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Studying the Factors effect on Separation of Two Solid Equivalent Particle According to Density and Determination the best Separation Point

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ABSTRACT

Density separation has many applications in metallurgy, medicine, clinical chemistry, microbiology, and agriculture. This study investigates the factors' effects on density separation in order to benefit from this technique. The separation quality depends on the velocity of particles because as the velocity of particles increases, the mean separation needs less time so it gives better separation, so the parameter effect on the value of the velocity is studied. These parameters were volume fractions, the diameter of the sphere, the density of the sphere, and the viscosity of the fluid. Each parameter was studied by calculating the velocity of particles using Stokes' law. The velocity of particles is directly proportional to some properties of particles. These properties are the diameter and density of a particle because as these properties increase, the mass of particles increases, which leads to increased kinetic energy, which increases turbulence. Turblance's velocity is increasing. The volume fraction of spheres is another property of particles' effects on density separation. This parameter is inversely proportional to velocity because a collision between particles increases, which decreases turbulence. Fluid properties also have an impact on density separation. This property is viscosity. Its effect deteriorates the efficiency of separation because viscosity is the resistance of the fluid to flow that serves to displace the particle, which leads to a reduction in the velocity of the particle. The maximum separation happens when the sink and float particles separate at the same time. That happens when the sink and float particles have the same velocity in the opposite direction. That means when the sum of velocities equals zero. In this research, the maximum separation was derived when the sum of velocities equaled zero.

1. Introduction

Separation of an analyst from interference is possible if at least one of their chemical or physical properties is significantly different. These techniques are used to determine the scale; the mass or density; the formation of complexes; the transition in physical conditions; chemical condition transition; and phase partitioning. Density separation has many applications in metallurgy, medicine, clinical chemistry, microbiology, and agriculture. Mineral densities typically range from 2.2 and 8 grams per cubic centimeter but are often between 2.5 and 3.5 grams per cubic centimeter of silicate minerals. Bromoform (2.84g/cc density) and di-iodomethane (3.31g/cc density) are ideal liquids for density separation. The flask's separatory funnel is placed on the adding spout and the sample is given a

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thorough rinse with the rough [coarse] solvent [1]. To promote crystallization in CaCl2 and NaCl solutions and increase CaCl and NaCl density in a stationary phase, particles are typically immersed in either alcohol-saturated or strongly alkaline solutions (with an excess of Ca(NO3)2, NaCl, or Zn(Cl) concentrations) [2].Although heavier plastics sink in a brine (salt) solution, lighter plastics float and can be extracted. Different brine solutions may be used to distinguish between different forms of plastic [3]. The Floatex Density Separator (FDS) is a concentrator that maximizes column separation efficiency via the use of fluidization and neutralization (fake liquid). In contrast to density fluid separation, where only the mass of the media has an effect, both the liquid density and upward liquid (teeter) flow have a significant influence on separation in the tete-d-dite [4].

Gluskoter et al. (1977) developed a standard procedure for such separations at the Illinois Geological Survey (IGS). Each element is classified according to its "organic affinity" (OA), a semiquantitative characteristic that shows whether the element "prefers" organic minerals in coal (organic affinity >1) or inorganic mineral phases (organic affinity 1). A density separation with an OA of one has minimal impact on the concentration of an element [5]. Quinn et al. [2017] found that a range of density separation techniques for isolating microplastics from sediment have been developed using a variety of brine solutions[6]. Klima and Kim [1996] conducted the tests to evaluate the effectiveness of a 25-mm diameter hydrocyclone in sorting fine particles. They demonstrate the feasibility of using a range of brine solutions in a single-stage process capable of consistently high recoveries for a variety of microplastic polymers with a diameter of 1 mm that are appropriate for monitoring programs. The study looked at how well tap water and brine solutions with sodium chloride (NaCl), sodium bromide (NaBr), sodium iodide (NaI), and zinc bromide (ZnBr2) removed ecologically important microplastics (size range: 200–400 m and 800–1000 m) from post-consumer goods[7].

Density separation has a range of medicinal applications. In vitro cell-cell contact is one of them. It is the technique of fractionating normal human bone marrow cells based on their buoyant density as determined by Haskill et al. [1972] [8]. . Hamburger et al. (1985) pioneered the use of Percoll discontinuous density gradients to differentiate single cells from adenocarcinoma effusions. Total cell regeneration was 67 +/-4% over 27 trials. Purification of macrophages (82% to 90% in the intermediate density fraction (1.056-1.067 g ml/1). The high density fraction (1.067-1.077 g ml/1) recovered lymphocytes with a purity of 92% (98%).In the lowest density fractions (up to 1.056 g ml-1), malignant adenocarcinoma cells (90%) were recovered with a purity of 79%[9]. Jonge and Bouwman [1977] performed research in which they defined the process of quantitative density separation[10]. The technique is based on the fact that meiobenthos and sediment have significantly different fundamental masses. Strebin et al. (1977) did a series of tests to see if a ferrofluid density separator could be used to separate micrometer-sized particles cx heavy minerals such as monazite and zircon from lighter minerals such as sillimanite and quartz[12]. Kohl and Nishiizumi [1992] refined quartz by performing density separation on the whole quartz fraction to exclude composite grains and the bulk of non-quartz minerals that are expected to be present in the 2.63g/-2.67 density fraction[13]. Hallam [1969] discovered that clay minerals have incompatible densities or are composed of a collection of mixed layer minerals that can only be distinguished by the density of isolated zones (or portions of them) that form in centrifuged density gradient columns containing various pretreated natural clays or clay mixtures[14]. Bacteria kept their capsules after being re-grown, but cells that didn't have capsules went back to having a mixed phenotype by Pactrick and Reid, 1983[15].

Laursen et al. [2003] purified spermatozoa utilizing a better-developed medium and discontinuous density gradient separation in assisted reproduction[16]. ULutz et al. [1992] demonstrated that self-forming PercollR gradients may be used to differentiate human red blood cells based on their density[17]. Rockne et al. [2003] established the use of density separation in microbiology by evaluating the effect of various density separation media on the survivability of Escherichia coli in order to determine its toxicity[18]. Alopes-Virella et al. (1977) developed a method for detecting high-density lipoprotein cholesterol using preparative ultracentrifugation, which separates lipoproteins in the solvent based on their density[19]. Taylor and Kenny (1985) argued that density isolation should be used as a standard technique for seed germination enhancement[20]. Takaki and Lima (2008) found that enclosing three-day-old seedlings in a 60 percent sucrose solution (w:v) enhanced the quality of germinated seeds[21]. Jordao et al. [1988] developed a technique for viable hormidium coriaceous seed selection utilizing a discontinuous sucrose gradient[22]. Taylor et al. [1978] demonstrated that sucrose solutions may be used to distinguish germinated from non-germinated seeds in Capsicum annuum L. and Apium graveolens L[23].

With this background, the separation of two solid spherical particles according to density is used when the particles are equal in size but different in density. To make this separation, we will take an intermediate fluid density does not react with the spheres. One of these particles had a density higher than fluid density, so it will sink; the other had a density lower than fluid density, so it will float to study the parameter effect on the separation. The particle velocity should be calculated if the two particles have the same velocity value and are opposite in direction, so the result will be zero, so the particles will separate at the same time, and that is the best separation. The importance of density separation led us to develop this type of separation in this research. So the parameter effect on density separation was studied in order to get a better separation. The indicator that determines the efficiency of the separation is the velocity of the particles, because if the velocity increases, the time decreases, and this thing leads to a faster separation. The velocity of the particles was calculated by the Stokes equation. The parameters' effect on the velocity of the particle was studied by taking different groups of spheres with different diameters, densities, and volume fractions and different fluids with different viscosities and determining the decrease and increase in velocity to control this method of separation.

2. Theoretical background and Methodology

Consider a combination of uniformly sized particles that has n components of densities injected into a fluid with intermediate density so the heavier sphere will sink and the lighter sphere will float.

2.1 Theoretical step to calculate velocity of particles .

Stokes' equation is used to compute the velocity of sinking float particles.that take up fractions of the total volume fraction [24].

The following formula is used to get the total volume fraction:

θ_i Supposed value for each types of sphere

$$\theta t = \sum_{i=1}^{n} \theta_i \qquad \ldots\ldots\ldots\ldots(1)$$

the residual volme fraction is for the fluid

$\theta t+\theta_f=100\%$

Note:where i=1, 2 n

The slurry's average density becomes

$$\rho_{\theta t} = \sum_{i=1}^{n} \rho_{pi}\, \theta_i + \rho_f (1-\theta_t) \qquad \ldots\ldots(2)$$

Let ρ_{pi} to define in terms of $\rho\theta t$ & the density difference δi

$$\rho_{pi} = \rho_{\theta t} + \delta_i \qquad \ldots\ldots\ldots(3)$$

The field's force on particle motion is dependent on δ_i .For δ_i >0 will be positive & for δ_i <0 is negative. After Barnea and Mirzahi's, [11], regimes were overthrown by the stokesthe average velocity $u_{\theta i}$ of particles (of type i) While traveling through an evenly distributed mixture, the Type equation is given by

$$u_{\theta i} = \frac{(\rho_{pi}-\rho_{\theta t})\ g\ d^2{}_i}{18\mu'_{\theta t}} \qquad \ldots\ldots\ldots(4)$$

$$\mu'_{\theta t} = \mu_{\theta t}(1+\theta_t{}^{1/3}) \qquad \ldots\ldots(4a)$$

$$\mu_{\theta t}=\mu_f \exp\left(\frac{5}{3}\frac{\theta_t}{1-\theta_t}\right) \qquad \ldots\ldots\ldots\ (4b)$$

3. Results and Discusion

The various material particles were included in the present study. They were divided into three groups. Each group contains two subgroups, viz., Sphere 1 and Sphere 2. The diameters and densities of spherical particles of groups one, two, and three were written in table 1. In group one, the sphere 1 subgroup consists of iron, steel, brass, and silver. while sphere 2 subgroups consist of molded nylon, Copal, coke, and coal. In Group Two, Sphere 1 subgroup consists of cork, wood cedar, and wood Douglas fir. while the sphere 2 subgroup consists of platinum, concrete, marble, and aluminum. In Group three, the Sphere 1 subgroup consists of yellow pine, red oak, paraffin wax, and wood dry. While sphere 2 subgroups consist of glass, granite, diamond, and lead crystal

Table1: Diameters and Densities of Spherical Particle of All Three Groups

Group	Diameter (cm)	Sphere 1	$\rho_{p_1}(g/cm^3)$	Sphere 2	$\rho_{p_2}(g/cm^3)$
Group one	0.18	Iron (cast)	7.21	Molded nylon	1.11
	0.26	Steel (cast)	7.85	Copal	1.15
	0.37	Brass	8.55	Coke	1.3
	0.48	Silver	10.5	Coal	1.51
Group Two	0.09	Cork	0.24	Platinum	2.14
	0.1	Wood (dry) red cedar	0.38	Concrete	2.37
	0.2	Wood (dry) douglas fir	0.53	Marble	2.56
	0.3	Wood (dry) douglas fir	0.53	Aluminium	2.64
Group Three	0.13	Yellow pine	0.7	Glass	2.58
	0.23	Red oak	0.7	Granite	2.69
	0.34	Paraffin wax	0.72	Diamond	3
	0.45	Wood dry	0.85	Lead crystal	3.1

The velocity of particles was calculated from equation 4 and written in tables from 2 to 12 . Tables 2 to 9 show the velocity at various volume fractions. Table 2 shows the estimated velocity at various volume fractions in order to investigate the impact of volume fraction of group one.

Table 2: Values of ρ_{θ_t}&δ_1&δ_2& δ & u_{θ_1}&u_{θ_2}&u_θ at Different Volume Fraction at Sulfur Dichloride, ρf = 1.620 g / cm^3, μf = 0.00901 g / cm.S for Group One.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ_t=0.701, θ_1=0.001, θ_2=0.7,	5.532	-4.42	1.67	-2.74	-9.231	3.502	-5.729
	5.980	-4.83	1.87	-2.96	-21.037	8.144	-12.893
	6.470	-5.17	2.08	-3.09	-45.602	18.346	-27.256
	7.835	-6.32	2.665	-3.66	-93.894	39.561	-54.332
θ_t=0.461, θ_1=0.001, θ_2=0.46,	4.1908	-3.081	3.019	-0.061	-82.341	80.694	-1.646
	4.485	-3.335	3.365	0.03	-185.973	187.646	1.672
	4.807	-3.507	3.743	0.236	-396.048	422.7	26.65
	5.704	-4.194	4.796	0.602	-797.114	911.53	114.416
θ_t=0.473, θ_1=0.003, θ_2=0.47,	4.245	-3.135	2.965	-0.17	-77.34	73.1504	-4.194
	4.546	-3.396	3.304	-0.092	-174.8	170.072	-4.735
	4.876	-3.576	3.6674	0.098	-372.7	382.992	10.215
	5.793	-4.283	4.707	0.424	-751.41	825.978	74.387
θ_t=0.58,θ_1=0.1, θ_2=0.48,	4.252	-3.142	2.958	-0.183	-33.59	31.623	-1.967
	4.563	-3.413	3.287	-0.126	-76.129	73.318	-2.8105
	4.914	-3.614	3.636	0.022	-163.25	164.246	0.996
	5.8714	-4.361	4.628	0.267	-331.57	351.88	20.313
θ_t=0.452, θ_1=0.002, θ_2=0.452,	4.134	-3.024	3.076	0.052	-84.806	86.264	1.458
	4.422	-3.272	3.428	0.156	-191.453	200.581	9.127
	4.737	-3.437	3.813	0.376	-407.273	451.828	44.55
	5.615	-4.105	4.885	0.78	-818.650	974.204	155.553

The result of velocity at various volume fractions is shown in Table 3 to investigate the impact of volume fraction on group two in heptan fluid.

Table 3: Values of ρ_{θ_t}&δ_1&δ_2& δ & u_{θ_1}&u_{θ_2}&u_θ at Different Volume Fraction Heptan ρf = 0.6795 g / cm^3, μf = 0.00389 g / cm. S for Group Two.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ1=0.0003, θ2=0.5, θt=0.5003,	1.409	-1.169	0.731	-0.438	-13.97	8.736	-5.234
	1.52	-1.14	0.85	-0.29	-16.82	12.54	-4.28
	1.619	-1.089	0.941	-0.148	-64.27	55.5	-8.77
	1.659	-1.129	0.981	-0.148	-149.92	130.26	-19.66
θ1=0.0003, θ2=0.4, θt=0.4003,	1.263	-1.023	0.877	-0.146	-22.55	19.33	-3.22
	1.355	-0.975	1.015	0.04	-26.54	27.6	1.06
	1.43	-0.9	1.13	0.23	98	123	25

	1.46	-0.93	1.18	0.25	-227.85	289.1	61.25
θ1=0.0001, θ2=0.3, θt=0.3001,	1.117	-0.877	1.023	0.146	-29.75	34.7	4.95
	1.18	-0.8	1.19	0.39	-33.5	49.83	16.33
	1.2435	-0.71	1.316	0.606	-119.52	120.5	100.98
	1.267	-0.737	1.373	0.636	-277.7	517.5	239.8
θ1=0.0003, θ2=0.43, θt=0.4303,	1.30	-1.06	0.84	-0.22	-20.32	16.10	-4.22
	1.40	-1.02	0.97	-0.05	-24.14	22.96	-1.18
	1.48	-0.95	-1.08	0.13	-89.95	102.26	12.31
	1.52	-0.99	1.12	0.13	-210.91	238.6	27.69
θ1=0.0004, θ2=0.38, θt=0.3804,	1.23	-0.99	0.91	-0.08	-25.68	23.6	-2.08
	1.32	-0.94	1.05	0.11	-30.10	33.62	3.52
	1.39	-0.86	1.17	0.31	-110.16	149.8	39.64
	1.42	-0.89	1.22	0.33	-256.52	351.64	95.12

Table 4 shows the velocity at various volume fractions in order to investigate the impact of volume fraction on group two in diethylether fluid.

Table 4: Values of ρ_{θ_t}&δ$_1$&δ$_2$& δ & u_{θ_1}&u_{θ_2}&u_θ at Different Volume Fraction for Group Two Diethylether 20 C^0 ρf = 0.714 g / cm^3, μf = 0.002448 g / cm.S

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ1=0.0003, θ2 = 0.5, θt=0.5003,	1.426	-1.186	0.714	-0.472	-22.7	13.69	-9.01
	1.54	-1.16	0.83	-0.33	-27.45	19.64	-7.81
	1.636	-1.106	0.924	-0.182	-104.72	87.48	-17.24
	1.67	-1.14	0.97	-0.17	-242.86	206.65	-36.21
θ1= 0.0003, θ2 =0.4, θt= 0.4003,	1.28	-1.04	0.86	-0.18	-0.18	29.4	-6.15
	1.37	-0.99	1	0.01	0.01	42.20	0.42
	1.45	-0.92	1.11	0.19	0.19	187.39	32.08
	1.48	-0.95	1.16	0.21	0.21	440.62	79.77
θ1 = 0.0001, θ2 =0.3, θt = 0.3001,	1.14	-0.9	1.26	0.1	-47.58	52.877	5.29
	1.21	-0.83	1.16	0.33		75.72	21.54
	1.267	-0.737	1.293	0.556	-54.18	337.6	145.16
	1.29	-0.76	1.35	0.59	-446.52	793.16	346.64
θ1 = 0.0003, θ2 =0.43, θt = 0.4303,	1.32	-1.08	0.82	-0.26	-31.75	24.10	-7.65
	1.42	-1.04	0.95	-0.09	-37.7	34.48	-3.22
	1.50	-0.97	1.06	0.09	-140.8	153.89	13.09
	1.54	-1.01	1.1	0.09	-329.9	359.33	29.43
θ1 = 0.0004, θ2 = 0.38, θt = 0.3804,	1.255	-1.015	0.885	-0.13	-38.25	33.35	-4.93
	1.34	-0.96	1.03	0.07	-44.67	47.67	3.25
	1.41	-0.88	1.15	0.27	-163.7	-163.7	50.35
	1.44	-0.91	1.2	0.29	-381.11	-381.11	121.45

Table 5 shows the velocity at various volume fractions in order to investigate the impact of volume fraction on group two in decan fluid.

Table 5: Values of ρ_{θ_t}&δ$_1$&δ$_2$& δ & u_{θ_1}&u_{θ_2}&u_θ at Different Volume Fraction Decan ρf =0.7263 g / cm^3,μf = 0.0085 g / cm.s for Group Two.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ1=0.0003, θ2 = 0.5, θt=0.5003,	1.43	-1.19	0.71	-0.48	-6.55	3.91	-2.64
	1.54	-1.16	0.83	-0.33	-7.89	5.64	-2.25
	1.642	-1.112	0.918	-0.194	-30.27	24.99	-5.28
	1.682	-1.152	0.958	-0.194	-70.56	58.67	-11.89
θ1=0.0003, θ2 =0.4, θt=0.4003,	1.291	-1.051	0.849	-0.202	-10.77	8.707	-2.063
	1.38	-1	0.99	-0.01	-12.66	12.53	-0.13
	1.45	-0.92	1.11	0.19	-46.59	56.21	9.62
	1.49	-0.96	1.15	0.19	-109.39	131.04	21.65
θ1=0.0001, θ2 = 0.3, θt=0.3001,	1.150	-0.91	0.99	0.08	-14.33	15.59	1.26
	1.21	-0.83	1.16	0.33	-16.13	22.55	6.42
	1.276	-0.746	1.284	0.538	-58.02	99.86	41.84
	1.30	-0.77	1.34	0.57	-143.75	234.5	99.75
θ1=0.0003, θ2 = 0.43, θt=0.4303,	1.33	-1.09	0.81	-0.28	-9.61	7.14	-2.47
	1.43	-1.05	0.94	-0.11	-11.43	10.23	-1.2
	1.51	-0.98	1.05	0.07	-42.68	45.73	3.05
	1.54	-1.01	1.1	0.09	-98.98	107.8	8.82

θ1=0.0004, θ2 =0.38, θt 0.3804,	1.26	-1.02	0.88	-0.14	-11.53	9.95	-1.58
	1.35	-0.97	1.02	0.05	-13.54	14.23	0.69
	1.42	-0.89	1.14	0.25	-49.69	63.65	13.96
	1.45	-0.92	1.19	0.27	-115.58	149.51	33.93

Table 6 shows the velocity at various volume fractions in order to investigate the impact of volume fraction on group three in toluene fluid.

Table 6: Values of δat Different Volume Fraction Toluene ρf =0.867 g /cm3, μf =0.0059 g/cm.S for Group Three.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ1=0.0003 θ2 = 0.52 θt=,0.523	1.75	-1.05	0.83	-0.22	-14.5	11.53	-3.05
	1.81	-1.11	0.88	-0.23	-48.2	38.28	-10.1
	1.97	-1.25	1.03	-0.22	-119.2	97.33	21.96
	2.02	-1.17	1.08	-0.09	-196.3	178.14	-18.19
θ1=,0.003 θ2 = 0.46 θt=0.463	1.65	-0.95	0.93	-0.02	-10.86	19.44	-0.49
	1.70	-1	0.99	-0.01	-65.71	64.54	-1.16
	1.84	-1.12	1.16	0.04	-0.163	0.169	0.005
	1.89	-1.04	1.21	0.17	-260.59	303.18	42.59
θ1=0.003 θ2 = 0.47 θt=0.473	1.67	-0.97	0.91	-0.06	-19.07	17.89	-1.17
	1.72	-1.02	0.97	-0.05	-62.77	60.73	-2.03
	1.86	-1.14	1.13	-0.01	-157.19	154.75	-2.43
	1.91	-1.06	1.19	0.13	-254.05	285.21	31.16
θ1=0.003 θ2 = 0.49 θt=0.493	1.70	-1	0.88	-0.12	-18.26	15.19	-2.06
	1.75	-1.05	0.94	-0.11	-56.73	50.79	-5.94
	1.91	-1.19	1.09	-0.1	-140.51	128.70	-11.81
	1.96	-1.11	1.14	0.03	229.6	235.80	6.20
θ1=0.005 θ2 = 0.34 θt=0.345	1.44	-0.74	1.44	0.4	-28.24	43.52	16.27
	1.48	-0.78	1.21	0.43	-93.21	144.6	51.39
	1.59	-0.87	1.41	0.54	-227.20	368.2	141.1
	1.62	-0.77	1.48	0.71	-352.2	677.1	324.8

Table 7 shows the velocity at various volume fractions in order to investigate the impact of volume fraction on group three in styrene fluid.

Table 7: Values of δ at Different Volume Styrene for Group Three ρf =0.903 g /cm3, μf =0.00696 g/cm.S.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ1=0.000 3 θ2 = 0.52 θt=,0.523	1.77	-1.07	0.81	-0.26	-12.60	9.54	-3.05
	1.83	-1.15	0.86	-0.27	-41.67	31.71	-9.95
	1.97	-1.25	1.03	-0.22	-118.84	97.92	-20.91
	2.02	-1.19	0.96	-0.23	-194.85	179.86	-14.99
θ1=,0.003 θ2 = 0.46 θt=0.463	1.67	-0.97	0.91	-0.06	-17.19	16.13	-1.05
	1.72	-1.02	0.97	-0.05	-56.60	53.82	-2.77
	1.86	-1.11	1.14	0.03	-138.98	137.26	-1.713
	1.91	-1.06	1.19	0.13	-225.17	252.78	27.61
θ1=0.003 θ2 = 0.47 θt=0.473	1.69	-0.99	0.89	-0.1	-16.50	14.83	-1.66
	1.74	-1.04	0.95	-0.09	-54.26	49.56	-4.69
	1.88	-1.16	1.12	-0.04	-132.26	127.69	-4.56
	1.93	-1.08	1.17	0.09	-215.70	233.68	17.98
θ1=0.003 θ2 = 0.49 θt=0.493	1.72	-1.02	0.86	-0.16	-14.92	12.58	-2.33
	1.88	-1.18	0.81	-0.37	54.03	37.08	-16.94
	1.92	-1.2	1.08	-0.12	-120.07	108.06	-12.1
	1.97	-1.12	1.13	0.01	197.66	196.13	1.52
θ1=0.005 θ2 = 0.34 θt=0.345	1.47	-0.77	1.11	0.34	-25.12	36.21	11.09
	1.50	-0.8	1.19	0.39	-178.54	265.58	87.04
	1.61	-0.89	1.39	0.5	-198.63	310.22	111.59
	1.64	-0.79	1.46	0.67	-308.85	570.79	261.94

Table 8 shows the velocity at various volume fractions in order to investigate the impact of volume fraction on group three in water.

Table 8: Values of ρ_{θ_t}&δ$_1$&δ$_2$& δ & u_{θ_1}&u_{θ_2}&u_θ at Different Volume Fraction Water ρf=1,=0.00891 for Group Three.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ1=0.000 3	1.82	-1.12	0.76	-0.36	-10.30	6.99	-3.30
	1.87	-1.17	0.82	-0.35	-33.68	23.60	-10.07

θ2 = 0.52	2.03	-1.31	0.97	-0.34	-82.42	61.03	-21.38
θt=,0.523	2.09	-1.24	1.01	-0.23	-136.66	111.31	-25.34
θ1=,0.003	1.72	-1.02	0.86	-0.16	-14.13	11.91	-2.21
θ2 = 0.46	1.77	-1.07	0.92	-0.15	-46.41	39.90	-6.50
θt=0.463	1.91	-1.19	1.09	-0.1	-112.79	103.31	-9.97
	1.96	-1.11	1.14	0.03	184.30	189.28	4.98
θ1=0.003	1.74	-1.04	0.84	-0.2	-13.54	10.93	-2.59
θ2 = 0.47	1.79	-1.09	0.9	-0.19	-44.40	36.66	-7.73
θt=0.473	1.93	-1.21	1.07	-0.14	-108.44	94.36	-14.08
	1.98	-1.13	-1.12	-0.01	-177.10	173.50	-3.6
θ1=0.003	1.77	-1.07	0.81	-0.26	-12.20	9.24	-2.95
θ2 = 0.49	1.82	-1.12	0.87	-0.25	-40.1	31.0	-8.92
θt=0.493	1.97	-1.25	1.03	-0.22	-97.55	80.38	-17.16
	2.02	-1.17	1.08	-0.09	-161.12	146.48	-14.63
θ1=0.005	1.53	-0.83	1.05	0.22	-20.94	26.49	5.55
θ2 = 0.34	1.57	-0.87	1.12	0.25	-68.72	88.47	19.75
θt=0.345	1.67	-0.95	1.33	0.38	-163.99	229.58	65.59
	1.71	-0.86	1.39	0.53	-260.05	420.31	160.26

Table 9 shows the velocity at various volume fractions in order to investigate the impact of volume fraction on group three in propylene carbouate..

Table 9: Values of δ at Different Volume Fraction Propylene Carbouate ρf =1.2g /cm3 , for Group Three.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
θ1=0.000	1.91	-1.21	0.67	-0.54	-3.97	2.20	-1.76
3	1.97	-1.27	0.72	-0.55	-13.06	7.40	-5.66
θ2 = 0.52	2.13	-1.41	0.87	-0.54	-31.69	19.55	-12.13
θt=,0.523	2.18	-1.33	0.92	-1.71	-52.36	36.22	-16.13
θ1=,0.003	1.83	-1.13	0.75	-0.38	-5.58	3.71	-1.86
θ2 = 0.46	1.88	-1.18	0.81	-0.37	-18.27	12.54	-5.72
θt=0.463	2.02	-1.3	0.98	-0.32	-44.08	32.81	-11.27
	2.07	-1.22	1.03	-0.21	-72.29	60.65	-11.63
θ1=0.003	1.84	-1.14	0.74	-0.4	-5.28	3.43	-1.84
θ2 = 0.47	1.89	-1.19	0.8	0.39	-17.26	11.60	-5.56
θt=0.473	2.04	-1.32	0.96	-0.36	-41.85	30.43	-11.41
	2.09	-1.24	1.01	-0.23	-68.87	56.09	-12.77
θ1=0.003	1.87	-1.17	0.71	-0.46	-4.75	2.88	-1.86
θ2 = 0.49	1.92	-1.22	0.77	-0.45	-15.53	9.80	-5.72
θt=0.493	2.08	-1.36	0.92	-0.44	-37.84	25.59	-12.24
	2.13	-1.28	0.97	-0.31	-62.38	47.27	-15.10
θ1=0.005	1.66	-0.96	0.92	-0.04	-8.63	8.27	-0.35
θ2 = 0.34	1.70	-1	0.99	-0.01	-28.15	27.87	-0.27
θt=0.345	1.81	-1.09	1.19	0.1	-67.05	73.21	6.16
	1.84	-0.99	1.26	0.27	-106.69	135.79	29.10

To investigate the impact of diameter on density separation, we computed the velocity at various diameters. The tables 10, 11, and 12 illustrate the δat various diameters for groups one, two, and three.

Table 10 shows the velocity at various diameters to investigate the impact of diameter on group one.

Table 10: Values of δat Different Diameter θt = 0.701, θt =0.461, θt =0.473, θt = 0.452 for Group One**.**

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
d1=0.18	5.532	-4.422	1.678	-2.744	-156.008	59.199	-96.808
	4.485	-3.335	3.365	0.03	89.135	89.937	0.801
	4.876	-3.576	3.674	0.098	-88.224	90.642	2.417
	5.615	-4.105	4.884	0.779	-115.122	136.969	21.846
d2=0.26	5.532	-4.422	-2.744	-2.744	-324.97	123.318	-201.66
	4.485	-3.335	0.03	0.03	-185.97	187.646	1.672
	4.876	-3.576	0.098	0.098	-184.07	189.118	5.044
	5.615	-4.105	0.779	0.779	-240.194	285.775	45.581
d3=0.37	5.532	-4.422	1.678	-2.744	-658.129	249.73	-408.391
	4.485	-3.335	3.365	0.03	-376.62	380.012	3.387

	4.876	-3.576	3.674	0.098	-372.776	382.992	10.216
	5.615	-4.105	4.884	0.779	-486.429	578.738	92.308
d4=0.48	5.532	-4.422	1.678	-2.744	-1107.61	420.304	-687.315
	4.485	-3.335	3.365	0.03	-633.852	639.553	5.701
	4.876	-3.576	3.674	0.098	-627.37	644.568	17.198
	5.615	-4.105	4.884	0.779	-818.65	974.004	155.35

Table 11 shows the velocity at various diameters to investigate the impact of diameter on group two.

Table 11. Values of δ at Different Diameter for Group Two θt = 0.5003, θt =0.4303, θt = 0.4003, θt=0.3001.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
d1=0.09	1.409	-1.169	0.731	-0.438	-13.97	8.7	-5.27
	1.406	-1.026	0.964	-0.062	-19.45	18.48	-1.19
	1.43	-0.9	1.13	0.23	-19.45	24.42	4.97
	1.26	-0.73	1.38	0.65	-24.761	46.81	22.05
d2=0.1	1.409	-1.169	0.731	-0.438	-17.24	10.7	-6.54
	1.406	-1.026	0.964	-0.062	-24.28	22.819	-1.46
	1.43	-0.9	1.13	0.23	-24.019	30.15	6.13
	1.26	-0.73	1.38	0.65	-30.57	57.79	27.22
d3=0.2	1.409	-1.169	0.731	-0.438	-68.99	43.14	-25.85
	1.406	-1.026	0.964	-0.062	-97.07	91.27	-5.87
	1.43	-0.9	1.13	0.23	-96.07	120.63	24.56
	1.26	-0.73	1.38	0.65	-122.29	231.17	108.88
d4=0.3	1.409	-1.169	0.731	-0.438	-155.23	97.07	-58.16
	1.406	-1.026	0.964	-0.062	-218.58	205.37	-13.21
	1.43	-0.9	1.13	0.23	-216.17	271.42	55.25
	1.26	-0.73	1.38	0.65	-275.15	520.15	245

Table 12 shows the velocity at various diameters to investigate the impact of diameter on group three.

Table 12. Values of ρ_{θ_t}&δ_1&δ_2& δ & u_{θ_1}&u_{θ_2}&u_θ at Different Diameter for Group Three θt = 0.5003, θt =0.4303, θt = 0.4003, θt=0.3001.

	$\rho_{\theta_t}\ g/cm^3$	δ_1	δ_2	δ	$u_{\theta_1} cm/s$	$u_{\theta_2}\ cm/s$	$u_\theta\ \ cm/s$
d1=0.13	1.75	-1.05	0.83	-0.22	-14.68	11.43	-3.24
	1.70	-1	0.99	-0.01	-20.99	20.58	-0.406
	1.86	-1.16	1.13	-0.02	-22.56	22.21	-0.35
	1.62	-0.77	1.48	0.71	-29.56	56.16	26.60
d2=0.23	1.75	-1.05	0.83	-0.22	-45.65	36.08	-9.56
	1.70	-1	0.99	-0.01	-65.41	64.75	-0.651
	1.86	-1.16	1.13	-0.02	-70.62	96.53	-1.09
	1.62	-0.77	1.48	0.71	-92.54	175.80	83.26
d3=0.34	1.75	-1.05	0.83	-0.22	-10.04	7.81	-2.22
	1.70	-1	0.99	-0.01	-143.63	140.79	-2.83
	1.86	-1.16	1.13	-0.02	-154.33	151.94	-2.39
	1.62	-0.77	1.48	0.71	-270.36	384.17	181.95
d4=0.45	1.75	-1.05	0.82	0.22	-175.94	136.96	-3.979
	1.70	-1	0.99	-0.01	-251.60	246.63	-4.962
	1.86	-1.16	1.13	-0.02	-201.92	266.16	-4.193
	1.62	-0.77	1.48	0.71	-353.71	679.87	326.16

if the particles sink higher velocity than float net velocity will be positive and if the particles float higher velocity than sink net velocity will be negative as shown intables from 2 to 12.The relationship between fluid and flow properties changes; turbulent flow and universal environments like jets, plumes, homogeneous turbulence, oceans, etc. have been reported by many authors [Kawanisi and Shiozaki, 2008; Eames et al., 2011; Ogholaja et al., 2018; Wang et al., 2018] [25,26,27,28]. Despite occupying a small percentage of the total flow volume, interfaces primarily controlled processes such as entrainment and dissipation and may serve as transport barriers [26]. Additionally, a previous study showed that for high turbulence intensities, regardless of the Stokes number, the respective settling velocity improves with increasing relative turbulence intensity. At intermediate turbulence intensities, it looks as if the settling data bifurcates, i.e., the particles with a high Stokes number settle slowly, while the particles with a low Stokes number settle faster. [25,27,28].

3.1. Effect of Volume Fraction on Density Separation

Figure 1 represents the u_θ Vs diameter at different θ_t. Figure 1A depicts the u Vs diameter at different t for group one using sulfur dichloride, and Figures 1B,C,D depict the u Vs diameter at different t for group two using heptane fluid, diethyl ether fluid, and decane fluid, respectively.Figure 1 E,F,G,H represent the u_θ Vs diameter at different θ_t for group two by using toluene fluid, styrene fluid, water fluid, and propylene fluid respectively . From Figures 1 and tables 2 to 9, it is found that as the volume fraction increased, the velocity decreased Because collision between particles increased, kinetic energy decreased, and as kinetic energy decreased, turbulence decreased, because turbulence is excessive kinetic energy, and as turbulence decreased, velocity decreased.

If the total velocity is positive, the mean sink parti cles will separate before the float particles because their particles have higher velocity than the float Figure 1 showed if the particles sink at a higher velocity, the velocity increased; if the particles float at a higher velocity than sink, the velocity also increased but in the opposite direction.

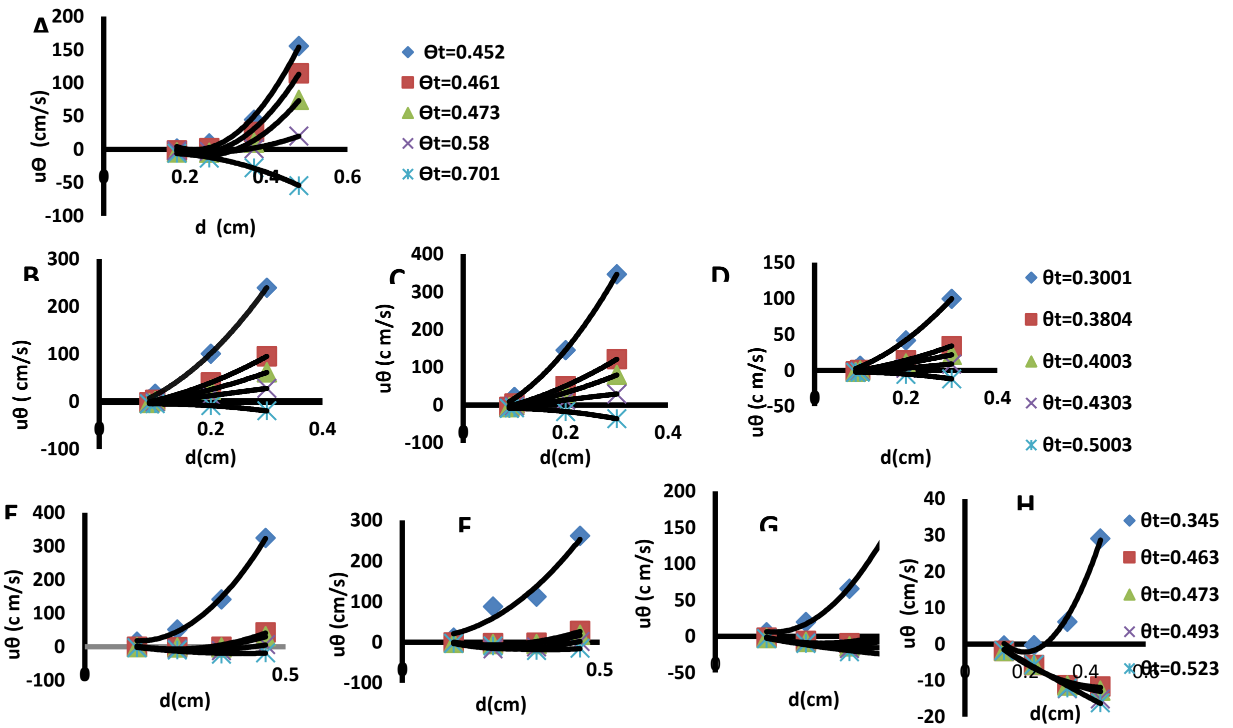


Figure 1: Graphical representation of the u_θ Vs Diameter at Different θ_t for Group One by Using Various Fluids.

(A)Group one and sulfur dichloride, (B) Group two and heptane fluid; (C) Group two and Diethyl ether fluid; (D) Group two and decane fluid; (E) Group three and toluene fluid; (F) Group three and styrene fluid; (G) Group three and water fluid; (H) Group three and propylene fluid.

3.2. The Effect of Diameter of Particles on Density Separation

The total velocity increased as diameter of particle increased (Figure 2 and Table 10 to 12) because increasing diameter sphere increased mass that lead to increasing kinetic energy and as the kinetic energy increased the turbulence increased. They previously shown that mild turbulence enhanced the settling velocity of big particles in a number of instances over its still-water value. For comparable flow configurations, the rise was greater when the turbulent Reynolds number was raised. The interplay of particle motions with tiny turbulence scales seems to be responsible for the increase in particle settling velocity. The ratio of particle diameter to the local kolmogorov length scale was shown to have a strong correlation with an increase in particle settling velocity. Only when this ratio was smaller than 0.5 was a decrease in settling velocity seen.[29,30,26].

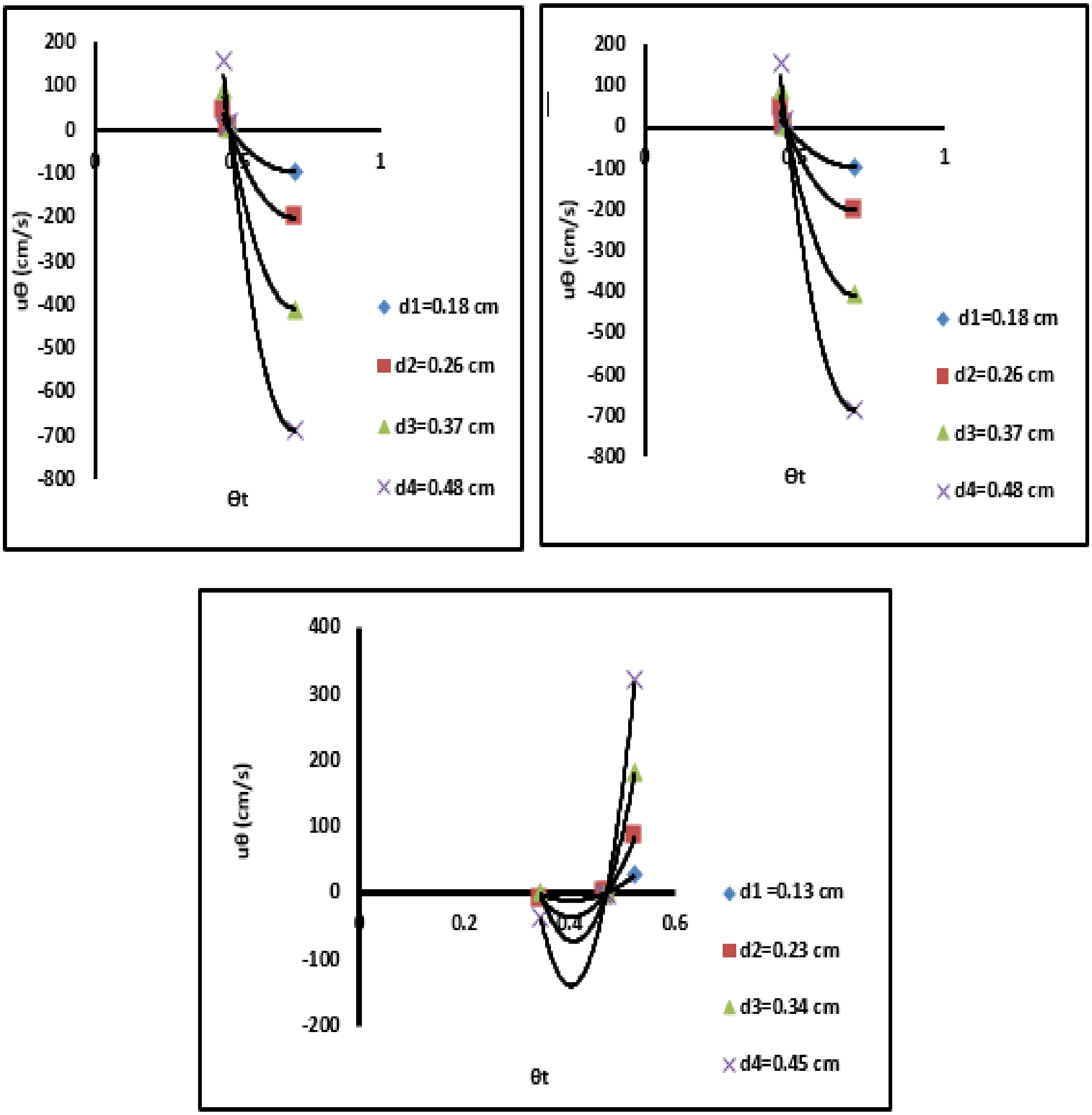


Figure 2: Graphical Representation of the u_{θ} Vs θ_t at Different Diameter.

The figures illustrate the impact of particle diameter on particle velocity. If particles sink at a faster rate, their velocity increases; if particles float at a faster rate, their velocity increases as well, but in the opposite direction

3.3. The Effect of Viscosity of the Fluid on Density Separation.

As the viscosity increased the velocity of sphere decreased as shown in figure3. since viscosity is a measure of the fluid's internal resistance to flow (as shown in figure 3 Table 3 to 5).

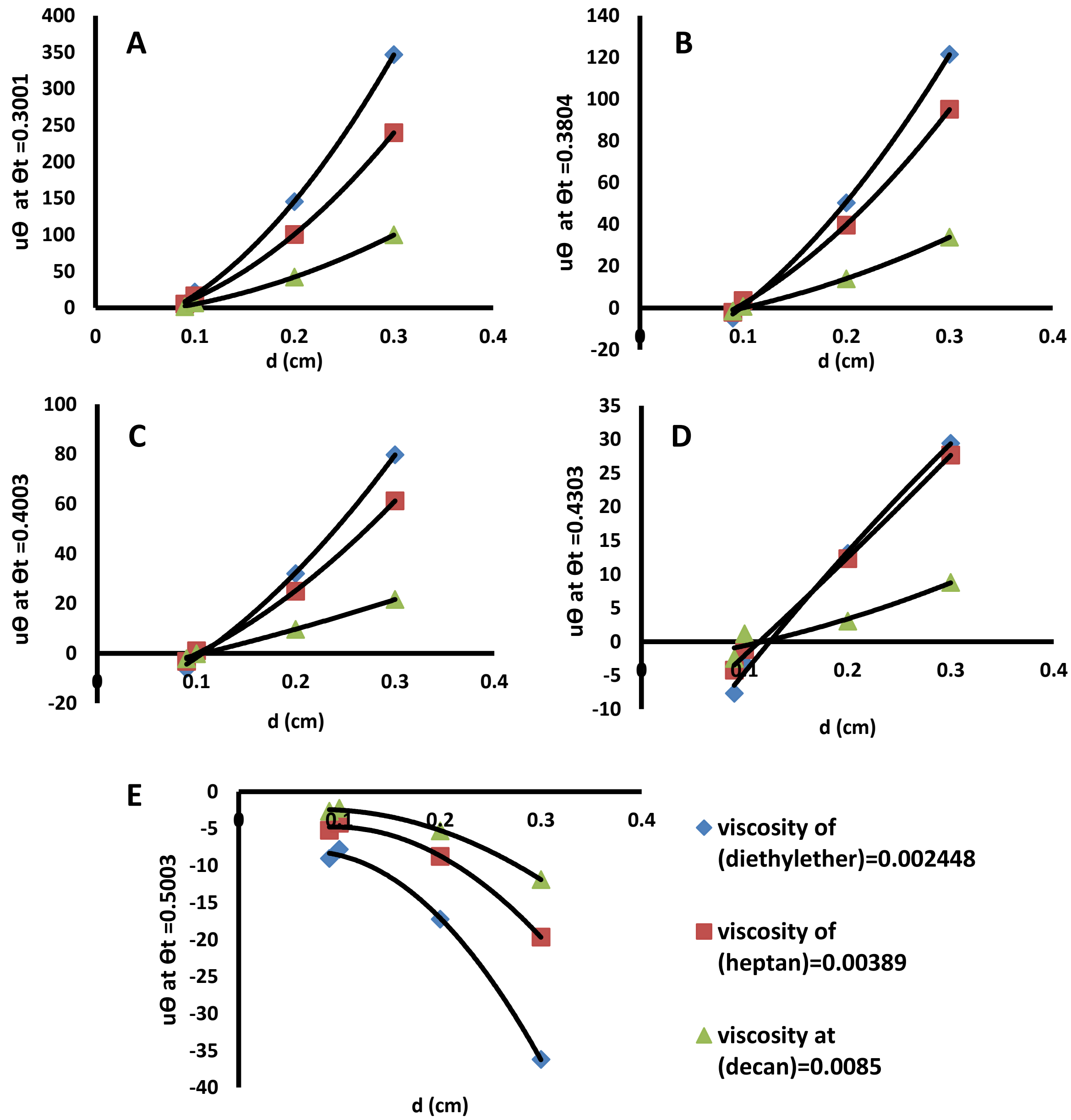
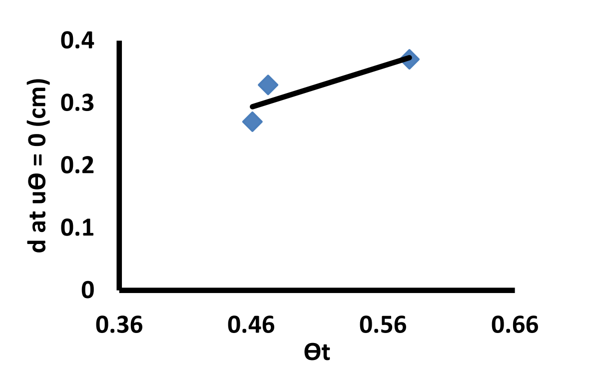
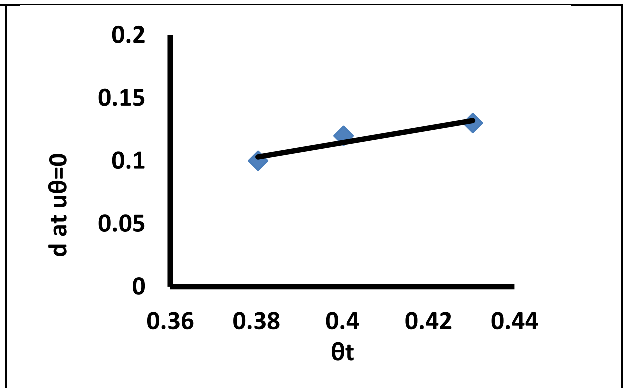
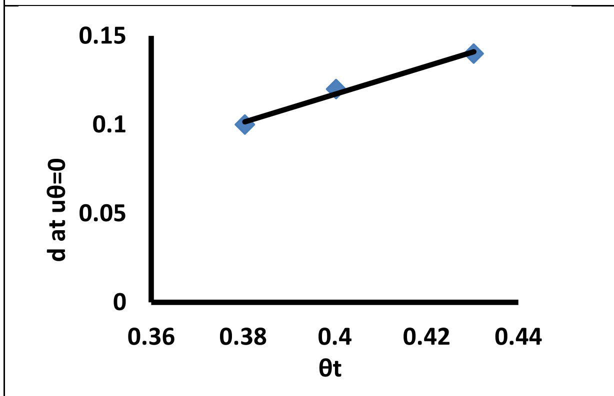
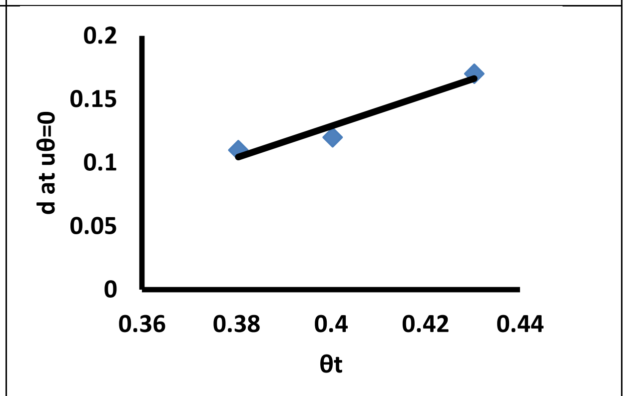
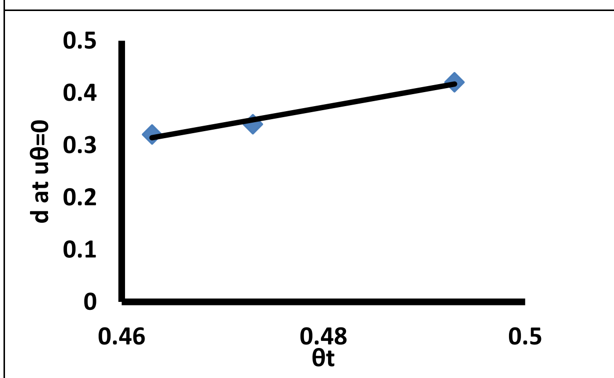
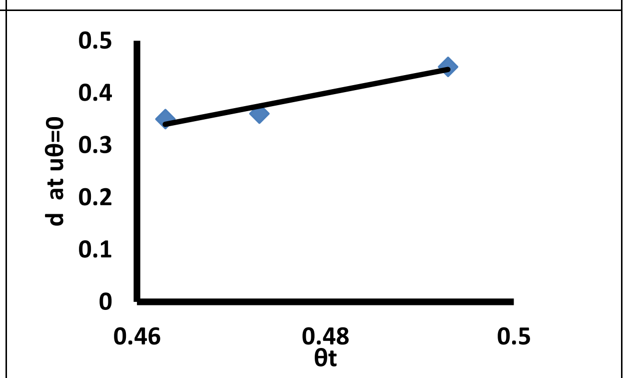


Figure 3: u_{θ} Vs Diameter of Spheres for Group Two

3.4 Best Separations of Spheres

From Figure 1, we derived diameter values when the total velocity was equal to zero. This was done to determine the best separation of the spheres when two spheres move at the same velocity in the opposite direction. In this case, all spheres can be separated at the same time. So, all the spheres that have a density lower than the intermediate fluid density were floated at the same time. All the spheres with a density higher than the intermediate fluid density were sunk at thesame velocity but in the opposite direction. From Figure 1

	
Sulfur dichloride	Heptane fluid
	
Diethyl ether fluid	Decane fluid
	
Toluene fluid	Styrene fluid

1, values of diameter at =0 vs. were derived in the various fluids and depicted in Figure 4.

Figure 4: Values of Diameter at u_θ =0 vs. θ_t Derived in Various Fluids.

4.Conclusion

This study showed that the efficiency of density separation increased as the velocity of the sphere increased because faster velocity needs less time . The factors that affected velocity studied in this research were these factors: volume fraction ,diameter and density of particle, and volume fraction, and it was found that as volume fraction increased, the velocity of particle decreased because collision between particles led to loss kinetic that decreased the turbulence . The other factor is the diameter of particle. As the diameter increased, the mass of the particle also increased , which increased the kinetic energy that

led to increased turbulence of the fluid . The velocity of particles has a direct relationship to fluid turbulence. The other factor is the viscosity of fluid. As the viscosity of fluid increased, the velocity of particles decreased because the viscosity is the resistance of fluid to flow, so as the internal resistance increased, the velocity decreased. Also in this research, the condition of maximum separation was determined when the total velocity equaled zero, meaning the velocity of sink and float sphere was equal in magnitude and opposite in direction when the diameter was determined . So, to improve separation according to density, it must control factors studied in this research.

Nomenclature

$\acute{g}$	is the acceleration approximately equal to the gravitational acceleration
$\boldsymbol{i}$	integer :denoting the ith fraction
t	denotes a total quantity
d,$\boldsymbol{d_i}$	particle size ,general (used also symbol of differentiation)and of ith fraction
δ	density difference
$\boldsymbol{\mu_f}$,$\boldsymbol{\mu_{\theta_t}}$	$\boldsymbol{\mu_f}$,$\boldsymbol{\mu_{\theta_t}}$
$\boldsymbol{\rho_p}, \boldsymbol{\rho_{\theta_t}}, \boldsymbol{\rho_f}$	Density of particles, slurry and fluid respectively.
$\boldsymbol{\theta_i}$,$\boldsymbol{\theta_t}$	fractional volume occupied by particles.
$\boldsymbol{u_{\theta i}}$	particle velocity with respect to the fluid at θ,and of ith fraction

References

[1] Koroznikova L., Klutke C., McKnight S., Hall S. (2008) The use of low-toxic heavy suspensions in mineral sands evaluation and zircon fractionation. The Journal of The Southern African Institute of Mining and Metallurgy, 108, 25-33

[2] Cresswell, G.M., 2001, July. Pre-concentration of base metal ores by dense medium separation. In SAIMM cooper, cobalt, nickel and zinc recovery conference (pp. 1-10).

[3] Vitz E, John W.Moore, Justin Shorb ,Adam Hahn ,2006 “Sorting Recyclable Plastics By density”Chemical & amp,Engineering News,March.No16, p,30-33

[4] Kumar CR, Mohanan S, Tripathy SK, Ramamurthy Y., Venugopalan T, Nikkam S (2011) “Prediction of process input interactions of Floatex Density Separator performance for separating medium density particles” International Journal of Mineral Processing, 100 136-141

[5] Gluskoter, H. J. (1977). Trace elements in coal: occurrence and distribution. Circular no. 499.

[6] Quinn, B., Murphy, F. and Ewins, C., 2017. Validation of density separation for the rapid recovery of microplastics from sediment. Analytical Methods, 9(9), pp.1491-1498.

[7] Klima, M. S., & Kim, B. H. (1996). The separation of fine, high density particles from a low-density soil matrix using a hydrocvclone. Journal of Environmental Science & Health Part A, 31(2), 305-323.

[8] J.S.Haskill, R.D. Mcknight and P.R.Galbraith , 1972, Cell-Cell Interaction in Vitro: Studied by Density Separation of Colony-forming, Stimulating, and Inhibiting Cells From Human Bone Marrow,Blood Journal,40.:394-399

[9] A.W. Hamburger, F.E. Dunn, and C.P. White, 1985 "Percoll density gradient separation of cells from human malignant effusions",British Journal of Cancer, 51(2):253-258.

[10] V.N.de Jonge & L.A. Bouwman 1977 " A simple density separation technique for quantitative isolation of meiobenthos using the colloidal

silica Ludox-TM ,Marine Biology 42 (2), 143-148

[11] Robert S.Strebin JR.,John W.Johson and Dean M.Robertson , 1977 "Wide-range density separation of mineral particles in a single fluid system" American Mineralogist, Volume62, pages 374-376

[12] Kumar CR, Singh RR, Venugopalan OK, Murty VS, Kumar SS 2006 " Effect of Teetering Pulp Density in Floatex Density Separator A_Case Study", Proceedings of the International Seminar on MineralProcessing Technology - ,Chennai, India. pp. 564

[13] Kohl C.P and Nishiizumi K, 1992"chemical isolation of quartz for measurement of in-situ-produced cosmogenic nuclides "Cosmochimica Acta,56,3583-3587.

[14] G.Halam .1969 "separation of clay mineral fractions with linear heavy liquid density gradient columns"department of regional soil science,Agricultural university ,Wagentingen,Holland clay minerals8,59

[15] Pactrick S, Reid J.H.1983. Separation of capsulate and non-capsulate Bactroids Fragilis on a discontinuous density gradient. Journal of Medical Microbiology, 16, 239-241.

[16] Laursen SB, Andersen CY, Hindkjaer J, Karin ERB, 2003 .A clinical study comparing pure sperm and sperm filter for density gradient separation of human spermatozoa in assisted reproduction. Acta Obstet Gynecol Scand, 82. 929-935.

[17] Hans ULutz,..et al. (1992) .Density separation of human red blood cells on self forming Percoll gradients: correlation with cell age", Biochimica et Biophysica Acta (BBA)-General Subjects 1116 (1), 1-10.

[18] Rockne KJ, Liang W, Young L.Y., Taghon GL (2003) .Toxicity of density separation media to Escherichia coli and Mycobacterium strain PC01:implications for density-separation of soils and sediments" FEMS Microbiology Ecology, 43, 185-189

[19] Alopes-Virella MF, Stone P, Ellis S, Colwell JA. (1977) .Cholesterol Determination in High-Density Lipoproteins separated by three Different Methods"Clinical chemistry,vol-23,NO.5, 882-884

[20] Taylor, A.G.; Kenny, T.J. (1985) "Improvement of germinated seed quality by density separation".Journal of American Horticultural Science, v.110, 347-349.

[21] Takaki M, Lima GPP. 2008 .Density separation of germinated seeds of melaleuca leucadendra(L.)L.(myrtaceae)" Naturalia, Rio Claro, v.31, p.34-38

[22] Jordão, L.R.; Lopes, V.B.; Takaki, M. 1988 "Selection of viable seeds in Hormidium coriaceum Lindl. (Orchidaceae) by density separation." Seed Science and Technology, v.16,p.515-519.

[23] Taylor, A.G.; Motes, J.E.; Price, H.C." 1978" Separating germinated from ungerminated seed by specific gravity". HorScience, v.13, p.481-482.

[24] Zimmels Y. (1985) .Theory of density separation of particulate system. Powder technology, 43127-139.

[25] Kawanisi K and Shiozaki R 2008. Turbulent Effects on the Settling Velocity of Suspended Sediment "Journal of Hydraulic Engineering Volume 134 Issue 2 - February

[26] Eames, I.; Flor, J. B. January 17, (2011). New developments in understanding interfacial processes in turbulent flows". Philosophical Transactions of the Royal Society A. 369: 702–705.

[27] T. Ogholaja, D.O njouenbwu and M. Fairweather, 2018"LES of particle collision and agglomeration in vertical channel flows" Computer Aided Chemical Engineering, 2018

[28] Y. Wang, K. M. Lam, and Y. Lu,2018"Settling velocity of fine heavy particles in turbulent open channel flow"Physics of Fluids 30, 095106

[29] Henry Watts,Matthew Moncrieff Pattison Muir,Henry Forster Morley • 1890,Watts' Dictionary of Chemistry - Volume 1 - Page 90

[30] Dabir S. V, Tushar K. Ghosh, Dasika H. L. Prasad, Nidamarty V.K. Dutt and Kalipatnapu Y. Rani 2007 "viscosity of liquid "Indian Institute of Chemical Technology, Hyderabad, India,Pages 1-8.