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Investigation of Sludge in Anaerobic Sludge Bed Bioreactor

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Abstract:

The variation in granular sludge properties from various up-flow anaerobic sludge bed (UASB) reactors and the application of coffee grit as a physical model to characterize granular sludge were investigated in this study. The methods applied for evaluation were density measurements, settling profile and velocity, diameter measurements, total solids and volatile solids, total suspended solids and volatile suspended solids and settleability of granular sludge. Experiments showed that coffee grits can be used as a physical model of granular sludge since it had similar characteristics especially in terms of settling and particle size while less so in terms of density but in a similar range. It was found that a weak correlation (R^2 = 0.15) between density and settling velocity for coffee grits which might due to the non-uniformity in shape and particle size variation of coffee grits. For the granular sludge, higher density leads to a faster settling velocity and vice versa (R^2 = 0.73). Moreover, it was found that Saugbrugs (new and old) properties were a slight changed with time, changes that may be good for process performance. Sample J (E-Convert old) had the highest size of granules (0.44 - 3.91 mm) and sample E (UASB – Econvert) had the lowest organic content which can be seen from its volatile to total solid ratio (0.55).

Contents

Preface

This report is performed as a Master Thesis subject FMH606 at University College of Southeast Norway (USN).

I would greatly like to express my gratitude to Rune Bakke and Eshetu Janka, the supervisors of the master thesis. Not only did they cooperated fully by holding a meeting regularly, but they provided useful information regarding this report based on their research experiences and knowledge. I also would like to show much appreciation to my family and friends for support and pray during my study in Norway.

Porsgrunn, June 15 2016

Hartantyo Seto Guntoro

1 Introduction

1.1 Background

Anaerobic digestion, AD, is a method where micro-organisms mineralize organic matter and generating biogas. Up-flow anaerobic sludge blanket (UASB) reactors are used to obtain high efficiency AD and tested this principle for various applications. Sludge retention time (SRT) is one of determining factors for the process efficiency and this depends on sludge characteristics. The variation in sludge quality become a reason of this topic and learn more about how to maintain adequate sludge quality to avoid problems.

1.2 Problem description

This master thesis project includes theoretical and experimental evaluation of sludge from various up-flow anaerobic sludge bed reactors (UASB). The main goal of this study was to investigate the variations in sludge characteristics. Coffee grits were used as physical model to characterize granular sludge and to test the experimental methods of this particular study was also another aim to conduct this study.

A total of three samples of coffee grits from different brands of coffee and seven samples of granular sludge from various UASB reactors at different periods are used. The list of the samples are in chapter 3 of this thesis. The structure of the report are as follows; chapter 2 describes literature study on UASB and granular sludge, chapter 3 describes material and methods used to investigate the anaerobic sludge characteristics, chapter 4 shows the results from several experiments conducted in the laboratory and chapter 5 describes the discussion of the results by comparing with relevant literatures.

The main granular sludge that were investigated in details were obtained from a full scale UASB wastewater treatment plant saugbrugs reactor at the Saugbrugs factory. The saugbrug UASB reactor is a reactor treating pulp and paper process wastewater at 'Norske Skog Saugbrugs' in Halden, Norway [1]. The parameters of saugbrugs reactor has been changed, hence the sludge before and after changing were investigated and the difference of the sludge were examined in this thesis.

2 Literature study

2.1 Anaerobic treatment

Anaerobic processes have been used for the treatment of domestic and industrial wastewater for over a century. These processes convert organic matter into methane [2]. The decomposition of organic matter occurs in four stages (Figure 2-1): hydrolysis, acidogenesis, acetogenesis and methanogenesis.

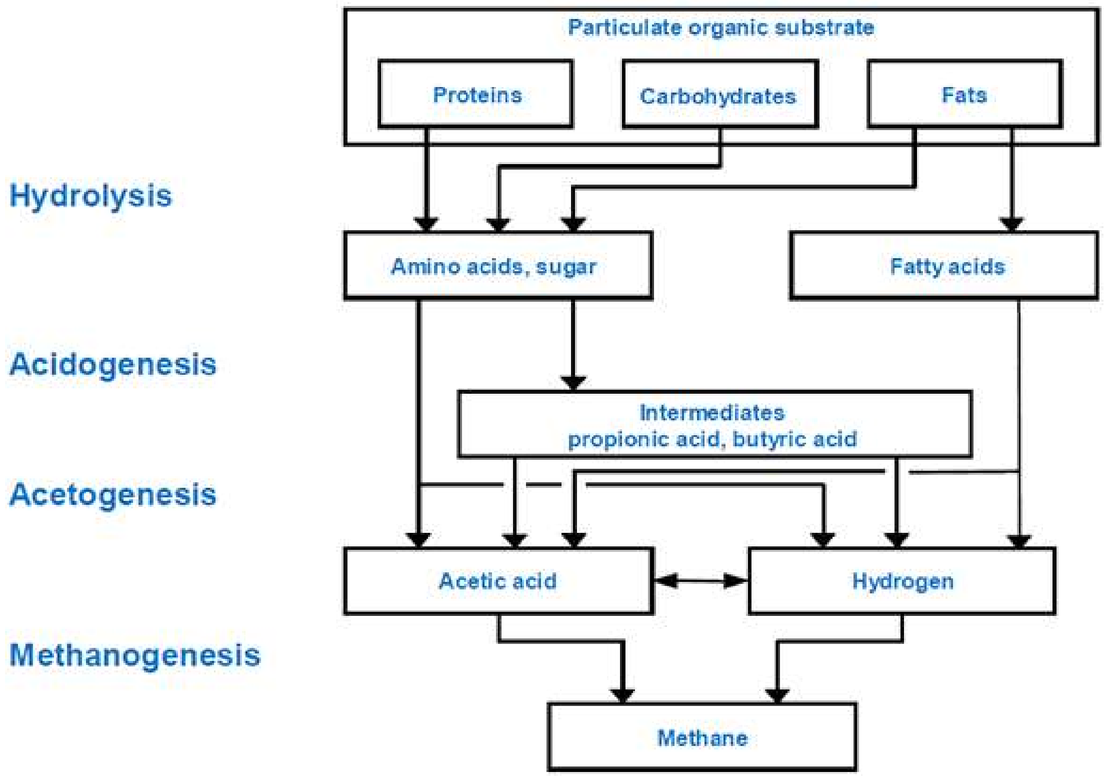


Figure 2-1. Degradation steps of anaerobic digestion process [3].

- *Hydrolysis*

Hydrolysis is the first stage of anaerobic digestion. In this stage, bacteria transform the particulate organic substrate into liquified monomers and polymers i.e. proteins, carbohydrates and fats are transformed to amino acids, monosaccharides and fatty acids respectively [3].

- *Acidogenesis*

Acidogenesis is the next step of anaerobic digestion after hydrolysis. In this step, acidogenesis microorganism further break down the biomass product after hydrolysis. These fermentative bacteria produce an acidic environment while acetic acids, hydrogen, carbon dioxide, alcohol [3].

- *Acetogenesis*

In this third stage, the rest of acidogenesis products i.e. propionic acid, butyric acid and alcohols are transformed by acetogenic bacteria into hydrogen, carbon and acetic acid [3].

- *Methanogenesis*

During this stage, microorganism converts the acetic acid and hydrogen to methane gas and carbon dioxide. Methanogens are the bactria responsible for this conversion. Waste stabilization is accomplished when carbon dioxide and methane gas are produced [3].

According to Lucas Seghezzo *et al*. (1998)[4], the advantages of anaerobic sewage treatment are as follow.

1. *High efficiency.*

   Even at high loading rates and low temperature, good removal efficiency can be achieved in the system [4].
2. *Low energy consumption.*

   The energy consumption of the reactor is almost negligible as far as no heating of the influent is needed to reach working temperature and the plant operation can be done by gravity .[4]
3. *Low sludge production.*

   Anaerobic bacteria have slow growth rate. Hence, the sludge production is low compare to aerobic method [4].
4. *Low space requirements.*

   The area needed for the reactor is small when high loading rates are accommodated [4].
5. *Low nutrients and chemical requirement.*

   An adequate and stable pH can be maintained without the addition of chemicals, especially in the case of sewage [4].
6. *Simplicity.*

   The construction and operation of the reactor is relatively simple [4].
7. *Flexibility*

   Can easily be applied on either a very large or a very small scale [4].

Beside the advantages, the anaerobic treatment also has some disadvantages. The disadvantages of anaerobic treatment are as follows [4].

1. *Possible bad odors.*

   Anaerobic process produces hydrogen sulfide, especially when the influent consist high concentration of sulphate. Hence, proper handling is required to avoid bad odors [4].

2. *Long start up.*

   When no good inoculum is available, the start-up takes longer than aerobic treatment due to methanogenic organisms has low growth rate [4].

3. *Low pathogen and nutrient removal.*

   Pathogen removal is partially only (except helminth eggs, which are effectively captured in the sludge bed) and nutrient removal is not complete and require post treatment [4].

4. *Necessity of post treatment.*

   Post treatment is generally required to reach the standard discharge of organic matters [4].

2.2 UASB reactor

One of the most notable developments in anaerobic treatment process technology was the up-flow anaerobic sludge blanket (UASB) reactor in the late 1970s in the Netherlands by Lettinga and his coworkers [5]. The schematic diagram of a laboratory scale UASB reactor is illustrated on Figure 2-2.

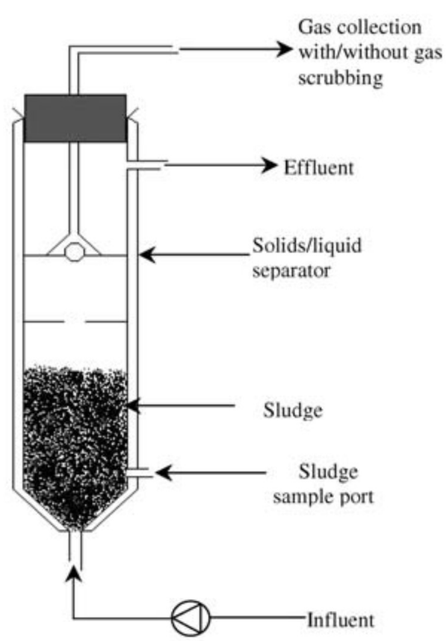


Figure 2-2. Schematic diagram of a laboratory scale UASB reactor [6]

Influent wastewater is distributed at the bottom of the UASB reactor and travels in an up-flow mode through the sludge blanket. Critical elements of the UASB reactor design are i) the influent distribution system, ii) the gas-solid separator and iii) the effluent withdrawal design [5].

The wastewater comes in contact with the micro-organisms as the wastewater passes through the sludge bed and anaerobic degradation of the wastewater organics occurs. The treated effluent leaves through an outlet at the top of the reactor. Upward hydraulic turbulence caused by produced biogas providing adequate mixing within the system, hence, mechanical mixing is not required. Three phase (i.e. gas-liquid-solid) separator at the top of reactor is to facilitate granule retention [6]. Granules with good settling properties settling back to the granular sludge bed, while flocculated and dispersed bacteria wash out of the reactor with the effluent.

One of the advantage of UASB reactor compared to traditional anaerobic treatment is the ability to retain high biomass concentrations despite the up-flow velocity of the wastewater and the production of biogas. The sludge retention time is almost independent of the hydraulic retention time. Consequently, the reactor can operate at short hydraulic retention times [7].

The important design consideration for UASB reactors are wastewater characteristics in terms of composition and solid contents, volumetric organic load, up-flow velocity, reactor volume, physical features including the influent distribution system and gas collection system [5].

2.3 Granular sludge

There are various types of conglomerates of microbes such as granules, pellets, flocs and flocculent sludge. According to Dolfing (1987) [8], pellets and granules are conglomerates with a dense structure and these conglomerates present a well-defined appearance after settling. Flocs and flocculent sludge are conglomerates with a loose structure and they form one homogeneous macroscopic layer after settling.

Granular sludge can be described as a spherical biofilm consisting of a densely packed anaerobic microbial consortium [9]. Granules from successful UASB reactor are very compact and have a high settling velocity. As such, they are able to withstand the effect both of the liquid up-flow velocity and hydraulic shear and become concentrated biomass [10]. According to Visser *et al.* (1991) [11], granule formation is generally thought to be the result of environmental pressures or selection, with any non-granular material being washed out of the reactor.

The diameter of sludge granules varies from 0.14 to 5 mm depending upon the wastewater used, the operational conditions and the analytical method. The granules shapes are vary depending on the condition of reactor, but they usually have spherical form [7].

Figure 2-3 shows the picture of granular sludge in microscope from one of UASB reactor (A) and the picture of anaerobic granule in scanning electron microscopy (SEM) (B).

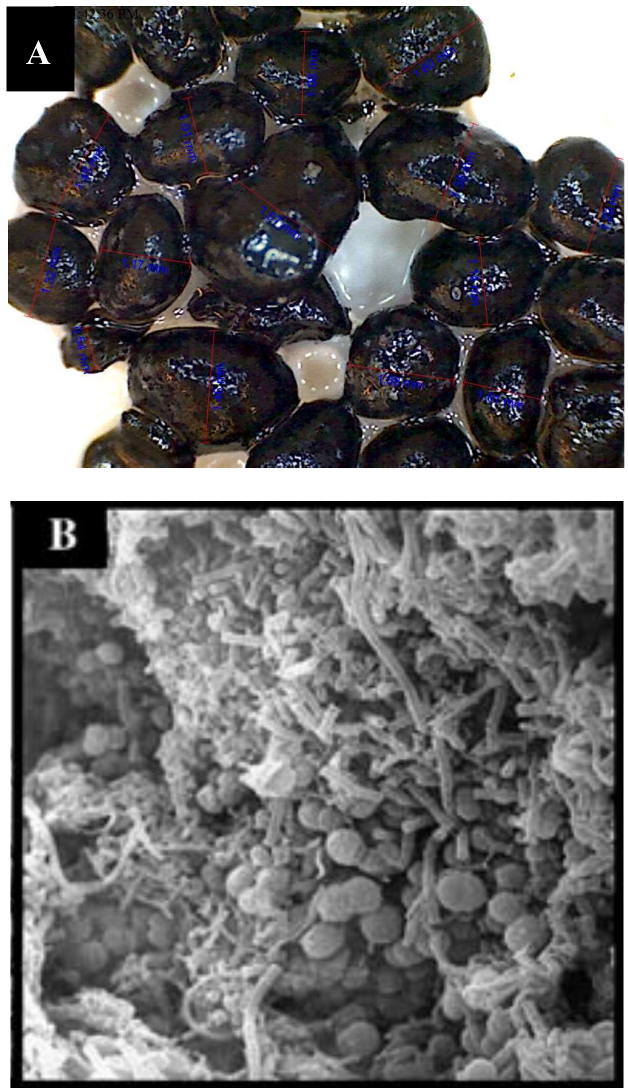


Figure 2-3. Sample of granular sludge in microscope in magnification 20x (A); and scanning electron micrograph (SEM) of anaerobic granules in magnification 2900 x (B) [6]

2.3.1 Mechanisms and models for anaerobic granulation

According to Yu Liu *et al.* (2002)[12], there are mechanisms and models for anaerobic granulation in UASB system to expedite granules development, design and operate granular sludge-based treatment system. The different granulation models in UASB are i) thermodynamic models (i.e. secondary minimum adhesion model, hydrophobic interaction and local dehydration models) and ii) surface tension model and structural models (i.e. inert matters in inert nuclei model, cation-bridged bacterial aggregates in divalent cation-bridge model, extracellular polymer (ECP) bound bacterial cells in ECP bonding model and Capetown's model, filamentous bacterial aggregates in spaghetti theory and crystallized nuclei formation model and syntrophic microcolonies in syntrophic microcolonies model) [12].

2.3.2 Anaerobic granulation influencing factors

The long start-up period required for the development of anaerobic granules is one of the major problem encountered with UASB. However, the use of granular sludge from in-operating UASB reactors as the seed material has the advantage of being able to achieve high organics removal within a short start-up period. The information on the major factors influencing anaerobic granules process is essential when researchers are looking for possible strategy for fast production of anaerobic granules. According to Yu Liu *et al.* (2002)[12], the factors are as follows :

1. *Up-flow velocity and hydraulic retention time*

   It has been observed that the granulation process in an UASB reactor was favored by the combination of high liquid up-flow velocity and short hydraulic retention time (HRT) [13]. A long HRT combined with a low liquid up-flow velocity may allow dispersed bacterial growth and be less favorable for microbe granulation while a short HRT combined with a high liquid up-flow velocity could cause washout of non-competent bacteria in granulation and subsequently promote sludge granulation [12].

2. *Organic loading rate*

   Organic loading rate (OLR) describes the degree of starvation of the microorganisms in a biological system. A low OLR means that the microorganisms are starved in the reactor and a high OLR would ensure a fast microbial growth [12].

3. *Characteristics of substrate*

   The substrate can be roughly classified into high-energy and low-energy feeds based on the free energy of oxidation of organics. High-energy carbohydrate feed during the UASB start-up period can sustain the acidogens and facilitate the formation of extracellular polymer (ECP) [12] .

   The complexity of substrate may exert a selection pressure on microbial diversity in anaerobic granules, which consequently influences the formation and microstructure of granules [12].

4. *Characteristics of seed sludge*

   The quality of a particular seed material can be judged in term of ash content, specific methanogenic activity (SMA) and the settleability, apart from its availability and cost. Possible seed materials are manure, fresh water sediments, septic tank sludge, digested sewage sludge and surplus sludge from anaerobic treatment plants. Aerobic activated sludge from sewage treatment plant is another type of seed sludge [12].

According to Yu Liu *et al.* (2002)[12], it might be expected that anaerobic granulation could be expedited simply by manipulating the composition of seed sludge. However, there is still lack of detail guidelines on which species in seed sludge should be a major component and how to manipulate the species in seed sludge.

5. *Addition of polymer*

One of important factors for the development of granules from non-granular sludge is the presence of nuclei or biocarrier for microbial attachment growth. Synthetic and natural polymers have been used in coagulation/flocculation processes. Chitosan may play a similar role as ECP substances and significantly enhanced the formation of anaerobic granules in UASB-like reactors. Freely moving polymeric chains may build a bridge between cells and can promote the formation of initial microbial nuclei which is the first step of microbial granulation [12].

6. *Addition of cations*

There is evidence that the presence of cations (positive divalent and trivalent ions) such as Fe^{2+}, Fe^{3+}, Ca^{2+}, and Mg^{2+} could bind to anion (negatively charged cells) to form a microbial nuclei [12].

7. *Reactor temperature*

An anaerobic system performance is closely related to temperature variation. Methanogenic bacteria, a core microbial component of UASB granules, grows slowly in wastewater and their generation time range from 3 days at 35 ^{o}C to as high as 50 days at 10 ^{o}C [14]. It shows that when the temperature is lower in an anaerobic reactor, the growth of methanogens would be inhibited. Although relatively high temperature encourages the growth of biosolids.

Most full-scale UASB operate in mesophilic range from 22 to 40 ^{o}C, with optimum temperature of 35 ^{o}C and under thermophilic condition, from 50 to 60 ^{o}C or even higher to 70 ^{o}C [12]. However, extreme thermophilic UASB reactors seem not to be beneficial since additional energy is required in order to maintain the reactor temperature [12].

8. *Reactor pH*

The effect of the reactor pH on anaerobic granulation had been observed by Teo *et al.* (2000)[15]. The research showed that the turbidity of granules decreased with the pH increased in a pH range of 8.5 – 11. It indicates that high pH condition would weaken the granular structure. The granular structure was relatively stable in pH range 5.5 to 8.0 and in pH range 5.0 to 3.0 the strength of granule was decreased [12].

2.3.3 Characterization of granular sludge

Characteristics of anaerobic granules can be determined by observing from its microstructure, methanogenic activity, surface properties, apparent color, density and size and mechanical strength.

1. *Microstructure*

   Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are often used to examine the surface and internal structure of granules. Fang *et al.*(1995)[16], MacLeod *et al.* (1990)[17] and Guiot *et al*. (1992)[18] had performed intense research on the ultrastructure of UASB. Based on those observation, a multi-layered structural model was proposed with the acidogenic bacteria dominating the outer layer while the inner layer mainly consist of methanotrix-like bacteria.

   Uniform structure of granules also found on researched by Grotenhuis *et al.* (1991)[19] and Fang *et al.* (1995)[16] when filamentous microorganisms were predominant on the surface and in the center of the granules and according to Fang *et al.* (1995)[16], a layered and uniform microstructure would be developed with proteins and carbohydrates as substrates.

2. *Methanogenic activity*

   Methanogenic activity is represented by the activity of methane-producing bacteria and it is defined as the methane production by unit biomass and time or methane production per unit reactor volume and time. This activity more generally determined by using closed bottle test. The methanogenic activity can be used as an indicator of inhibitory effects on anaerobic granules and to evaluate the performance of a system [12].

3. *Surface properties*

   It has been well known that some environmental conditions such as starvation, oxygen level and liquid ionic strength can change hydrophobicity of cell surface [12]. The hydrophobicity of cell surface is an important affinity force in the self-immobilization and attachment of cells.

   The strength of granules quantified by turbidity and surface charge of granules has been researched and measured by Quarmby and Forster (1995)[10]. The result suggested that when the surface negative charge increased, the granules tended to become weaker. It can be concluded that the surface characteristics of sludge is closely correlated with the anaerobic granulation.

4. *Apparent color*

   Anaerobic granules have a dark brown or black surface in general. Granules could become lighter with a hollow core and were gray or even white at low organic loading rate (OLR) and liquid up-flow velocity. The gray and white granules were extremely soft and weak mechanical stress could break up the wall of granules. While at high OLR and liquid up-flow velocity, granules remained dark black and had dense structure [20].

The apparent color of granules should be dependent upon chemical composition, microbial and given hydrodynamic conditions. Thus, the changes in granule color may reflect changes in composition and metabolism of granules [12].

5. *Density and size*

   A higher density leads to a faster settling velocity of sludge while geometric size of granules has dual effects on the performance of UASB system. The probability of washout of granules from the system would be increased if the size of granules is too small. On the other hand, an increase in size of granules would reduce the efficiency of mass transfer inside the granule. The resultant size and density of anaerobic granules are dependent on many factors such as OLR, microbial species, hydrodynamic conditions and so on. Medium size of granules with a diameter of 1.0-2.0 mm with narrow size distribution of granules look the most attractive in industrial practice. The relatively high density of individual granules cause them to settle rapidly and good settleability of granules simplify the separation of effluent from the granules and lead to a simple design and operational [12].

6. *Mechanical strength*

   The stability of granules influenced by the strength of granules. Higher strength leads to a more stable and compact structure of granules. Sonication is one of the method to quantify the strength of granules. Quarmby and Forster (1995)[10] reported that turbidity of sonicated granules was linearly related to the applied COD concentration. A lower COD loading rate would result in higher strength of anaerobic granules and vice versa.

   The other method was proposed by Ghangrekar *et al.*(1996)[21]. The proposed that granular strength could be expressed in term of an integrity coefficient (%). Integrity coefficient is defined as the ratio of solid in the supernatant to the total weight of granular sludge after 5 min of shaking at 200 rev/min on platform shaker. A low integrity coefficient represents granules able to withstand high shear and abrasion. Thus, the lower integrity coefficient the greater is the strength of granules.

2.4 Particle settling theory

In general, the settling of particles can be analyzed by means of classic laws of sedimentation formed by Newton and Stokes [5]. Newton's law yields the terminal particle velocity by equating the gravitational force of the particle to the frictional resistance or drag force. The forces are illustrated in Figure 2.4 below.

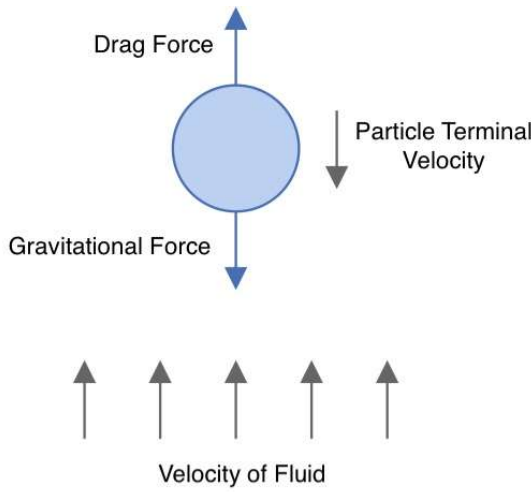


Figure 2-4. Illustrating of forces in Newton's law of settling theory.

The gravitational force is given by

$$F_G = (\rho_P - \rho_W)gV_P \qquad [2\text{-}1]$$

Where F_G = gravitational force (kg m/s^2)

ρ_P = density of particle (kg/m^3)

ρ_W = density of water (kg/m^3)

g = acceleration due to gravity (9.81 m/s^2)

V_P = volume of particle (m^3)

The frictional drag force is given by

$$F_d = \frac{C_d A_P \rho_W v_P^2}{2} \qquad [2\text{-}2]$$

Where F_d = frictional drag force (kg m/s^2)

C_d = drag coefficient (unitless)

A_p = cross-sectional of projected area of particles in direction of flow (m^2)

ρ_W = density of water (kg/m^3)

v_P = particle settling velocity (m/s)

Equating the gravitational force to the frictional drag force for spherical particles yields Newton's law :

$$v_{p(t)} = \sqrt{\frac{4g}{3C_d}\left(\frac{\rho_p - \rho_w}{\rho_w}\right) d_P} \approx \sqrt{\frac{4g}{3C_d}(sg_p - 1)d_p} \qquad [2\text{-}3]$$

Where $v_{P(t)}$ = terminal velocity of particle (m/s)

d_P = diameter of particle (m)

sg_p = specific gravity of the particle

The coefficient of drag d_P takes on different values depending on the flow regime surrounding the particle. The drag coefficient is a function of Reynolds number for particles that are approximately spherical is approximated by equation below [5].

$$C_d = \frac{24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34 \qquad [2\text{-}4]$$

While the Reynolds number N_R for settling particles is defined as

$$N_R = \frac{v_p d_p \rho_w}{\mu} = \frac{v_p d_p}{\mu} \qquad [2\text{-}5]$$

Where μ = dynamic viscosity (Ns/m^2)

v = kinematic viscosity (m^2/s)

For non-spherical particles, equation [2-3] needs to be modified and has been proposed by Gregory *et al.* (1999)[22]. The equation is as follows.

$$v_{p(t)} = \sqrt{\frac{4g}{3C_d\emptyset}\left(\frac{\rho_p - \rho_w}{\rho_w}\right) d_P} \approx \sqrt{\frac{4g}{3C_d\emptyset}(sg_p - 1)d_p} \qquad [2\text{-}6]$$

Where ø is a shape factor. The value of the shape factor is 1.0 for spheres, 2.0 for sand grains and up to and greater than 20 for fractal floc.

There are three more or less distinct regions, depending on the Reynold's number. There are laminar $(N_R < 1)$, transitional $(N_R = 1\ to\ 2000)$ and turbulent $(N_R > 2000)$ [5].

2.4.1 Settling in the laminar region

For Reynold's number less than about 1, the predominant force governing for the settling process is viscosity. Assuming spherical particles, the terminal (settling) velocity of particle equation as below [5].

$$v_p = \frac{g(\rho_p - \rho_w)d_p^2}{18} \approx \frac{g(sg_p - 1)d_p^2}{18v} \qquad [2\text{-}7]$$

2.4.2 Settling in the transition region

Assuming spherical particles, equation [2-3] can be used to determine settling velocity of particle in the transition region [5].

2.4.3 Settling in the turbulent region

In the turbulent region, the predominant forces are inertial forces. A value of 0.4 is used for the coefficient of drag. If the value of 0.4 is substituted into equation [2-6] for C_d and assume sphere particle, the resulting equation as follow [5].

$$v_{p(t)} = \sqrt{3.33g\left(\frac{\rho_p - \rho_w}{\rho_w}\right)d_P} \approx \sqrt{3.33g(sg_p - 1)d_p} \qquad [2\text{-}8]$$

2.5 Hydrodynamics of UASB reactor

The hydrodynamics characteristics of up-flow anaerobic sludge blanket (UASB) reactors has been investigated by Ren *et al.* (2009)[23]. The study was set up a number of continuously stirred tank reactors (CSTRs) in series to visualize a UASB reactor. The hydrodynamics of such bioreactor was described with an increasing-sized CSTRs (ISC) model. Another studies on UASB hydrodynamics have shown that they could be well described by multi-CSTR (continuous stirred tank reactor) model with commonly used the equal-sized CSTRs (ESC) model and extended equal-sized CSTRs (EESC) model. The schematic diagrams of those models is shown in Figure 2-5.

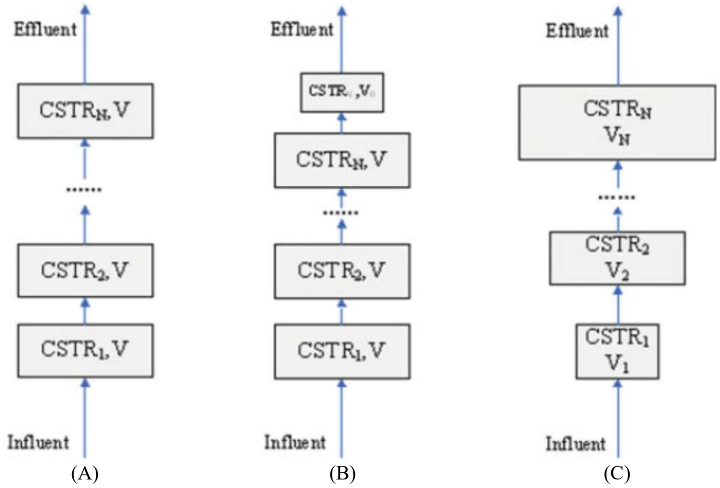


Figure 2-5. A schematic diagram of the model: (A) ESC model; (B) EESC model; (C) ISC model [23].

According to Ren *et al.* (2009)[23], the dispersion coefficient decreased along the axial of the UASB reactor with gradually increasing tank size in the ISC model. The model validation was using experimental results from both laboratory-scale H_2-producing and full-scale CH_4-producing UASB reactors. The simulation result demonstrated that the ISC was better than the other models. The schematic diagram of the laboratory-scale H_2-producing UASB reactor is shown in Figure 2-6.

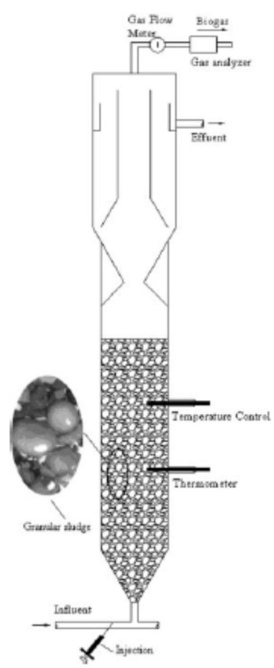
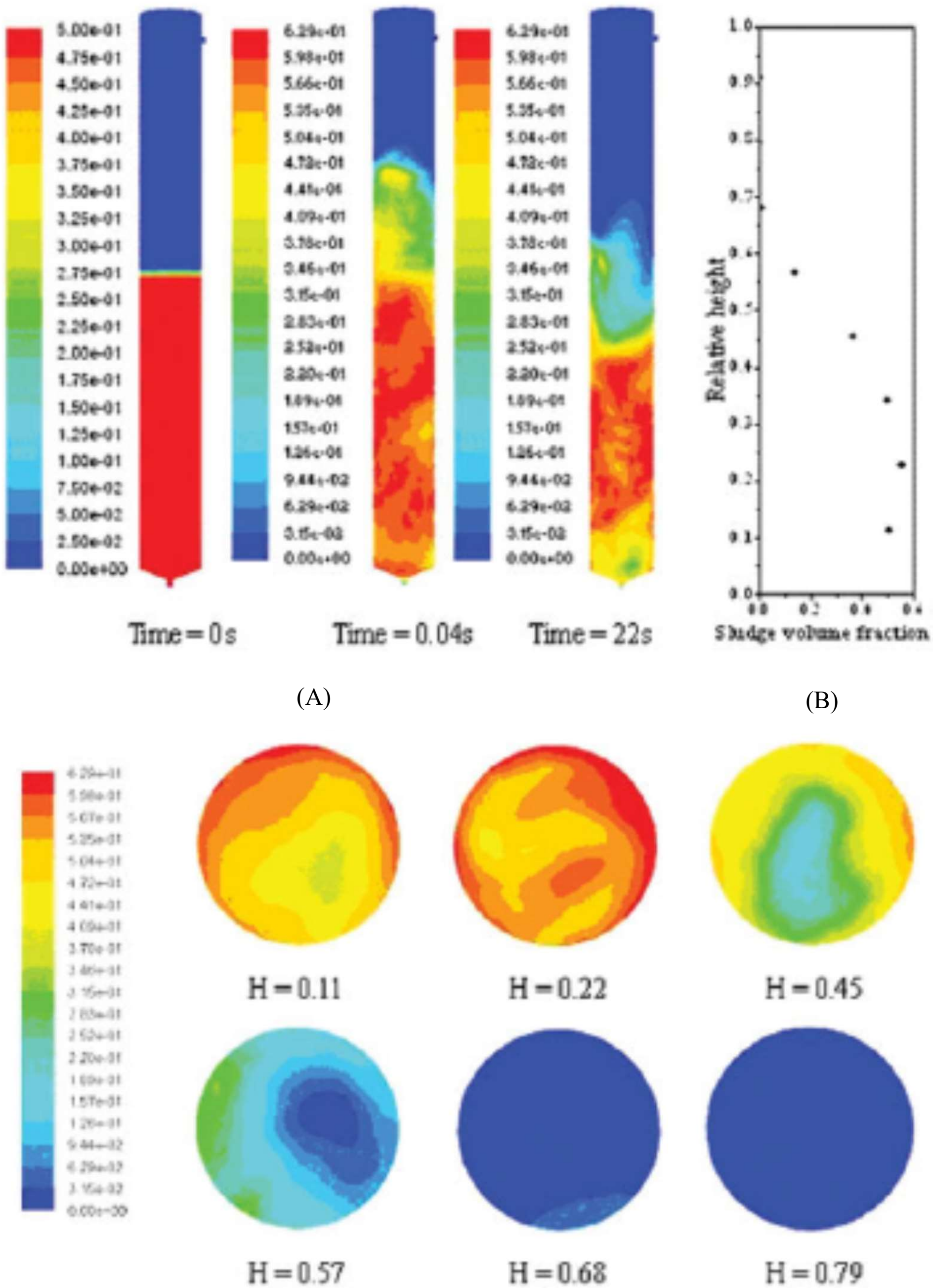


Figure 2-6. A schematic diagram of the laboratory-scale H_2-producing UASB reactor and pulse injection [23].

A three-dimensional computational fluid dynamics (CFD) simulation was also performed in the study with an Eulerian-Eulerian three-phase-fluid approach to visualize the phase holdup and to explore the flow patterns in UASB reactors and in terms of the flow pattern and dead zone fractions, the results from CFD simulation and the ISC model were comparable [23]. The solid phase holdup distribution in the UASB reactor is shown in Figure 2-7.



(A) (B) (C)

Figure 2-7. Transient model predictions of the laboratory-scale H_2-producing UASB reactor at HRT of 4.3 h: (A) sludge volume fraction contours of sludge volume fraction at 0.11, 0.22 and 22 s; (B) average sludge volume fraction along the reactor height at 22 s; and (C) sludge volume fraction contours of sludge volume fraction of the reactor cross section at 22 s [23].

3 Materials and methods

There are seven samples of granular sludge which were collected from several different full and laboratory scale wastewater treating reactors to be examined in these experiments. Also three different coffee grit samples were used as a physical model to characterize granular sludge. Sample D (HyVAB – Hyberid Vertical Anaerobic Biofilm Bioreactor) and sample E (UASB E-Convert) were treating wastewater from oil refinery. Sample I and J (E-Convert new and old) were from an IR/IC (internal circulation) reactor treating wastewater from paper mill. Sample F (EGSB reactor) was a sulphid removal reactor fed with synthetic feed which consist of sodium bicarbonate, sulphide and nitrate solutions. And sample G and H (Saugbrugs new and old) were from reactor treating pulp and paper process wastewater at 'Norske Skog Saugbrugs' in Halden, Norway [1]. The sample list and identification are shown in Table 3-1.

Table 3-1 Sample list and identification

Sample ID	Granular Sludge
A	Coffee Grit 1
B	Coffee Grit 2
C	Coffee Grit 3
D	HyVAB
E	UASB E-Convert
F	EGSB Reactor
G	Saugbrugs (New)
H	Saugbrugs (Old)
I	E-Convert (New)
J	E-Convert (Old)

3.1 Density measurement

Specific sludge density was measured with the pycnometer method [24]. The weight (m_o) and volume of the pycnometer were known and the weight of the pycnometer together with inserted sludge were determined $(m_o + m_s)$. The pycnometer was filled with water (m_T) and the weight of water (m'_{H_2O}) was determined by

$$m'_{H_2O} = m_T - (m_o + m_s) \qquad [3\text{-}1]$$

The filled water volume (V'_{H_2O}) was obtained as

$$V'_{H_2O} = \frac{m'_{H_2O}}{\rho_{H_2O}} \quad [3\text{-}2]$$

The volume of measured sludge (V_s) was measured from the difference between the volume of water that fills the empty pycnometer (V) and the previously determined water volume (V'_{H_2O}).

$$V_s = V - V'_{H_2O} = \frac{m_{H_2O} - m'_{H_2O}}{\rho_{H_2O}} \quad [3\text{-}3]$$

The density of water (ρ_{H_2O}) is temperature dependent, hence temperature measurement of the water was required.

The granules sludge density (ρ_s) was calculated as

$$\rho_s = \frac{m_s}{\rho_s} \quad [3\text{-}4]$$

3.2 Settling profile and settling velocity of granular sludge

A glass cylinder of 0.06 m diameter and 0.425 m depth was used in this experiment to determine the settling profile [25]. A granule was randomly selected and time recorded for each granule and twenty granules were measured for each sample. The time of settling was recorded using stopwatch when the granular sludge was reached at each distance point every 0.1 m. Figure 3-1 shown the experimental set-up. The fluid used in this experiment was distilled water with temperature measured was 21.5°C

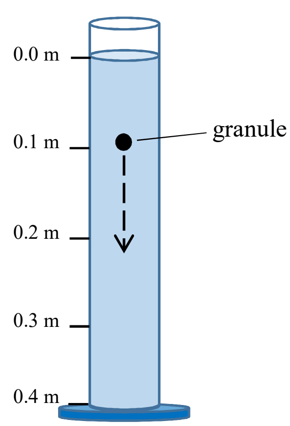


Figure 3-1. Experimental set-up to determine the settling properties.

The average settling time velocity $(\overline{v})$ for this experiment was calculated through simple relation between distance $(x - x_0)$ and time (Δt).

$$\overline{v} = \frac{x - x_0}{\Delta t} \quad [3\text{-}5]$$

3.3 Granule sludge diameter measurement

The VMS-001 USB Microscope, as shown in Figure 3-2, was used to measure sludge diameter. Calibration of microscope was done before all the measurements following the calibration and measurement procedure as described in manual and quick start guides provided by manufacturer (appendix 2). Properly stirred samples were conducted to obtain good range of granular size measured. Three measurement for each sample was conducted to obtain measurement statistics.

Figure 3-2. VMS -001 USB Microscope

3.4 Total solids and volatile solids

Total solids (TS) of sample was obtained by separating the solid and liquid phase by evaporation. Percent total solid can be calculated as the ratio between sample weight before the evaporation (m_o) and the weight after evaporation (m_e) multiply by 100.

$$\%\,Total\ Solids = \frac{m_e}{m_o}\ x\ 100 \quad [3\text{-}6]$$

Evaporation process was done by drying oven with 105 ± 3°C (Termaks B8133 incubator) for about overnight. The procedure was referred to Laboratory Analytical Procedure by National Renewable Energy Laboratory, U.S Department of Energy [26].

Solid remaining after evaporation were dried, weighed and then ignited at 530 °C for 15 minutes. The loss of weight by ignition was a measure of the volatile solids.

On the other word, the volatile solids can be generated as a formula below.

$$\% \, Volatile \, Solids = \frac{Weight \, after \, evaporation - Weight \, after \, ignition}{Weight \, before \, the \, evaporation} \, x \, 100 \quad [3\text{-}7]$$

$$\% \, Volatile \, Solids = \frac{m_e - m_i}{m_o} \, x \, 100 \quad [3\text{-}8]$$

3.5 Total suspended solid and volatile suspended solid

Total suspended solid (TSS) and volatile suspended solid (VSS) experiments were conducted in accordance with standard methods [27].

3.6 Settleability of sludge

Andras *et al.* (1989) developed a simple method to evaluate the settling properties of sludge granules by fraction exited under certain up-flow velocities in a fractionating device [28]. Figure 3-3 shows the schematic of the experiment.

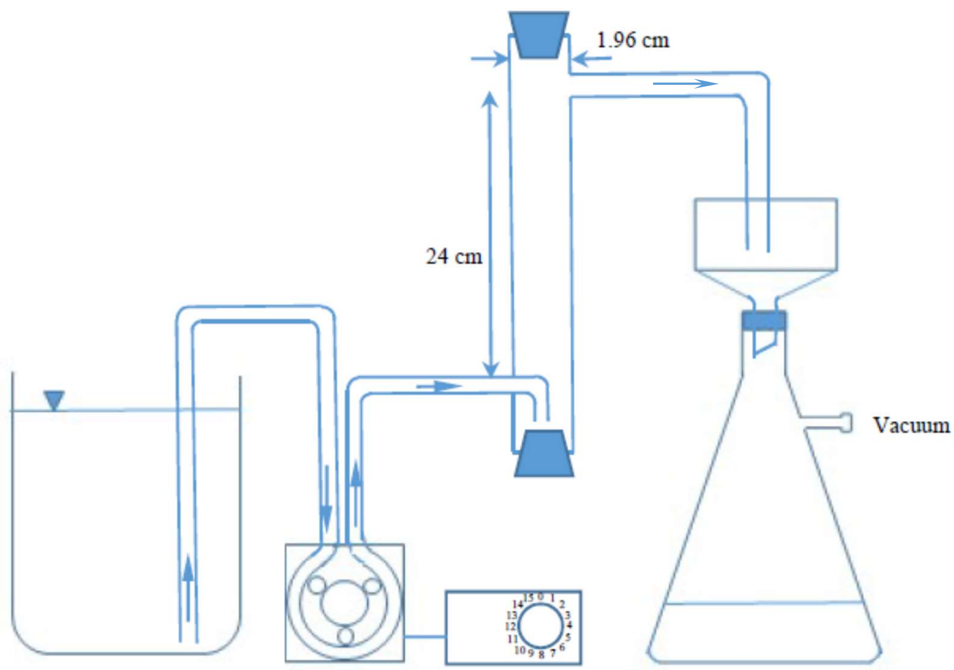


Figure 3-3. Up-flow velocity test apparatus.

For the coffee grit experiments, about 1/3 of the glass tube volume filled with the coffee grit. For the granules, about 5 ml of granules were separated into twelve fractions under up-flow liquid velocities of 1.2, 2.2, 3.2, 4.2, 5.2, 8.2, 10.1, 15.1, 19.7, 44.7, 99.4, 187 mh^{-1}, respectively and at each velocity for five minutes. Each fraction from the fractionation device was collected in a glass fiber filter (i.e. 0.45 µm pore size and 1.5 mm diameter) (VWR, Oslo, Norway). The sludge diameter of each fraction also measured by VMS-001 USB Microscope (Veho, Southampton, UK) and the pictures were taken. TSS and VSS in each fraction were also determined using the method described by Andras *et al.* (1989) [28].

4 Results

4.1 Density of samples

Figure 4-1 presents the densities measured experimentally for three different coffee grit (sample A, B and C) and seven different granular sludge (sample D, E, F, G, H, I and J). Coffee grit samples had significantly higher density than all granules investigated. Granule densities varied from 1.01 to 1.09 g/cm^3 with sample D (HyVAB) had the lowest and sample J (E-Convert (old) had the highest density.

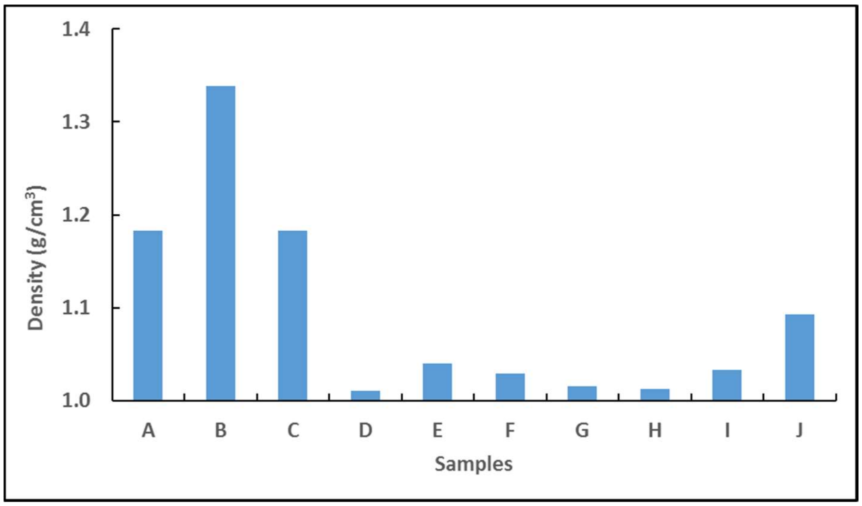


Figure 4-1. Densities of three coffee grit (A-C) and seven granular sludge (D-J).

The density values were taken three times each samples and average values were calculated. The density values in the graph were in average. The detail value of density measurement is shown in Appendix 3.

4.2 Settling time profile

Settling time profiles measured for all samples are presented in Figure 4-2. E-Convert (old) granules (sample J) settled fastest (137.8 m/h) and HyVAB (sample D) settled slowest (26.5) while coffee grit samples settled in between granular sludge settling range.

Average settling velocity of each granular sludge was calculated with equation 3-5 and the results are presented in Table 4-1. E-Convert (old) and UASB E-Convert granules had much higher settling velocities (137.8 and 132.6 m/h, respectively). Saugbrugs (old) had the second lowest (26.6 m/h) while the Saugbrugs (new) settled about 10 % faster than the old (29.6 m/h).

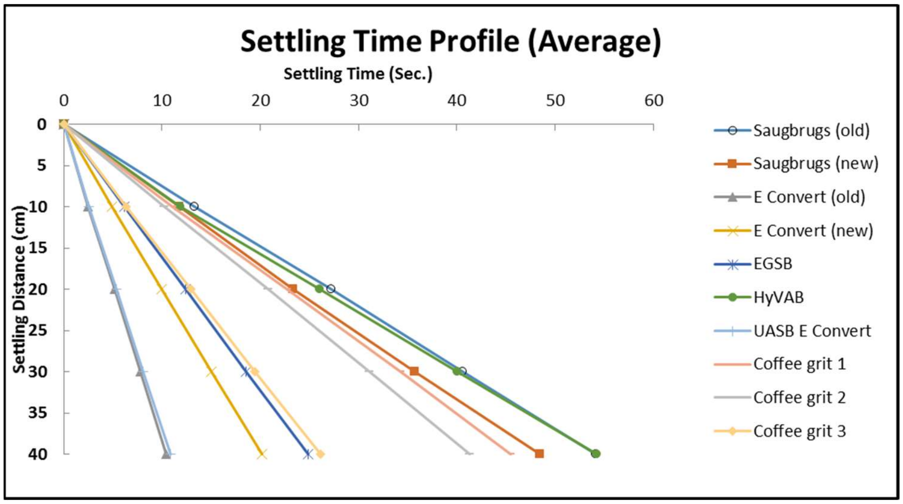


Figure 4-2. Settling time profile of three coffee grits and seven granular sludge.

Table 4-1. The calculated average settling velocity of three coffee grits and seven granular sludge.

Sample ID	Granular Sludge	Average settling velocity (m/h)
A	Coffee Grit 1	31.6
B	Coffee Grit 2	34.8
C	Coffee Grit 3	55.0
D	HyVAB	26.5
E	UASB E-Convert	132.6
F	EGSB Reactor	57.9
G	Saugbrugs (New)	29.6
H	Saugbrugs (Old)	26.6
I	E-Convert (New)	71.2
J	E-Convert (Old)	137.8

4.3 Granular sludge diameter range

The calibration of microscope was done before diameter measuring (Figure 4-3). The calibration method was in accordance with microscope manual procedure (Appendix 2). The result was for one millimeter distance, the microscope measured 0.89 mm. Hence, the correction factor for the microscope diameter measurement was 1.12.

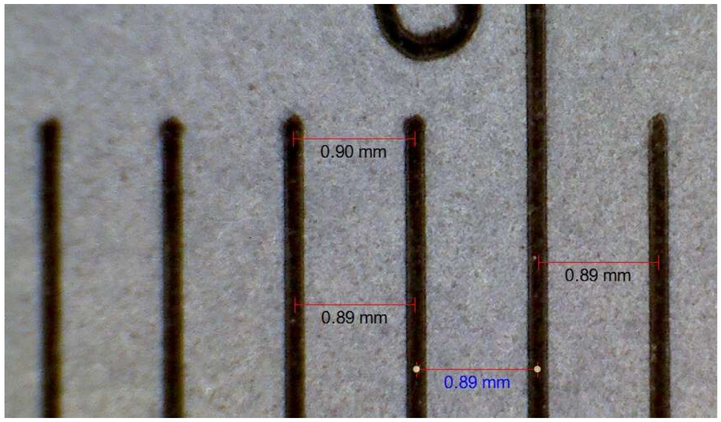


Figure 4-3. Measurement calibration of VMS – 001 USB Microscope.

Hence, every measured values was multiplied by the correction factor (i.e. 1.12) to obtain the correct value of the measurement.

4.3.1Sample A – Coffee grit 1

The diameter range for coffee grit 1 was from 0.3 – 1.06 mm (0.27 – 0.95 mm before multiplying with correction factor). Figure 4-4 shows the measuring result.

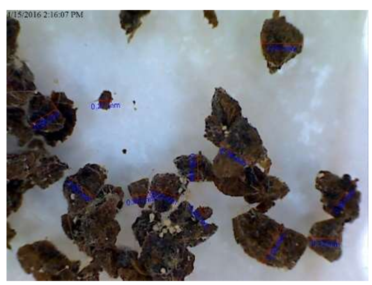


Figure 4-4. The VMS-001 USB microcope picture and the measured diameter of coffee grit 1 with the range from 0.3 – 1.06 mm.

4.3.2Sample B – Coffee grit 2

The diameter range for coffee grit 2 was 0.35-1.23 mm (0.32 – 1.1 mm before multiplying with correction factor). Figure 4-5 shows the measuring result.

Figure 4-5. The VMS-001 USB microcope picture and the measured diameter of coffee grit 2 with the range from 0.35 – 1.23 mm.

4.3.3 Sample C – Coffee grit 3

The diameter range for coffee grit 3 was 0.23-1.23 mm (0.21 – 1.1 mm before multiplying with correction factor). Figure 4-6 shows the measuring result.

Figure 4-6. The VMS-001 USB microcope picture and the measured diameter of coffee grit 3 with the range from 0.23 – 1.23 mm.

4.3.4 Sample D – HyVAB

The diameter range granules sampled from HyVAB reactor was 0.52 – 2.25 mm (0.47 – 2.01 mm before multiplying with correction factor). Figure 4-7 shows the measurement of three samples.

Figure 4-7. The VMS-001 USB microcope picture and the measured diameter of granules sampled from HyVAB reactor with the range from 0.52 – 2.25 mm.

4.3.5 Sample E – UASB E-Convert

The diameter range for granular sludge sampled from a UASB E-Convert was 0.60 – 2.74 mm (0.54 – 2.44 mm before multiplying with correction factor). Figure 4-8 shows the three-samples measurement result.

Figure 4-8. The VMS-001 USB microscope picture and the measured diameter of granules sampled of UASB – E Convert with the range from 0.6 – 2.74 mm.

4.3.6 Sample F – EGSB reactor

The diameter range for EGSB reactor was 0.41 – 2.32 mm (0.37 – 2.07 mm before multiplying with correction factor). Figure 4-9 shows the measured results.

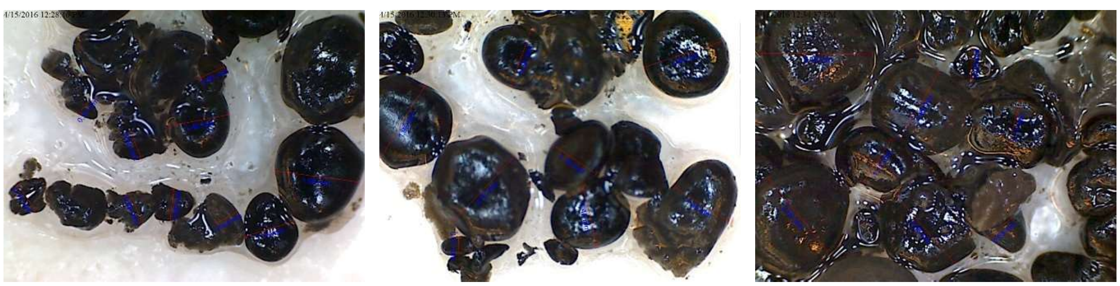


Figure 4-9. The VMS-001 USB microscope picture and the measured diameter of granules sampled from EGSB reactor with the range from 0.41 – 2.32 mm..

4.3.7 Sample G – Saugbrugs (new)

The diameter range for Saugbrugs (new) was 0.58 – 1.73 mm (0.52 – 1.54 mm before multiplying with correction factor). Figure 4-10 shows the measured results.

Figure 4-10. The VMS-001 USB microscope picture and the measured diameter of granules sampled from Saugbrugs (new) with the range from 0.58 – 1.73 mm.

4.3.8 Sample H – Saugbrugs (old)

The diameter range for Saugbrugs (old) was 0.22 – 1.35 mm (0.20 – 1.21 mm before multiplying with correction factor). Figure 4-11 shows the measured results.

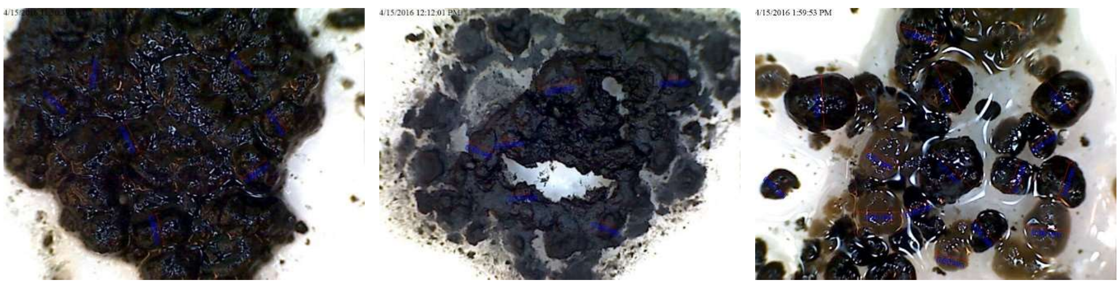


Figure 4-11. The VMS -001 USB microscope picture and the measured diameter of granules sampled from Saugbrugs (old) with the range from 0.22 – 1.35 mm.

4.3.9 Sample I – E-Convert (new)

The diameter range for E-Convert (new) was 0.20 – 3.75 mm (0.18 – 3.34 mm before multiplying with correction factor). Figure 4-12 shows the measured results.

Figure 4-12. The VMS -001 USB microscope picture and the measured diameter of granules sampled from E-Convert (new) with the range from 0.2 – 3.75 mm.

4.3.10 Sample J – E-Convert (old)

The diameter range for E-Convert (old) was 0.44 – 3.91 mm (0.4 – 3.48 mm before multiplying with correction factor). Figure 4-13 shows the measured results.

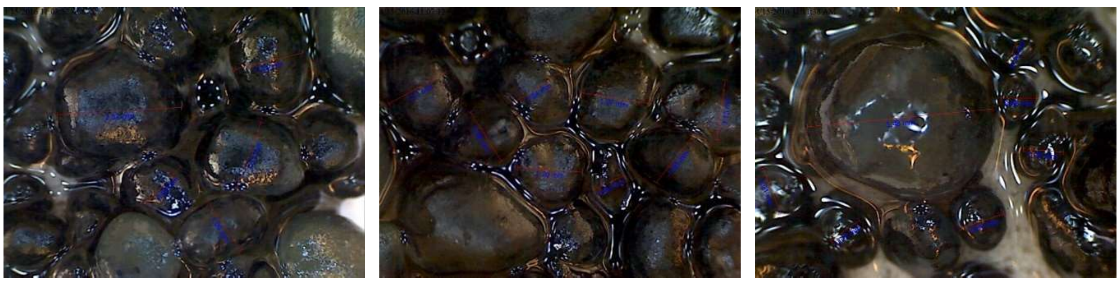


Figure 4-13 The VMS -001 USB microscope picture and the measured diameter of granules sampled from E-Convert (old) with range from 0.44 – 3.91 mm.

4.3.11 Summary of diameter measurements

From diameter measurements, it was found that the coffee grit samples particle diameter (i.e sample A, B and C) were in the range of granular sludge particle diameter. Sample H (Saugbrugs (old)) had the smallest diameter range (0.22 – 1.35 mm) while sample J (E-Convert (old)) had the highest diameter range (0.44 – 3.91 mm).

4.4 Total solids and volatile solids

The summary result of percent total solids, volatile solids and the ratio between volatile solids and total solids (VS/TS) for every samples are presented in Table 4-2. The detail result is presented in Appendix 4.

Coffee grits had the highest organic content (VS/TS) of about 97 % for all three samples. The real granules varied much more, from about 55 % to 86 % organics, with a significant fraction of inorganics (fixed solids).

Table 4-2 Summary of percent total solids and volatile solids and its ratio of three coffee grits and seven granular sludge.

Sample ID		% TS	%VS	VS/TS
A	Coffee Grit 1	40.425	38.863	0.961
B	Coffee Grit 2	41.626	40.897	0.983
C	Coffee Grit 3	38.638	37.751	0.977
D	HyVAB	5.603	4.586	0.819
E	UASB E-Convert	13.097	7.188	0.549
F	EGSB Reactor	6.943	4.930	0.710
G	Saugbrugs (New)	6.355	5.381	0.847
H	Saugbrugs (Old)	6.905	5.958	0.863
I	E-Convert (New)	10.602	8.186	0.772
J	E-Convert (Old)	19.262	12.119	0.629

4.5 Total suspended solid (TSS) and volatile suspended solid (VSS)

These measurements were conducted for Saugbrugs (new) and Saugbrugs (old) granular sludge only (sample G and H) to investigate if VSS/TSS changed with time. Table 4-3 shows the result and the detail is presented in Appendix 5.

The VSS/TSS ratio was lower in the old than in the new sample, so the amount of organic compared to fixed solids increased. The opposite trend was seen when measuring VS/TS (Table 4-2).

Table 4-3 TSS and VSS results of granular sludge samples from Saugbrugs new and old sample.

Sample	Sample ID	TSS (g/L)	VSS (g/L)	VSS/TSS
G	Saugbrugs (new)	34.5	32.67	0.95
H	Saugbrugs (old)	33.67	30.63	0.91

4.6 Settleability

4.6.1 Settleability of coffee grits

The settleability test was started with all coffee grit samples to test and established the method and the appropriate vertical velocities. Afterwards these were used to investigate the real granular sludge (saugbrugs new and saugbrugs old) to know the physical characteristics of the granular sludge.

From this experiment, settling velocity profile of each particular sample can be depicted by plotting up-flow velocity versus TSS exited from the glass test device. The percentage of total solids (TS) exited versus up-flow velocities were also investigated.

4.6.1.1 Coffee grit 1

Up-flow velocities profile for coffee grit 1 for TSS exited and TS exited in percent (%) is shown in Figure 4-14. The detail of the result is presented in Appendix 6. The highest TSS exited was about 500 mg/L with 8.2 m/h up-flow velocity and the highest TS exited in percent (%) was about 2.6 % with the same up-flow velocity.

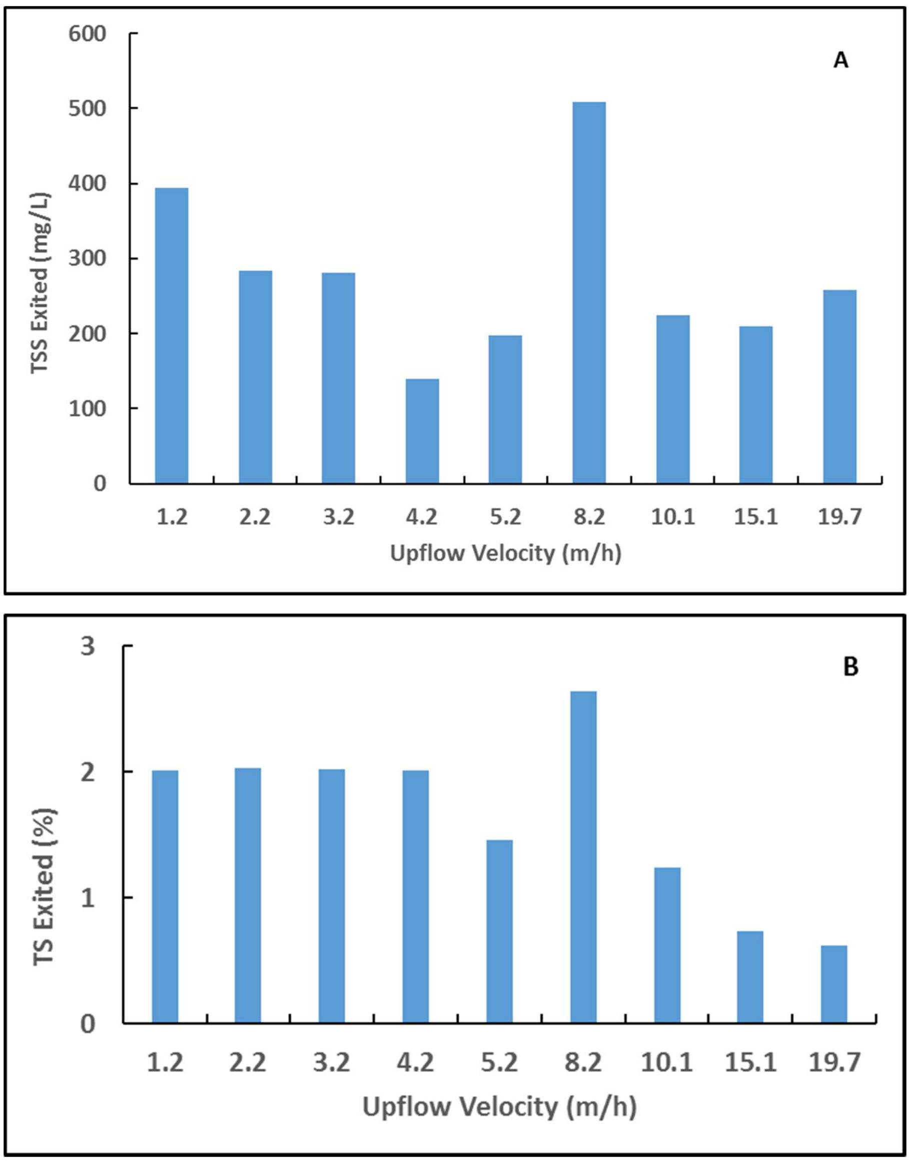


Figure 4-14. The TSS exited in mg/L (A) and TS exited in percent (%) (B) for coffee grit 1 as a function of Up-flow velocities.

4.6.1.2 Coffee grit 2

Up-flow velocities profile for coffee grit 2 for TSS exited and TS exited in percent (%) is shown in Figure 4-15. The detail result is shown in Appendix 6. The highest TSS exited was about 2250 mg/L with 1.2 m/h up-flow velocity and the highest TS exited in percent (%) was about 1.2 % with 2.2 m/h up-flow velocity.

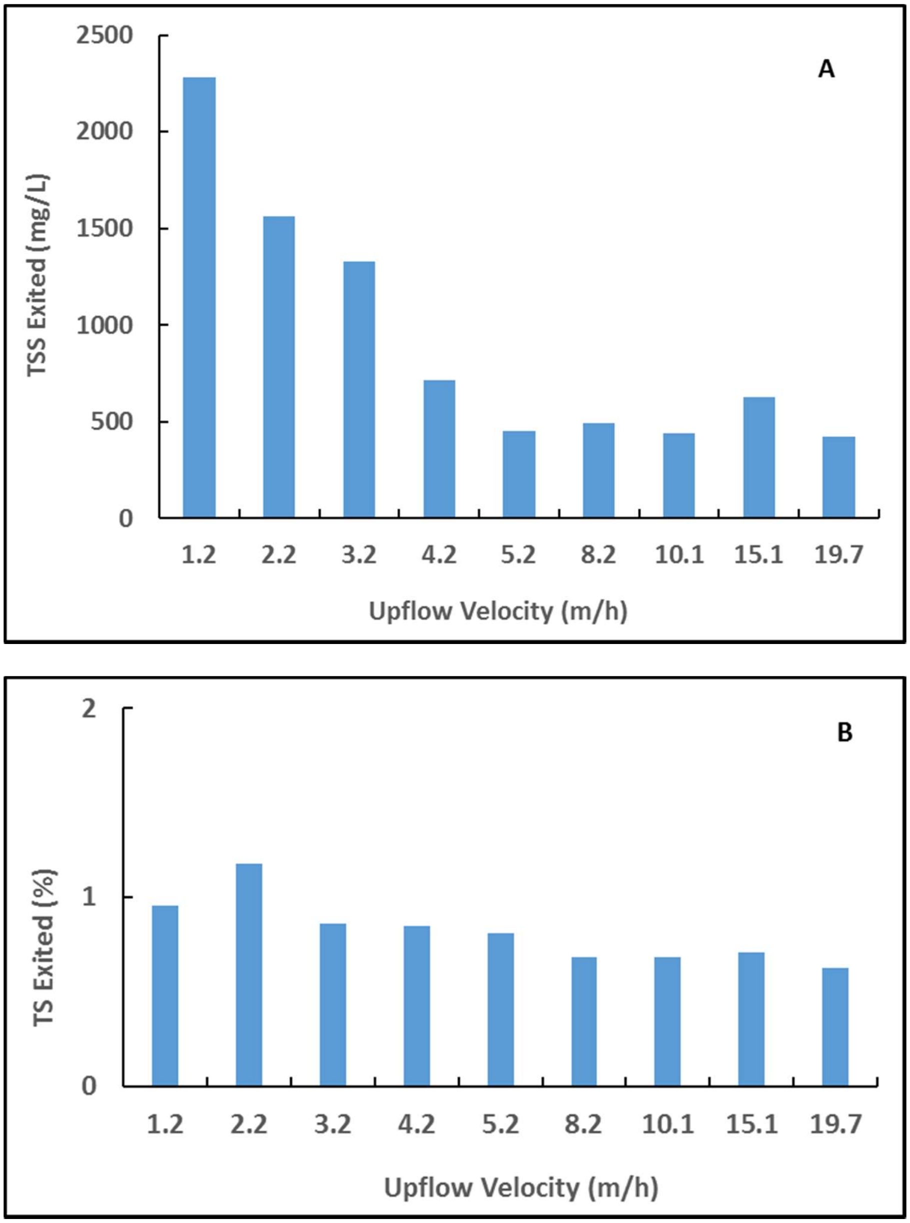


Figure 4-15. The TSS exited in mg/L (A) and TS exited in percent (%) (B) for coffee grit 2 as a function of Up-flow velocities.

4.6.1.3 Coffee grit 3

Up-flow velocities profile for coffee grit 3 for TSS exited and TS exited in percent (%) is shown in Figure 4-16 below. The detail result is shown in Appendix 6. The highest TSS exited was about 900 mg/L with 2.2 m/h up-flow velocity and the highest TS exited in percent (%) was about 2.6 % with 8.2 m/h up-flow velocity.

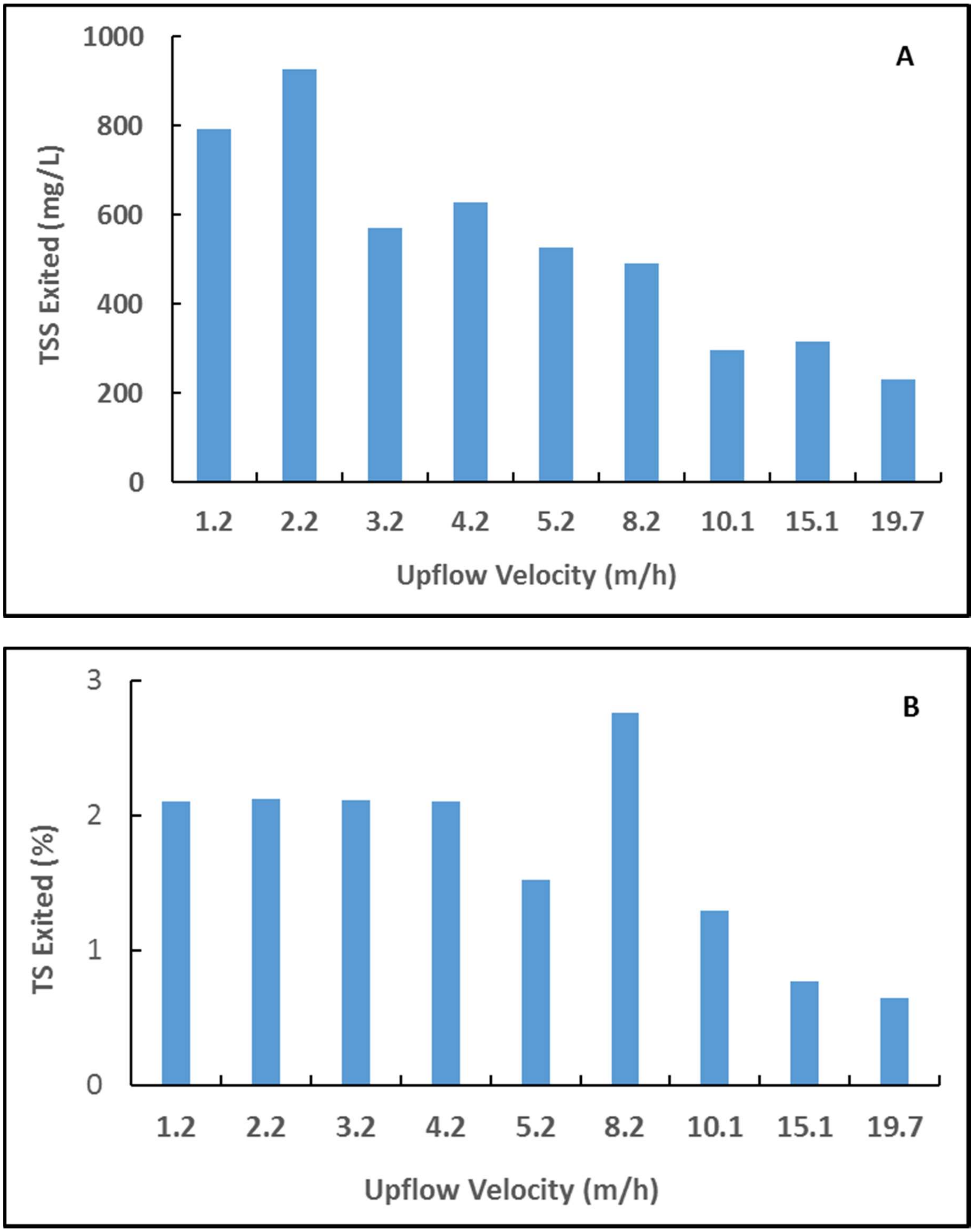


Figure 4-16. The TSS exited in mg/L (A) and TS exited in percent (%) (B) for coffee grit 3 as a function of Up-flow velocities.

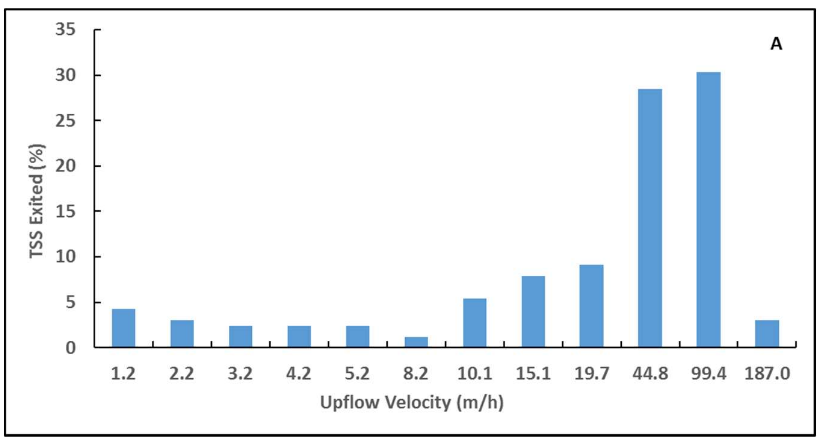
4.6.2 Settleability of granular sludge

The settleability experiment for granular sludge was conducted with the same procedure and method used in the experiment for coffee grit. However, the higher up-flow velocities were included to ensure that the sludge was completely exited from the glass test device. The additional higher up-flow velocities which were tested to the granular sludge were 44.8, 99.4 and 187 m h^{-1}. These flow range were achieved by adjusting and calibrating the water flowing from a tap to the test reactor.

During the test, pictures were also taken for each fraction by microscope (Veho, Southampton, UK) and diameter of exited sludge for each fraction was measured.

4.6.2.1 Saugbrugs (old) – Sample H

Up-flow velocities profile for saugbrugs (old) for TSS exited in percent (%) and cumulative solid loss plot in percent (%) is shown in Figure 4-17. It was shown that about 30 % of TSS exited in up-flow velocities 44.8 and 99.4 m/h (Fig. 4-17A) which made about 66 % and 96 % cumulative TSS exited in those up-flow velocities respectively (Fig. 4-17B).



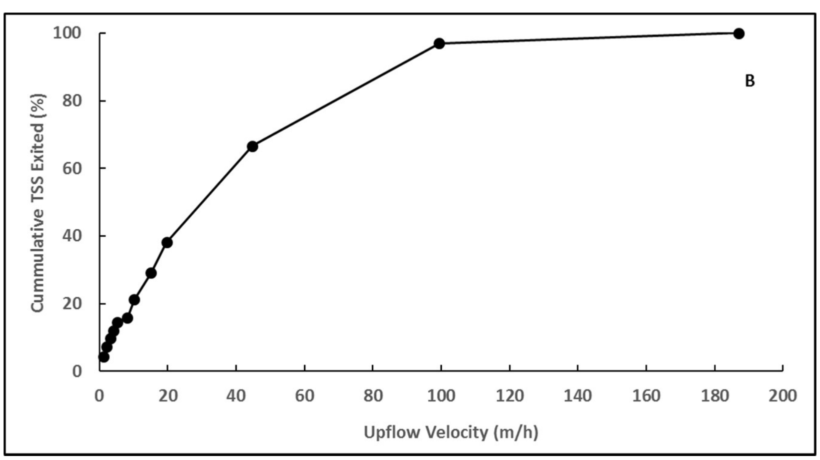


Figure 4-17. The TSS exited in percent (%) (A) and cumulative TSS exited in percent (%) (B) for granular sludge from Saugbrugs (old) as a function of Up-flow velocities.

4.6.2.2 Saugbrugs (new) – Sample G

Up-flow velocities profile for saugbrugs (new) for TSS exited in percent (%) and cumulative solid loss plot in percent (%) is shown in Figure 4-18. It was shown that about 50 % of TSS exited in up-flow velocity 44.8 m/h (Fig. 4-17A) which made about 82 % cumulative TSS exited in that up-flow velocity (Fig. 4-17B).

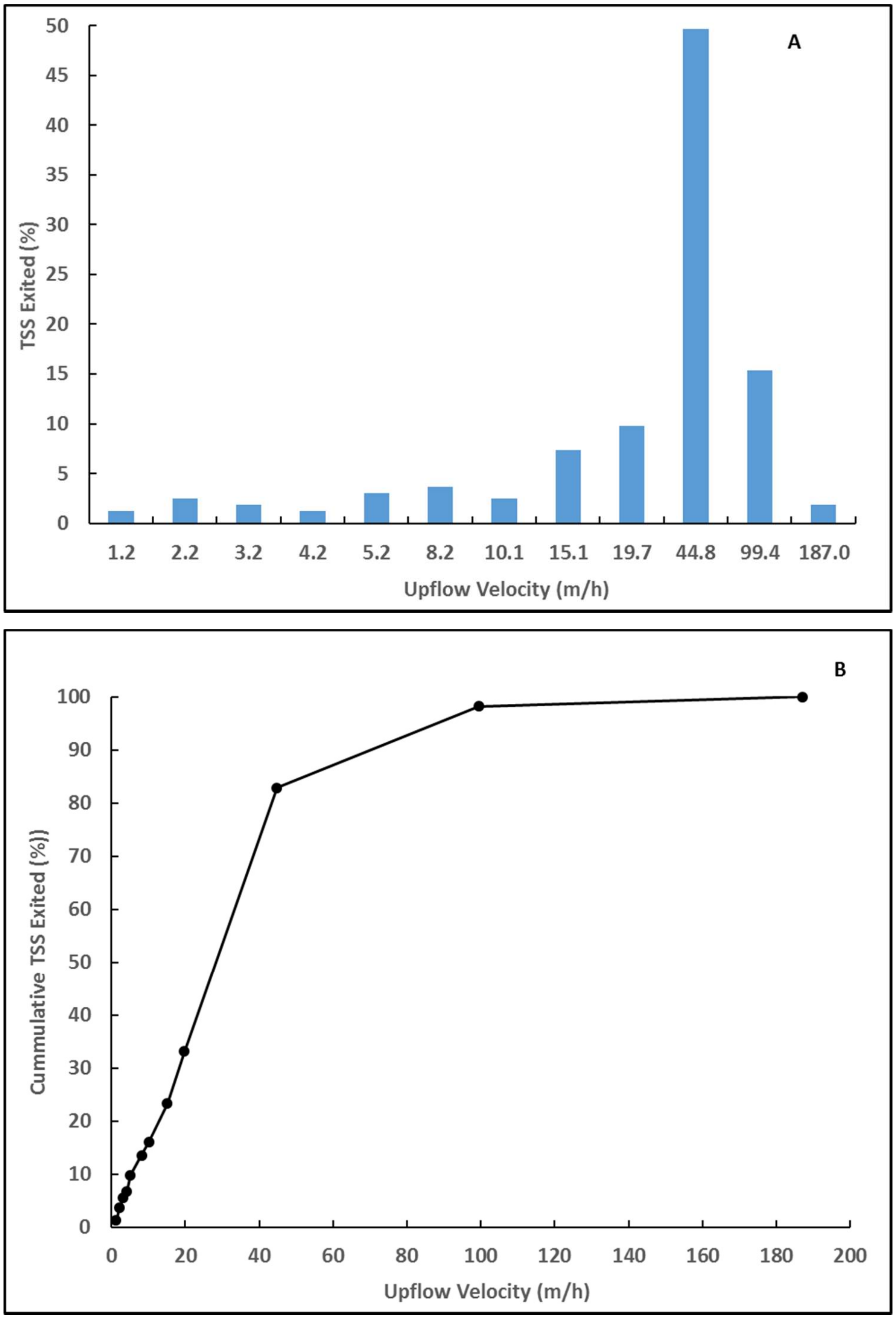


Figure 4-18. The TSS exited in percent (%) (A) and cumulative TSS exited in percent (%) (B) for granular sludge from Saugbrugs (new) as a function of Up-flow velocities.

4.7 Granules size distribution

Diameter measurement of each fraction from settleability experiments was conducted to obtain granules size distribution. The results are shown in the following sections.

4.7.1 Saugbrugs (old) – Sample H

- *Up-flow velocity 1.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.06 – 0.19 mm (0.05 – 0.17 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-19.

Figure 4-19. The granular size distribution of Saugbrugs (old) exited at 1.2 m h^{-1} up-flow velocity with range from 0.06 – 0.19 mm.

- *Up-flow velocity 2.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.09 – 0.38 mm (0.08 – 0.34 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-20.

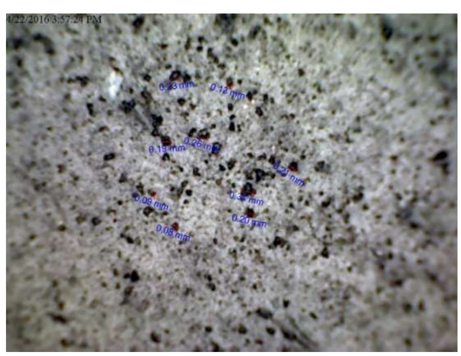


Figure 4-20. The granular size distribution of Saugbrugs (old) exited at 2.2 mh^{-1} up-flow velocity with range from 0.09 – 0.38 mm.

➢ *Up-flow velocity 3.2 m h-1*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.06 – 0.20 mm (0.05 – 0.18 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-21.

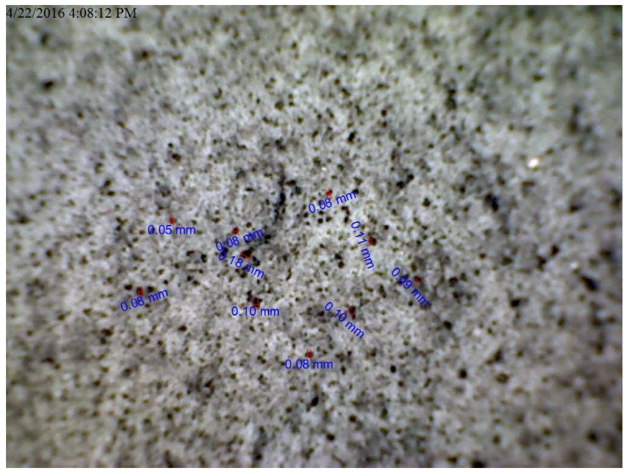


Figure 4-21. The granular size distribution of Saugbrugs (old) exited at 3.2 m h^{-1} up-flow velocity with range from 0.06 – 0.20 mm.

➢ *Up-flow velocity 4.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.10 – 0.25 mm (0.09 – 0.23 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-22.

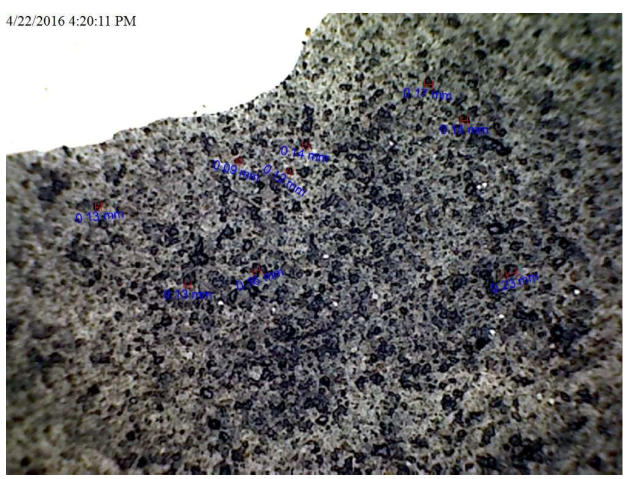


Figure 4-22. The granular size distribution of Saugbrugs (old) exited at 4.2 m h^{-1} up-flow velocity with range from 0.10 – 0.25 mm.

➢ *Up-flow velocity 5.2 m h⁻¹*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.14 – 0.32 mm (0.13 – 0.29 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-23.

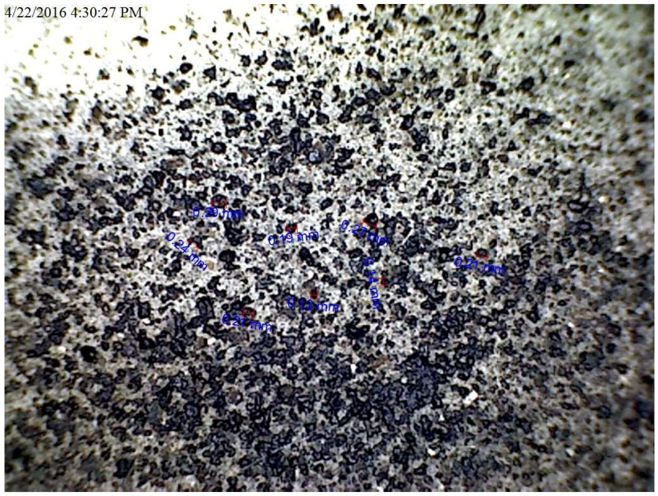


Figure 4-23. The granular size distribution of Saugbrugs (old) exited at 5.2 m h^{-1} up-flow velocity with range from 0.14 – 0.32 mm.

➢ *Up-flow velocity 8.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.22 – 0.46 mm (0.20 – 0.41 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-24.

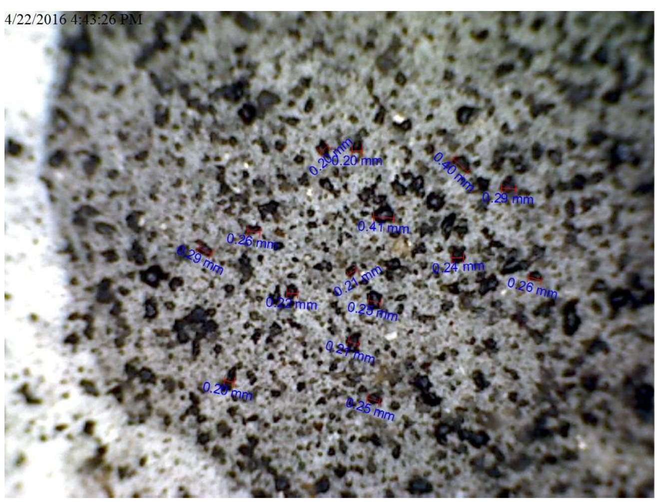


Figure 4-24. The granular size distribution of Saugbrugs (old) exited at 8.2 m h^{-1} up-flow velocity with range from 0.22 – 0.46 mm.

- *Up-flow velocity 10.1 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.34 – 0.74 mm (0.31 – 0.66 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-25.

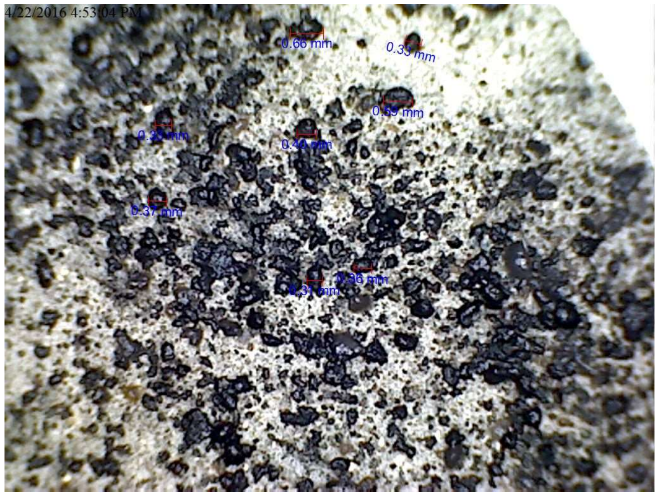


Figure 4-25. The granular size distribution of Saugbrugs (old) exited at 10.1 m h^{-1} up-flow velocity with range from 0.34 – 0.74 mm.

- *Up-flow velocity 15.1 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.31 – 0.64 mm (0.28 – 0.64 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-26.

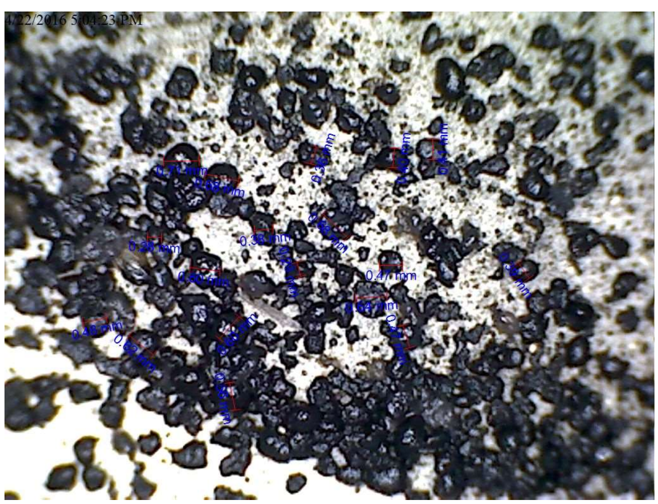


Figure 4-26. The granular size distribution of Saugbrugs (old) exited at 15.1 m h^{-1} up-flow velocity with range from 0.31 – 0.64 mm.

- *Up-flow velocity 19.7 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.38 – 0.77 mm (0.34 – 0.69 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-27.

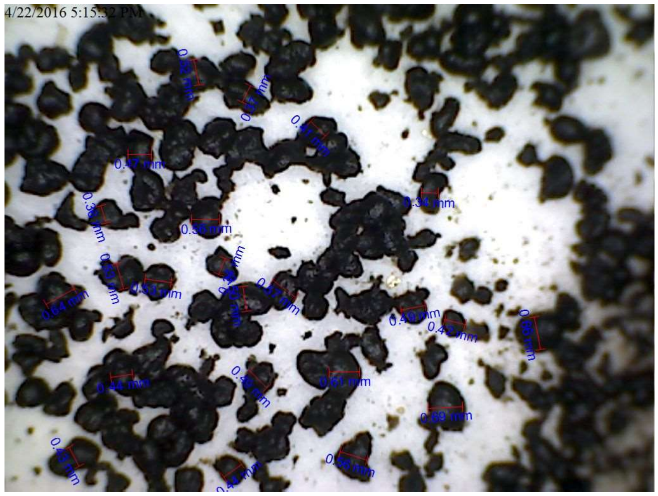


Figure 4-27. The granular size distribution of Saugbrugs (old) exited at 19.7 m h^{-1} up-flow velocity with range from 0.38 – 0.77 mm.

- *Up-flow velocity 44.7 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.46 – 1.20 mm (0.41 – 1.07 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-28.

Figure 4-28. The granular size distribution of Saugbrugs (old) exited at 44.7 m h^{-1} up-flow velocity with range from 0.46 – 1.20 mm.

- *Up-flow velocity 99.4 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.74 – 2.12 mm (0.66 – 1.89 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-29.

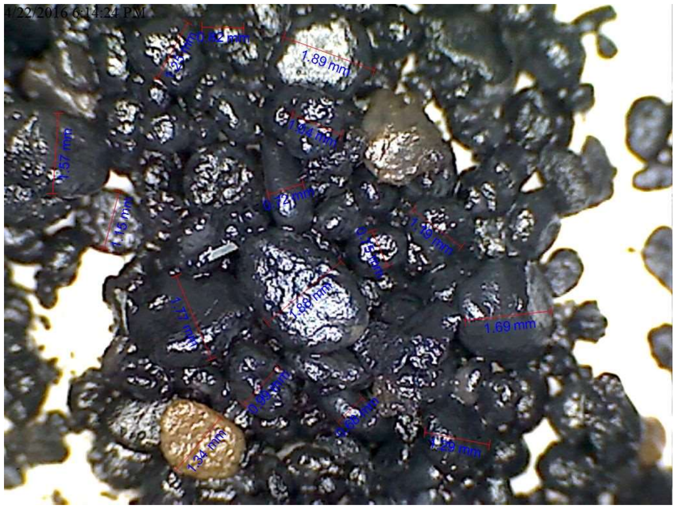


Figure 4-29. The granular size distribution of Saugbrugs (old) exited at 99.4 m h^{-1} up-flow velocity with range from 0.74 – 2.12 mm.

- *Up-flow velocity 187 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.97 – 3.0 mm (0.87 – 2.69 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-30.

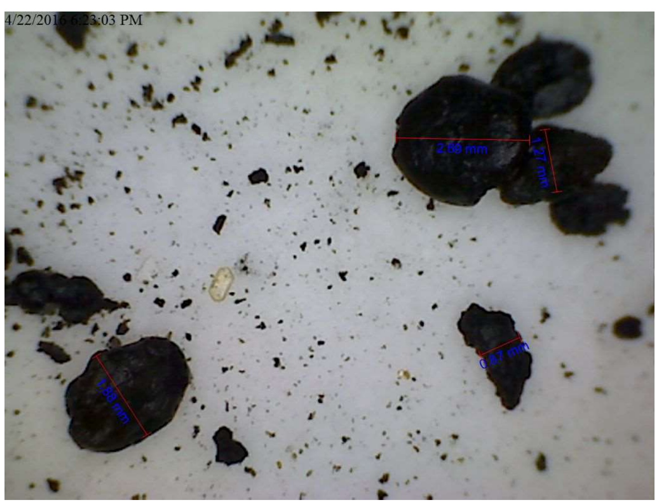


Figure 4-30. The granular size distribution of Saugbrugs (old) exited at 187 m h^{-1} up-flow velocity with range from 0.97 – 3.0 mm.

4.7.2 Saugbrugs (new) – Sample G

➢ *Up-flow velocity 1.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.01 – 0.21 mm (0.01 – 0.19 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-31.

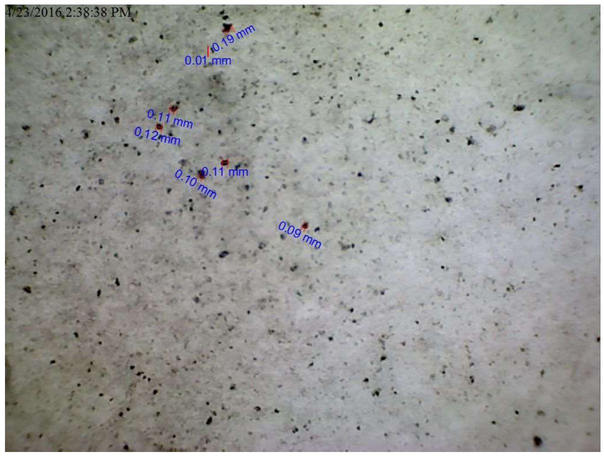


Figure 4-31. The granular size distribution of Saugbrugs (new) exited at 1.2 m h^{-1} up-flow velocity with range from 0.01 – 0.21 mm.

➢ *Up-flow velocity 2.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.13 – 0.35 mm (0.12 – 0.32 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-32.

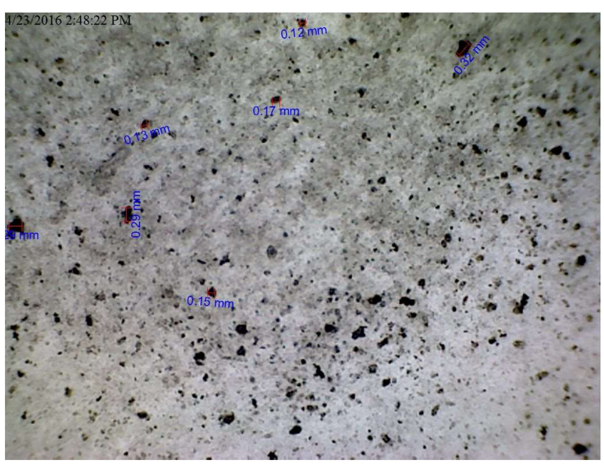


Figure 4-32. The granular size distribution of Saugbrugs (new) exited at 2.2 m h^{-1} up-flow velocity with range from 0.13 – 0.35 mm.

- *Up-flow velocity 3.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.21 – 0.38 mm (0.19 – 0.38 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-33.

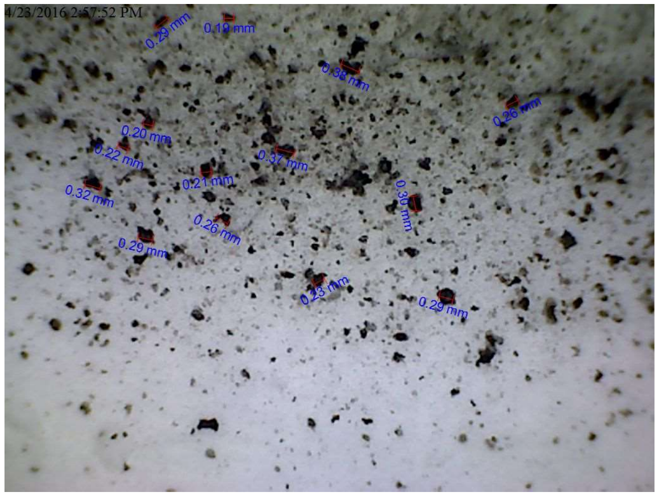


Figure 4-33. The granular size distribution of Saugbrugs (new) exited at 3.2 m h^{-1} up-flow velocity with range from 0.21 – 0.38 mm..

- *Up-flow velocity 4.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.26 – 0.6 mm (0.24 – 0.54 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-34.

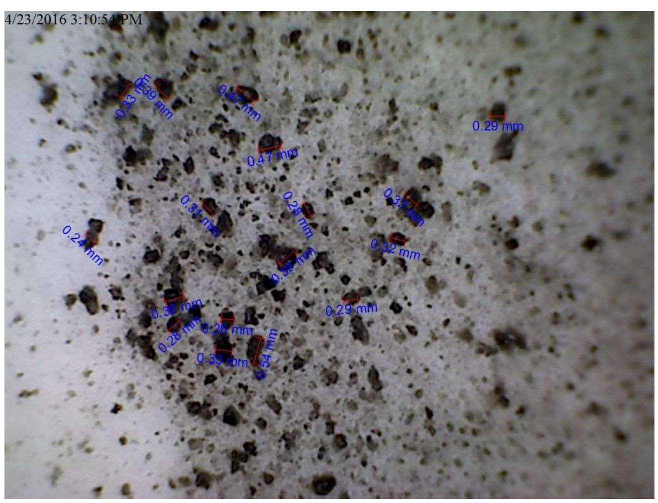


Figure 4-34. The granular size distribution of Saugbrugs (new) exited at 4.2 m h^{-1} up-flow velocity with range from 0.26 – 0.6 mm.

➢ *Up-flow velocity 5.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.19 – 0.38 mm (0.17 – 0.34 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-35.

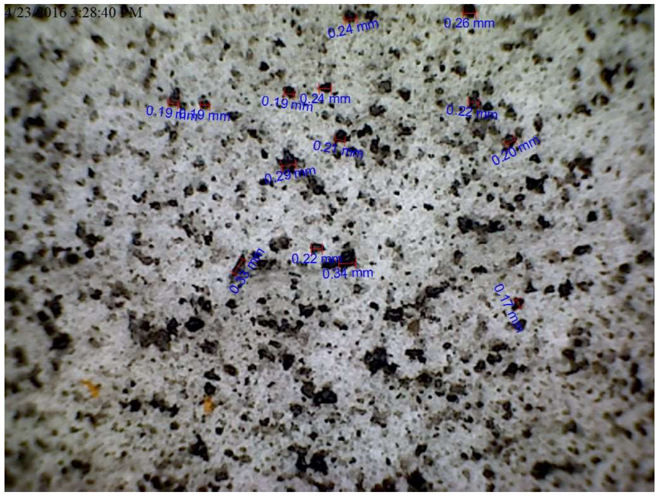


Figure 4-35. The granular size distribution of Saugbrugs (new) exited at 5.2 m h^{-1} up-flow velocity with range from 0.19 – 0.38 mm.

➢ *Up-flow velocity 8.2 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.22 – 0.49 mm (0.20 – 0.44 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-36.

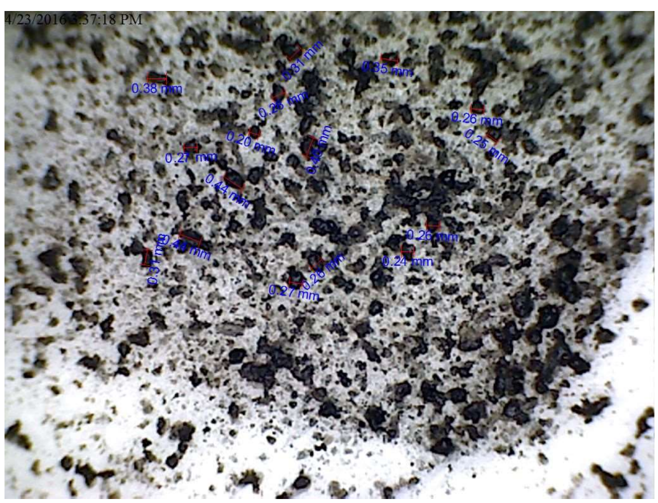


Figure 4-36. The granular size distribution of Saugbrugs (new) exited at 8.2 m h^{-1} up-flow velocity with range from 0.22 – 0.49 mm.

➢ *Up-flow velocity 10.1 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.16 – 0.44 mm (0.15 – 0.40 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-37.

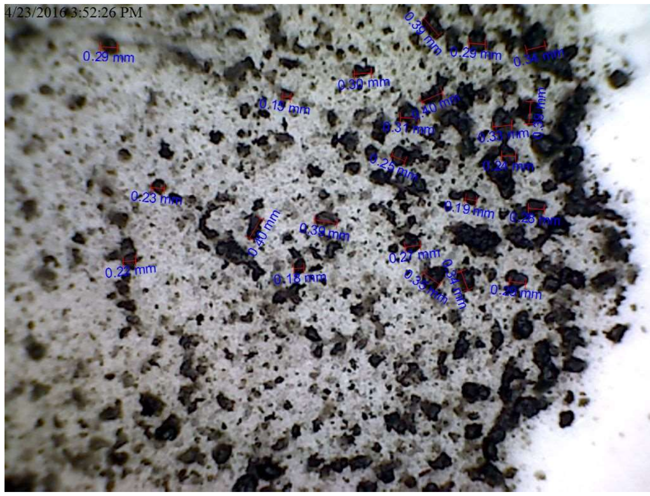


Figure 4-37. The granular size distribution of Saugbrugs (new) exited at 10.1 m h^{-1} up-flow velocity with range from 0.16 – 0.44 mm.

➢ *Up-flow velocity 15.1 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.26 – 0.66 mm (0.24 – 0.59 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-38.

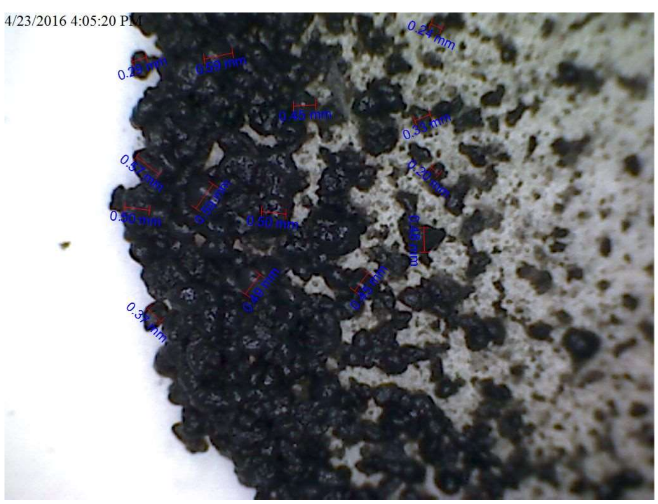


Figure 4-38. The granular size distribution of Saugbrugs (new) exited at 15.1 m h^{-1} up-flow velocity with range from 0.26 – 0.66 mm.

- *Up-flow velocity 19.7 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.55 – 0.79 mm (0.49 – 0.71 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-39.

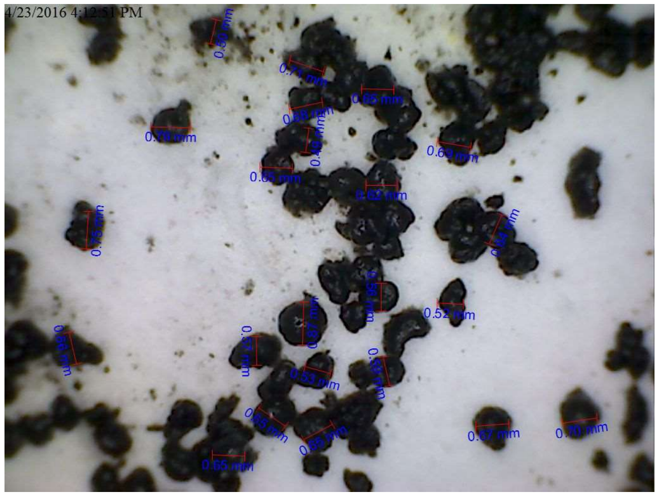


Figure 4-39. The granular size distribution of Saugbrugs (new) exited at 19.7 m h^{-1} up-flow velocity with range from 0.55 – 0.79 mm.

- *Up-flow velocity 44.7 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.79 – 1.48 mm (0.71 – 1.32 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-40.

Figure 4-40. The granular size distribution of Saugbrugs (new) exited at 44.7 m h^{-1} up-flow velocity with range from 0.79 – 1.48 mm.

➢ *Up-flow velocity 99.4 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 0.85 – 1.34 mm (0.76 – 1.20 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-41.

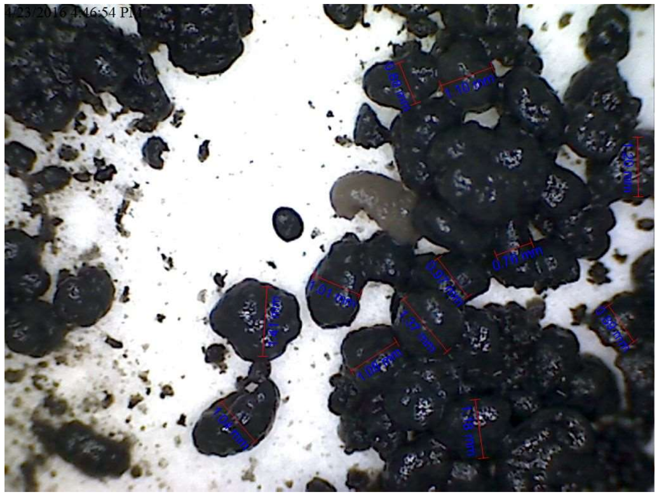


Figure 4-41. The granular size distribution of Saugbrugs (new) exited at 99.4 m h^{-1} up-flow velocity with range from 0.85 – 1.34 mm.

➢ *Up-flow velocity 187 m h^{-1}*

The diameter range of granular sludge which were washed out (exited) from the glass test device are 1.17 – 1.71 mm (1.05 – 1.53 mm before multiplying with correction factor). The measured size distribution is shown in Figure 4-42.

Figure 4-42. The granular size distribution of Saugbrugs (new) exited at 187 m h^{-1} up-flow velocity with range from 1.17 – 1.71 mm.

4.7.3 Summary of Saugbrugs (old and new) granules size distribution

The summary of saugbrugs (old and new) granules size distribution is shown in Table 4-4. The trend shows that higher up-flow velocity leads to bigger diameter of granules which were exited from glass test device for both granules sludge samples (Saugbrugs old and new).

Table 4-4. The summary of Saugbrugs (old and new) granules size distribution according to up-flow velocity.

Up-flow Velocity (m/h)	Size distribution (mm)	
	Saugbrugs (old)	**Saugbrugs (new)**
1.2	0.06 - 0.19	0.01 - 0.21
2.2	0.09 - 0.38	0.13 - 0.35
3.2	0.06 - 0.20	0.21 - 0.38
4.2	0.1 -0.25	0.26 - 0.6
5.2	0.14 - 0.32	0.19 - 0.38
8.2	0.22 - 0.46	0.22 - 0.49
10.1	0.34 - 0.74	0.16 - 0.44
15.1	0.31 - 0.64	0.26 - 0.66
19.7	0.38 - 0.77	0.55 - 0.79
44.7	0.46 - 1.2	0.79 - 1.48
99.4	0.74 - 2.12	0.85 - 1.34
187	0.97 - 3.00	1.17 - 1.71

5 Discussion

5.1 Relation between density and settling velocity

According to Figure 4-1 in chapter 4, the different coffee grit had densities higher than but rather close to the density of granular sludge. In fact, this was one of the main reason that this study has used coffee grits as a physical model to characterize the granular sludge as the availability of adequate and different granular sludge samples were limited.

The relation between density and settling velocity for every samples is shown in Figure 5-1. It can be seen that even though the coffee grit samples had higher densities, but they did not have faster settling velocities compare to real granular sludge (sample D, G and H) which had lower densities than coffee grits.

In order to observe and discuss the relation between density of the different samples and the setting velocity, the coffee grit samples (sample A, B and C) and granular sludge samples (sample D, E, F, G, H, I and J) were separated in this discussion. Provided that coffee grit and granular sludge have different characteristics.

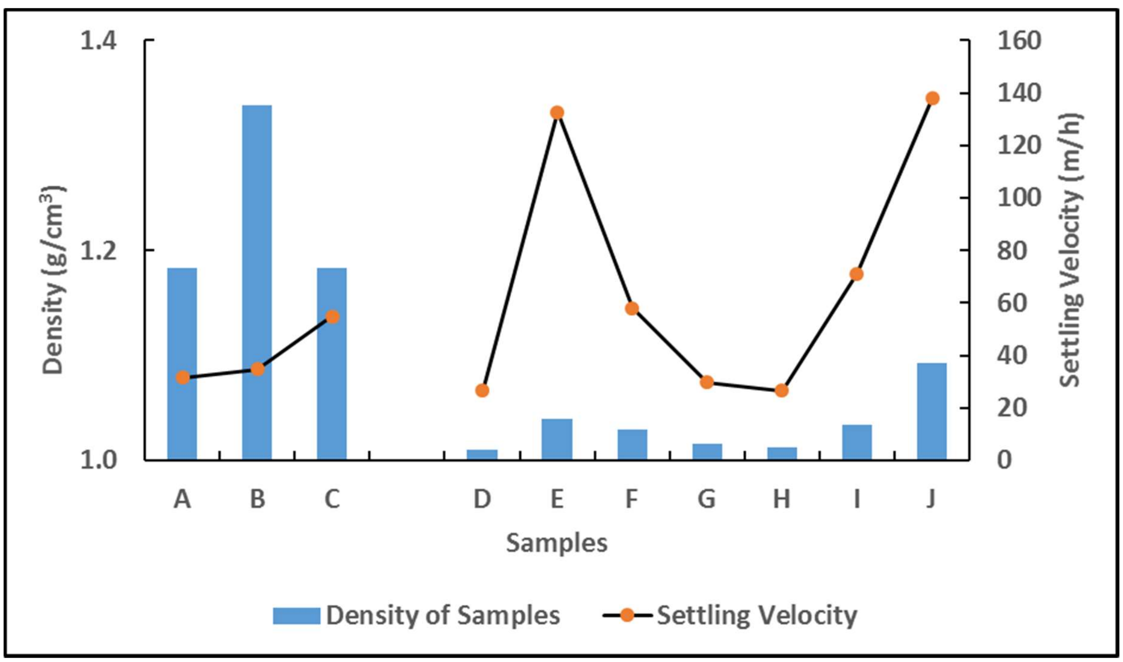


Figure 5-1. Measured density of three coffee grits (sample A-C) and seven granular sludge (sample D-J) along with the settling velocity for the same samples.

5.1.1 Coffee grits

For the coffee grit, the graph of density along with the settling velocity is shown in Figure 5-2.

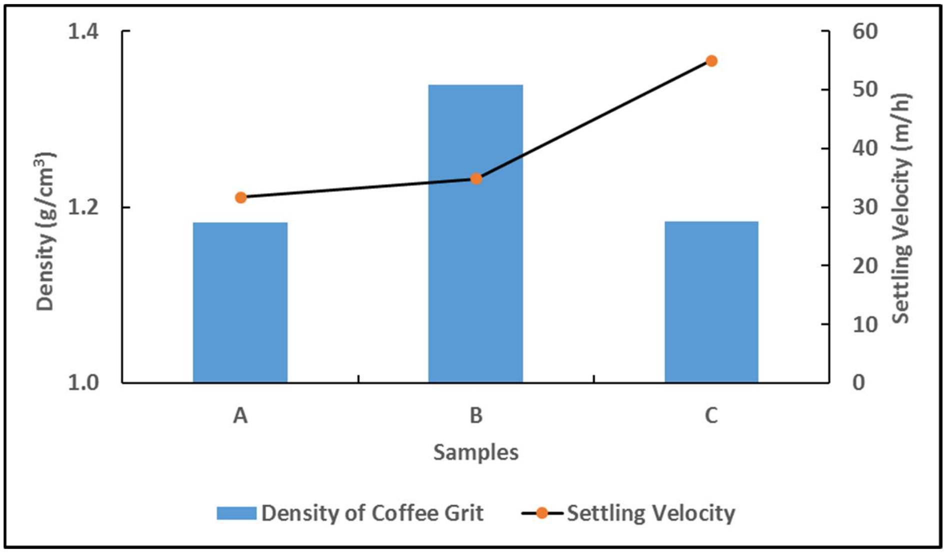


Figure 5-2 The density range of three coffee grits along with the settling velocity.

The study has shown that there was weak correlation between density and settling velocity for all coffee grits tested (Figure 5-3). The observed coefficient of determination (R^2) between density and settling velocity was 0.15.

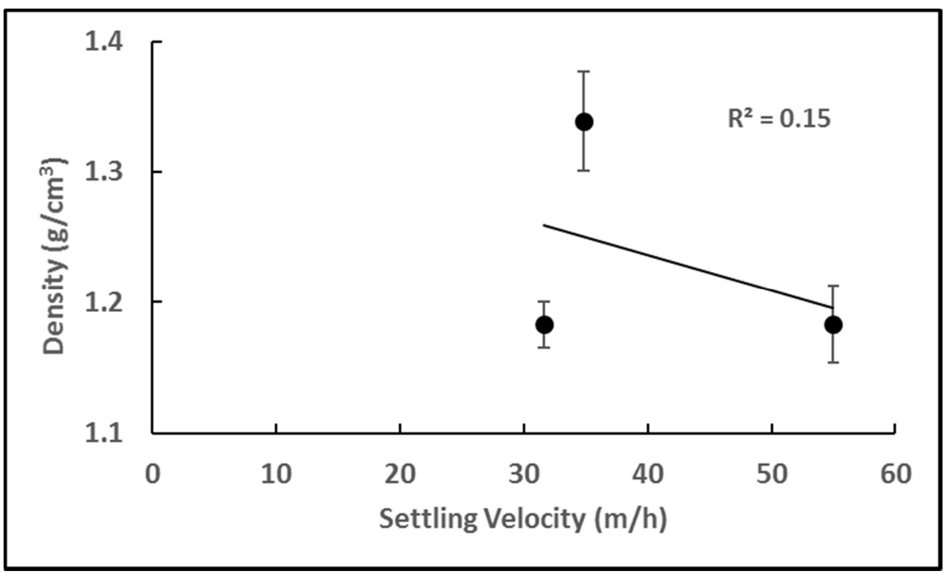


Figure 5-3. Correlation of density with average settling velocity for three coffee grits. The error bar represents the standard error and n=3.

It is known that the shape of coffee grit particles were not sphere and the shape were un-uniform as seen in Figure 4-4 until 4-6. According to Gregory *et al.*(1999)[22], the shape factor (ø) and the size of particle (d) were also the variables to determine the settling velocity (Equation 2-6).

Thus, the un-uniformity of shape and the particle size variation of coffee grits made a weak correlation between density and settling velocity.

5.1.2 Granular sludge

For the granular sludge, the graph of density and its settling velocity is shown in Figure 5-4. The samples are ordered from higher to lower density. Hence, the graph shows that the higher density of granules, the higher average settling velocity and vice versa. Sample J (E-Convert old) had the highest density and settling velocity (1.09 g/cm^3 and 137.8 m/h) while sample D (HyVAB) had the lowest density and settling velocity (1.01 g/cm^3 and 26.6 m/h) among other granular sludge samples.

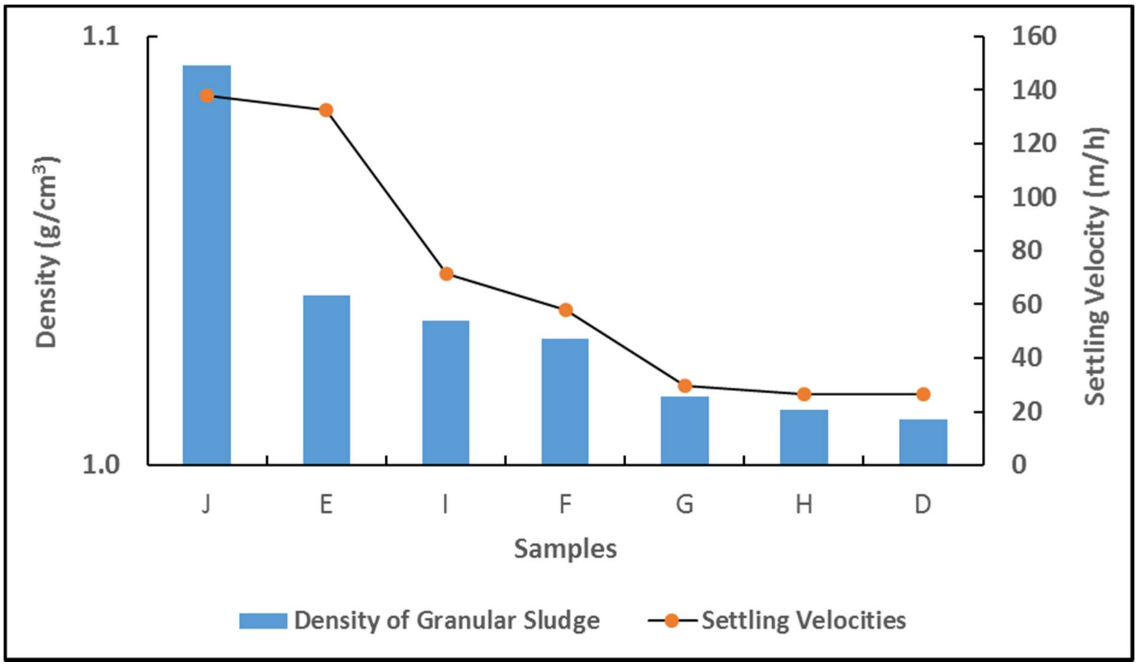


Figure 5-4. The density for seven granular sludge along with the settling velocity.

A strong correlation (R^2 = 0.73) between the granules density (ρ) and the average settling velocity $(\bar{v})$ have been found in the study. The equation 5-1 depicts the correlation and figure 5-5 shows the correlation graph.

$$\rho = 0.0005\bar{v} + 0.9989 \quad [5\text{-}1]$$

This correlation is in accordance with Yu Liu *et al.* (2002)[12] that a higher density leads to a faster settling velocity of sludge.

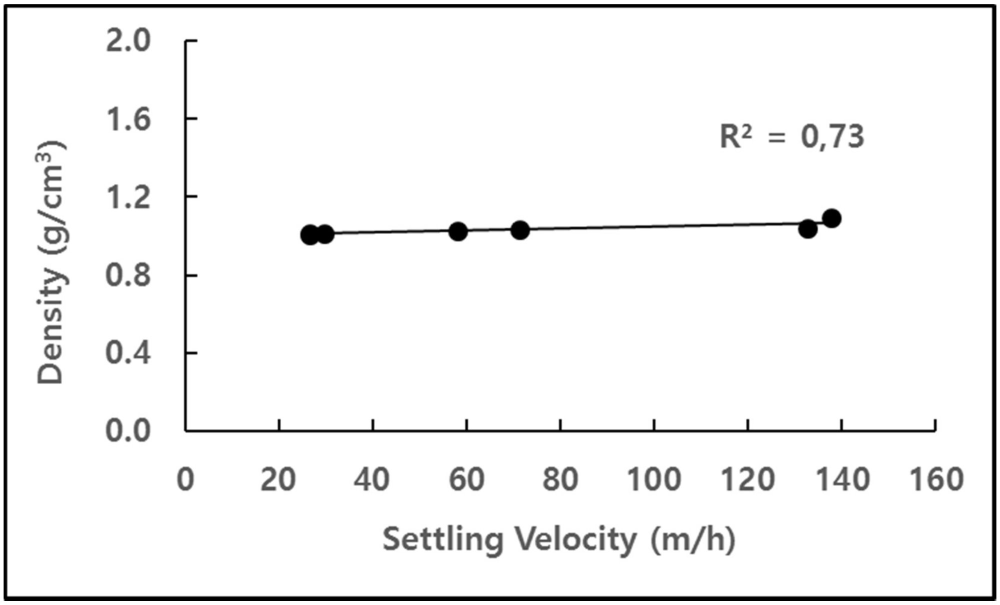


Figure 5-5 Correlation of density with average settling velocity for seven granular sludge. The error bar represents the standard error and n=3.

5.2 Relation between density and VS/TS

The ratio between volatile to total solid (VS/TS) is an indicator of the organic fraction in the sludge solids and it is also a good indicator of its level of digestion. For undigested sludge, VS/TS ratio ranges from 0.75 to 0.80, whereas for digested sludge the range is from 0.60 to 0.65 [29].

According to Table 4-2 on chapter 4 above, coffee grit samples (sample A, B and C) have higher VS/TS value than granular sludge samples (Sample D, E, F, G, H, I and J). Sample A, B and C have volatile to total solid ratio 0.96, 0.98 and 0.98 respectively. It means that over 95% of solids are organic solids. In fact, it obvious that the coffee grits are organic matters and undigested.

For the granular sludge, the range of volatile to total solids ratio is from 0.55 to 0.86. The lower of the ratio means the lower of volatile solid content compared to its total solids. On the other words, the sludge has lower organic solid compare to its total solids. Extracellular polymeric (ECP) substances are known to make up to 70% of the organic matter in sludge. The ECP is considered to be responsible for the sludge's poor dewaterability due to its high water retention capacity [30]. Thus, according to H Saveyn *et al.* (2009) [30], the lower organic content in the sludge leads to good dewaterability of sludge.

Sample E (UASB E-convert) has the better dewaterability according to its volatile to total solid ratio among the other samples followed by sample J, F, I, D, G, H respectively.

The statistical relation between coffee grit density and its VS/TS according to the experiments result has shown a week correlation ($R^2 = 0.49$).

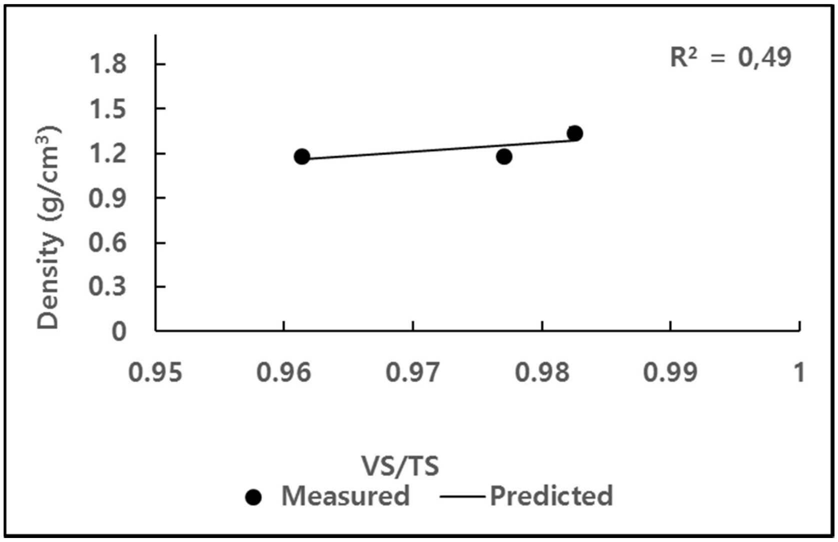


Figure 5-6. The correlation of density with the ratio of VS/TS for coffee grit. The error bar represents the standard error and n = 3.

The same weak correlation ($R^2 = 0.47$) also occurred for density and VS/TS of the granular sludge (Figure 5-7). However, the correlation between the density of coffee grit and granular sludge with its VS/TS were different. Coffee grit had a positive correlation while granular sludge had negative correlation.

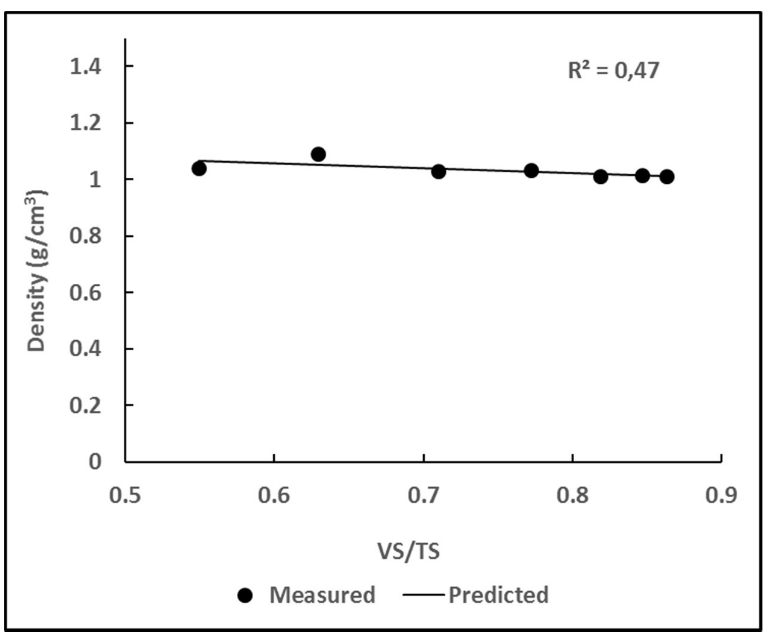


Figure 5-7. The correlation of density with the ratio of VS/TS of granular sludge. The error bar represents the standard error and n=3.

5.3 The size of granules

The diameter measurement results from chapter 4.3 summarized in Table 5-1.

Table 5-1 Summary of diameter range of three coffee grits and seven granular sludge.

Sample ID	**Granular Sludge**	**Diameter range (mm)**
A	Coffee Grit 1	0.3 – 1.06
B	Coffee Grit 2	0.35 – 1.1
C	Coffee Grit 3	0.23 – 1.23
D	HyVAB	0.52 – 2.25
E	UASB E-Convert	0.6 – 2.74
F	EGSB Reactor	0.41 – 2.32
G	Saugbrugs (New)	0.58 – 1.73
H	Saugbrugs (Old)	0.22 – 1.35
I	E-Convert (New)	0.20 – 3.75
J	E-Convert (Old)	0.44 – 3.91

In term of size, it is found out that coffee grit samples (i.e. sample A, B and C) have the same range of size with granular sludge. This shows that it is convincing and a simple alternative to use the coffee grits as physical model to characterize granular sludge. Provided that, the diameter measurement range result for granular sludge were in accordance with the previous studies. According to Dolfing [8], the diameter range of sludge granules varies from 0.14 to 5 mm. Yu Liu (2002) [12] reported that narrow size distribution of granules was preferable and medium-size granules with diameter 1.0 – 2.0 mm was the most attractive in industrial practice. Sample G and H (saugbrugs (new) and saugbrugs (old)) were the narrowest size distribution and closest to coffee grits among real granule samples. Sample H (saugbrugs old) was also had the smallest size of granules (0.22 – 1.35 mm) among other granular sludge samples. The smaller size of granules, the better mass transfer. Thus, sample H (saugbrugs old) had the better mass transfer among other granular sludge samples.

Sample J (E-Convert old) had the highest size of granules (0.44-3.91 mm) and according to Jing Wu *et al.* (2016) [31], positive relationship was obtained between granule size and biogas production rate. The higher granule size, the higher biogas production.

5.4 Settling properties of coffee grit samples

According to the result in chapter 4.6.1, the cumulative solid loss (i.e. TS and TSS exited) for coffee grit 1, 2 and 3 (sample A, B and C) versus up-flow velocity is shown in Figure 5-8.

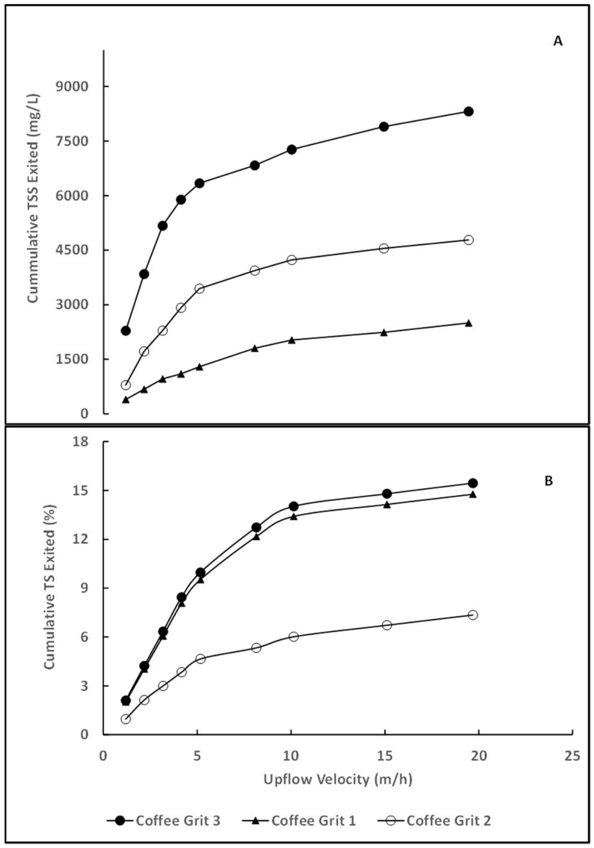


Figure 5-8. Cumulative solid loss plot for coffee grit 1, 2 and 3 (A) TSS exited and (B) percentage TS exited as a function of up-flow velocity.

The maximum up-flow velocity during the experiment for coffee grits (19.68 m/h) was not sufficient to remove the overall solids (coffee grits) in the glass reactor. It can be seen from the graph (Figure 5-8 B) that the cumulative total solid exited from the reactor were only 14.76 percent for coffee grit 1, 7.35 percent for coffee grit 2 and 15.45 percent for coffee grit 3. Thus, the settling properties and size distribution of each samples hardly observed from the result. To insure that, additional higher up-flow velocities were tested in the settleability of granular sludge experiment (chapter 4.6.2).

5.5 Saugbrugs reactor investigation

According to the result data (chapter 4), it was found that the density, average settling velocity and sludge size were almost similar between Saugbrugs (new) and Saugbrugs (old) granular sludge. Even though it was informed that there were parameter changes inside the reactor, the properties of those sludge were almost similar. The summary table for the differences between Saugbrugs (new) and Saugbrugs (old) is shown in Table 5-2.

Table 5-2. Properties of Saugbrugs (old) and Saugbrugs (new) granular sludge.

Sludge	Density (g/cm^3)	Size (mm)	Average settling velocity (m/h)
Saugbrugs (old)	1.013	0.22 – 1.35	26.61
Saugbrugs (new)	1.016	0.58 – 1.73	29.69

The physical properties for those saugbrugs sludge were almost similar, however the values were slightly different. According Quarmby and Forster (1995)[9], the different pH values in the reactor resulted in changes in the physical characteristics of granules, especially the size, density and volatile solid content. It was possible that the pH values in the reactor were change which resulted Saugbrugs (new) and Saugbrugs (old) granular sludge.

Meanwhile, the average settling velocities were related to the densities where higher density leads to higher settling velocity [12].

In terms of organic contents, the VSS/TSS ratio was lower in the saugbrugs (old) than in the saugbrugs (new) sample (Table 4-3), thus the amount of organic compared to fixed solids increased. The opposite trend was seen when measuring VS/TS (Table 4-2).

5.5.1 Settling properties of saugbrugs (new) and saugbrugs (old) (sample G & H)

The result from chapter 4.6.2 shows that the most of sludge were exited from the glass reactor (washed out) at the up-flow velocity 44.75 m/h with about 49 % TSS for sample G (saugbrugs (new)). While sample H (saugbrugs (old)) only about 28 % at the up-flow velocity 44.75 m/h while the most of the sludge (30 %) were exited on 99.43 m/h up-flow velocity (Figure 4-17 A and 4-18 A).

The comparison of those two samples in cumulative percent of TSS exited vs up-flow velocity shows in Figure 5-9.

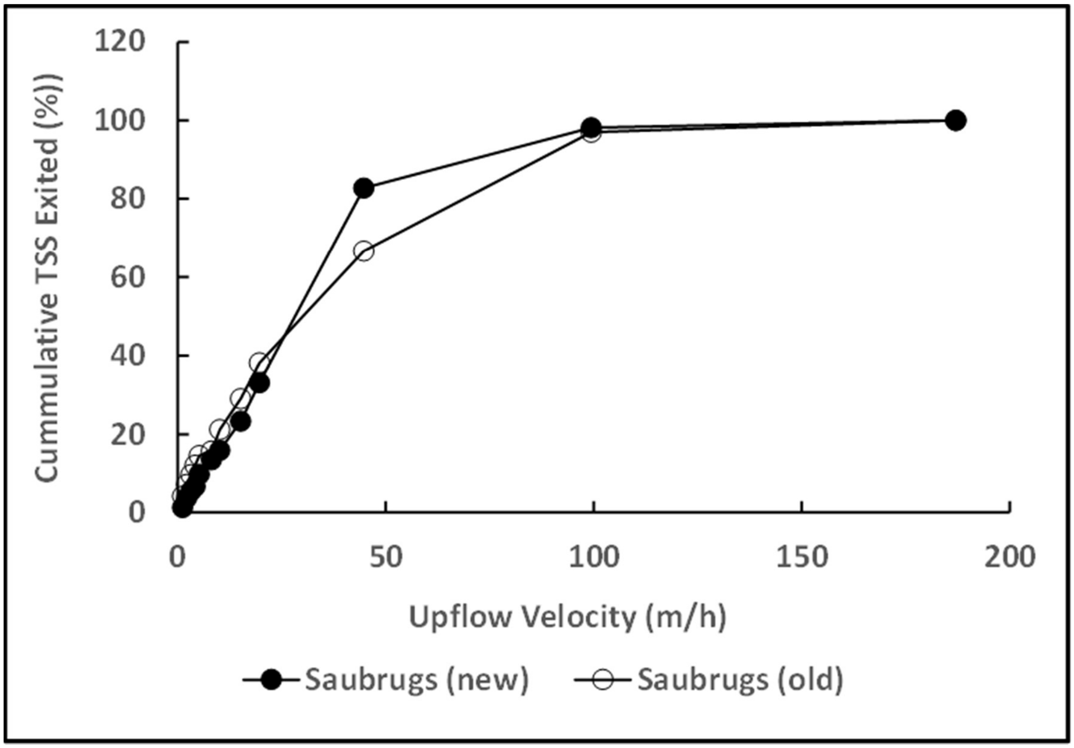


Figure 5-9. The cumulative solid loss as TSS exited for Saugbruggs (new and old) as a function of up-flow velocity.

According to Figure 5-9, it is shown that sample H has lower cumulative TSS exited on the same up-flow velocity (44.75 m/h and 99.43 m/h). However, overall result between those samples were almost similar.

5.5.2 Granular sludge size distribution for saugbrugs (new) and saugbrugs (old) (sample G & H)

The diameter of granules for each up-flow velocity were calculated using the equation [2-3] is shown in Figure 5-10.

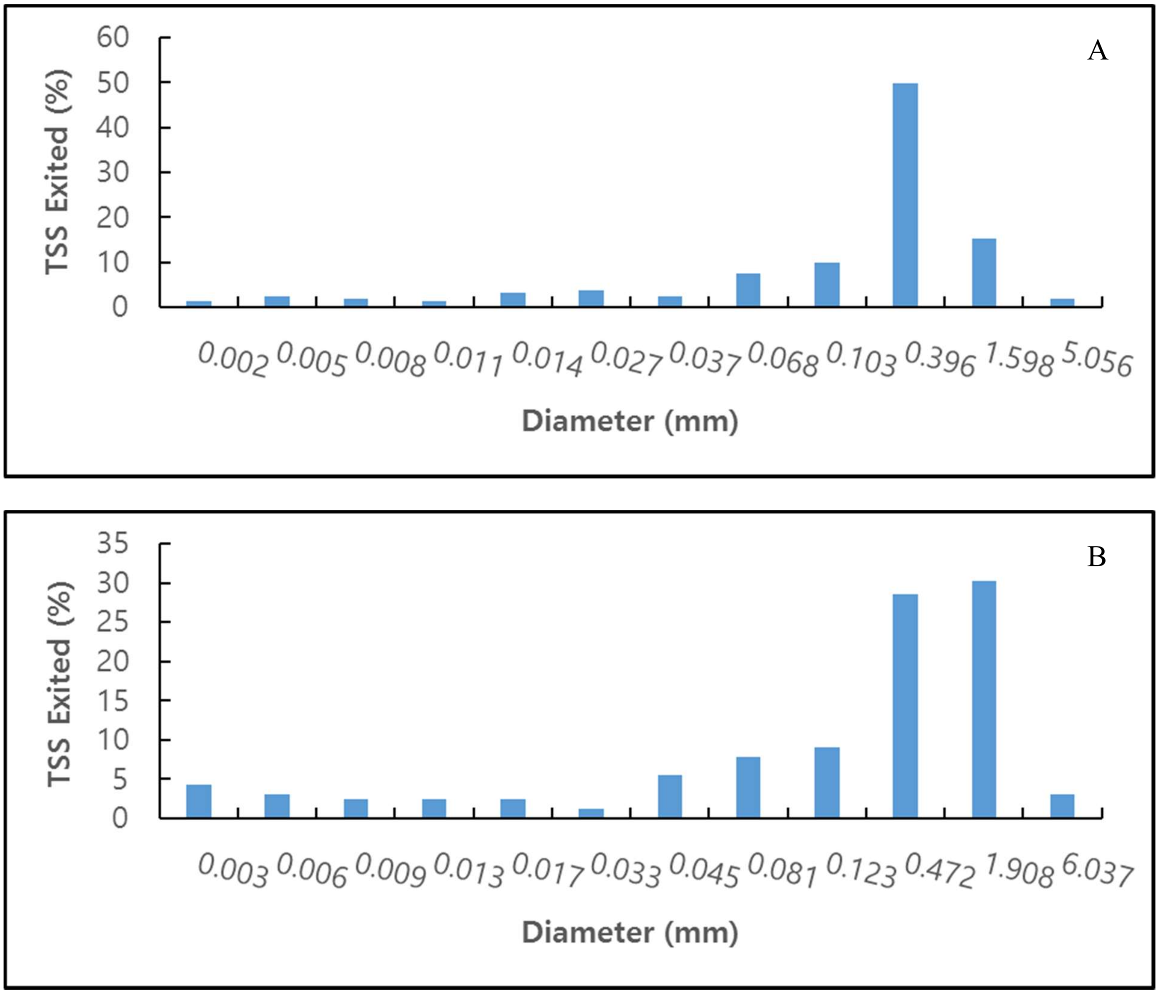


Figure 5-10 Particle size distribution for (A) Saugbrugs–new and (B) Saugbrugs–old.

The diameter size of granules which were exited from the glass reactor on each up-flow velocity were measured and recorded (chapter 4.7). The majority of diameter size for Saugbrugs (new) was 0.396 mm which was about 50 % of total TSS exited and the majority of diameter size for Saugbrugs (old) was 0.472 and 1.908 mm which were about 28 % and 30 % respectively.

There were differences of the result between calculated diameter size and measured diameter size. This was due to the range of selecting particle to be measured was narrow. For example, for up-flow velocity 1.19 m/h on saugbrugs – new (Figure 4.31), shows that the range of particle size is 0.01 – 0.21 mm (value after corrected by correction factor). However, there are many smaller particles which were not measured. The smaller particles size could be around 0.002 mm and it is corresponding to the calculation result. In fact that the exited particles in this up-flow velocity (1.19 m/h) were not complete granular sludge but broken pieces of granular sludge.

There was no correlation (R^2 = 0.01) between the granule diameter and the ratio of VSS/TSS is shown in Figure 5-11.

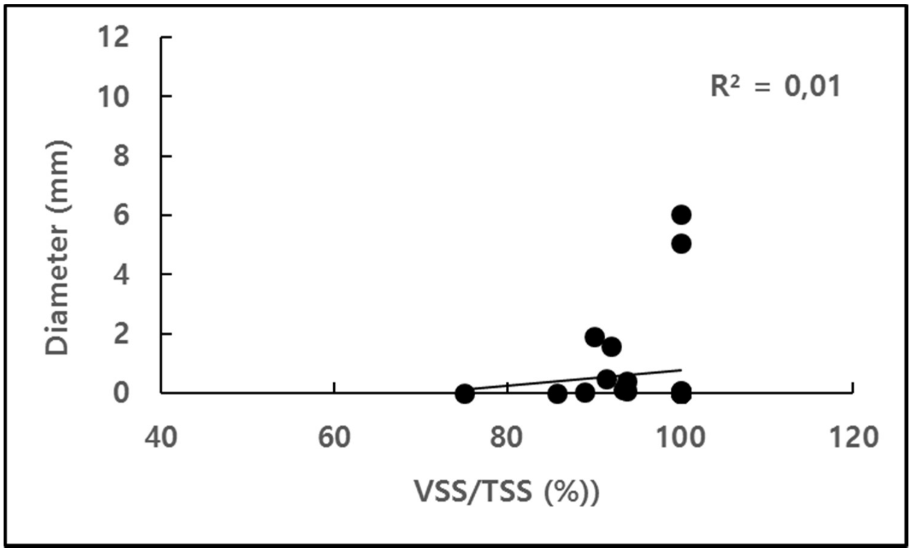


Figure 5-11. The correlation of granule diameter with the ratio of VSS/TSS.

However, A. G. Vlyssides *et al.* (2008)[32] have found that granule diameter and the ratio VSS/TSS has a significant correlation (R^2 = 0.97) by observed about 100 sludge samples. Equation [5-2] depicts the correlation.

$$d = -8x10^{-4} log\left(1 - \frac{VSS/_{TSS}}{97.27}\right) \quad [5\text{-}2]$$

The usage of sludge from various reactors in Vlyssides *et al.*(2008) [32] experiments with 100 sludge samples might be factors why the correlation was different between the previous study and this study. This study was only use sludge from one reactor with several sludge samples.

6 Conclusion

Based on the result from the experiments and the discussion, it can be concluded that;

1. Coffee grit can be used as a physical model of granular sludge because it had similar characteristics especially in terms of settling and particle size. While less so in terms of density but in similar range. The organic content (VS/TS) of coffee grits were the higher (about 97 %) among real granules.
2. The non-uniformity in shape and particle size variation of coffee grit might make a weak correlation (R^2 = 0.15) between density and settling velocity for coffee grit samples.
3. The correlation between density and VS/TS for coffee grits and granular sludge showed the same weak correlation (R^2 = 0.49 and 0.47, respectively).
4. Higher density of granular sludge led to a faster settling velocity and vice versa (R^2 = 0.73). Sample J (E-Convert old) had the highest density and settling velocity (1.09 g/cm^3 and 137.8 m/h) while sample D (HyVAB) had the lowest density and settling velocity (1.01 g/cm^3 and 26.6 m/h) compared to other granular sludge samples.
5. Saugbrugs (new and old) had the smallest size of granules (0.58 – 1.73 mm and 0.22 – 1.35 mm, respectively) which was good for mass transfer. The saugbrugs (new) had 10 % higher settling velocity than the saugbrugs (old). VSS/TSS ratio was lower in the saugbrugs (old) than in the saugbrugs (new) sample, so the amount of organic to fixed solids increased while opposite trend was seen when measuring VS/TS. The properties were a slight changed with time, that may be good for process performance.
6. There were similar properties in the physical characteristics of Saugbrugs granules (old and new) i.e. density and size. Even though, it was informed that the reactor parameters were slightly changed.
7. Sample J (E-Convert old) had the highest size of granules (0.44 - 3.91 mm) and sample E (UASB – Econvert) had the lowest organic content which can be seen from its volatile to total solid ratio (0.55).

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Appendices

Appendix 1: Project description.

Appendix 2: Manual and quick start guides VMS-001 USB microscope.

Appendix 3: The detail value of density measurement.

Appendix 4: The detail result of total solid (TS) and volatile solid (VS) measurement.

Appendix 5: The detail result of total suspended solid (TSS) and volatile suspended solid (VSS) for Saugbrugs granular sludge.

Appendix 6: The detail result of totals suspended solid (TSS) and total solid (TS) for coffee grit samples.

Appendix 1

Telemark University College

Faculty of Technology

FMH606 Master's Thesis

Title: Investigation of sludge in anaerobic sludge bed bioreactors

TUC supervisors: Rune Bakke and Eshetu Janka Wakjera

External partner: -

Task description: The master thesis project will include theoretical and experimental evaluation of sludge from various up-flow anaerobic sludge bed reactors (UASB) to investigate variations in sludge characteristics. Experimental work, including sampling and analysis of samples, largely come from full and pilot scale plants operated by others. Coffee grits are used as physical model to characterize granular sludge and to test experimental methods for such.

Task background: Anaerobic digestion, AD, is a method where micro-organisms mineralize organic matter, generating biogas. UASB reactors are used to obtain high efficiency AD and we test this principle for various applications. Sludge retention time (SRT) is the determining factor for the process efficiency and this depends on sludge characteristics. We (including our connections in the industry) observe variations in sludge quality and therefore want to learn more about how to maintain adequate sludge quality and avoid problems.

Student category:

EET or PT student.

Practical arrangements:

Work will mainly be carried out at TUC.

Signatures:

Student (date and signature): 13 APRIL 2016

Supervisor (date and signature): 13.4.16

Adress: Kjølnes ring 56, NO-3918 Porsgrunn, Norway. **Phone:** 35 57 50 00. **Fax:** 35 55 75 47.

Appendix 2

User instructions

Introduction

Thank you for your choice of our product - it is a high-tech while easy to use Digital Microscope. With this unit you will see a unique and “bigger” world.

It’s easy to zoom in on stamps, coins, paper currency, plants, insects, rocks and minerals, and so much more.

We recommend reading this manual first to get the best out of this unit.

Computer System Requirements:

- Windows 2000/XP/VISTA/WIN7&Mac
- P4 1.8 or above
- RAM: 256M
- Video Memory: 32M
- USB port: 2.0
- CD-ROM Drive

Technical Specifications

Image sensor	2 Mega Pixels (interpolated to 5M)
Still capture resolution	2560x2048 (5M), 2000x1600, 1600x1280 (2M), 1280x1024, 1024x960, 1024x768, 800x600, 640x480, 352x288, 320x240, 160x120
Video capture resolution	2560x2048 (5M), 2000x1600, 1600x1280 (2M), 1280x1024, 1024x960, 1024x768, 800x600, 640x480, 352x288, 320x240, 160x120
Focus Range	Manual focus from 10mm to 500mm
Frame Rate	Max 30f/s under 600 Lus Brightness
Magnification Ratio	20x to 200x
Video format	AVI
Photo format	JPEG or BMP
Light source	8 LED (adjustable by control wheel)
PC interface	USB2.0
Power source	5V DC from USB port
Operation system	Windows2000/XP/Vista/Win7/ Mac
OSD language	English, German, Spanish, Korean, French, Russian

Bundle software	MicroCapture with measurement & calibration function
Size	110mm (L) x 33mm (R)

- **Install the software**

Connecting the Microscope to Computer!! It is must to connect the Microscope to Computer before software installation.

Insert the driver CD into CD-ROM Drive and this will automatically display the following interface:

1. Install the driver by clicking **install *Microscope Driver***
   The Install Shield Wizard will walk you through the whole process. Click on the "***Next***" button to continue.

2. Install the MicroCapture software
   Click ***MicroCapture software*** and then reboot the system when asked.

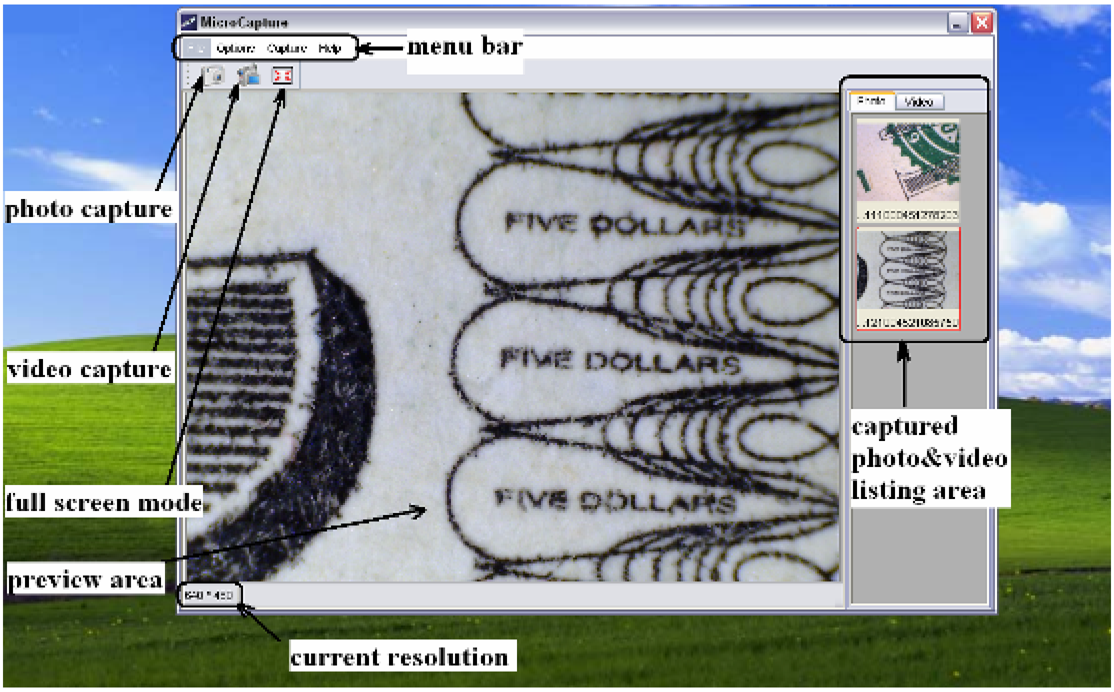
3. You can also browse the User's manual in PDF format and the CD contents by choosing the corresponding menus.

A Quick Look at the Digital Microscope

1/ Remove protective lens cap from microscope before use.
2/ Use the FOCUS WHEEL to adjust focus on the subject.
3/ The SNAPSHOT BUTTON enables user to capture snapshots by hardware; photo capture by software is discussed later on in this manual.
4/ Light control wheel enables you to adjust the LED light brightness

- **Start Microscope**

Connect your Microscope to your PC USB port, start the software by clicking the  icon generated on the desktop after installation and you will see the following screen pop up.

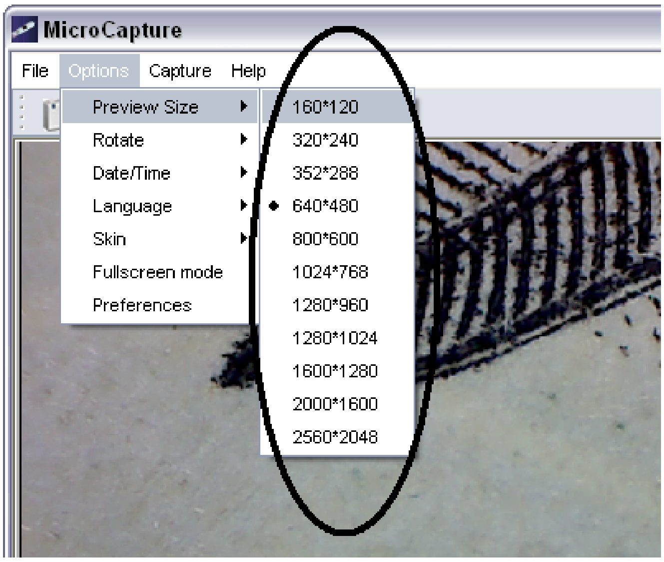


1. When the Microscope is disconnected from your PC USB port, the screen will display "***No Device detected, please connect your Microscope directly to your PC USB port***."

> No Device detected, please connect your Microscope directly to your PC USB port.

- **Change preview size**

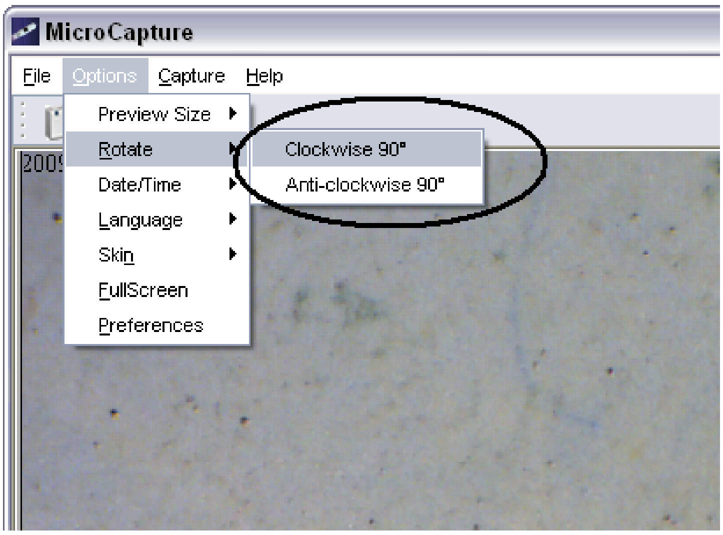
  You can change the preview size by the following operation:



Note: The size of the photo taken is equivalent to the preview size selected in the Options menu/Preview Size.

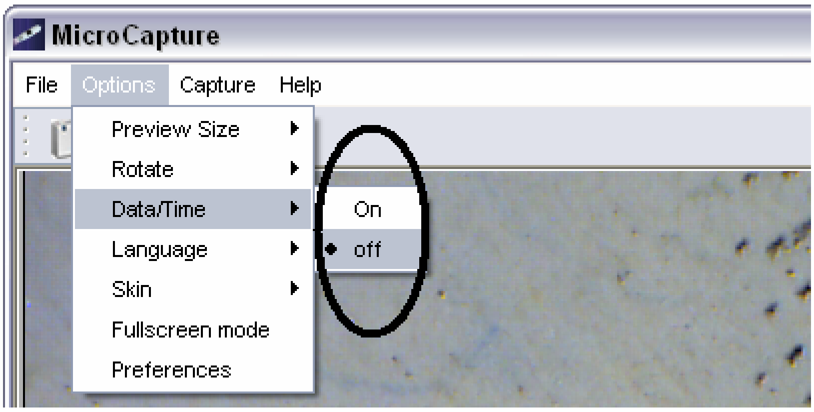
- Rotate the output image angle

  You can rotate the output image clockwise and counter-clockwise.



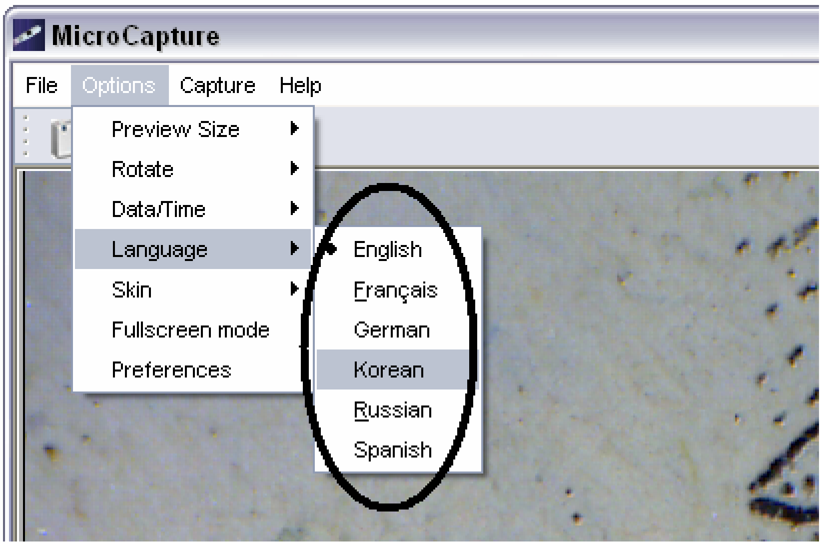
- **Date/Time**

  You can display or turn off Date/Time by the following operation:



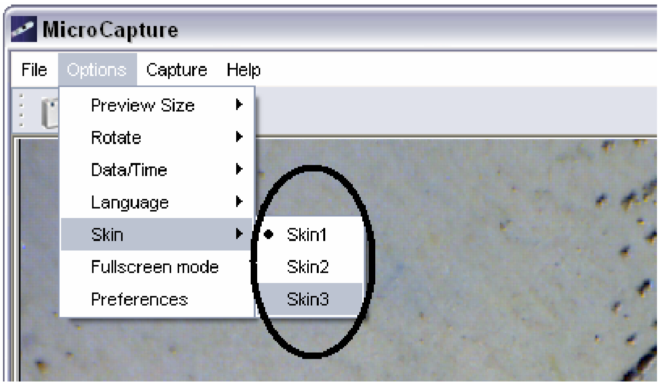
- **Language**

  You can choose On Screen Display language by the following operation:



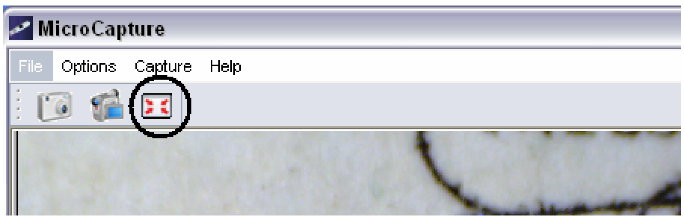
- **Skin**

  You can choose to change the appearance of your MicroCapture screen by the following operation:

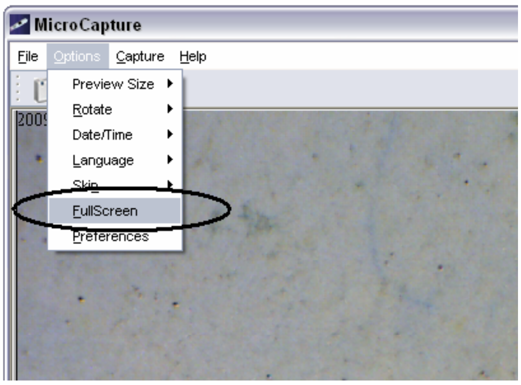


- **Full screen**

1. You can enter & quit full screen mode by:
   1) Double-clicking the preview area.
   2) Clicking the full screen icon:

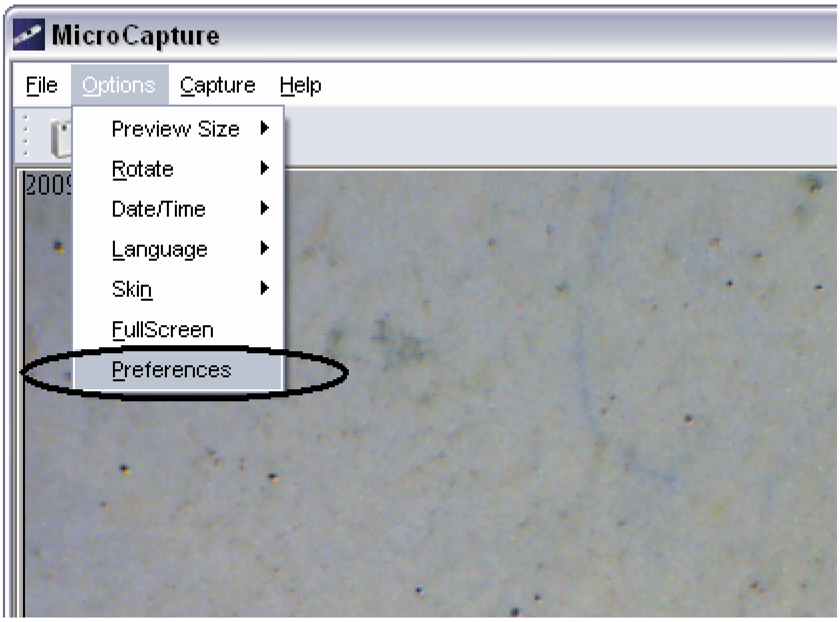


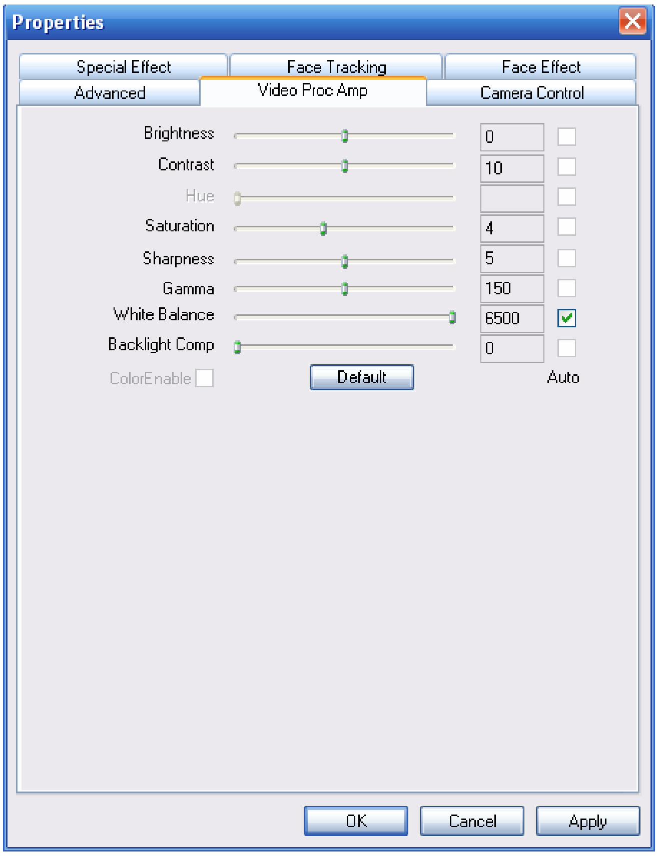
   3) Choose ***Full screen mode*** from menu.



When in full screen mode, click on the Full screen icon to turn off and restore toolbars and menus.

- **Preferences**





Major operations under preferences include Brightness, Contrast, Saturation, white balance etc.

- **Capture**

1. Photo capture

You can take photos by either of the following ways:

1) Click the camera button 

2) Choose ***Capture*** and then click ***Photo***

3) By pressing F11

Captured photos are saved automatically and image thumbnails will be available on the right side of the MicroCapture screen for further editing. For editing photo, please refer to later operations.

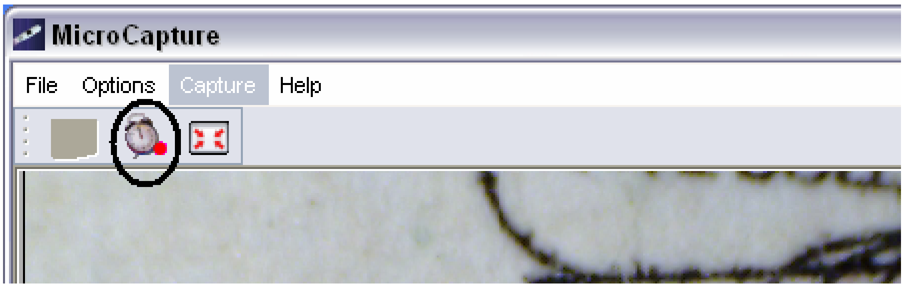
2. Video capture

You can record video by either of the following two ways:

1) Click the video camera button 

2) Choose from the menu bar ***Capture*** and then click ***Video***

When recording, there is a red dot flashing on the video camera button.



Video is saved in AVI format.

Stop capture:

1) Click the flashing video camera button

2) Choose ***Capture*** and then click ***Stop capturing***

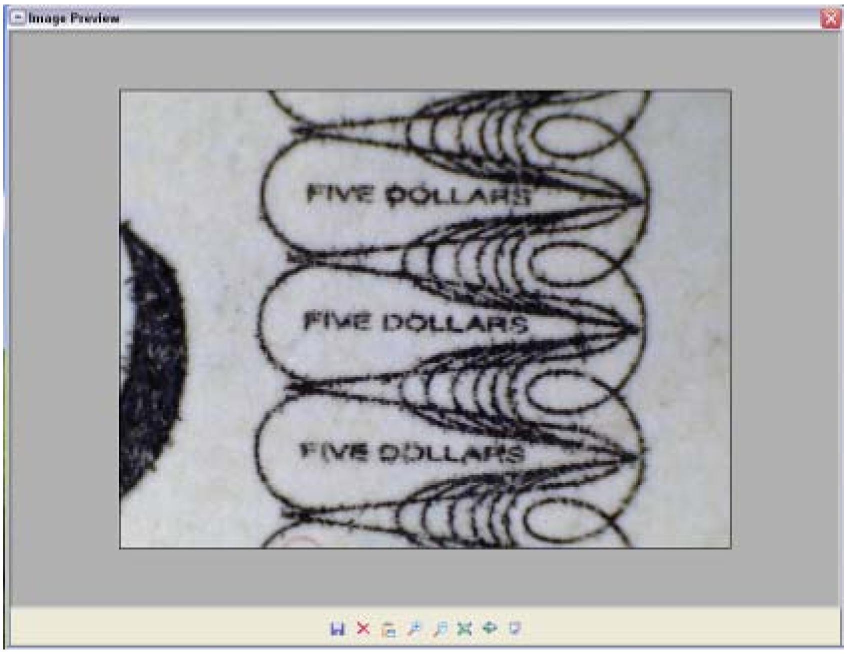
Note: Please note the best pixels for video capturing is 640x480.

- **Edit photos**

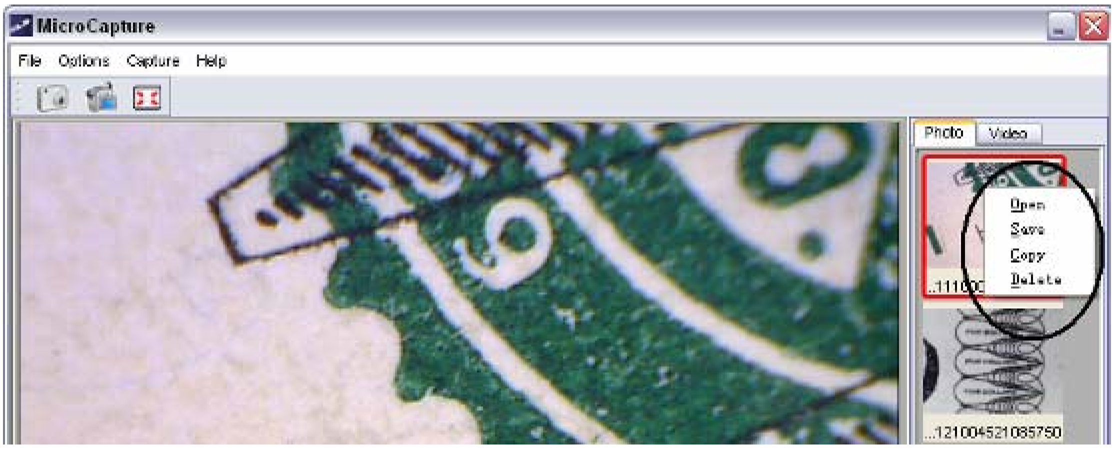
1. Preview photos

1) Clicking on an image thumbnail will display the image selected on the preview area, with its size displayed on the left-bottom corner.

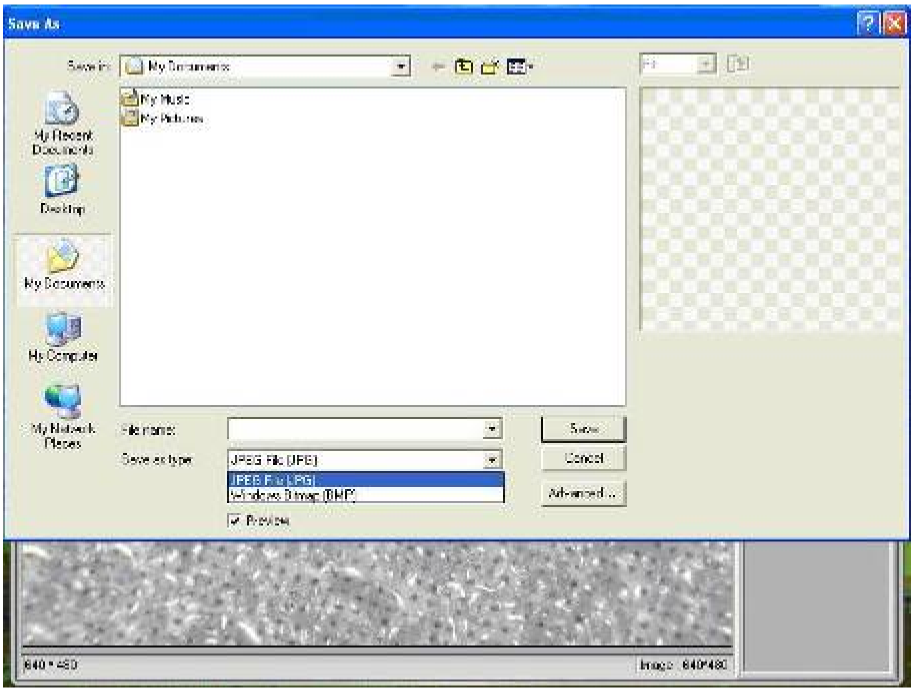
2) You can double click the image thumbnail and an independent preview box will pop up as shown below:



2. Save photos



You can save photo by right clicking on the thumbnail and then choose ***Save***.



The file can be saved in either jpeg or bmp. The jpeg size in which the photo is saved is the maximum allowed for jpeg. You can choose to decrease the size by adjusting quality. Click the Advanced button to view and select jpeg save options.

3. Delete photos

By right clicking and then choosing ***Delete***, you can delete the selected photo

Or, at the independent preview box you can choose delete icon to delete the previewed photo.

4. Copy photos

Right click on the thumbnail and then choose ***Copy***.

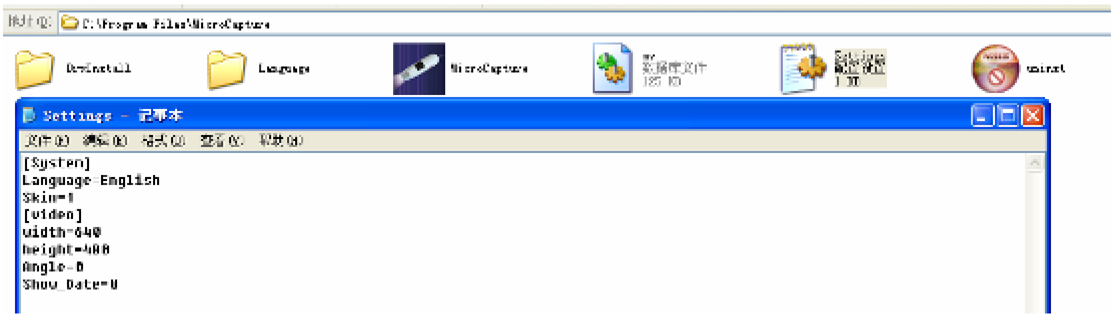
- **Edit videos**

  You can right click the video small icon listed on the right column and then choose ***Play***, ***Copy***, and ***Delete*** etc.

- **Quit MicroCapture**

- **Tips:**

You can preset the preview window size, output image angle, language etc by editing an .ini file named settings at ***C:\Programs\MicroCapture***.

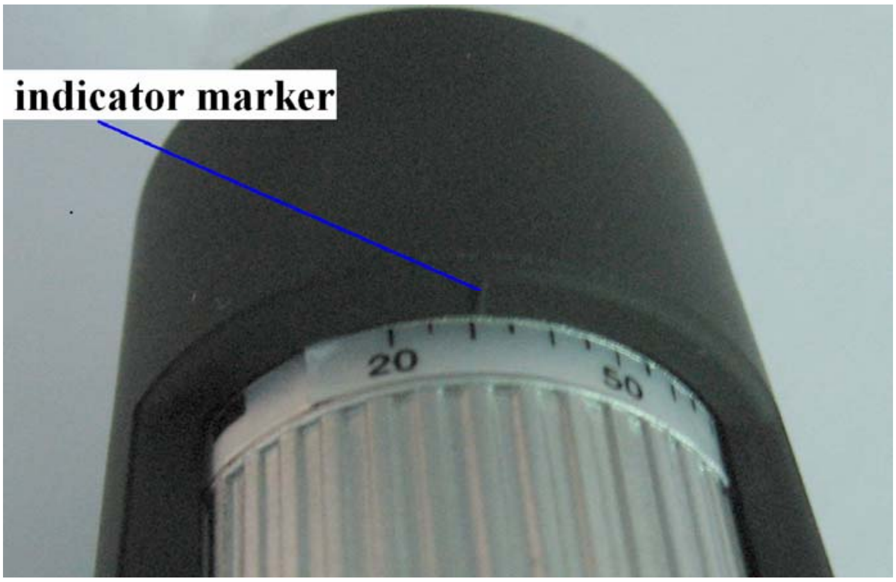


How to use measurement & calibration function

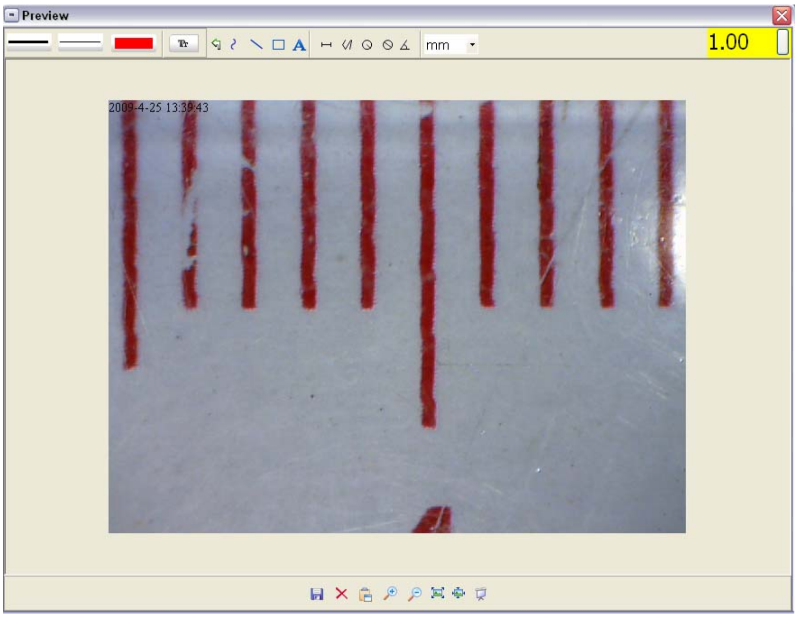
1 Point the microscope onto a target object e.g. a ruler; rotate the focus wheel to get a clear focus.

2 When the focus at the clearest point, take a snapshot

3 Watch the calibration at the lower-end of the focus wheel; note down the magnification value that corresponds to the indicator marker on the microscope body as shown below. That value is the magnification at which the focus was set and the image taken. (This is very important, since only with the magnification ratio noted down can the object size be worked out at later steps!!)



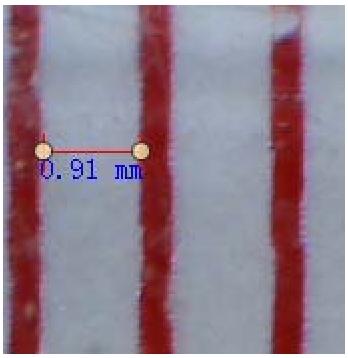
4 Open the captured photo double clicking on the thumbnail. A preview window will open



5 Input the magnification ratio noted down into the box indicated at the top right corner of the preview window. (Please note it is necessary to input the magnification ratio noted down on step3; otherwise the measurement is meaningless.)

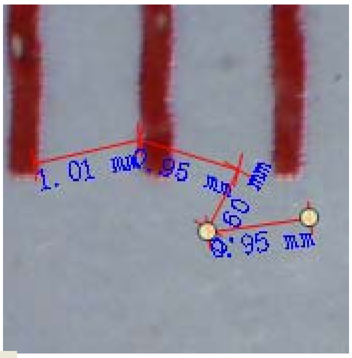
6 Now you can measure the size of the whole or part of the object you have taken using the available options. Click on the icons on top of the window. Following are the options:

1) Direct line: click , left-click mouse to choose a start point and drag mouse to an end point, Notice that the measurement is displayed. Release the mouse when done.

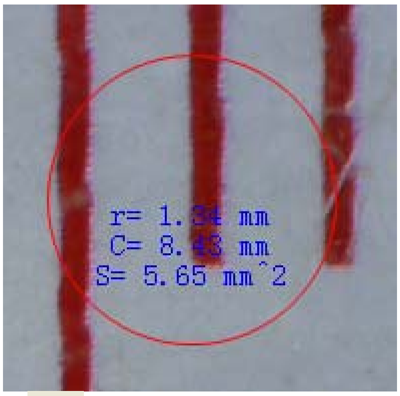


2) Multi-line: click , left-click mouse to choose a start point and drag to an end point. Notice that the measurements are displayed as you go along. Release mouse when done. You can continue measuring from

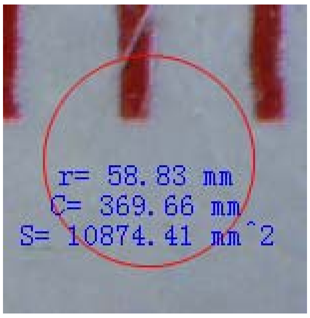
the previous end point to a next point and so on.

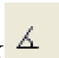


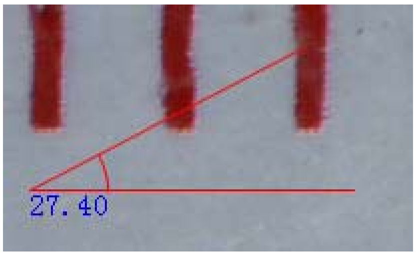
3) Circle-radius: click , left-click to choose a start point for a circle; draw the circle to an end point, release the mouse, and the radius of the circle will be displayed.



4) Circle-diameter: click , left-clicking to choose a start point for a circle; draw the circle to an end point, release the mouse, and the radius of the circle will be displayed.

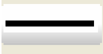
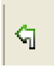


5) Angle: click , left-click to choose a start point for an angle, draw the line to another point and then release the mouse to create one line for an angle. Move your mouse to bring out another line of the angle, left-click when the angle is ok. The angle value will then display.



6) Unit: click , you can choose the unit at which the measured values display. Units available include: pixels / inches / km / mt / mm / cm / micro

7 Other operations you can carry out on the photo taken include:

1) : make notes on the photo taken
2) : select font, font style, font size etc
3) : draw line, box etc on the photo
4) : line color
5) : line thickness
6) : line type
7) : undo operation

Note:

1. The magnification ratio you are allowed to input is from 20 to 200. Do not input any value beyond that.
2. The measurement value worked out by the software is only for reference; it may not be 100% correct.
3. The measurement function is only available on Windows Operating System.

Instructions for Mac software

Part I How to Install the Software

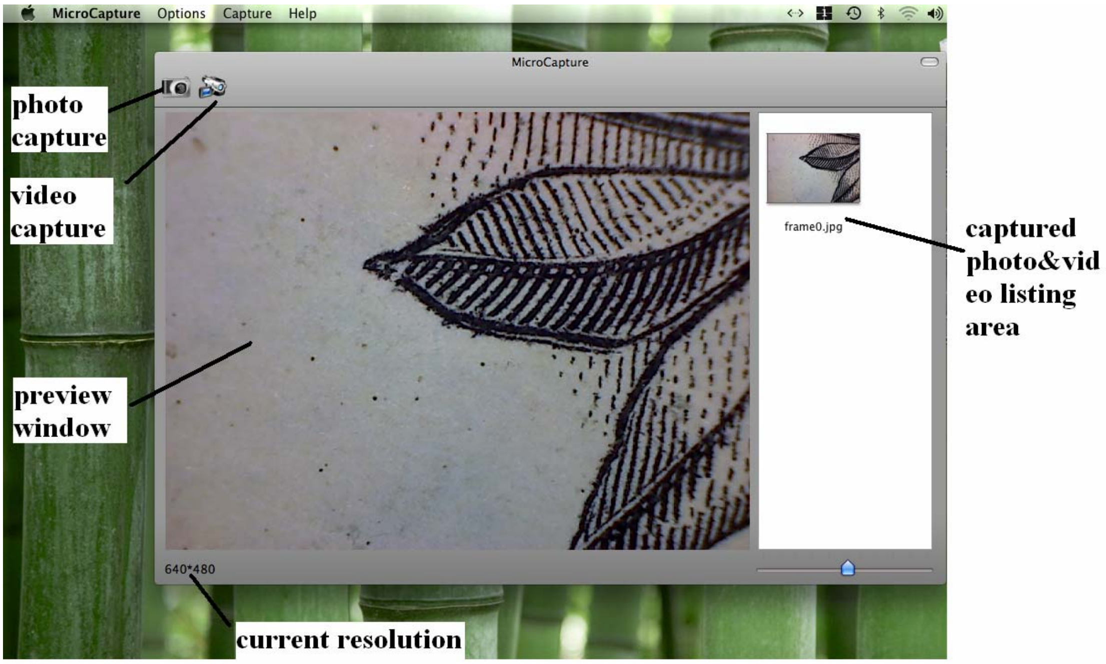
Open ***mac*** folder from the disc and copy ***MicroCapture*** onto your desktop for daily use.

Part II How to use MicroCapture

1. Plug your Microscope into PC USB port.
2. Double click MicroCapture icon to open the MicroCapture window. The microscope is now ready to use.

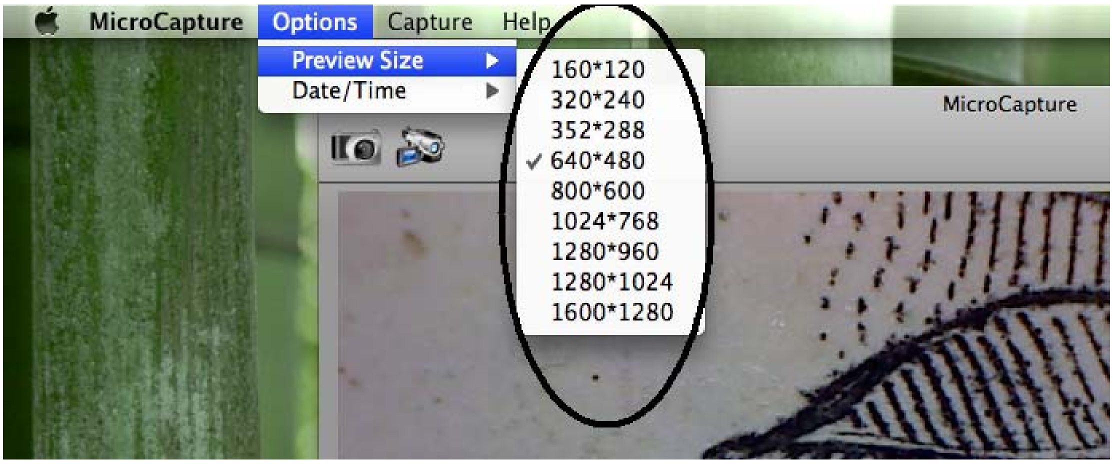
3. Preview

At the central window, you can preview the magnified subject.



4. Change preview resolution

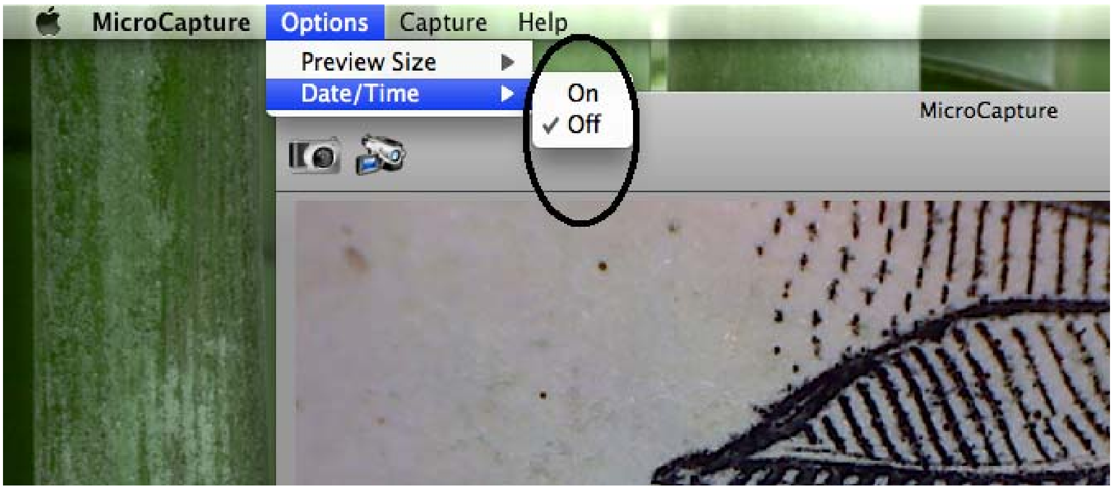
From ***Options***, you can choose the preview resolution. The current resolution will be displayed at the left bottom corner of the preview window.



Please note that the preview window size always remains at 640x480 but the current resolution will show at the left bottom corner.

5. Date/Time

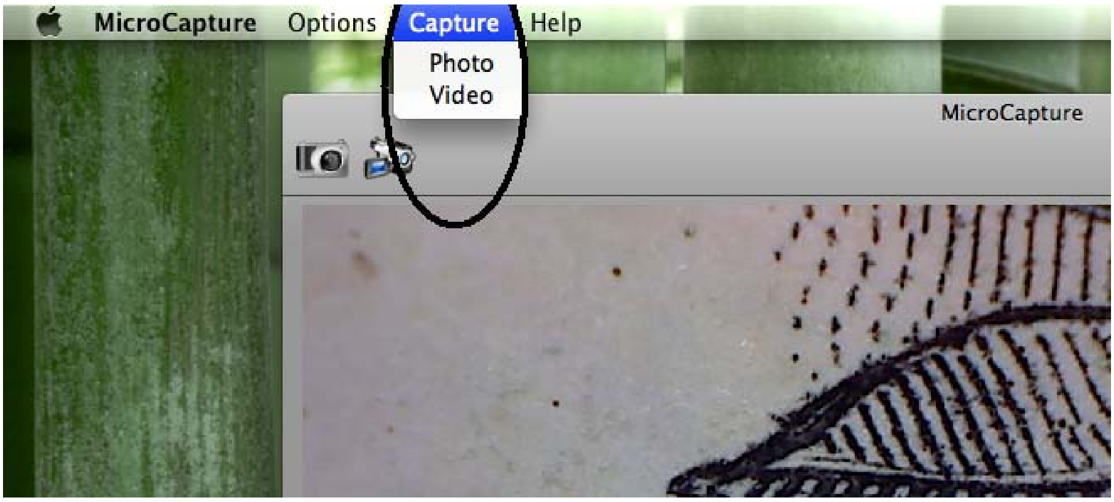
From ***Options***, you can turn the date/time on or off.



6. Photo capture

You can capture photo by:

1) Choosing ***Capture/Photo***



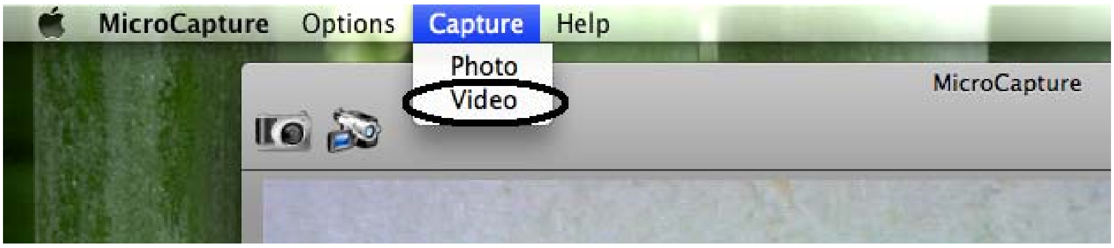
2) clicking photo capture icon

The captured photos will appear as thumbnails on the right side of the preview window.

7. Video capture

You can capture video by:

1) choosing ***Capture/Video***



2) clicking video capture icon

Note: After clicking on the icon, the video capture icon will turn red to indicate video clip recording. Click the red icon again, to stop recording!!

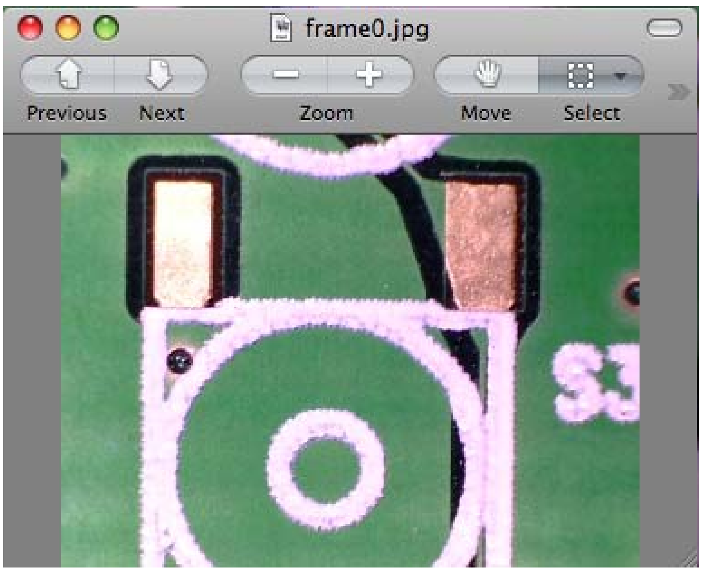
The captured videos will be appear as thumbnails on the right side of the preview window under Video tab.

8. Photo & Video editing

Captured photo & video appear as thumbnails on the right side of the preview window.

1) photo

Double click a photo thumbnail to open in the main preview window



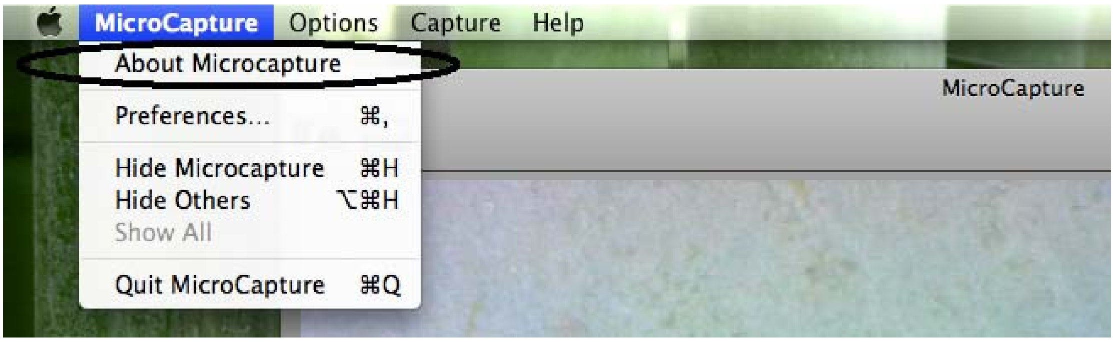
You can then carry out operations as you normally do on Mac system.

2) Video

Click a video clip thumbnail, the video will play automatically.

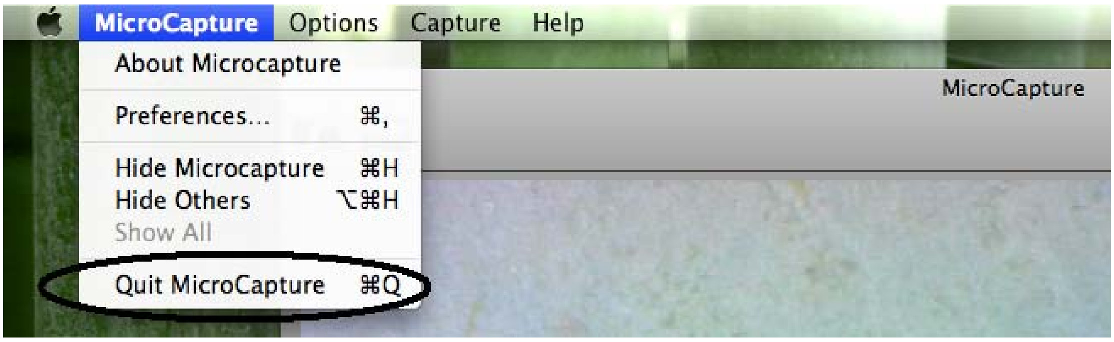
9. Help info

By choosing ***About MicroCapture***, you can get help info from your local agent.



10.Quit MicroCapture

Choose ***Quit MicroCapture*** as follows, you can quit the software.



Safety:

- The Microscope is not waterproof, so keep it dry.
- Do not use it in a humid place like bathrooms. A dry environment will maintain its life to maximum.
- Use the Microscope only at -5℃-50℃.
- Sudden temperature change may form dew inside the Microscope like entering a warm room in cold winter. Put it inside a handbag or plastic bag to slow down temperature changes.
- Do not point Microscope lens to the sun or strong light for a long time. Powerful light may hurt the light-sensitive electronics.
- Avoid touching the lens.
- The white LEDs which illuminate the Microscope target field are very bright. Do not stare directly into these LEDs as it may damage your eyes.
- The clear plastic distance shell sometimes picks up dirt or toxic material from a microscopically observed surface. Be careful that this doesn’t get in contact with the human skin. Always wash carefully or disinfect as needed.
- Do not unplug the Microscope from USB port when LEDs are on. This may cause information loss or circuit damage. Please always close MicroCapture and then unplug the Microscope.

For support in the UK please visit our FAQ/Technical and Download center on our website.

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or technical support contact:

technical@veho-uk.com

Appendix 3

water temperature	23	(C)
water density at 23 deg C	0.99754	g/cm3

Measuring	**weight of pycnometer (g)**	**weight of pycno + water (g)**	**weight of water (g)**	**volume of pycno (cm3)**
1	35.3667	59.9597	24.593	24.65364797
2	35.3671	59.9588	24.5917	24.65234477
3	35.367	59.9585	24.5915	24.65214427
Average	**35.36693333**	**59.959**	**24.59206667**	**24.65271234**
Standard Deviation	**0.000**	**0.001**	**0.001**	**0.001**

Measuring	**weight of 50 ml tube (g)**	**weight tube + water (g)**	**weight of water (g)**	**Volume of tube (cm3)**
1	40.4096	90.0806	49.671	49.79349199
2	40.4094	90.0802	49.6708	49.7932915
3	40.4095	90.0794	49.6699	49.79238928
Average	**40.4095**	**90.08006667**	**49.67056667**	**49.79305759**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**

Sample A : **Coffee grit 1**

Measuring	**Weight of empty pycnometer (g)**	**weight of pycno + solid coffee grit (g)**	**weight of pycno + solid coffee grit + water (g)**	**weight of water (g)**	**weight of coffee grit (g)**	**volume water V' (cm3)**	**Volume coffee grit (cm3)**	**density of coffee grit (g/cm3)**
1	35.3638	36.1403	60.0772	23.9369	0.7765	23.99592999	0.656782351	1.182279028
2	35.3635	36.1401	60.077	23.9369	0.7766	23.99592999	0.656782351	1.182431286
3	35.3635	36.1402	60.0768	23.9366	0.7767	23.99562925	0.657083091	1.182042287
Average	**35.3636**	**36.1402**	**60.077**	**23.9368**	**0.7766**	**23.99582974**	**0.656882598**	**1.182**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1	35.3648	36.6151	60.1796	23.5645	1.2503	23.62261162	1.030100714	1.213764812
2	35.3648	36.6153	60.1795	23.5642	1.2505	23.62231088	1.030401454	1.213604654
3	35.3646	36.6149	60.1793	23.5644	1.2503	23.62251138	1.030200961	1.213646703
Average	**35.36473333**	**36.6151**	**60.17946667**	**23.56436667**	**1.250366667**	**23.62247796**	**1.030234377**	**1.214**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1	35.3667	36.168	60.0672	23.8992	0.8013	23.95813702	0.694575322	1.153654578
2	35.3667	36.1677	60.0668	23.8991	0.801	23.95803677	0.694675569	1.153056241
3	35.3662	36.1678	60.0665	23.8987	0.8016	23.95763578	0.695076555	1.153254263
Average	**35.36653333**	**36.16783333**	**60.06683333**	**23.899**	**0.8013**	**23.95793652**	**0.694775815**	**1.153**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
							Average density	**1.183**

Sample B : **Coffee grit 2**

Measuring	**Weight of empty pycnometer (g)**	**weight of pycno + solid coffee grit (g)**	**weight of pycno + solid coffee grit + water (g)**	**weight of water (g)**	**weight of coffee grit (g)**	**volume water V' (cm3)**	**Volume coffee grit (cm3)**	**density of coffee grit (g/cm3)**
1	35.3763	36.4356	60.2437	23.8081	1.0593	23.86681236	0.785899981	1.347881443
2	35.3763	36.4351	60.2436	23.8085	1.0588	23.86721334	0.785498994	1.34793298
3	35.3764	36.4352	60.2437	23.8085	1.0588	23.86721334	0.785498994	1.34793298
Average	**35.37633333**	**36.4353**	**60.24366667**	**23.80836667**	**1.058966667**	**23.86707968**	**0.785632656**	**1.348**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1	35.3876	36.329	60.2494	23.9204	0.9414	23.9793893	0.673323041	1.398140183
2	35.3889	36.3289	60.2487	23.9198	0.94	23.97878782	0.673924521	1.394814954
3	35.3824	36.3287	60.2484	23.9197	0.9463	23.97868757	0.674024768	1.403954343
Average	**35.3863**	**36.32886667**	**60.24883333**	**23.91996667**	**0.942566667**	**23.9789549**	**0.673757443**	**1.399**
Standard Deviation	**0.003**	**0.000**	**0.000**	**0.000**	**0.003**	**0.000**	**0.000**	**0.004**
1	35.3692	36.5332	60.21	23.6768	1.164	23.73518856	0.917523775	1.268631976
2	35.3688	36.533	60.2104	23.6774	1.1642	23.73579004	0.916922296	1.26968229
3	35.3688	36.5329	60.2102	23.6773	1.1641	23.7356898	0.917022542	1.269434443
Average	**35.36893333**	**36.53303333**	**60.2102**	**23.67716667**	**1.1641**	**23.73555613**	**0.917156204**	**1.269**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
							Average density	**1.339**

Sample C : **Coffee grit 3**

Measuring	**Weight of empty pycnometer (g)**	**weight of pycno + solid coffee grit (g)**	**weight of pycno + solid coffee grit + water (g)**	**weight of water (g)**	**weight of coffee grit (g)**	**volume water V' (cm3)**	**Volume coffee grit (cm3)**	**density of coffee grit (g/cm3)**
1	35.3669	37.5667	60.257	22.6903	2.1998	22.74625579	1.90645655	1.153868416
2	35.3668	37.5666	60.2572	22.6906	2.1998	22.74655653	1.90615581	1.154050466
3	35.3669	37.5667	60.257	22.6903	2.1998	22.74625579	1.90645655	1.153868416
Average	**35.36686667**	**37.56666667**	**60.25706667**	**22.6904**	**2.1998**	**22.74635604**	**1.906356303**	**1.154**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1	35.3693	37.5487	60.255	22.7063	2.1794	22.76229525	1.890417093	1.152867274
2	35.369	37.5487	60.2548	22.7061	2.1797	22.76209475	1.890617586	1.152903695
3	35.369	37.5487	60.255	22.7063	2.1797	22.76229525	1.890417093	1.153025969
Average	**35.3691**	**37.5487**	**60.25493333**	**22.70623333**	**2.1796**	**22.76222842**	**1.890483924**	**1.153**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1	35.376	37.0765	60.3036	23.2271	1.7005	23.28437957	1.368332765	1.242753256
2	35.3757	37.0768	60.304	23.2272	1.7011	23.28447982	1.368232519	1.243282832
3	35.3758	37.0765	60.3034	23.2269	1.7007	23.28417908	1.368533258	1.242717332
Average	**35.37583333**	**37.0766**	**60.30366667**	**23.22706667**	**1.700766667**	**23.28434616**	**1.368366181**	**1.243**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
							average density	**1.183**

Temp of water 23 (C)
water density at 23 ^{o}C 0.99754 (g/cm3)

Measuring	weight of pycnometer (g)	weight of pycno + water (g)	weight of water (g)	volume of pycno (cm3)
1	35.3667	59.9597	24.593	24.654
2	35.3671	59.9588	24.5917	24.652
3	35.367	59.9585	24.5915	24.652
Average	**35.367**	**59.959**	**24.592**	**24.653**
Standard Deviation	**0.000**	**0.001**	**0.001**	**0.001**

Measuring	weight of 50 ml tube (g)	weight tube + water (g)	weight of water (g)	Volume of tube (cm3)
1	40.2958	90.048	49.7522	49.875
2	40.2961	90.0478	49.7517	49.874
3	40.296	90.0472	49.7512	49.874
Average	**40.296**	**90.048**	**49.752**	**49.874**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**

Sample D : **HyVAB**

Measuring	weight of 50 ml tube (g)	weight of tube + sludge (g)	weight of sludge (g)	density of sludge (g/cm3)
1	40.2958	90.7252	50.4294	1.011
2	40.2961	90.7264	50.4303	1.011
3	40.296	90.729	50.433	1.011
Average	**40.296**	**90.727**	**50.431**	**1.011**
Standard Deviation	**0.000**	**0.002**	**0.002**	**0.000**
1	40.2958	90.6875	50.3917	1.010
2	40.2961	90.6887	50.3926	1.010
3	40.296	90.6902	50.3942	1.010
Average	**40.296**	**90.689**	**50.393**	**1.010**
Standard Deviation	**0.000**	**0.001**	**0.001**	**0.000**
1	40.2958	90.673	50.3772	1.010
2	40.2961	90.6735	50.3774	1.010
3	40.296	90.6741	50.3781	1.010
Average	**40.296**	**90.674**	**50.378**	**1.010**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**
				1.011 Average sludge density

Sample E : **UASB E - Convert**

Measuring	weight of pycno (g)	weight of pycno + solid granule (g)	weight of pycno + solid granule + water (g)	weight of water (g)	weight of granule (g)	volume water V' (cm3)	Volume granular sludge (cm3)	density of granular sludge (g/cm3)
1	35.4093	36.844	60.0127	23.1687	1.4347	23.22583556	1.426876784	1.005482755
2	35.4097	36.8441	60.013	23.1689	1.4344	23.22603605	1.42667629	1.005413779
3	35.4098	36.8441	60.0137	23.1696	1.4343	23.22673777	1.425974564	1.005838418
Average	**35.410**	**36.844**	**60.013**	**23.169**	**1.434**	**23.226**	**1.427**	**1.006**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1	35.3765	36.9933	60.0607	23.0674	1.6168	23.12428574	1.528426596	1.057819855
2	35.3789	36.9933	60.0613	23.068	1.6144	23.12488722	1.527825116	1.056665441
3	35.3774	36.9934	60.0623	23.0689	1.616	23.12578944	1.526922897	1.058337656
Average	**35.378**	**36.993**	**60.061**	**23.068**	**1.616**	**23.125**	**1.528**	**1.058**
Standard Deviation	**0.001**	**0.000**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
1	35.3797	36.539	60.0347	23.4957	1.1593	23.55364196	1.09907038	1.054800513
2	35.3796	36.5392	60.0353	23.4961	1.1596	23.55404295	1.098669393	1.055458546
3	35.3781	36.5393	60.0359	23.4966	1.1612	23.55454418	1.09816816	1.057397257
Average	**35.379**	**36.539**	**60.035**	**23.496**	**1.160**	**23.554**	**1.099**	**1.056**
Standard Deviation	**0.001**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**	**0.000**	**0.001**
							Average Density	1.040

Sample F : **EGSB Reactor**

Measuring	weight of pycno (g)	weight of pycno + solid granule (g)	weight of pycno + solid granule + water (g)	weight of water (g)	weight of granule (g)	volume water V' (cm3)	Volume granular sludge (cm3)	density of granular sludge (g/cm3)
1	35.3754	36.857	59.995	23.138	1.4816	23.19505985	1.457652492	1.016428818
2	35.3755	36.8576	59.9953	23.1377	1.4821	23.19475911	1.457953232	1.016562101
3	35.3755	36.858	59.9958	23.1378	1.4825	23.19485935	1.457852985	1.016906379
Average	**35.375**	**36.858**	**59.995**	**23.138**	**1.482**	**23.195**	**1.458**	**1.017**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1	35.3736	36.9875	60.0094	23.0219	1.6139	23.07867354	1.574038802	1.025324152
2	35.3739	36.9877	60.0097	23.022	1.6138	23.07877378	1.573938556	1.025325922
3	35.3753	36.9879	60.0105	23.0226	1.6126	23.07937526	1.573337076	1.024955189
Average	**35.374**	**36.988**	**60.010**	**23.022**	**1.613**	**23.079**	**1.574**	**1.025**
Standard Deviation	**0.001**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**	**0.000**	**0.000**
1	35.3742	36.3333	60.0113	23.678	0.9591	23.73639152	0.916320816	1.046685815
2	35.3746	36.3332	60.0116	23.6784	0.9586	23.73679251	0.915919829	1.046598151
3	35.3743	36.334	60.0119	23.6779	0.9597	23.73629128	0.916421062	1.04722604
Average	**35.374**	**36.334**	**60.012**	**23.678**	**0.959**	**23.736**	**0.916**	**1.047**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
							Average Density	**1.030**

Sample G : **Saubrugs (new)**

Temp of water 21 (oC)

Water density at 21 C 0.99799 (g/cm3)

Measuring	weight of 50 ml tube (g)	weight tube + water (g)	weight of water (g)	Volume of tube (cm3)
1	40.2969	90.026	49.7291	49.829
2	40.2966	90.0259	49.7293	49.829
3	40.2963	90.0256	49.7293	49.829
Average	**40.297**	**90.026**	**49.729**	**49.829**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**

Measuring	weight of 50 ml tube (g)	weight tube + sludge (g)	weight of sludge (g)	Density of Sludge (g/cm3)
1	40.2969	90.9237	50.6268	1.016
2	40.2966	90.9231	50.6265	1.016
3	40.2963	90.9226	50.6263	1.016
Average	**40.297**	**90.923**	**50.627**	**1.016**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**

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Sample H : **Saubrugs (Old)**

Temp of water 22.5 (oC)

Water density at 22.5 C 0.997655 (g/cm3) http://www.simetric.co.uk/si_water.htm

Measuring	weight of 50 ml tube (g)	weight tube + water (g)	weight of water (g)	Volume of tube (cm3)
1	40.4709	90.1936	49.7227	49.840
2	40.4707	90.1936	49.7229	49.840
3	40.4702	90.1934	49.7232	49.840
Average	**40.471**	**90.194**	**49.723**	**49.840**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**

Measuring	weight of 50 ml tube (g)	weight tube + sludge (g)	weight of sludge (g)	Density of Sludge (g/cm3)
1	40.4709	90.9526	50.4817	1.013
2	40.4709	90.9522	50.4813	1.013
3	40.4708	90.9524	50.4816	1.013
Average	**40.471**	**90.952**	**50.482**	**1.013**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**

Sample I : **E convert New**

Measuring	weight of 50 ml tube (g)	weight of tube + solid granule (g)	weight of pycno + solid granule + water (g)	weight of water (g)	weight of granule (g)	volume water V' (cm3)	Volume granular sludge (cm3)	density of granular sludge (g/cm3)
1	40.3003	44.844	90.1866	45.3426	4.5437	45.43392218	4.395468224	1.033723774
2	40.3	44.8446	90.1864	45.3418	4.5446	45.43312057	4.396269836	1.033740005
3	40.2999	44.8442	90.1868	45.3426	4.5443	45.43392218	4.395468224	1.033860278
Average	**40.300**	**44.844**	**90.187**	**45.342**	**4.544**	**45.434**	**4.396**	**1.034**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Sample J : **E convert OLD**

Measuring	weight of 50 ml tube (g)	weight of tube + solid granule (g)	weight of pycno + solid granule + water (g)	weight of water (g)	weight of granule (g)	volume water V' (cm3)	Volume granular sludge (cm3)	density of granular sludge (g/cm3)
1	40.4655	45.3884	90.6191	45.2307	4.9229	45.3370153	4.503	1.093299354
2	40.4653	45.3881	90.6189	45.2308	4.9228	45.33711554	4.503	1.093301483
3	40.4654	45.3879	90.6186	45.2307	4.9225	45.3370153	4.503	1.09321052
Average	**40.465**	**45.388**	**90.619**	**45.231**	**4.923**	**45.337**	**4.503**	**1.093**
Standard Deviation	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Appendix 4

Sample	Weight of Cup (g)	Weight of cup + sample (g)	Weight sample (g)	Weight of cup + sample after dried (g)	Weight of cup + sample after burnt (g)	% TS	% VS	VS/TS	VS/TS (%)
A	1.8777	4.0507	2.173	2.7561	1.9115				
	1.8775	4.0506	2.1731	2.756	1.9115				
	1.8776	4.0505	2.1729	2.756	1.9116				
Average	**1.8776**	**4.0506**	**2.173**	**2.756033333**	**1.911533333**	**40.42491**	**38.86332**	**0.961371**	**96.13706**
B	1.8714	6.4931	4.6217	3.7948	1.9047				
	1.8709	6.493	4.6221	3.795	1.9046				
	1.8707	6.4929	4.6222	3.795	1.9047				
Average	**1.871**	**6.493**	**4.622**	**3.794933333**	**1.904666667**	**41.62556**	**40.89716**	**0.982501**	**98.25011**
C	1.8943	2.9838	1.0895	2.3149	1.9038				
	1.8941	2.9837	1.0896	2.315	1.9037				
	1.8936	2.9828	1.0892	2.3149	1.9035				
Average	**1.894**	**2.983433333**	**1.089433333**	**2.314933333**	**1.903666667**	**38.63782**	**37.75051**	**0.977035**	**97.70352**
D	1.8868	4.6906	2.8038	2.044	1.9211				
	1.887	4.6898	2.8028	2.0441	1.9208				
	1.8873	4.6892	2.8019	2.0441	1.9047				
Average	**1.88703333**	**4.689866667**	**2.802833333**	**2.044066667**	**1.915533333**	**5.602664**	**4.585836**	**0.81851**	**81.85099**
E	1.88	2.6857	0.8057	1.9857	1.928				
	1.8804	2.6847	0.8043	1.9857	1.9278				
	1.8806	2.6842	0.8036	1.9857	1.9278				
Average	**1.88033333**	**2.684866667**	**0.804533333**	**1.9857**	**1.927866667**	**13.09662**	**7.188432**	**0.548877**	**54.88769**
F	1.9053	2.5016	0.5963	1.9467	1.9173				
	1.9053	2.5014	0.5961	1.9467	1.9172				
	1.9053	2.5018	0.5965	1.9467	1.9174				
Average	**1.9053**	**2.5016**	**0.5963**	**1.9467**	**1.9173**	**6.942814**	**4.930404**	**0.710145**	**71.01449**
G	1.8901	2.5004	0.6103	1.9292	1.8964				
	1.8905	2.5	0.6095	1.9291	1.8962				
	1.8905	2.4992	0.6087	1.929	1.8963				
Average	**1.89036667**	**2.499866667**	**0.6095**	**1.9291**	**1.8963**	**6.354936**	**5.38146**	**0.846816**	**84.68158**
H	1.881	2.5781	0.6971	1.9294	1.8878				
	1.8813	2.5785	0.6972	1.9293	1.8878				
	1.8814	2.5783	0.6969	1.9294	1.8879				
Average	**1.88123333**	**2.5783**	**0.697066667**	**1.929366667**	**1.887833333**	**6.905126**	**5.958301**	**0.862881**	**86.28809**
I	1.8949	3.3119	1.417	2.0451	1.9292				
	1.8949	3.3117	1.4168	2.0452	1.9291				
	1.895	3.3112	1.4162	2.0451	1.9292				
Average	**1.89493333**	**3.3116**	**1.416666667**	**2.045133333**	**1.929166667**	**10.60235**	**8.185882**	**0.772082**	**77.20817**
J	1.8853	3.4179	1.5326	2.1806	1.9949				
	1.8854	3.418	1.5326	2.1806	1.9948				
	1.8855	3.4174	1.5319	2.1805	1.9949				

Average	**1.8854**	**3.417766667**	**1.532366667**	**2.180566667**	**1.994866667**	**19.26214**	**12.11851**	**0.629136**	**62.91361**

Appendix 5

Saugbugs Old **Sample quantity is 5 ml**
period per sample 5 min

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of filter (g)	Weight of filter after dried (g)	Weight of filter after burn (g)	TSS (g/mL)	TSS (mg/L)	VSS (g/mL)	VSS (mg/L)	VSS/TSS
1	1.19	6	30	0.146	0.153	0.147					
				0.146	0.153	0.147					
				0.147	0.153	0.147					
Average				**0.146**	**0.153**	**0.147**	0.0014	**1400**	0.0012	**1200**	**0.857**
2	2.18	11	55	0.151	0.157	0.152					
				0.152	0.157	0.152					
				0.152	0.157	0.151					
Average				**0.152**	**0.157**	**0.152**	0.001	**1000**	0.001	**1000**	**1.000**
3	3.18	16	80	0.154	0.1584	0.154					
				0.154	0.1583	0.154					
				0.154	0.1583	0.154					
Average				**0.154**	**0.158**	**0.154**	0.0008	**800**	0.0008	**800**	**1.000**
4	4.17	21	105	0.152	0.156	0.152					
				0.152	0.156	0.152					
				0.153	0.156	0.152					
Average				**0.152**	**0.156**	**0.152**	0.0008	**800**	0.0008	**800**	**1.000**
5	5.17	26	130	0.154	0.158	0.1536					
				0.154	0.158	0.1534					
				0.154	0.158	0.1535					
Average				**0.154**	**0.158**	**0.154**	0.0008	**800**	0.0008	**800**	**1.000**
6	8.15	41	205	0.147	0.149	0.147					
				0.147	0.149	0.147					
				0.147	0.15	0.147					
Average				**0.147**	**0.149**	**0.147**	0.0004	**400**	0.0004	**400**	**1.000**
7	10.14	51	255	0.153	0.162	0.154					
				0.153	0.162	0.154					
				0.153	0.162	0.154					
Average				**0.153**	**0.162**	**0.154**	0.0018	**1800**	0.0016	**1600**	**0.889**
8	15.11	76	380	0.1509	0.164	0.151					
				0.1508	0.164	0.151					
				0.1509	0.164	0.151					
Average				**0.151**	**0.164**	**0.151**	0.0026	**2600**	0.0026	**2600**	**1.000**
9	19.68	99	495	0.152	0.167	0.153					
				0.152	0.167	0.153					
				0.152	0.167	0.153					
Average				**0.152**	**0.167**	**0.153**	0.003	**3000**	0.0028	**2800**	**0.933**
10	44.75	225	1125	0.153	0.2	0.157					
				0.153	0.2	0.157					
				0.153	0.2	0.157					
Average				**0.153**	**0.200**	**0.157**	0.0094	**9400**	0.0086	**8600**	**0.915**
11	99.43	500	2500	0.154	0.204	0.159					
				0.154	0.204	0.159					
				0.154	0.204	0.159					
Average				**0.154**	**0.204**	**0.159**	0.01	**10000**	0.009	**9000**	**0.900**
12	187	940	4700	0.153	0.1582	0.153					
				0.153	0.1581	0.153					
				0.153	0.1582	0.153					
Average				**0.153**	**0.158**	**0.153**	0.001	**1000**	0.001	**1000**	**1.000**
								33000.000			

Saugbugs New **Sample quantity is 5 ml**
period per sample 5 min

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of filter (g)	Weight of filter after dried (g)	Weight of filter after burn (g)	TSS (g/mL)	TSS (mg/L)	VSS (g/mL)	VSS (mg/L)	VSS/TSS
1	1.19	6	30	0.152	0.154	0.152					
				0.152	0.154	0.152					
				0.152	0.154	0.152					
Average				**0.152**	**0.154**	**0.152**	0.0004	**400**	0.0004	**400**	**1.000**
2	2.18	11	55	0.152	0.1561	0.1522					
				0.152	0.156	0.1521					
				0.153	0.1559	0.1522					
Average				**0.152**	**0.156**	**0.153**	0.0008	**800**	0.0006	**600**	**0.750**
3	3.18	16	80	0.1182	0.1213	0.1174					
				0.1183	0.1214	0.1176					
				0.1184	0.1215	0.1175					
Average				**0.118**	**0.121**	**0.118**	0.0006	**600**	0.0006	**600**	**1.000**
4	4.17	21	105	0.1168	0.1192	0.1162					
				0.1171	0.1193	0.1163					
				0.117	0.1195	0.1164					
Average				**0.117**	**0.119**	**0.117**	0.0004	**400**	0.0004	**400**	**1.000**
5	5.17	26	130	0.1152	0.1194	0.115					
				0.1151	0.1195	0.1151					
				0.1151	0.1196	0.1151					

Average				**0.115**	**0.120**	**0.115**	0.001	**1000**	0.001	**1000**	**1.000**
6	8.15	41	205	0.1167	0.1228	0.1165					
				0.1163	0.1227	0.1166					
				0.1168	0.1226	0.1166					
Average				**0.117**	**0.123**	**0.117**	0.0012	**1200**	0.0012	**1200**	**1.000**
7	10.14	51	255	0.1532	0.1567	0.1523					
				0.1533	0.1566	0.1521					
				0.1532	0.1566	0.1523					
Average				**0.153**	**0.157**	**0.153**	0.0008	**800**	0.0008	**800**	**1.000**
8	15.11	76	380	0.1533	0.1651	0.153					
				0.1535	0.1652	0.1533					
				0.1535	0.1651	0.1533					
Average				**0.153**	**0.165**	**0.153**	0.0024	**2400**	0.0024	**2400**	**1.000**
9	19.68	99	495	0.15	0.166	0.151					
				0.15	0.166	0.151					
				0.15	0.166	0.151					
Average				**0.150**	**0.166**	**0.151**	0.0032	**3200**	0.003	**3000**	**0.938**
10	44.75	225	1125	0.152	0.233	0.157					
				0.152	0.232	0.157					
				0.152	0.233	0.157					
Average				**0.152**	**0.233**	**0.157**	0.0162	**16200**	0.0152	**15200**	**0.938**
11	99.43	500	2500	0.1554	0.1799	0.1566					
				0.1554	0.1802	0.1568					
				0.1555	0.1801	0.1569					
Average				**0.155**	**0.180**	**0.157**	0.005	**5000**	0.0046	**4600**	**0.920**
12	187	940	4700	0.1525	0.1549	0.1519					
				0.1524	0.1549	0.152					
				0.1524	0.1548	0.152					
Average				**0.152**	**0.155**	**0.152**	0.0006	**600**	0.0006	**600**	**1.000**

Appendix 6

Coffee 1 Sample quantity is 1/3 of reactor

Period per sample (min) 5

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of cup (g)	Weight filter + cup (g)	Weight of filter + cup after dried (g)	Weight of filter + cup after burn (g)	TSS (g/mL)	TSS (mg/L)
1	1.19	6	30	2.2501	2.4063	2.4181	2.4057		
				2.2501	2.4063	2.4182	2.4058		
				2.2505	2.4063	2.4181	2.4053		
Average				**2.250**	**2.406**	**2.418**	**2.406**	0.000394444	**394.444**
2	2.18	11	55	2.2542	2.409	2.4243	2.4096		
				2.2542	2.4088	2.4245	2.4098		
				2.2539	2.4086	2.4244	2.4094		
Average				**2.254**	**2.409**	**2.424**	**2.410**	0.000283636	**283.636**
3	3.18	16	80	2.2435	2.3934	2.4157	2.3935		
				2.2434	2.3929	2.4156	2.3935		
				2.2436	2.3932	2.4157	2.3934		
Average				**2.244**	**2.393**	**2.416**	**2.393**	0.00028125	**281.250**
4	4.17	21	105	2.2491	2.4072	2.4218	2.4054		
				2.2491	2.4067	2.4216	2.4053		
				2.2492	2.4073	2.4218	2.4052		
Average				**2.249**	**2.407**	**2.422**	**2.405**	0.000139683	**139.683**
5	5.17	26	130	2.2688	2.4291	2.4545	2.4276		
				2.2687	2.4288	2.4545	2.4274		
				2.2688	2.4289	2.4549	2.4273		
Average				**2.269**	**2.429**	**2.455**	**2.427**	0.000197692	**197.692**
6	8.15	41	205	2.2559	2.4141	2.518	2.4126		
				2.2558	2.414	2.5182	2.412		
				2.2558	2.4139	2.5182	2.412		
Average				**2.256**	**2.414**	**2.518**	**2.412**	0.000507967	**507.967**
7	10.14	51	255	2.2558	2.4147	2.472	2.4147		
				2.256	2.4148	2.4721	2.4143		
				2.2559	2.4148	2.4721	2.4142		
Average				**2.256**	**2.415**	**2.472**	**2.414**	0.000224706	**224.706**
8	15.11	76	380	2.2542	2.4106	2.49	2.4098		
				2.2544	2.4101	2.4902	2.4099		
				2.2542	2.4106	2.4902	2.41		
Average				**2.254**	**2.410**	**2.490**	**2.410**	0.000209737	**209.737**
9	19.68	99	495	2.2565	2.4153	2.5428	2.4169		
				2.2568	2.415	2.5429	2.4168		
				2.2568	2.4155	2.5428	2.4168		
Average				**2.257**	**2.415**	**2.543**	**2.417**	0.00025771	**257.710**

Reactor 1
Coffee 2 Sample quantity is 1/3 of reactor

Period per sample (min) 5

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of cup (g)	Weight filter + cup (g)	Weight of filter + cup after dried (g)	Weight of filter + cup after burn (g)	TSS (g/mL)	TSS (mg/L)
1	1.19	6	30	1.8942	2.0434	2.1117	2.0412		
				1.894	2.0433	2.1118	2.0412		
				1.8942	2.0432	2.1119	2.0411		
Average				**1.894**	**2.043**	**2.112**	**2.041**	0.002283333	**2283.333**
2	2.18	11	55	1.892	2.0395	2.1255	2.0395		
				1.892	2.0398	2.1255	2.0394		
				1.8919	2.0395	2.1254	2.0394		
Average				**1.892**	**2.040**	**2.125**	**2.039**	0.001561212	**1561.212**
3	3.18	16	80	1.8764	2.0227	2.1293	2.0231		
				1.8763	2.0228	2.1291	2.023		
				1.8762	2.0227	2.129	2.023		
Average				**1.876**	**2.023**	**2.129**	**2.023**	0.00133	**1330.000**
4	4.17	21	105	1.859	2.0103	2.0855	2.0101		
				1.86	2.0101	2.0855	2.01		
				1.8599	2.0102	2.0853	2.01		
Average				**1.860**	**2.010**	**2.085**	**2.010**	0.000716508	**716.508**
5	5.17	26	130	1.8657	2.0226	2.081	2.0216		
				1.8657	2.0225	2.0809	2.0217		
				1.8657	2.0225	2.0808	2.0217		

Average				**1.866**	**2.023**	**2.081**	**2.022**	0.000448974	**448.974**
6	8.15	41	205	1.8829	2.0372	2.138	2.0368		
				1.8829	2.0372	2.1381	2.0369		
				1.8828	2.0372	2.1382	2.0369		
Average				**1.883**	**2.037**	**2.138**	**2.037**	0.000492195	**492.195**
7	10.14	51	255	1.871	2.0288	2.1402	2.0282		
				1.871	2.0287	2.1405	2.0283		
				1.8711	2.0287	2.1404	2.0282		
Average				**1.871**	**2.029**	**2.140**	**2.028**	0.000437778	**437.778**
8	15.11	76	380	1.8794	2.0365	2.2742	2.0377		
				1.8795	2.0365	2.2742	2.0375		
				1.8795	2.0365	2.2738	2.0375		
Average				**1.879**	**2.037**	**2.274**	**2.038**	0.000625175	**625.175**
9	19.68	99	495	1.8973	2.0489	2.2571	2.0497		
				1.8971	2.049	2.2572	2.0499		
				1.8972	2.0491	2.2571	2.0498		
Average				**1.897**	**2.049**	**2.257**	**2.050**	0.000420471	**420.471**

Reactor 1
Coffee 3 Sample quantity is 1/3 of reactor

Period per sample (min) 5

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of cup (g)	Weight filter + cup (g)	Weight of filter + cup after dried (g)	Weight of filter + cup after burn (g)	TSS (g/mL)	TSS (mg/L)
1	1.19	6	30	1.8724	2.0295	2.0533	2.028		
				1.8728	2.0299	2.0535	2.0279		
				1.8725	2.0295	2.0533	2.028		
Average				**1.873**	**2.030**	**2.053**	**2.028**	0.000791111	**791.111**
2	2.18	11	55	1.8958	2.0528	2.104	2.0545		
				1.896	2.0531	2.104	2.0543		
				1.8958	2.0531	2.1038	2.0543		
Average				**1.896**	**2.053**	**2.104**	**2.054**	0.000926061	**926.061**
3	3.18	16	80	1.8735	2.0283	2.0742	2.0265		
				1.8732	2.0284	2.0741	2.0264		
				1.8732	2.0283	2.0739	2.0265		
Average				**1.873**	**2.028**	**2.074**	**2.026**	0.000571667	**571.667**
4	4.17	21	105	1.8847	2.0447	2.1104	2.0427		
				1.8847	2.0447	2.1107	2.0427		
				1.8847	2.0443	2.1107	2.0426		
Average				**1.885**	**2.045**	**2.111**	**2.043**	0.000628889	**628.889**
5	5.17	26	130	1.8757	2.0299	2.0984	2.028		
				1.8753	2.0299	2.0984	2.028		
				1.8755	2.0298	2.0984	2.0278		
Average				**1.876**	**2.030**	**2.098**	**2.028**	0.000527179	**527.179**
6	8.15	41	205	1.889	2.0426	2.1431	2.0408		
				1.8894	2.042	2.1429	2.0408		
				1.8892	2.0419	2.1429	2.0405		
Average				**1.889**	**2.042**	**2.143**	**2.041**	0.000491707	**491.707**
7	10.14	51	255	1.868	2.0214	2.0965	2.0199		
				1.8682	2.021	2.0969	2.0199		
				1.868	2.0215	2.097	2.0199		
Average				**1.868**	**2.021**	**2.097**	**2.020**	0.000296078	**296.078**
8	15.11	76	380	1.8756	2.0289	2.1491	2.0273		
				1.8756	2.0286	2.149	2.0275		
				1.8756	2.0289	2.149	2.0272		
Average				**1.876**	**2.029**	**2.149**	**2.027**	0.000316404	**316.404**
9	19.68	99	495	1.9096	2.0624	2.1762	2.0608		
				1.9097	2.062	2.1764	2.0608		
				1.9096	2.0624	2.1763	2.0606		
Average				**1.910**	**2.062**	**2.176**	**2.061**	0.00023037	**230.370**

Sample A

Reactor 1
Coffee 1 Sample quantity is 1/3 of reactor
Period per sample (min) 0.5

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of cup (g)	Weight sample + cup (g)	Weight of sample + cup after dried (g)	Weight of sample + cup after burn (g)	% TS	% VS	VS/TS
1	1.19	6	3	1.8725	5.3056	1.9004	1.8828			
				1.8724	5.3046	1.9004	1.8827			
				1.8725	5.3037	1.9003	1.8828			
Average				**1.872**	**5.305**	**1.900**	**1.883**	0.812897587	**0.513**	0.630824373
2	2.18	11	5.5	1.8954	7.6346	1.9426	1.9122			
				1.8954	7.634	1.9425	1.9121			
				1.8953	7.633	1.9423	1.912			
Average				**1.895**	**7.634**	**1.942**	**1.912**	0.820771979	**0.529**	0.64472753
3	3.18	16	8	1.8728	9.8883	1.9382	1.8971			
				1.8727	9.8875	1.9381	1.8973			
				1.8726	9.8872	1.9382	1.8972			
Average				**1.873**	**9.888**	**1.938**	**1.897**	0.816805227	**0.511**	0.625763747
4	4.17	21	10.5	1.8841	12.4213	1.9697	1.9247			
				1.8839	12.4204	1.9697	1.9248			
				1.884	12.4193	1.9698	1.9247			
Average				**1.884**	**12.420**	**1.970**	**1.925**	0.813692303	**0.427**	0.524883359
5	5.17	26	13	1.8748	14.2844	1.9478	1.8973			
				1.8747	14.2834	1.9477	1.8973			
				1.8747	14.2829	1.9479	1.8972			
Average				**1.875**	**14.284**	**1.948**	**1.897**	0.588827851	**0.407**	0.691605839
6	8.15	41	20.5	1.8829	19.212	2.0096	1.9234			
				1.8829	19.211	2.097	1.9233			
				1.8828	19.2099	2.097	1.9234			
Average				**1.883**	**19.211**	**2.068**	**1.923**	1.067630034	**0.834**	0.781081081
7	10.14	51	25.5	1.871	33.1884	2.0275	1.9296			
				1.871	33.1864	2.0274	1.9293			
				1.8711	33.1851	2.0273	1.9294			
Average				**1.871**	**33.187**	**2.027**	**1.929**	0.49932515	**0.313**	0.626518866
8	15.11	76	38	1.8794	38.4361	1.9885	1.9104			
				1.8795	38.4339	1.9884	1.9104			
				1.8795	38.431	1.9885	1.9106			
Average				**1.879**	**38.434**	**1.988**	**1.910**	0.298187349	**0.213**	0.71559633
9	19.68	99	49.5	1.8973	48.1153	2.0137	1.9218			
				1.8971	48.1136	2.0136	1.9217			
				1.8972	48.1101	2.0137	1.9218			
Average				**1.897**	**48.113**	**2.014**	**1.922**	0.252006168	**0.199**	0.789066972

Sample B

Reactor 1
Coffee 2 Sample quantity is 1/3 of reactor
Period per sample (min) 0.5

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of cup (g)	Weight sample + cup (g)	Weight of sample + cup after dried (g)	Weight of sample + cup after burn (g)	% TS	% VS	VS/TS
1	1.19	6	3	1.8936	5.4293	1.9075	1.8975			
				1.8933	5.429	1.9073	1.8974			
				1.8928	5.4285	1.9072	1.8974			
Average				**1.893**	**5.429**	**1.907**	**1.897**	0.39878949	**0.280**	0.70212766
2	2.18	11	5.5	1.8922	7.653	1.9203	1.9051			
				1.8921	7.6525	1.9203	1.905			
				1.8921	7.6522	1.9204	1.9051			
Average				**1.892**	**7.653**	**1.920**	**1.905**	0.489546504	**0.265**	0.541371158
3	3.18	16	8	1.8775	10.2299	1.9074	1.8813			
				1.8775	10.2294	1.9075	1.8813			
				1.8775	10.229	1.9074	1.8813			
Average				**1.878**	**10.229**	**1.907**	**1.881**	0.358400051	**0.313**	0.873051225
4	4.17	21	10.5	1.861	12.8245	1.8995	1.8651			
				1.8608	12.8238	1.8996	1.8652			
				1.8609	12.8233	1.8995	1.8653			
Average				**1.861**	**12.824**	**1.900**	**1.865**	0.35239853	**0.313**	0.888697153
5	5.17	26	13	1.8663	16.2058	1.915	1.8703			
				1.8664	16.2048	1.9146	1.87			
				1.8663	16.204	1.9146	1.8702			
Average				**1.866**	**16.205**	**1.915**	**1.870**	0.337551958	**0.311**	0.920798898
6	8.15	41	20.5	1.8842	23.5115	1.9457	1.8877			
				1.8842	23.5109	1.9458	1.8876			
				1.8841	23.5099	1.9456	1.8876			
Average				**1.884**	**23.511**	**1.946**	**1.888**	0.284526155	**0.268**	0.943661972
7	10.14	51	25.5	1.8712	28.3167	1.9463	1.8766			
				1.8712	28.3154	1.946	1.8764			
				1.8715	28.315	1.9461	1.8763			
Average				**1.871**	**28.316**	**1.946**	**1.876**	0.282983669	**0.264**	0.931403118
8	15.11	76	38	1.8804	40.1558	1.9935	1.8856			
				1.8805	40.1546	1.9933	1.8856			
				1.8806	40.1532	1.9936	1.8857			
Average				**1.881**	**40.155**	**1.993**	**1.886**	0.29515224	**0.282**	0.954558867
9	19.68	99	49.5	1.897	52.1585	2.0287	1.908			
				1.8982	52.1534	2.0286	1.9078			
				1.8979	52.1477	2.0287	1.9076			
Average				**1.898**	**52.153**	**2.029**	**1.908**	0.260601659	**0.241**	0.92288114

Sample C

Reactor 1
Coffee 3 Sample quantity is 1/3 of reactor
Period per sample (min) 0.5

Sample	Vertical Velocity (m/h)	Pump flow rate (ml/min)	Total volume in period (ml)	Weight of cup (g)	Weight sample + cup (g)	Weight of sample + cup after dried (g)	Weight of sample + cup after burn (g)	% TS	% VS	VS/TS
1	1.19	6	3	1.8952	4.9053	1.9111	1.8995			
				1.8951	4.9051	1.9111	1.8996			
				1.8952	4.9047	1.9112	1.8995			
Average				**1.895**	**4.905**	**1.911**	**1.900**	0.530477541	**0.385**	0.72651357
2	2.18	11	5.5	1.8941	7.8805	1.9278	1.9086			
				1.8941	7.8799	1.9277	1.9087			
				1.894	7.8793	1.9277	1.9086			
Average				**1.894**	**7.880**	**1.928**	**1.909**	0.562439092	**0.319**	0.567326733
3	3.18	16	8	1.8776	10.208	1.9272	1.895			
				1.8776	10.2075	1.927	1.895			
				1.8776	10.2071	1.9271	1.8949			
Average				**1.878**	**10.208**	**1.927**	**1.895**	0.594242451	**0.386**	0.649158249
4	4.17	21	10.5	1.8611	13.0684	1.9314	1.8857			
				1.861	13.0678	1.9314	1.8857			
				1.8611	13.0671	1.9315	1.8858			
Average				**1.861**	**13.068**	**1.931**	**1.886**	0.627898192	**0.408**	0.649455234
5	5.17	26	13	1.8671	16.3946	1.9559	1.8932			
				1.867	16.3941	1.9559	1.893			
				1.8672	16.3935	1.956	1.893			
Average				**1.867**	**16.394**	**1.956**	**1.893**	0.611506417	**0.433**	0.707692308
6	8.15	41	20.5	1.8842	23.858	2.0035	1.9223			
				1.884	23.857	2.0038	1.9221			
				1.884	23.8562	2.0036	1.9222			
Average				**1.884**	**23.857**	**2.004**	**1.922**	0.544152672	**0.371**	0.681070532
7	10.14	51	25.5	1.8725	28.9671	1.9945	1.9015			
				1.8724	28.9663	1.9945	1.9013			
				1.8722	28.9657	1.9945	1.9014			
Average				**1.872**	**28.966**	**1.995**	**1.901**	0.45077631	**0.344**	0.762281659
8	15.11	76	38	1.8809	41.6547	2.0207	1.9084			
				1.8808	41.6535	2.0208	1.9082			
				1.8807	41.6523	2.0206	1.9083			
Average				**1.881**	**41.654**	**2.021**	**1.908**	0.351748813	**0.283**	0.803431022
9	19.68	99	49.5	1.9003	54.5668	2.0222	1.907			
				1.9003	54.5633	2.0223	1.9073			
				1.9002	54.5585	2.0221	1.9071			
Average				**1.900**	**54.563**	**2.022**	**1.907**	0.231536866	**0.218**	0.943685074