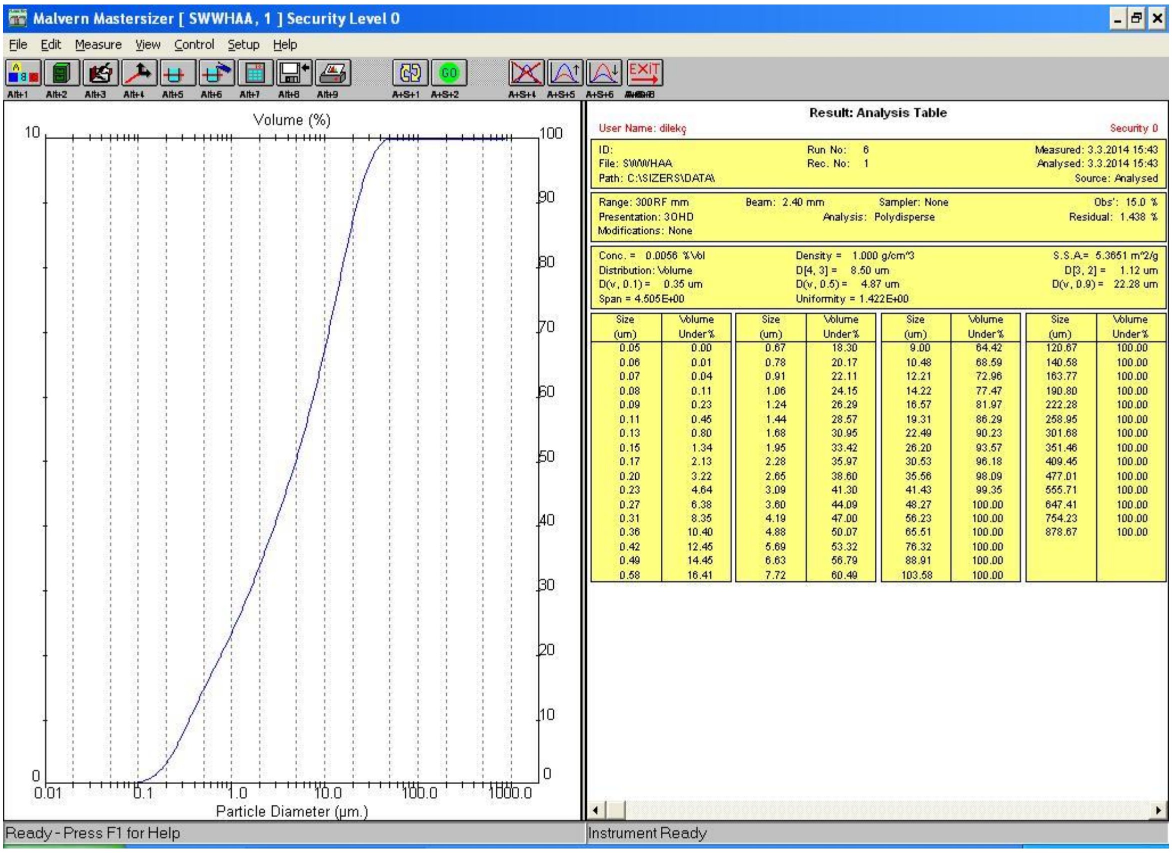
Conc. = 0.0033 %Vol
Density = 1.000 g/cm^3
S.S.A.= 8.2485 m^2/g
Distribution: Volume
D[4, 3] = 3.36 um
D[3, 2] = 0.73 um
D(v, 0.1) = 0.27 um
D(v, 0.5) = 1.69 um
D(v, 0.9) = 8.76 um
Span = 5.025E+00
Uniformity = 1.584E+00

Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%
0.05	0.00	0.67	28.82	9.00	90.41	120.67	100.00
0.06	0.02	0.78	31.77	10.48	92.61	140.58	100.00
0.07	0.08	0.91	34.90	12.21	94.49	163.77	100.00
0.08	0.19	1.06	38.25	14.22	96.08	190.80	100.00
0.09	0.38	1.24	41.85	16.57	97.40	222.28	100.00
0.11	0.72	1.44	45.71	19.31	98.46	258.95	100.00
0.13	1.27	1.68	49.78	22.49	99.24	301.68	100.00
0.15	2.13	1.95	53.99	26.20	99.76	351.46	100.00
0.17	3.38	2.28	58.27	30.53	100.00	409.45	100.00
0.20	5.11	2.65	62.54	35.56	100.00	477.01	100.00
0.23	7.36	3.09	66.74	41.43	100.00	555.71	100.00
0.27	10.11	3.60	70.80	48.27	100.00	647.41	100.00
0.31	13.21	4.19	74.69	56.23	100.00	754.23	100.00
0.36	16.45	4.88	78.39	65.51	100.00	878.67	100.00
0.42	19.65	5.69	81.85	76.32	100.00		
0.49	22.79	6.63	85.03	88.91	100.00		
0.58	25.86	7.72	87.89	103.58	100.00		

Fig 5. PSD of feed for wastewater hydrocyclone

Table 3. PSD of feed downstream and overflow of wastewater hydrocyclone

Size, µm	**Feed**			**Downstream**			**Overflow**		
	Amount (%)	**Cumulative oversize (%)**	**Cumulative Undersize (%)**	**Amount (%)**	**Cumulative oversize (%)**	**Cumulative Undersize (%)**	**Amount (%)**	**Cumulative oversize (%)**	**Cumulative Undersize (%)**
SIZES*	***RESULT***	**Σ (+) (%)**	**Σ (-) (%)**	***RESULT***	**Σ (+) (%)**	**Σ (-) (%)**	***RESULT***	**Σ (+) (%)**	**Σ (-) (%)**
.0582	0.0225	100.00		0.01183	100.00		0.01139	100.00	
.0679	0.05548	99.98	0.02	0.03267	99.99	0.01	0.0298	99.99	0.01
.0791	0.10814	99.92	0.08	0.06688	99.96	0.04	0.06258	99.96	0.04
.0921	0.19493	99.81	0.19	0.1231	99.89	0.11	0.12292	99.90	0.10
.1073	0.33596	99.62	0.38	0.21344	99.77	0.23	0.2322	99.77	0.23
.125	0.55231	99.28	0.72	0.35058	99.55	0.45	0.41792	99.54	0.46
.1456	0.85763	98.73	1.27	0.54284	99.20	0.80	0.70553	99.12	0.88
.1697	1.25399	97.87	2.13	0.79192	98.66	1.34	1.11088	98.42	1.58
.1977	1.7288	96.62	3.38	1.09084	97.87	2.13	1.63276	97.31	2.69
.2303	2.2498	94.89	5.11	1.42014	96.78	3.22	2.24289	95.67	4.33
.2683	2.74683	92.64	7.36	1.73611	95.36	4.64	2.85822	93.43	6.57
.3125	3.1033	89.89	10.11	1.96569	93.62	6.38	3.32238	90.57	9.43
.3641	3.23748	86.79	13.21	2.05701	91.65	8.35	3.51229	87.25	12.75
.4242	3.20554	83.55	16.45	2.04368	89.60	10.40	3.48914	83.74	16.26
.4941	3.1381	80.35	19.65	2.00595	87.55	12.45	3.41904	80.25	19.75
.5757	3.06474	77.21	22.79	1.96022	85.55	14.45	3.33437	76.83	23.17
.6707	***2.96115***	***74.14***	***25.86***	***1.88836***	***83.59***	***16.41***	***3.19556***	***73.50***	***26.50***
.7813	2.95621	71.18	28.82	1.86837	81.70	18.30	3.1667	70.30	29.70
.9103	3.13166	68.23	31.77	1.94126	79.83	20.17	3.34941	67.13	32.87
.0604	3.34608	65.10	34.90	2.03532	77.89	22.11	3.5851	63.78	36.22
.2354	3.59684	61.75	38.25	2.1483	75.85	24.15	3.88012	60.20	39.80
.4393	3.86003	58.15	41.85	2.27225	73.71	26.29	4.21187	56.32	43.68
.6767	4.07305	54.29	45.71	2.38252	71.43	28.57	4.49458	52.11	47.89
.9534	4.20667	50.22	49.78	2.47065	69.05	30.95	4.6786	47.61	52.39
.2757	4.2782	46.01	53.99	2.55088	66.58	33.42	4.7841	42.93	57.07
.6512	4.27343	41.73	58.27	2.62489	64.03	35.97	4.78712	38.15	61.85
.0887	4.19634	37.46	62.54	2.70202	61.40	38.60	4.69218	33.36	66.64
.5983	4.06161	33.26	66.74	2.79323	58.70	41.30	4.54249	28.67	71.33
.192	3.89304	29.20	70.80	2.91264	55.91	44.09	4.25232	24.13	75.87
.8837	3.70186	25.31	74.69	3.06551	53.00	47.00	3.91787	19.88	80.12
.6895	3.45887	21.61	78.39	3.25386	49.93	50.07	3.53662	15.96	84.04
.6283	3.1757	18.15	81.85	3.46693	46.68	53.32	3.09453	12.42	87.58
.7219	2.85974	14.97	85.03	3.69702	43.21	56.79	2.60753	9.33	90.67
.996	2.52804	12.11	87.89	3.93469	39.51	60.49	2.10518	6.72	93.28
0.4804	2.19515	9.59	90.41	4.16458	35.58	64.42	1.61949	4.61	95.39
2.2096	1.88086	7.39	92.61	4.37607	31.41	68.59	1.19187	2.99	97.01
4.2242	1.59212	5.51	94.49	4.50483	27.04	72.96	0.84535	1.80	98.20
6.5712	1.3226	3.92	96.08	4.50398	22.53	77.47	0.58219	0.96	99.04
9.3055	1.05308	2.60	97.40	4.32327	18.03	81.97	0.31904	0.37	99.63
2.4909	0.78356	1.54	98.46	3.93241	13.71	86.29	0.05589	0.06	99.94
6.2019	0.51404	0.76	99.24	3.34194	9.77	90.23	0	0.00	100.00
0.5252	0.24453	0.24	99.76	2.61091	6.43	93.57	0	0.00	100.00
5.5618	0	0.00	100.00	1.91278	3.82	96.18	0	0.00	100.00
1.4295	0	0.00	100.00	1.25531	1.91	98.09	0	0.00	100.00
8.2654	0	0.00	100.00	0.6523	0.65	99.35	0	0.00	100.00
6.2292	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
5.507	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
6.3157	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
8.9077	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
03.5775	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
20.6678	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
40.578	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
63.7733	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
90.7959	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
22.2773	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
58.953	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
01.6802	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
51.4575	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
09.4479	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
77.0068	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
55.713	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
47.4056	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
54.2275	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
78.675	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00



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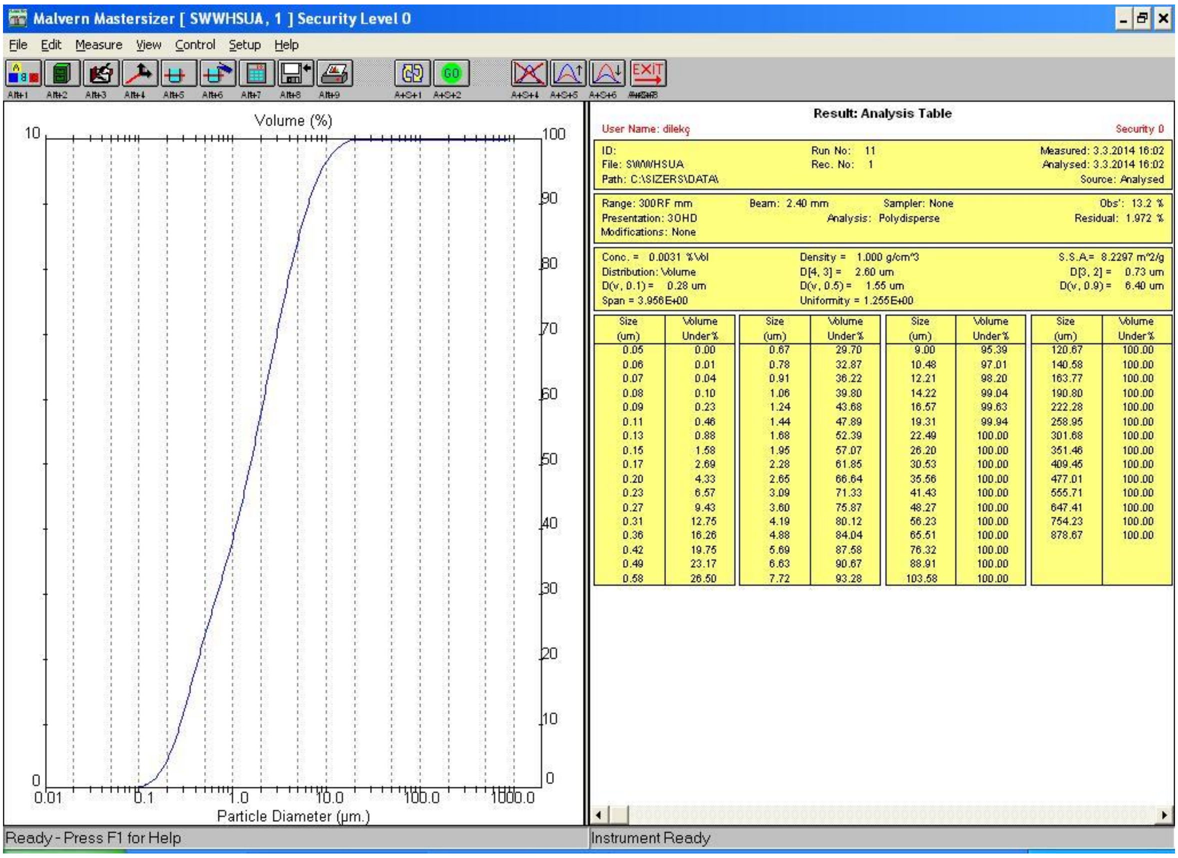
Beam: 2.40 mm
Sampler: None
Obs': 15.0 %
Presentation: 3OHD
Analysis: Polydisperse
Residual: 1.438 %
Modifications: None

Conc. = 0.0056 %Vol
Density = 1.000 g/cm^3
S.S.A.= 5.3651 m^2/g
Distribution: Volume
D[4, 3] = 8.50 um
D[3, 2] = 1.12 um
D(v, 0.1) = 0.35 um
D(v, 0.5) = 4.87 um
D(v, 0.9) = 22.28 um
Span = 4.505E+00
Uniformity = 1.422E+00

Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%
0.05	0.00	0.67	18.30	9.00	64.42	120.67	100.00
0.06	0.01	0.78	20.17	10.48	68.59	140.58	100.00
0.07	0.04	0.91	22.11	12.21	72.96	163.77	100.00
0.08	0.11	1.06	24.15	14.22	77.47	190.80	100.00
0.09	0.23	1.24	26.29	16.57	81.97	222.28	100.00
0.11	0.45	1.44	28.57	19.31	86.29	258.95	100.00
0.13	0.80	1.68	30.95	22.49	90.23	301.68	100.00
0.15	1.34	1.95	33.42	26.20	93.57	351.46	100.00
0.17	2.13	2.28	35.97	30.53	96.18	409.45	100.00
0.20	3.22	2.65	38.60	35.56	98.09	477.01	100.00
0.23	4.64	3.09	41.30	41.43	99.35	555.71	100.00
0.27	6.38	3.60	44.09	48.27	100.00	647.41	100.00
0.31	8.35	4.19	47.00	56.23	100.00	754.23	100.00
0.36	10.40	4.88	50.07	65.51	100.00	878.67	100.00
0.42	12.45	5.69	53.32	76.32	100.00		
0.49	14.45	6.63	56.79	88.91	100.00		
0.58	16.41	7.72	60.49	103.58	100.00		

Ready - Press F1 for Help
Instrument Ready

Fig 6. PSD of overflow for wastewater hydrocyclone



Result: Analysis Table

User Name: dilekç Security 0

ID:
File: SWWHSUA
Path: C:\SIZERS\DATA\
Run No: 11
Rec. No: 1
Measured: 3.3.2014 16:02
Analysed: 3.3.2014 16:02
Source: Analysed

Range: 300RF mm
Beam: 2.40 mm
Sampler: None
Obs': 13.2 %
Presentation: 3OHD
Analysis: Polydisperse
Residual: 1.972 %
Modifications: None

Conc. = 0.0031 %Vol
Density = 1.000 g/cm^3
S.S.A.= 8.2297 m^2/g
Distribution: Volume
D[4, 3] = 2.60 um
D[3, 2] = 0.73 um
D(v, 0.1) = 0.28 um
D(v, 0.5) = 1.55 um
D(v, 0.9) = 6.40 um
Span = 3.956E+00
Uniformity = 1.255E+00

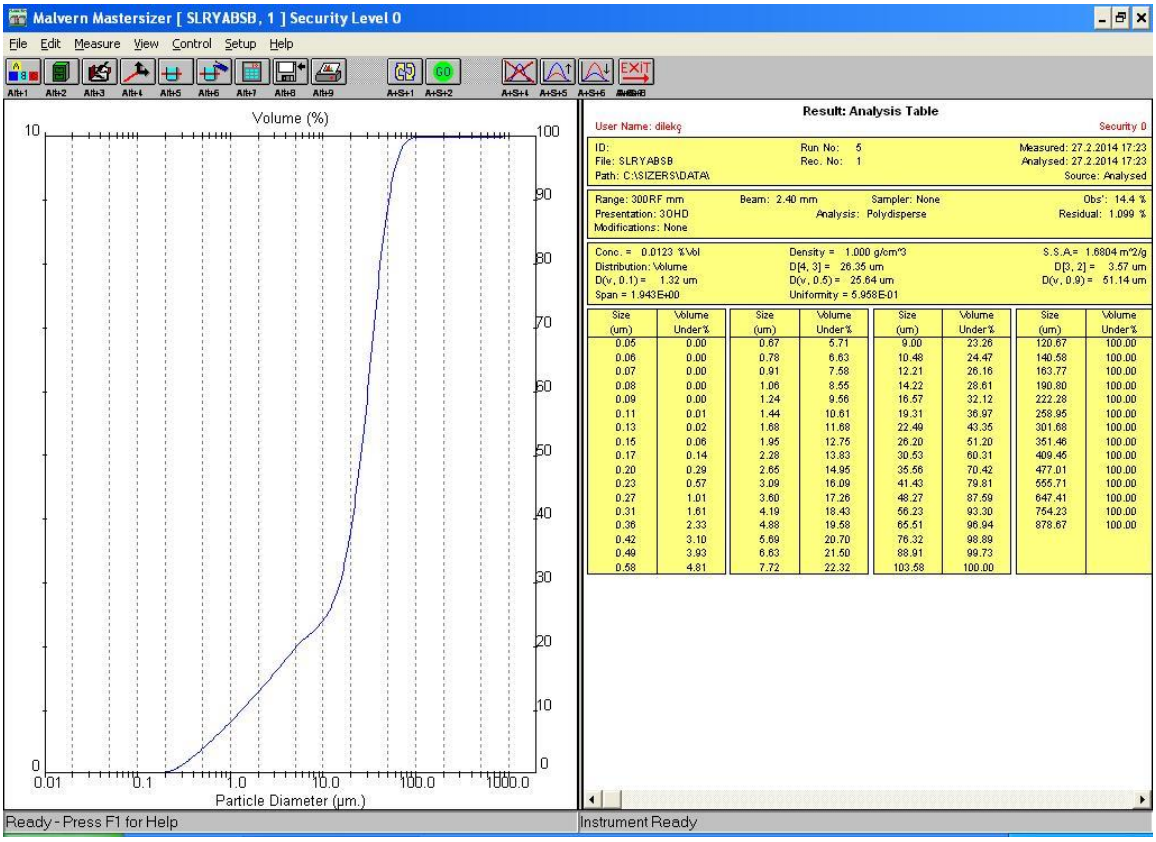
Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%
0.05	0.00	0.67	29.70	9.00	95.39	120.67	100.00
0.06	0.01	0.78	32.87	10.48	97.01	140.58	100.00
0.07	0.04	0.91	36.22	12.21	98.20	163.77	100.00
0.08	0.10	1.06	39.80	14.22	99.04	190.80	100.00
0.09	0.23	1.24	43.68	16.57	99.63	222.28	100.00
0.11	0.46	1.44	47.89	19.31	99.94	258.95	100.00
0.13	0.88	1.68	52.39	22.49	100.00	301.68	100.00
0.15	1.58	1.95	57.07	26.20	100.00	351.46	100.00
0.17	2.69	2.28	61.85	30.53	100.00	409.45	100.00
0.20	4.33	2.65	66.64	35.56	100.00	477.01	100.00
0.23	6.57	3.09	71.33	41.43	100.00	555.71	100.00
0.27	9.43	3.60	75.87	48.27	100.00	647.41	100.00
0.31	12.75	4.19	80.12	56.23	100.00	754.23	100.00
0.36	16.26	4.88	84.04	65.51	100.00	878.67	100.00
0.42	19.75	5.69	87.58	76.32	100.00		
0.49	23.17	6.63	90.67	88.91	100.00		
0.58	26.50	7.72	93.28	103.58	100.00		

Ready - Press F1 for Help
Instrument Ready

Fig 7. PSD of downstream of wastewater hydrocyclone

Table 4. PSD of feed overflow and downstream of gypsum hydrocyclone

Size, µm	Feed			Downstream			Overflow		
	Amount (%)	Cumulative oversize (%)	Cumulative Undersize (%)	Amount (%)	Cumulative oversize (%)	Cumulative Undersize (%)	Amount (%)	Cumulative oversize (%)	Cumulative Undersize (%)
SIZES	*RESULT*	Σ (+) (%)	Σ (-) (%)	*RESULT*	Σ (+) (%)	Σ (-) (%)	*RESULT*	Σ (+) (%)	Σ (-) (%)
0.0582	0.00009	100.00		0.00011	100.00		0.0225	100.00	
0.0679	0.00029	100.00	0.00	0.00033	100.00	0.00	0.05548	99.98	0.02
0.0791	0.00081	100.00	0.00	0.00086	100.00	0.00	0.10814	99.92	0.08
0.0921	0.00218	100.00	0.00	0.00216	100.00	0.00	0.19493	99.81	0.19
0.1073	0.00584	100.00	0.00	0.0054	100.00	0.00	0.33596	99.62	0.38
0.125	0.01509	99.99	0.01	0.01299	99.99	0.01	0.55231	99.28	0.72
0.1456	0.03604	99.98	0.02	0.02918	99.98	0.02	0.85763	98.73	1.27
0.1697	0.07826	99.94	0.06	0.06028	99.95	0.05	1.25399	97.87	2.13
0.1977	0.15407	99.86	0.14	0.11428	99.89	0.11	1.7288	96.62	3.38
0.2303	0.27491	99.71	0.29	0.19872	99.77	0.23	2.2498	94.89	5.11
0.2683	0.43812	99.43	0.57	0.31227	99.58	0.42	2.74683	92.64	7.36
0.3125	0.60424	98.99	1.01	0.43021	99.26	0.74	3.1033	89.89	10.11
0.3641	0.71657	98.39	1.61	0.51612	98.83	1.17	3.23748	86.79	13.21
0.4242	0.7742	97.67	2.33	0.56835	98.32	1.68	3.20554	83.55	16.45
0.4941	0.82854	96.90	3.10	0.61985	97.75	2.25	3.1381	80.35	19.65
0.5757	0.88268	96.07	3.93	0.6703	97.13	2.87	3.06474	77.21	22.79
0.6707	0.89612	95.19	4.81	0.68687	96.46	3.54	2.96115	74.14	25.86
0.7813	0.92615	94.29	5.71	0.7061	95.77	4.23	2.95621	71.18	28.82
0.9103	0.94498	93.37	6.63	0.69228	95.07	4.93	3.13166	68.23	31.77
1.0604	0.97399	92.42	7.58	0.6817	94.37	5.63	3.34608	65.10	34.90
1.2354	1.01031	91.45	8.55	0.66923	93.69	6.31	3.59684	61.75	38.25
1.4393	1.04895	90.44	9.56	0.65514	93.02	6.98	3.86003	58.15	41.85
1.6767	1.06633	89.39	10.61	0.6362	92.37	7.63	4.07305	54.29	45.71
1.9534	1.06704	88.32	11.68	0.62545	91.73	8.27	4.20667	50.22	49.78
2.2757	1.08609	87.25	12.75	0.64502	91.11	8.89	4.2782	46.01	53.99
2.6512	1.11587	86.17	13.83	0.6882	90.46	9.54	4.27343	41.73	58.27
3.0887	1.14576	85.05	14.95	0.74472	89.77	10.23	4.19634	37.46	62.54
3.5983	1.16477	83.91	16.09	0.80082	89.03	10.97	4.06161	33.26	66.74
4.192	1.16767	82.74	17.26	0.84991	88.23	11.77	3.89304	29.20	70.80
4.8837	1.15186	81.57	18.43	0.89251	87.38	12.62	3.70186	25.31	74.69
5.6895	1.1259	80.42	19.58	0.94209	86.48	13.52	3.45887	21.61	78.39
6.6283	0.80059	79.30	20.70	1.02531	85.54	14.46	3.1757	18.15	81.85
7.7219	0.8181	78.50	21.50	1.19071	84.52	15.48	2.85974	14.97	85.03
8.996	0.94013	77.68	22.32	1.49668	83.33	16.67	2.52804	12.11	87.89
10.4804	1.20961	76.74	23.26	1.9949	81.83	18.17	2.19515	9.59	90.41
12.2096	***1.69033***	***75.53***	***24.47***	***2.72773***	***79.83***	***20.17***	***1.88086***	***7.39***	***92.61***
14.2242	2.44522	73.84	26.16	3.71456	77.11	22.89	1.59212	5.51	94.49
16.5712	3.50906	71.39	28.61	4.92738	73.39	26.61	1.3226	3.92	96.08
19.3055	4.8579	67.88	32.12	6.28451	68.47	31.53	1.05308	2.60	97.40
22.4909	6.37249	63.03	36.97	7.65612	62.18	37.82	0.78356	1.54	98.46
26.2019	7.85091	56.65	43.35	8.91463	54.52	45.48	0.51404	0.76	99.24
30.5252	9.1117	48.80	51.20	9.99977	45.61	54.39	0.24453	0.24	99.76
35.5618	10.10905	39.69	60.31	9.7558	35.61	64.39	0	0.00	100.00
41.4295	9.38766	29.58	70.42	8.6601	25.85	74.15	0	0.00	100.00
48.2654	7.78204	20.19	79.81	6.94389	17.19	82.81	0	0.00	100.00
56.2292	5.71574	12.41	87.59	4.97958	10.25	89.75	0	0.00	100.00
65.507	3.63587	6.70	93.30	3.09902	5.27	94.73	0	0.00	100.00
76.3157	1.94854	3.06	96.94	1.58944	2.17	97.83	0	0.00	100.00
88.9077	0.84013	1.11	98.89	0.58222	0.58	99.42	0	0.00	100.00
103.5775	0.2712	0.27	99.73	0	0.00	100.00	0	0.00	100.00
120.6678	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
140.578	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
163.7733	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
190.7959	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
222.2773	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
258.953	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
301.6802	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
351.4575	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
409.4479	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
477.0068	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
555.713	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
647.4056	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
754.2275	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00
878.675	0	0.00	100.00	0	0.00	100.00	0	0.00	100.00



Result: Analysis Table

User Name: dilekç Security 0

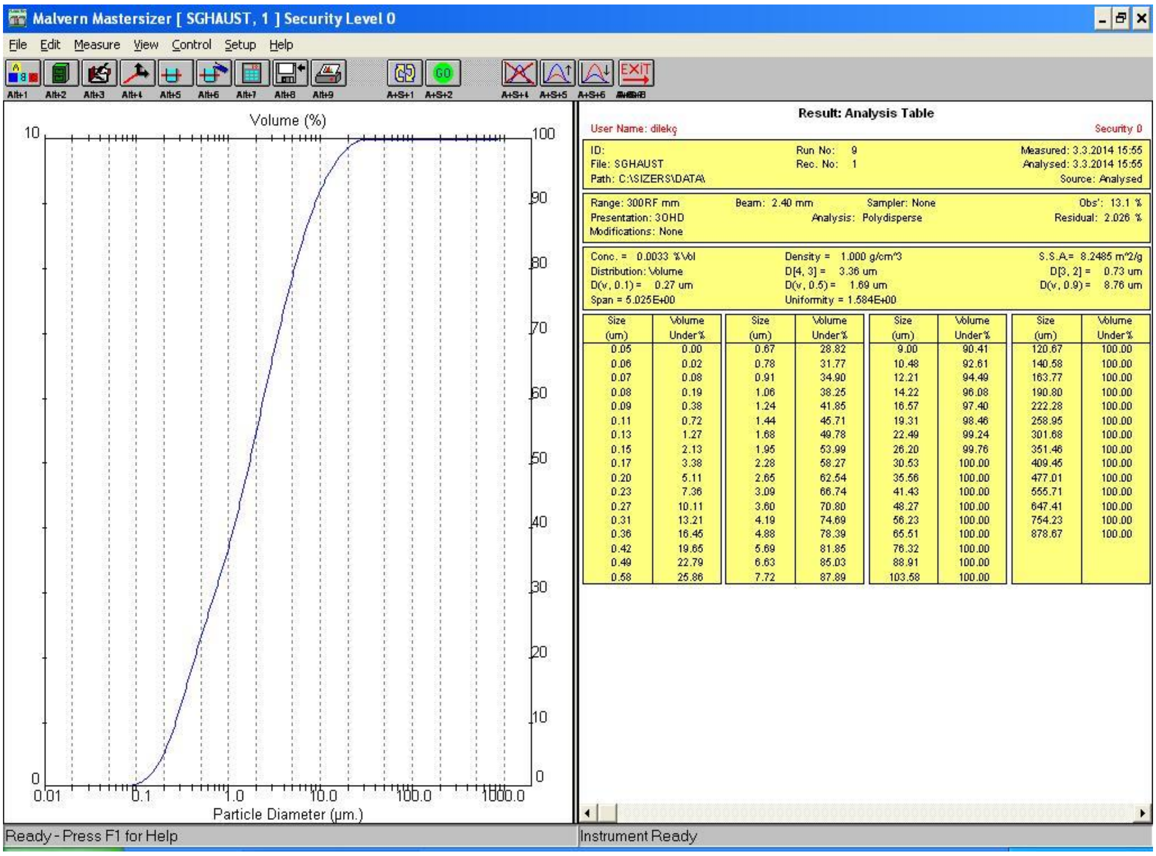
ID: Run No: 5 Measured: 27.2.2014 17:23
File: SLRYABSB Rec. No: 1 Analysed: 27.2.2014 17:23
Path: C:\SIZERS\DATA\ Source: Analysed

Range: 300RF mm Beam: 2.40 mm Sampler: None Obs': 14.4 %
Presentation: 3OHD Analysis: Polydisperse Residual: 1.099 %
Modifications: None

Conc. = 0.0123 %Vol Density = 1.000 g/cm^3 S.S.A.= 1.6804 m^2/g
Distribution: Volume D[4, 3] = 26.35 um D[3, 2] = 3.57 um
D(v, 0.1) = 1.32 um D(v, 0.5) = 25.64 um D(v, 0.9) = 51.14 um
Span = 1.943E+00 Uniformity = 5.958E-01

Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%
0.05	0.00	0.67	5.71	9.00	23.26	120.67	100.00
0.06	0.00	0.78	6.63	10.48	24.47	140.58	100.00
0.07	0.00	0.91	7.58	12.21	26.16	163.77	100.00
0.08	0.00	1.06	8.55	14.22	28.61	190.80	100.00
0.09	0.00	1.24	9.56	16.57	32.12	222.28	100.00
0.11	0.01	1.44	10.61	19.31	36.97	258.95	100.00
0.13	0.02	1.68	11.68	22.49	43.35	301.68	100.00
0.15	0.06	1.95	12.75	26.20	51.20	351.46	100.00
0.17	0.14	2.28	13.83	30.53	60.31	409.45	100.00
0.20	0.29	2.65	14.95	35.56	70.42	477.01	100.00
0.23	0.57	3.09	16.09	41.43	79.81	555.71	100.00
0.27	1.01	3.60	17.26	48.27	87.59	647.41	100.00
0.31	1.61	4.19	18.43	56.23	93.30	754.23	100.00
0.36	2.33	4.88	19.58	65.51	96.94	878.67	100.00
0.42	3.10	5.69	20.70	76.32	98.89		
0.49	3.93	6.63	21.50	88.91	99.73		
0.58	4.81	7.72	22.32	103.58	100.00		

Fig 8. PSD of feed to gypsum hydrocyclone



Result: Analysis Table

User Name: dilekç Security 0

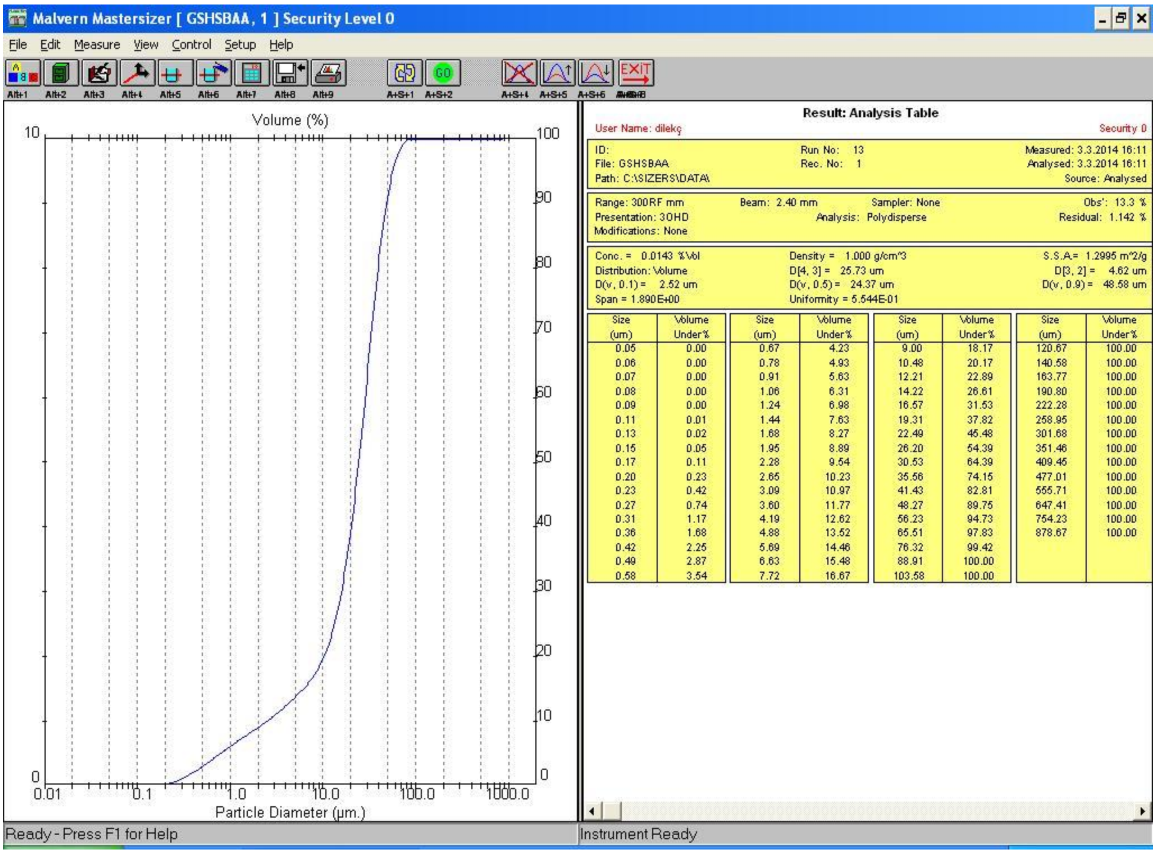
ID: Run No: 9 Measured: 3.3.2014 15:55
File: SGHAUST Rec. No: 1 Analysed: 3.3.2014 15:55
Path: C:\SIZERS\DATA\ Source: Analysed

Range: 300RF mm Beam: 2.40 mm Sampler: None Obs': 13.1 %
Presentation: 3OHD Analysis: Polydisperse Residual: 2.026 %
Modifications: None

Conc. = 0.0033 %Vol Density = 1.000 g/cm^3 S.S.A.= 8.2485 m^2/g
Distribution: Volume D[4, 3] = 3.36 um D[3, 2] = 0.73 um
D(v, 0.1) = 0.27 um D(v, 0.5) = 1.69 um D(v, 0.9) = 8.76 um
Span = 5.025E+00 Uniformity = 1.584E+00

Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%
0.05	0.00	0.67	28.82	9.00	90.41	120.67	100.00
0.06	0.02	0.78	31.77	10.48	92.61	140.58	100.00
0.07	0.08	0.91	34.90	12.21	94.49	163.77	100.00
0.08	0.19	1.06	38.25	14.22	96.08	190.80	100.00
0.09	0.38	1.24	41.85	16.57	97.40	222.28	100.00
0.11	0.72	1.44	45.71	19.31	98.46	258.95	100.00
0.13	1.27	1.68	49.78	22.49	99.24	301.68	100.00
0.15	2.13	1.95	53.99	26.20	99.76	351.46	100.00
0.17	3.38	2.28	58.27	30.53	100.00	409.45	100.00
0.20	5.11	2.65	62.54	35.56	100.00	477.01	100.00
0.23	7.36	3.09	66.74	41.43	100.00	555.71	100.00
0.27	10.11	3.60	70.80	48.27	100.00	647.41	100.00
0.31	13.21	4.19	74.69	56.23	100.00	754.23	100.00
0.36	16.45	4.88	78.39	65.51	100.00	878.67	100.00
0.42	19.65	5.69	81.85	76.32	100.00		
0.49	22.79	6.63	85.03	88.91	100.00		
0.58	25.86	7.72	87.89	103.58	100.00		

Fig 9. PSD of overflow for gypsum hydrocyclone



Result: Analysis Table

User Name: dilekç Security 0

ID: Run No: 13 Measured: 3.3.2014 16:11
File: GSHSBAA Rec. No: 1 Analysed: 3.3.2014 16:11
Path: C:\SIZERS\DATA\ Source: Analysed

Range: 300RF mm Beam: 2.40 mm Sampler: None Obs': 13.3 %
Presentation: 3OHD Analysis: Polydisperse Residual: 1.142 %
Modifications: None

Conc. = 0.0143 %Vol Density = 1.000 g/cm^3 S.S.A.= 1.2995 m^2/g
Distribution: Volume D[4, 3] = 25.73 um D[3, 2] = 4.62 um
D(v, 0.1) = 2.52 um D(v, 0.5) = 24.37 um D(v, 0.9) = 48.58 um
Span = 1.890E+00 Uniformity = 5.544E-01

Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%	Size (um)	Volume Under%
0.05	0.00	0.67	4.23	9.00	18.17	120.67	100.00
0.06	0.00	0.78	4.93	10.48	20.17	140.58	100.00
0.07	0.00	0.91	5.63	12.21	22.89	163.77	100.00
0.08	0.00	1.06	6.31	14.22	26.61	190.80	100.00
0.09	0.00	1.24	6.98	16.57	31.53	222.28	100.00
0.11	0.01	1.44	7.63	19.31	37.82	258.95	100.00
0.13	0.02	1.68	8.27	22.49	45.48	301.68	100.00
0.15	0.05	1.95	8.89	26.20	54.39	351.46	100.00
0.17	0.11	2.28	9.54	30.53	64.39	409.45	100.00
0.20	0.23	2.65	10.23	35.56	74.15	477.01	100.00
0.23	0.42	3.09	10.97	41.43	82.81	555.71	100.00
0.27	0.74	3.60	11.77	48.27	89.75	647.41	100.00
0.31	1.17	4.19	12.62	56.23	94.73	754.23	100.00
0.36	1.68	4.88	13.52	65.51	97.83	878.67	100.00
0.42	2.25	5.69	14.46	76.32	99.42		
0.49	2.87	6.63	15.48	88.91	100.00		
0.58	3.54	7.72	16.67	103.58	100.00		

Fig 10. PSD of downstream for gypsum hydrocyclone

4. CONCLUSIONS

In this study, separation efficiencies of gypsum and waste water hydrocyclones in WFGD system in a power plant were calculated. In order to carry out separation efficiency calculation, raw data of particle size analysis carried out with Malvern Mastersizer for each sample (a total of 5) was employed. Respective percentages of overflow and downstream for each hydrocyclone were obtained from this raw data. Seperation efficiency for gypsum hydrocyclone was calculated as 77.5 % while it was calculated as 4.0 % for waste water hydrocyclone. Based on the results obtained, it can be emphasized that more analysis on each hydrocyclone especially on waste water hydrocyclone should be carried out. Referring to the study of Dwari et al., [17] separation efficiency is very little for the particles below 60 µm. Although low separation efficiency for fine particles might be understandable, there is a strong requirement of possible increase in terms of environment. This study would be very helpful for future studies on waste water purification systems in power plants and separation efficiency on hydrocyclones.

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