Influence of flocculation on sewage sludge thickening and dewatering

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INFLUENCE OF FLOCCULATION ON SEWAGE SLUDGE THICKENING AND DEWATERING

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Abstract

The characterisation of sludge to assess in laboratory its amenability to thickening and dewatering could be respectively carried out by the drainability index and the dryness limit determination. Flocculation conditions are known to influence markedly sludge drainability and the role of main corresponding parameters : polymer nature, dosing and mixing time on drainability index was quantified. The dewaterability of 6 sludges of different origin was compared as well as the influence of 3 main operating conditions : solids load, pressure and time of expression on the dryness limit of a mineral and organic sludge.

Key words : sludge flocculation, bootest, drainability index, dryness limit, thickening, dewatering

INTRODUCTION

The effectiveness and cost of sludge treatment and disposal operations are strongly affected by its volume and, consequently, by its water content or solids concentration, so thickening and dewatering are important steps in the total sludge processing train and has serious impact on subsequent operations. Sludge conditioning is a means to improve the removal of water during the thickening and dewatering process. Chemical products are classically used to neutralize or destabilize the chemical or physical forces acting on colloidal and particulate matters, suspended in the sludge, to form larger aggregates called "flocs" with different mechanisms [1]. Due to the complex nature of flocs, sludges display a wide variation of physical, chemical and biological properties. Many parameters such as particle size, surface properties, extracellular polymeric substances, cationic salts may influence significantly their thickenability and dewaterability [2] [3]. Due to the current problem of anticipating the behaviour of flocs, some laboratory tests were classically used to assess their thickenability and dewaterability such as gravity drainage methods, CST, measurement of the specific resistance and cake solids content in filtration compression cells or funnel-type vacuum units or more specific devices for belt presses [4] or centrifuge [5]. Thickenability indexes were defined for sedimentation process [6] and a new index for gravity filtration was proposed in recent work to qualify sludge drainability [7]. Flocculation conditions are known to influence markedly sludge drainability and consequently but opposite effects of flocculation conditions on each parameters can be hidden in the drainaibility index. They have also an influence on sludge dewaterability and the optimum for thickenability or dewaterability is generally not the same [8]. Dewaterability can be described by the concept of the dryness limit defined in the French Standard FD-T 97001 [9] which represents the maximal dryness obtained at an infinite time that could be achieved by filtration-compression test under pressure. Suppliers and users of dewatering equipments agree on the fact that this is fundamental data of sludge to give guarantees on the performances of their machines. Each supplier has its own correlation between the dryness limit and the dryness obtained on their equipment [10].This paper deals with the influence of flocculation conditions on sludge thickenability characterized by the drainability index and their subsequent dewaterability characterized by the dryness limit. The role of operating conditions in the determination of this parameter, in view of the revision of the corresponding standard, is also discussed.

MATERIALS AND METHODS

Sludges

Experiments were carried out on different sludges :

- Diluted activated sludge (0.5% DS, 65% VM), sampled at a municipal wastewater treatment plant near Pau (64, France).
- Common activated sludge (1% DS, 67% VM), sampled at a municipal wastewater treatment plant at La Chatres (77, France).
- Concentrated activated sludge (3% DS, 61% VM), sampled at a municipal wastewater treatment plant near Agen (47, France).
- Water supply treatment sludge (2.5% DS, 26% VM) sampled at Nerac plant (47, France)
- Digested sludge (3% DS, 64% VM) sampled at Tours plant (37, France)
- Food industry sludge (2.5% DS, 73% VM) sampled near Royan (17, France)
- Synthetic mineral sludge (11.6% DS, 0% VM) composed of a mixture of kaolin (10% DS) and calcium chloride (0.165% DS)

Polyelectrolytes

Cationic polymer of different charge density, molecular weight, physico-chemical form (powder, emulsion) and structure (linear chain, cross-linked backbone, structured) were supplied by manufacturers SNF FLOERGER and BASF. Quantity of polyelectrolyte solution was fixed according to the required dose of polyelectrolyte (actives matters) by quantity of dry sludge (kg/T DS).

Flocculation

Diluted activated sludges (like those coming from Pau plant) were flocculated in a conventional apparatus used in wastewater treatment called a “jar tester” composed of six position gang stirrer for agitating the biosolids wastewater in 1 L beakers at a controlled speed (and shear) while polymer flocculants or coagulants are added. The device and protocol can’t be applied to other sludge conditioning owing to high solids concentration and higher viscosity of flocculated suspension and different kinetics. Sludge flocculation experiments were made with a new kind of device called “bootest” developed by IFTS and already described in previous work [11]. The two flocculators of 90 mm diameter are stirred in the same conditions with measurement and control of time and speed mixing, impeller position (function of the sludge volume) as specified in prEN 14742 [12].

Sludge thickening

Drainage tests were made by pouring the flocculated sludge from the jastester to a gravity drainage cell or by transferring it automatically from the flocculator to the drainage part of the bootest. Drainage cells are equipped with filter cloth reference Si030904 from Rai-Tillières (French manufacturer). The mass of filtrate is recorded during the test by a weight sensor connected to a computer. The parameters for drainage kinetics are the ratio of the filtrate mass over the sludge initial mass at different times as recommended in EN 14701-4 [13]. The time required to recover 90% of the total mass of filtrate, the final sludge dryness after thickening and the solids content in the filtrate were specially measured to calculate the drainability index developed in previous work [7] and expressed by the following equation :

$$E_g = \ln\left(\frac{P_1}{P_2^{\alpha} \times P_3^{\beta}}\right) = \ln\left(\frac{\frac{Si_f}{Si_0}}{\left(\frac{t_{90}}{60}\right)^3 \times \left(\frac{SM_r}{Si_0}\right)^{\frac{1}{4}}}\right)$$

Sludge dewatering

Dewatering tests are made in a filtration-compression stand equipped of 3 cylindrical stainless steel cells of 70 mm internal diameter . A perforated disk was located at the bottom of the cylinder to support a synthetic filtering medium (reference of 05-1010-SK-008 from Sefar Fyltis was used in this study). Pressure was applied by a piston moved hydraulically on flocculated thickened sludges by gravity filtration, linked to a displacement sensor to measure cake height. Mass of filtrate versus time was recorded during expression and reached an asymptote where no filtrate was released from the cake by mechanical compression. The corresponding dry solids content of the cake is called dryness limit which corresponds to the dryness of cake obtained in an infinite time as defined in FD-T 97001-1 [9]. For compressible sludges, it is difficult to obtain the asymptote in a reasonable test time and we propose to assess it by extrapolating cumulative curves of filtrate mass versus time according to the simple mathematic model :

$$S = \frac{a * t}{b + ct} = \frac{a}{c + \frac{b}{t}}$$

The determination of the slope of the model linearized form enables to assess the dryness limit (S_∞)

$$\frac{t}{S} = \frac{b}{a} + \frac{ct}{a} \qquad S\infty = \frac{a}{c}$$

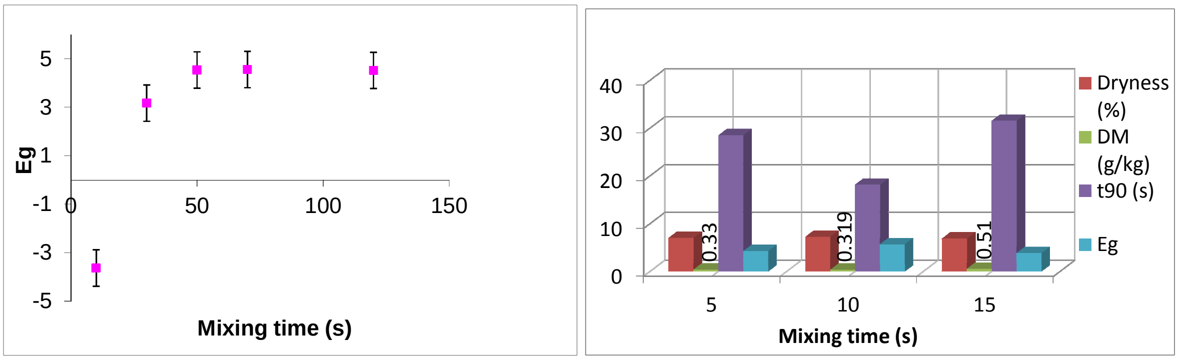
RESULTS AND DISCUSSION

Repeatibility

Repeatibility of the measurement of drainability index was evaluated for the concentrated activated sludges sampled near Agen flocculated by cross-linked polymer EM 440 BD with a dosage of 15 kg/T DS, a mixing time and speed of 10 s and 700 tr/min and a charge of sludge of 1.6 kg DS/m^2. The test carried out 7 times enabled to assess a mean drainability index of 5.46±0.35 with characteristic time t_{90} équal to 22±7s, sludge dryness equal to 7.20±0.08% and solids content equal to 0.328±0.038 g/L. The most important variation of the drainability index is linked to the kinetics parameters as it appears with an exponent -3 in the calculation formula. Another tests were carried out 5 times with the diluted activated sludge from Pau and flocculated in a jar-tester by a linear polymer EM 640L with a dosage of 6.2 kg/T DS, a mixing time and speed of 30 s and 300 tr/min and a charge of sludge of 0.45 kg DS/m^2. The test carried out 5 times showed a mean drainability index of 3.87±0.75 with characteristic time t_{90} équal to 44±9s, sludge dryness equal to 4.09±0.12% and solids content equal to 0.206±0.03 g/L. The deviation of the drainability index obtained with a transfer of the flocculated sludge from the flocculator to the drainage cell by an operator is higher than the index obtained by an automatic transfer carried out in the bootest as it was already shown in previous papers [11].
Repeatibility of the measurement of the dryness limit of the thickened sludge was only made with 2 tests in the same conditions (pressure : 4 bar, filtration time : 16 h, charge of sludge : 2.4 kg DS/m^2). Results showed a mean dryness limit of 30.5± 0.1%.

Influence of flocculation hydrodynamics conditions on drainability index

It is well known that flocculation conditions influences strongly the efficiency of a drainage process, particularly mixing time which is the parameter which is not fixed in the standard prEN 14742 since it depends on sludge and polymer characteristics. [12]. Figures 1a-b point out the influence of this parameter on drainability index for diluted and concentrated activated sludge.



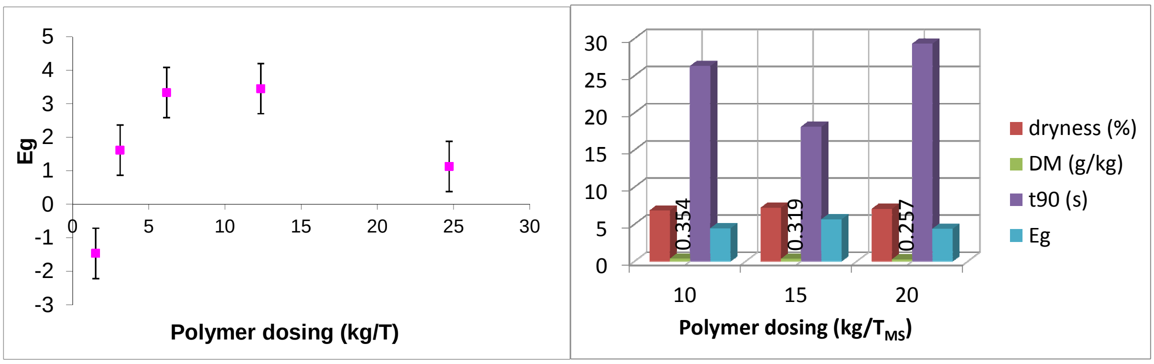
(a) Diluted activated sludge (b) Concentrated activated sludge

Figure 1 : Influence of mixing time on drainability index

Experiments carried out on diluted activated sludge show a plateau for the drainability index beyond 30 s mixing time, whereas a 10 s mixing time decreases significantly drainage kinetics, thickened sludge dryness and filtrate quality. The optimum mixing time for concentrated activated sludge is much lower, close to 10 s. Below this value, flocs are not completely formed and a 15 s mixing time, modifies particle size distribution and then alters the drainage kinetics and filtrate quality, leading to a decrease of drainability index from 5.5 to 3.8.

Influence of polymer dosing on drainability index

Polymer dosage is known to affect drainage kinetics [11] but equivalent drainage kinetics can be obtained in a wide range of polymer dosing [8]. Figures 2a-b point out the influence of this parameter on drainability index for diluted and concentrated activated sludge.



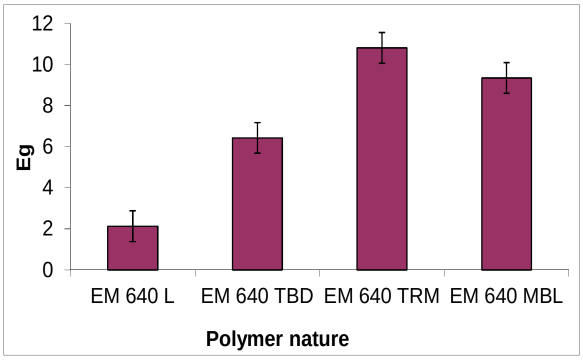
(a) Diluted activated sludge (b) Concentrated activated sludge

Figure 2 : Influence of polymer dosing on drainability index

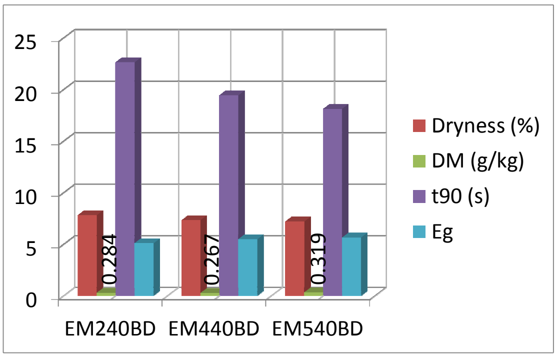
Experiments carried out on diluted activated sludge show an optimum range of EM 640 L between 6 and 13 kg/t DS. A polymer dosing below 6 kg/T DS affects kinetics parameter, sludge dryness and filtrate quality because flocs are too small whereas a polymer dosing higher than 13 kg/T DS affects only kinetics parameter owing to increase of filtrate viscosity. The same trend is observed with the concentrated activated sludge for which the optimum drainability index falls down from 5.5 to 4.4 at 10 and 20 kg/T DS. At 10 kg/T DS, flocs break down easily when falling on to the filter cloth whereas at 20 kg/T MS, viscosity is too high (the time of measurement of residual suspended matters was 4 times higher).

Influence of polymer nature on drainability index

The mechanism of polymer-induced flocculation depends upon the nature of interaction between polymer and sludge and polymer nature affects strongly floc formation, thickenability and mechanical resistance. Structured high molecular weight emulsion polymers are known to form large and bulky flocs, of high drainability but require higher dosage and mixing time at a given speed than linear polymers. Linear polymers lead to smaller flocs of lower filtration rate and increasing the cationicity has a detrimental effect on performances [14]. Figure 3a-b point out the influence of polymer structure on diluted activated sludge drainability and the influence of polymer cationicity on concentrated activated sludge.



(a) Diluted activated sludge



(b) Concentrated activated sludge

Figure 3 : Influence of polymer nature on drainability index

Experiments carried out on diluted activated sludge point out the better drainability index obtained with structured (EM 640 TRM) and crosslinked polymer (EM 640 MBL) comparatively to linear polymers (EM 640 L). The drainability index variations are mainly linked to kinetics parameter rather than thickened sludge dryness and filtrate solids content. Large loose or bulky flocs with great proportion of free filtrate are often required for thickening. Cationicity have a lower influence if flocs are correctly formed, that is the case with high to medium charge density and medium to low molecular weight polyelectrolytes [15]. A 20% cationicity polymer leads to a drainability index of 5.1 which is close to those obtained with 40 and 50% cationicity polymers (5.4 and 5.5). The predominant influence of polymer structure on drainability index comparatively to polymer cationicity was already shown in other work [7]. Nevertheless it is probably true only in a limited range of cationicity, depending on sludge.

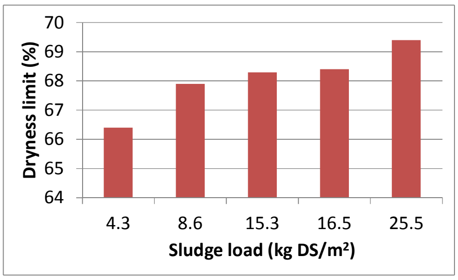
Influence of sludge and corresponding flocculation conditions on dewaterability

Sludges of different origins were flocculated in the optimal way concerning their drainability. Table 1 summarizes their characteristics before dewatering.

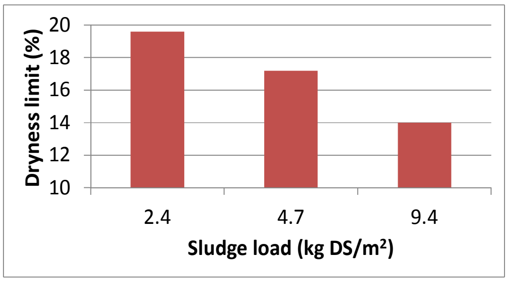
Table 1 : Sludge characteristics before dewatering

Sludge	Activated (common)	Activated (concentrated)	Food industry	Water Supply	Digested	Mineral synthetic
Polymer	Zetag 9048 FS	EM 540 BD	EM 640 TBD	Zetag 8140	Zetag 8185	AN 926 SH
Nature	cationic crosslinked	Cationic structured	Cationic structured	Cationic linear	Cationinc linear	Anionic linear
Dosing (kg/T DS)	6.5	15	21	7	26	2
Sludge dryness (%) after thickening	4.4	7.2	6.3	6.9	4.6	27.7
Eg	4.3	5.5	2.2	0.3	-3	-1.8

Dewaterability of these different sludges was assessed by the calculation of their dryness limit. As specified in FD-T 97001-1, the dryness limit was mainly dependent on 3 parameters : solids load, pressure and compression time. Preliminary experiments were carried out to highlight their influence on mineral (synthetic) and organic sludges (concentrated activated sludge) as illustrated in figures 4a-b, 5a-b and 6 a-b. Results show opposite behaviour between mineral and activated sludge.



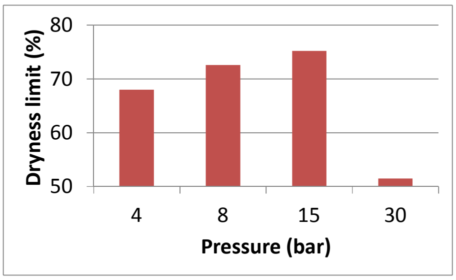
(a) Synthetic mineral sludge



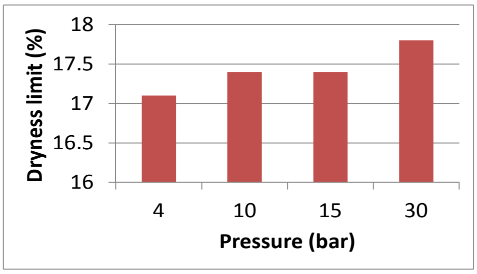
(b) Concentrated activated sludge

Figure 4 : Influence of solid load on dryness limit (Pressure : 4 bar, compression time : 16 h and 4 h respectively for mineral and organic sludges)

Dryness limit of mineral sludges increases slightly from 66 to 69% with charge load in the range 4-25 kg DS/m^2 whereas it decreases from 20 to 14% in a lower range of charge load (2-9 kg DS/m^2) for organic sludges. The decrease of dryness of sewage sludges with solids load was observed in other work [8].



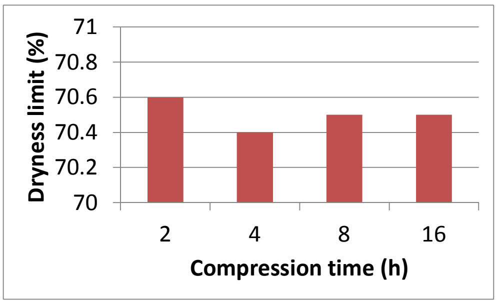
(a) Synthetic mineral sludge



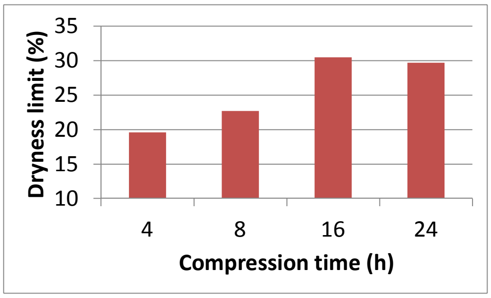
(b) Concentrated activated sludge

Figure 5 : Influence of pressure on dryness limit (Solids load : 16 and 5 kg DS/m^2, compression time : 16 h and 4 h respectively for mineral and organic sludges)

Dryness limit of mineral sludges increases from 68 to 75% with pressure varying from 4 to 15 bar. At 30 bar, dryness limit falls down to 50%, probably to flocs breakage. Dryness limit of compressible organic sludges does not vary significantly with pressure as shown in other works [8] [10].



(a) Synthetic mineral sludge



(b) Concentrated activated sludge

Figure 6 : Influence of compression time on dryness limit (Pressure : 4 bar, solids load : 16 and 2.4 kg DS/m^2 respectively for mineral and organic sludges)

Dryness limit of mineral sludges is independent from compression time in the range 2-16 h because the cake compression kinetics of flocculated thickened sludge is very fast. It is not the case of organic sludge where it takes 16 hours to have complete dewatering, owing to the slow and continuous deformation of the cake during expression [16].
Table 2 summarizes the dryness limit of sludges of different origins in comparison to dryness obtained on industrial centrifuges.

Table 2 : Sludge characteristics after dewatering

Sludge	Activated (common)	Activated (concentrated)	Food industry	Water Supply	Digested	Mineral synthetic
Charge load (kg DS/m^2)	2	2	2	2	2	4
Pressure (bar)	4	4	4	4	4	4
Compression time (h)	16	16	16	16	16	16
Cake thickness (mm)	10	8	8	2	13	3
Dryness limit (%)	23.4	30.5	24.4	52	22.9	66.4
Dryness on centrifuge (%)	21.5	18	19	23	21	No data
Ratio	0.92	0.59	0.78	0.44	0.92	No data

Results show that sludges of highest drainability index don’t give the better dewaterability characteristics since the mineral sludges, difficult to thicken by gravity filtration, have highest dryness limit.. Nevertheless, correlation is not only linked to the volatile matter contents. Except for water supply treatment sludges for which the dryness limit was obtained with a too low cake thickness, the dryness obtained on centrifuge correspond to 0.8-0.9 of the dryness limit when the operating conditions are optimized for a dewatering purpose (that was probably not the case for the plant where concentrated activated sludge was sampled).

CONCLUSIONS

For sludge thickening by gravity filtration, drainability index, including all the 3 most important parameters : concentration ratio (ability of sludge to be thickened), kinetics of water release and quality of filtrate (abililty of sludge to be flocculated) is a good tool for flocculation conditions choice, provided that the more adapted laboratory device is used for repeatable experiments as the bootest for concentrated sludges. A good drainability index is due in most cases to a fast kinetics of water release and is mainly modified by polymer nature (structure, cationicity), dosing and mixing time.
The concept of “dryness limit” is a good parameter to assess sludge dewaterability and is most significantly modified (depending if sludge is mineral or organic) by solids load, expression pressure and time. A consensus will have to be found for choosing these parameters for the development of a future standard.
Results show that the sludge, which displays the best drainability index, may present a low dewaterability and further work is needed to define a “dewaterability index” which includes flocs mechanical resistance, not taken into account in the drainability index.

SYMBOLS

DS, DM : dry solids or dry matters
E_g : drainability index
M : mass of filtrate after drainage (g)
M_o : mass of sludge before drainage (g)
P_1 : concentration factor
P_2 : kinetics parameters
P_3 : filtrate quality parameter
Si_f : dryness of thickened sludge by drainage process (%)

Si_0 : sludge concentration (% or g/kg)
SM_r : residual suspended matters (g/kg)
$S\infty$: dryness limit
t : compression time (s)
t_{90} : drainage time to eliminate 90% of the total volume of filtrate (s)
VM : volatile matters
α, β, a, b, c : constant parameters

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