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FACTORS AFFECTING THE DEWATERING EFFICIENCY OF CHEMICAL SLUDGES

Thickening and dewatering of chemical sludges originating from coagulation of water and wastewaters is discussed. Enhancement of various dewatering processes is achieved through: combination of water and wastewater sludges, coagulant recovery, use of coagulant aids and parameters optimization in centrifuging, vacuum and pressure filtration. Factors affecting the efficiency of sludge dewatering include also novel chemical and thermal conditioning methods, temperature, reaction- pH, and sludge aging.

1. INTRODUCTION

The observed rapid increase of the volume of coagulation sludges originating during treatment of water and wastewaters is the result of the continuous increase of the suspended solids raw waste loading, the need for tertiary treatment of biological effluents and of the deteriorating quality of surface water supplies. Only in United States, the coagulation of raw water with aluminium sulphate results in an annual residual sludge amounting to ten million tons. Thus, the established practice of discharging chemical sludges from water treatment processes to rivers had to be curtailed.

This almost exponential increase of the volume of chemical sludge has created an urgent need for improvement of the economics of the coagulation process:

1) through decrease of the basic coagulant dose by applying various coagulant aids;
2) by upgrading the efficiency of existing chemical sludge dewatering equipment;
3) by reuse of the chemical sludge in an unchanged form;
4) through recovery of coagulants from sludge;
5) by introduction of novel sludge dewatering and disposal methods.

Based on the results of authors' own research and interpretation of other investigators' work, certain factors influencing the efficiency of dewatering sludges originating in the coagulation of water and wastewater will be presented, followed by recomendation for further research.

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2. PRINCIPLES OF DEWATERING

Evaluation of sludge properties and selection of treatment methods is based on chemical composition of the coagulation sludge. The aim of applied treatment is to decrease the volume by decreasing the water content of sludge. Dewatering achieves a degree of moisture removal intermediate between the processes of thickening and drying, and allows for solids concentrations of 20 to 30% with organic sludges and around 60% with some inorganic sludges. Part of the water in the chemical sludge is bound with the solid phase surface, while part of the water fills the interspaces as free water (unbound). The water existing in chemical compounds or in the hydrate crystals is not considered in the sludge dewatering studies; it is assumed that it is incorporated in the solid phase. Less stable are the physico-chemical forms of water bindings, occurring at the surface of particles due the interparticle forces. Mechanically bound water is in most cases the free water enclosed in a three-dimensional structure of the solid phase, and is amemable to conditioning and dewatering processes. The volume of this water may be 50 times the solids volume for sludges with good settling properties. In case of chemical sludges the volume of aggregate particles may be anywhere up to 200 times the volume of actual solids.

The changes in the quantity of bound water determine the efficacy of dewatering and are dependent upon the value of the electrokinetic potential; the lowest value of the potential corresponds to the isoelectric point of the particles.

In summary, the dewaterability of the chemical sludge depends on factors such as concentration, size, shape and surface characteristics of sludge particles, the extent and structuring of aggregation, the viscosity, ionic strength and pH of the suspending water. Since the theoretical modelling is presently unable to estimate exactly the influence of individual factors, the filterability predictions are based on performance parameters which reflect the combined influence of the variables. The principal descriptive parameters singled out are specific resistance to filtration (r) or the capilary suction time (CST), and the compressibility coefficient (s).

Presently used, economically efficient methods of chemical sludge dewatering, excluding biological treatment of combined sludges, are presented in fig. 1.

3. THICKENING

Removal of free-unbound water from sludge occurs during settling and gravitational thickening. Present knowledge of these processes does not allow for establishing theoretical principles of sedimentation and thickening based on physical, chemical and structural properties of the sludge, expressed in mathematical terms. Detailed knowledge of settling and thickening properties calls for individual analysis of given sludge. The effects of both processes are expressed in terms of the velocity of subsidence of the interface between the sludge and the supernatant.

Typical results of sedimentation and thickening of post-coagulation sludge, attained from authors' work at Tomaszów water treatment plant (No. 1) are presented in fig. 2.

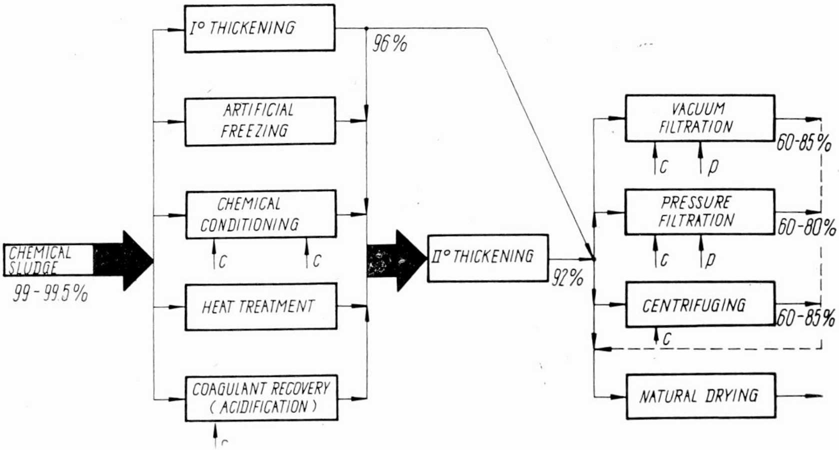

Fig. 1. Alternative methods of dewatering chemical sludges. (In brackets: sludge moisture usually attained); *c* — indicates possibility of coagulant addition; *p* — precoat may be applied

Rys. 1. Alternatywne metody odwadniania osadów chemicznych (w nawiasach: uzyskiwane uwodnienie osadów); *c* — oznacza możliwość wprowadzenia koagulanta wspomagawczego; *p* — możliwość stosowania podkładów, np. okrzemowych do filtracji

The times required for optimum decrease of the volume are denoted by letter K_n. Fig. 3 presents the K_n values versus the initial water contents of the sludge for three different waterworks [26]. Plant 2 sludge, containing no coagulants, had the best settling and thickening properties. The alum sludge from plant 1, contained microscopic and colloidal particles and settled and thickened much slower than the plant 2 sludge and ferric hydroxide sludge from plant 3.

It should be noted here that conversely to wastewater treatment practice (both tertiary and primary), slow mixing of thickening sludge is very seldom practiced with waterworks sludge. Mixing tends to decrease the process time by increasing the contact opportunity and agglomeration and yielding denser underflows, however it decreases quality of supernatant water.

Thickener loadings vary with nature of sludge between 15 and 150 kg solids/m^2 day, producing underflows between 0.2 and 10% d. w. solids.

Polymer addition is an effective and widely used process that greatly enhances settling and thickening. The mechanism responsible here is based principally on adsorption activity of the polymers functional groups, which join the solid phase surface by hydrogen bondings, and on the lowering of the electrokinetic potential of the particles and their flocculation. Polymers (i. e. synthetic organic polyelectrolytes) used for conditioning sludges of inorganic origin are usually of anionic or ampholytic ("non-ionic") type while sludges with high organic content usually call for cationic polyelectrolytes [24]. Since the world market offers at the moment almost 200 different polyelectrolytes, an optimized

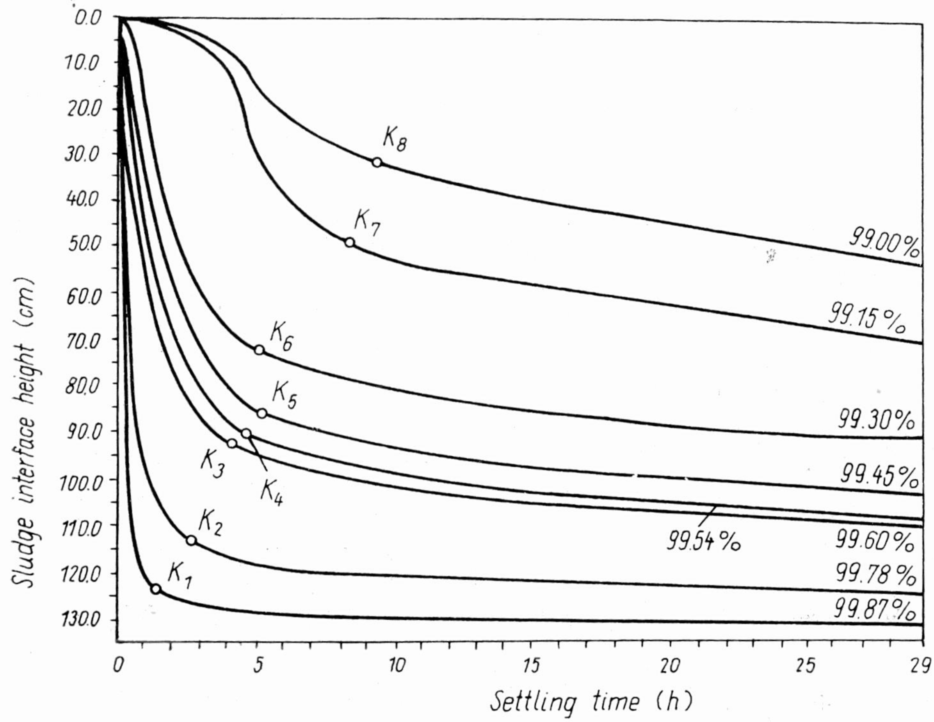

Fig. 2. Settling and thickening curves for alum sludge from water treatment plant at Tomaszów, for various initial solids content. Points *K* denote the beginning of thickening phase

Rys. 2. Krzywe sedymentacji i zagęszczania osadów pokoagulacyjnych o różnych uwodnieniach z zakładów oczyszczania wody w Tomaszowie Mazowieckim. Punkty *K* oddzielają proces sedymentacji od zagęszczenia

selection of the coagulant and an aid is impossible without experiments. Examples of such studies are presented in figures 4 and 5. It should be stated here that results of polymer addition are much more rapid, and evident with sludge that contain smaller doses of the primary coagulant.

In summary, gravitational thickening is a viable, cost-effective process that should always precede subsequent dewatering. The complexity of factors involved in the process calls for basing the design on pilot studies and allowing for maximum operational flexibility in full scale.

4. COMBINING WATER AND WASTEWATER SLUDGES

The simplest method of "disposal" of water treatment sludge is the discharge to the sewer system, wherever the sewerage construction and regulations permit. Although several large cities practice this method, the general contention so far has been that introduction of these sludges to the wastewaters decreases the efficiency of primary wastewater sedimentation, of anaerobic and aerobic digestion, etc. The more systematic research in the recent years has documented that:

1. Sludges from coagulation of water improve the primary settling of wastewater, provided that their dose will not exceed the optimum for given wastes and/or that polymers will be used;

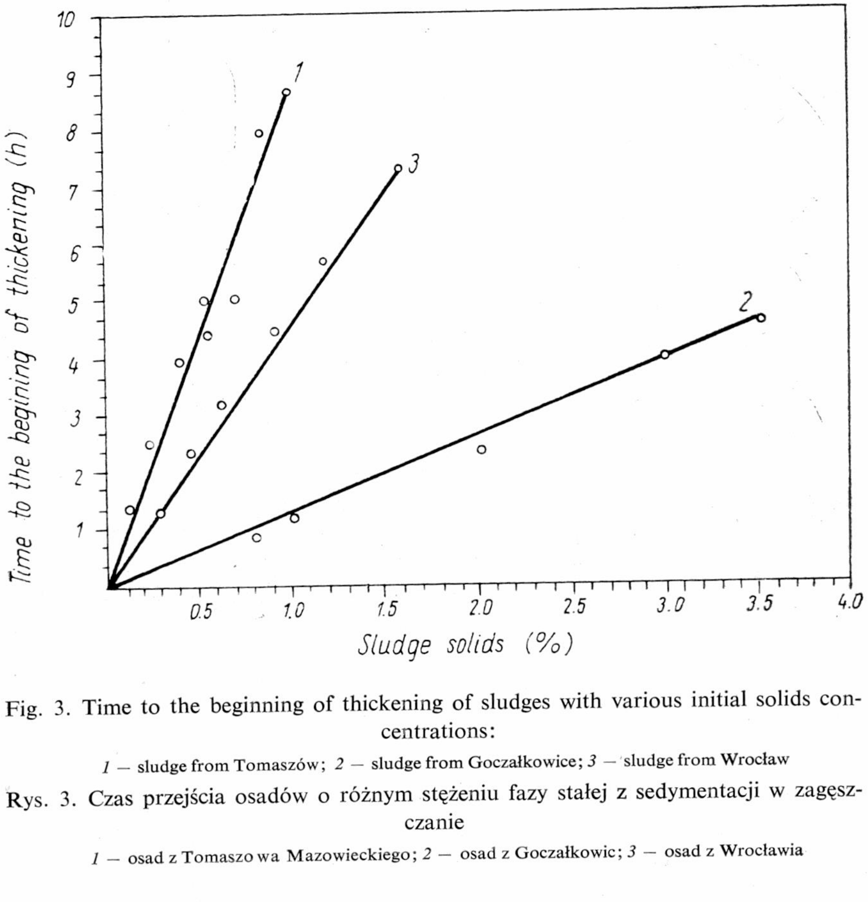

Fig. 3. Time to the beginning of thickening of sludges with various initial solids concentrations:

1 – sludge from Tomaszów; *2* – sludge from Goczałkowice; *3* – sludge from Wrocław

Rys. 3. Czas przejścia osadów o różnym stężeniu fazy stałej z sedymentacji w zagęszczanie

1 – osad z Tomaszowa Mazowieckiego; *2* – osad z Goczałkowic; *3* – osad z Wrocławia

2. Presence of chemical sludges in wastewaters improves the phosphorus removal efficiency in the biological treatment;

3. Sludge from lime coagulation of water significantly improves the efficiency of wastewater sludge dewatering processes;

4. The participation of alum and iron sludges from water treatment in wastewater sludge will not deteriorate the latter's dewatering properties if some additional conditioning is provided;

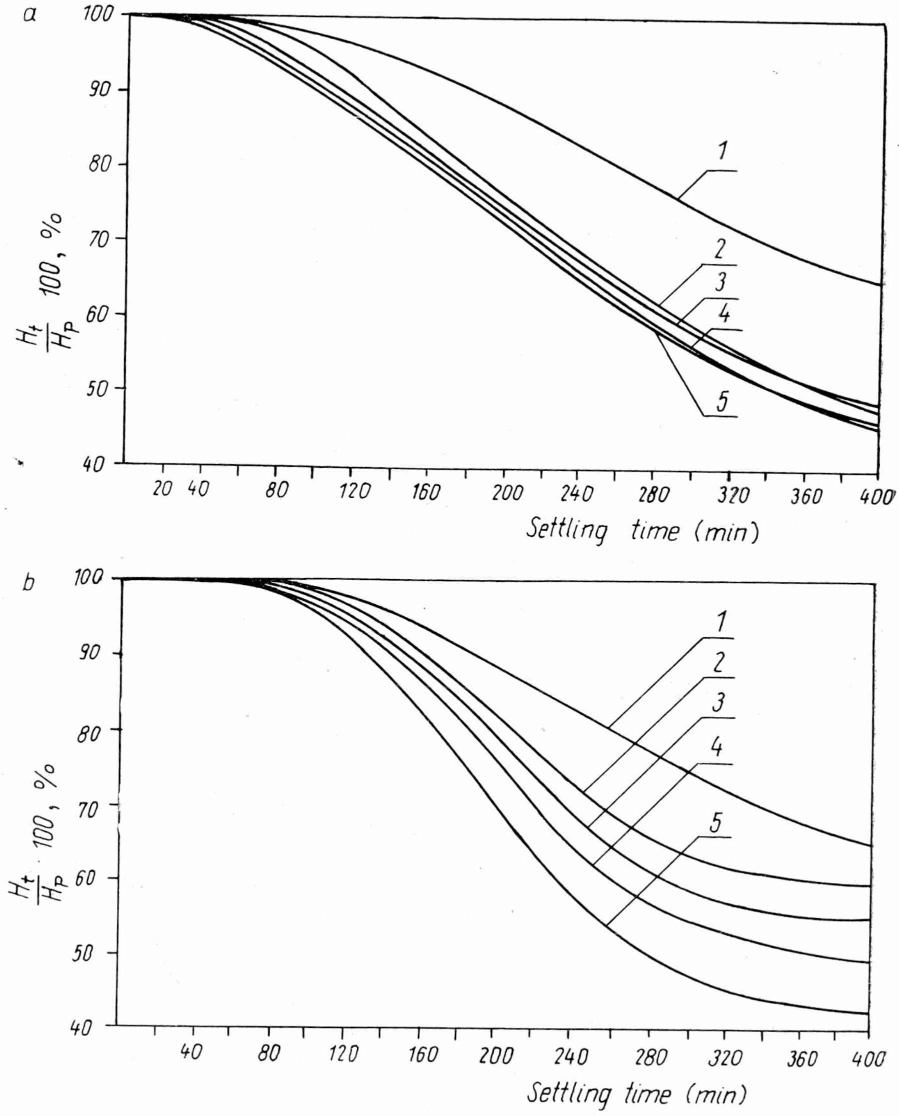

Fig. 4. Effects of polyelectrolytes on settling and thickening of sludge from Tomaszów waterworks at initial water contents of 99.11%:

a — metakrylamid, *b* — gigamid, H_t/H_p-ratio of final to initial sludge-supernatant interface
1 — unconditioned sludge, and *2*, *3*, *4*, *5*, — sludge conditioned with polyelectrolytes at respective doses of 1.0; 2.0; 4.0; and 8.0 g/m³

Rys. 4. Wpływ metakrylamitu, giganitu na przebieg sendymentacji i zagęszczania osadu z Tomaszowa Mazowieckiego o uwodnieniu 99,11%

a — makrokrylamid, *b* — gigamid, H_p — wysokość warstwy osadu na początku sedymentacji, H_t — wysokość warstwy osadu w czasie sedymentacji i zagęszczania
1 — osad bez dodatku polielektrolitu, *2* — dawka 1,0 mg/dm³, *3* — dawka 2.0 mg/dm³, *4* — dawka 4,0 mg/dm³, *5* — dawka 8,0 mg/dm³

5. Water coagulation sludge may in many cases substitute for fresh coagulants in the precipitation of raw wastewaters or biological effluents;

6. Overloading with water coagulation sludge (e. g. batch discharges) results similarly to the overdose of coagulant or a polymer (see fig. 5).

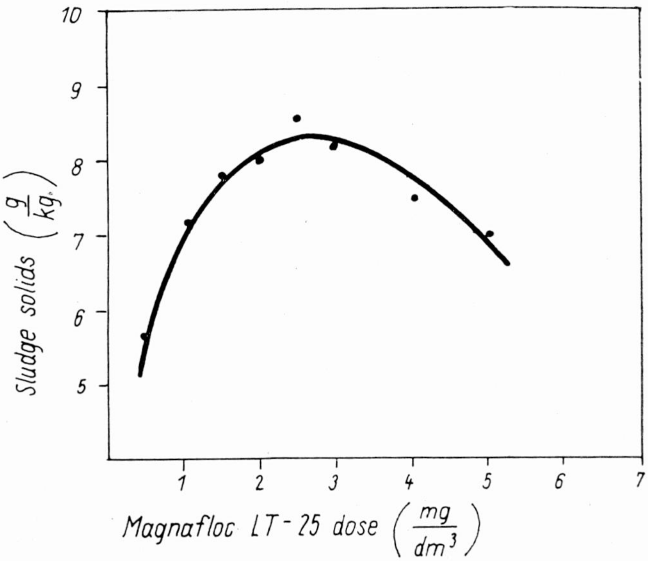

Fig. 5. Effect of Magnafloc LT-25 on thickening of sludge from Warsaw waterworks

Rys. 5. Wpływ Magnafloku LT-25 na efekty sedymentacji i zagęszczania osadów z warszawskich pulsatorów

Taking these findings into account the process of combining water treatment sludge with wastewater sludges should be considered as one of the principal methods of disposal of chemical coagulation sludge.

5. FILTRATION

Principles of filtration have been developed on the basis of empirical evidence; the theory of the process, however is not yet fully elaborated. The equations used for analysis of most problems refer to ideal sludge conditions (Carman-Kozeny, Gale, Cornell, etc.) and thus the coefficients have to be determined empirically. The empirical approach, which involves Büchner funnel tests and filter leaf tests, and other more complex models of the full-scale filters, yields information on the two principal filterability parameters: specific resistance to filtration (r) and the compressibility coefficient (s).

Sludges from coagulation of water with aluminium sulphate are compressible and difficult to dewater by filtration. The compressibility coefficient for these sludges varies from 1.030 to 1.25, while their specific resistance varied in our work between

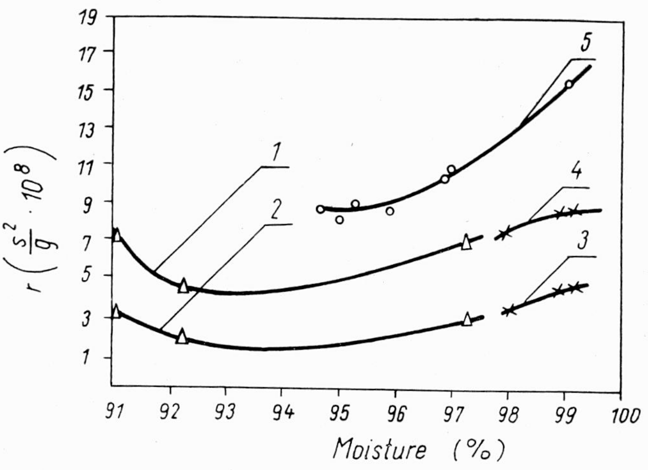

Fig. 6. Influence of initial water contents in waterworks sludges on their specific resistance r:

1, 2 — sludge from Tomaszów at 748 G/cm^2 and 299 G/cm^2, respectively; *3, 4* — sludge from Bobr River at 272 G/cm^2 and 680 G/cm^2, respectively; and *5* — sludge from Wrocław at 680 G/cm^2

Rys. 6. Wpływ uwolnienia osadów na wartość oporu właściwego

1, 2 — osad z Tomaszowa Mazowieckiego (748 G/cm^2 i 299 G/cm^2), *3, 4* — osad koagulacji domieszek wody z rzeki Bóbr (272 G/cm^2 i 680 G/cm^2), *5* — osad z Wrocławia (680 G/cm^2)

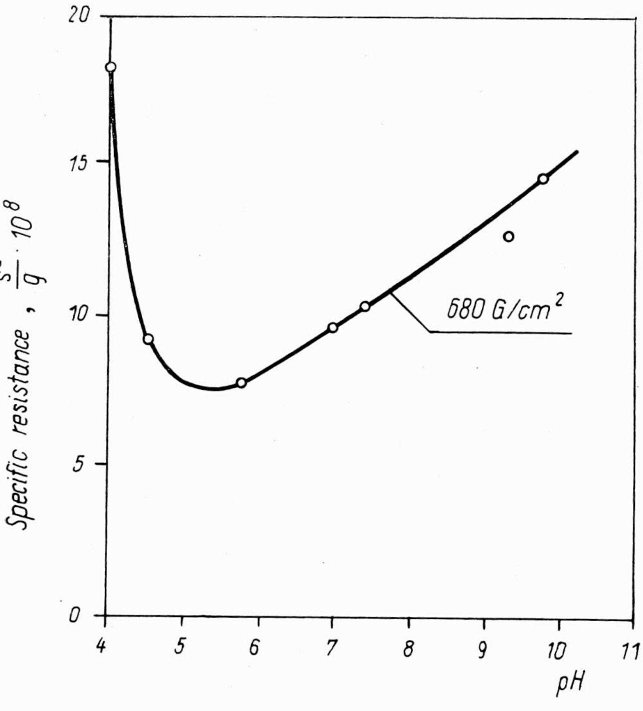

Fig. 7. Effect of varying pH on filtrability of Tomaszów waterworks alum sludge at initial moisture of 98.2%

Rys. 7. Zmiana wartości oporu właściwego osadu pokoagulacyjnego o uwodnieniu 98,2% z Tomaszowa Mazowieckiego w zależności od odczynu

$74\text{-}300 \times 10^{11}$ m/kg. Other authors quote for alum water coagulation sludges values of $r = (54–204) \times 10^{11}$ m/kg at initial solids content $TS = 0.98–7.8\%$, and iron sludges $r = (7.2–48.8) \times 10^{11}$ m/kg at total solids content $TS = 3.9–8.5\%$ [22].

The value of specific resistance varies with temperature, pH and initial moisture content in the chemical coagulation sludge as illustrated by figures 6 and 7 [2]. The mechanism responsible for such change in "r", as shown in fig. 7, is of chemical nature, while influence of concentration in fig. 6 and of temperature is more of physical nature.

Similar relationships may be obtained by using a much simpler technique of measuring the capillary suction time — *CST* [17]. The *CST* relates to "r" by a simple reggression equation which takes into account the solids content *TS*:

$$\log(CST/\%TS) = A \log r - B.$$

The existence of a distinct relationship between the initial solids concentration of the chemical coagulation sludge and the *CST* or specific resistance has also been found by other authors [12, 13].

It should be noted that our experiments included also pilot scale tests on a model rotating vacuum filter (Area $= 1\ m^2$) and on a model multi-frame filter press (Area $= 0.25\ m^2$). The results indicated that lab-bench filterability determinations give a very rough and frequently inadequate estimate of the filter yields in larger scales.

5.1. SLUDGE AGING

Aging has significant effect on the filterability of sludge from coagulation processes. The process of aging occurs in sludge after prolonged storage and consists in formation of new interparticle bondings, which create a three dimensional structure which increases their mechanical strength. In case of sludges of wastewater origin the phenomena of facultative biochemical stabilization also take part. As a rule, aging results in a decrease of moisture in sludge and an increase of its specific resistance.

The change of specific resistance with the increasing storage time, presented in fig. 8 is characteristic of chemical sludges containing large amounts of organic matter. In the studies from which the graph in fig. 8 has been taken, the sludge was obtained by alum coagu-

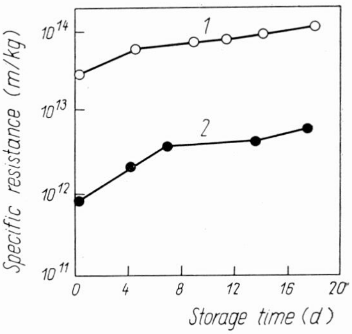

Fig. 8. Change of specific resistance as the result of aging; 1 — raw wastewater coagulation sludge, 2 — the same sludge after 30 days of aerobic stabilization

Rys. 8. Zmiana oporu właściwego w wyniku starzenia się: 1 — osad z koagulacji ścieków surowych, 2 — ten sam osad po 30 dniach stabilizacji tlenowej lation of raw municipal wastes and subsequently subjected to aerobic stabilization [8]. Although aerobic stabilization, as any other mineralization process decreases the initial value of specific resistance, *r*, the course of the aging process seems to be analogous, regardless of the time of stabilization. In any case the most rapid increase of "*r*" occurs during the first days of storage.

The knowledge of the process of aging of coagulation sludge should be taken into account in the scale-up of dewatering equipment, particularly is case of small sludge processing plants. As demonstrated in fig. 8 after only four days of storage of stabilized chemical sludge, its specific resistance has increased five times the initial value.

5.2. SLUDGE CONDITIONING

In newly designed water or wastewater treatment plants, sludge treatment and dewatering are optimized elements (selection of the type and efficiency of primary coagulants, methods of recovery, etc.) of importance equalling that of the water or wastewater treatment train. In existing plants sludges were usually regarded separately, and had to be additionally conditioned before filtration. It is indispensable to conduct an optimization analysis of the dewatering system to select type and level of required conditioning.

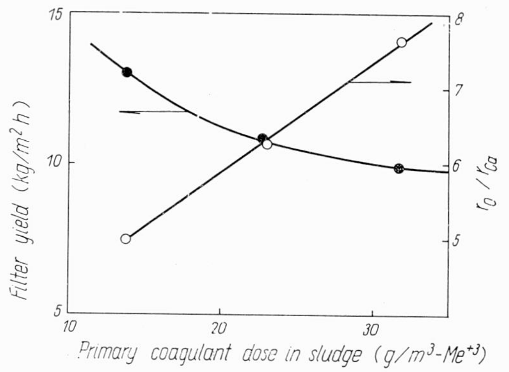

Fig. 9. Filtration of primary wastewater coagulation sludge, conditioned with lime, at various primary coagulant doses

Rys. 9. Filtracja osadu z koagulacji ścieków surowych, kondycjonowego wapnem, przy różnych dawkach koagulanta pierwotnego

Two types of conditioning methods are presently used in practice: chemical conditioning and thermal preparation. Chemical conditioning usually involves coagulation with lime. Because of the applicability of lime to conditioning of chemical sludges it is always advisable to consider lime as the primary coagulant, particularly in case of wastewaters. Another group of conditioning chemicals involves a variety of soluble polymers.

Effects of lime conditioning on the vacuum filtration are presented in fig. 9. The graphs have been made from the results reported by FARRELL et al. [9] for conditioning primary sewage sludge precipitated with aluminum or ferric hydroxides. The relationship of the ratio of specific resistance of sludge prior to conditioning (r_0) and after lime conditioning (r_{Ca}) versus increasing coagulant dose, indicates that lime may improve filterability of sludges many times regardless of the detrimental effect of increasing dose of primary coagulant. Data was extracted from runs with lime dose of 0.21–0.25 g $Ca(OH)_2$/g d. w. of sludge.

The dose of conditioning agent should always be determined experimentally since the dose range used in practice varies significantly. For example, at Atlanta waterworks sludge is conditioned for pressure filtration with a lime dose of 10–15% of sludge dry weight [21], while in another lime conditioning case of vacuum filtration of water coagulation sludge doses of 20 kg/m^3 (i. e. 50–100% per sludge d. w.) were applied [12].

5.3. THERMAL CONDITIONING

Thermal conditioning involves heat treatment, presently used more often, and freezing, a novel conditioning method that yields extremely filterable sludge although at high cost.

Heat treatment has been applied for digested wastewater sludge and chemical sludges usually with significant savings in maintenance costs. In the largest sludge heat conditioning plant, in Kalamazoo, USA, some 30% savings are effected as compared to chemical conditioning at 26 kg/cm^2 pressure and temperature of 450 K [27]. Thermal conditioning of combined wastewater sludges (activated and chemical), besides cost savings, frequently yields better technological effect than lime treatment. In another case of combined chemical and activated sludges heat treatment resulted in vacuum filter cakes with 40% d. w. and yields up to 45 kg TS/m^2 d [14].

Heat treatment breaks the colloidal structure of chemical sludge and decreases the viscosity of the sludge water. Studies on vacuum filtration of water coagulation sludge heated to 350–360 K produced cakes with 80–84% moisture contents and filter yield up to 9.1 kg d. w./m^2 h [21].

The increase of temperature, however, may result in the evolution of odors, significant deterioration of quality of filtrate and increase of the sludge chemical activity towards the filter media. The use of Fuller earth precoats at loadings of 0.2–0.4 kg/m^2 will prevent the contact of the chemical coagulation sludge particles with the filter media and facilitate the removal of sludge cake after filtration. The moisture of cakes obtained with this precoating technique applied to pure chemical sludges is around 80%, however, the low yields-up to 4.5–9.0 kg/m^2 h make the process economics questionable.

Freezing of chemical coagulation sludges is a new artificial conditioning process which consists of regularly repeated sludge freezing-thawing cycles. During the freezing phase, the formation and enlargement of ice crystals from sludge water is observed, accompanied by the occurence of large pressures directed at solid particles. The thawing phase is accompanied by subsidence of dewatered particles that exhibit completely different structural, physicochemical, technological and hydromechanical properties when compared to raw coagulation sludge.

The process of freezing results in destruction of anizotropy in the bound water interface which yields an increase of the free water volume and leads to formation of grain-

-like solid particles. The water physicochemically bound to coagulation sludge particles evidences relatively high resistance to low temperatures. The destruction to this type of water bonding is considered the primary reason for the irreversible changes in the sludge properties during freezing; it calls, however, for large amounts of heat energy.

The principal factors affecting the efficiency of phase separation and dewatering are velocity and time of freezing, specific resistance of sludge, and concentration of dissolved solids in the sludge water portion. The most effective dewatering requires, according to LOGSDON and EDGERLEY [19] small freezing velocities, not exceeding 4×10^{-2} to 6×10^{-2} m/h which should result in complete phase separation. Large values of specific resistance significantly reduce the flow of sludge water through the sludge to the ice, and similarly to large freezing velocities, lead to incomplete phase separation which decreases the process efficiency. Optimal parameters for freezing water coagulation sludges are presented in the classic work by DOE et al. [7] based on pilot and full scale studies in Stocks and Fishmoor, UK.

So far, indirect freezing with heat exchange has been primarily applied in full-scale. Although the results of this conditioning were exceeding all expectations, accompanied by high dependability of equipment, the unfavourable economics prohibited its wider use beyond individual waterworks in UK, Japan and West Germany.

Recent work has proved, however, that freezing may be a cost-effective conditioning technique at large waterworks (capacities over 100 000 m^3/d) and at temperatures of 258 to 269 K and times of 25 to 70 minutes. Table 1 presents results of alum sludge conditioning from three pilot plants [29].

Parallel studies into the improvement of economics of this truly the most efficient conditioning technique, have proved that the direct freezing may also find application and at

Table 1

Effects of freezing on dewatering of alum sludge

Water treatment plant	Vacuum filtration		Gravity thickener underflow solids (%)
	Yield (kg d.w./m^2 h)	Cake solids (%)	
Chicago			
no conditioning*	3.6	20	2 to 4
after freezing**	151	34	20
Salt Lake City			
no conditioning*	1	18	1.5 to 3
after freezing**	252	25	19
Erie Co.			
no conditioning*	4	21	2.5 to 5
after freezing**	302	33	22

* Full scale data from filters with Fullers earth precoat.

** Pilot scale data — minimum numbers eited.

much more competitive costs [25] — with reasonable technological effects [filterability improvement by 350% and sludge settleability improvement by 100%).

In conclusion natural freezing of the coagulation sludge should also be mentioned. The process is applicable to cold and moderate climates. The practice in USA [10] involves lagooning after empirical calculations of retention times based on sludge depth and meteorological conditions.

5.4. VACUUM FILTRATION

Vacuum filters are conventionally the most popular dewatering devices. Depending on the type of chemical sludge and the conditioning applied the filter yields usually range from 7 to 80 kg/m^2.d (dry weight -d. w.) at cake solids contents equal to 13–34% d. w., with feed solids concentrations from 1–7% d. w.

Although recently pressure filters and centrifuges gain wider acceptance for dewatering chemical sludges, there are numerous examples of dewatering lime or alum precipitated wastewater sludges where vacuum filters have definitely outperformed the centrifuges [15], and other equipment [11].

The improvement of efficiency of filtration equipment is the most feasible through polymer conditioning. The type of filter media, cycle and formation times, and vacuum applied usually play a less significant role.

Polyelectrolytes are attractive because they induce no increase of the sludge volume, although the costs may at times be prohibitive. Another disadvantage is the unstable conditioning effect as a result of changes in sludge composition. Optimal dose is always determined experimentally and depends on type and concentration of sludge, its pH, admixtures and type and molecular weight of the polymer. As a rule, anionic polymers are the most efficient at neutral pH values. Cationic polyelectrolytes are effective at pH below 7.0, however, their lower molecular weight calls for larger doses.

The improvement of filtration efficiency in case of large molecular weight polymers is in most cases reflected by the improvement of filtration rate and not the filter cake solids concentration. This is related to the establishment of structural matrix and improvement of the resistance of sludge cake to compression. The mechanism is illustrated by the example taken from the studies of water coagulation with alum [22] where the compressibility coefficient is increasing with the application of various polyelectrolytes — fig. 10.

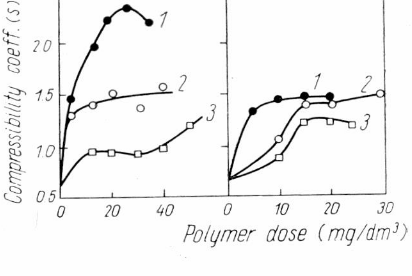

Fig. 10. Increase of the compressibility coefficient of alum water coagulation sludge after conditioning with polymers: *1* — anionic, *2* — cationic, *3* — nonionic

Rys. 10. Wzrost współczynnika ściśliwości osadu z koagulacji siarczanem glinowym w wyniku kondycjonowania polielektrolitami: *1* — anionowymi, *2* — kationowymi, *3* — niejonowymi

An optimum polyelectrolyte dose for the post-coagulation sludge increases with the increase of the solids contents of the sludge applied to the filter and with the increase of filter yield. Similar relationships are found for wastewater chemical sludges, which should always be conditioned with polymers since they contain very difficult to dewater solids built of phosphorous compounds.

Good example of factors influencing the optimum polymer dose is provided by data from six water treatment plants collected by Novak and O'Brien [22] during vacuum filtration test of alum sludges — fig. 11.

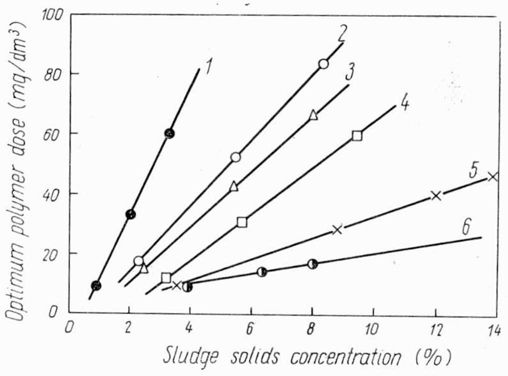

Fig. 11. Effects of initial solids and cake solids contents on optimum polymer dose, for cake solids: *1* — 22% d. w., *2* — 27%, *3* — 32%, *4* — 40%, *5* — 48%, *6* — 57%

Rys. 11. Wpływ uwodnienia osadu odwadnianego i placka na optymalną dawkę polielektrolitu dla suchej masy placka: *1* — 22%, *2* — 27%, *3* — 32%, *4* — 40%, *5* — 48%, *6* — 57%

5.5. PRESSURE FILTRATION

Pressure filters were applied successfully for the first time in Great Britain. Presently used filters have to be automated in order to be competitive with other dewatering equipment. The time of filter cycle (or "pressing time") depends on nature of sludge and may equal 0.5–20 hours. Even though no mechanical pressing is involved the compressibility coefficient plays a major role here. Since some of the sludges could not be conditioned by either vacuum or pressure filters because of compressibility of the cake, gravity (rotary) filters had to be invented.

The pressure filter allows the decrease of moisture in chemical coagulation sludge usually to 75–80%, sometimes approaching 50–60%. The results of pressure filters have recently been compared with the results of centrifuging and vacuum filtration of sludge from four water treatment plants. Alum sludge, which yielded gravity underflow concentrations of 2% d. w., was dewatered equally well on the vacuum filters and centrifuges yielding cakes of 20–30% solids d. w. Pressure filters dewatered the alum sludge from the same waterworks down to 40–50% solids in the filter cake [16].

Full scale application of pressure filters to dewatering of sludge from coagulation of water with ferric hydroxide yields good results at Neuilly-sur-Marne combined water and wastewater sludge treatment plant, where cakes with 46% d. w. solids are attained [5]. At Antwerp waterworks lime sludge dewatering on pressure filters yields 40% solids in

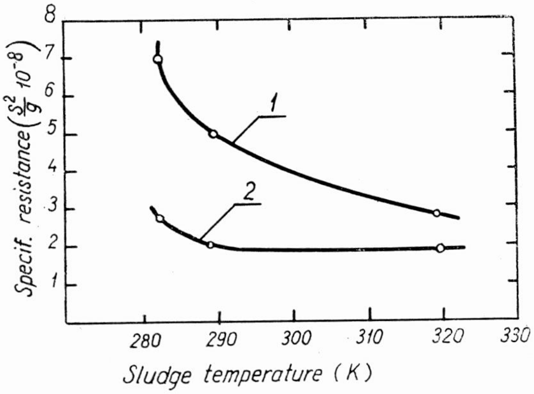

Fig. 12. Influence of temperature on specific resislance of Wrocław waterworks sludge at initial solids 95.02%,

1, 2 – respectively at 680 and 272 G/cm²

Rys. 12. Wpływ temperatury na wartość oporu właściwego osadu z Wrocławia o uwodnieniu 95,02%

1 – 680 G/cm², *2* – 272 G/cm²

cakes; similar results are obtained in pressure filtration of primary wastewater sludge mixed with lime water coagulation sludge at Wassau [1].

Due to operational inconveniences and novelty involved in application of the pressure filters to chemical sludge dewatering their design should always be preceded by cost-effective comparison with other equipment. Such was the case at Evans waterworks where such an analysis proved that pressure fllters will be more economical than vacuum filters and centrifuges [28].

The efficiency of pressure filtration is influenced by similar parameters that affect vacuum or gravity filtration. Of the least known factors, temperature seems to play a significant role in filtration. Fig. 12 illustrates the improvement in filtreability of water coagulation sludge from Wrocław waterworks, while fig. 13 presents the decrease of pressure filter cycle time with the increase of temperature. Fig. 13 has been obtained by interpreting the results of full scale pressure filter operation at Antwerp waterworks [6].

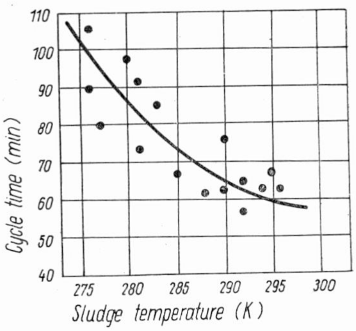

Fig. 13. Effect of temperature on pressure filter cycle time Antwerp waterworks sludge

Rys. 13. Wpływ temperatury na cykl filtracji ciśnieniowej osadów z oczyszczalni wody dla Antwerpii

6. CENTRIFUGATION

Dewatering by centrifugation is effected by sedimentation and thickening under large centrifugal forces, although this analogy to gravitational thickening is not complete. The centrifuge exerts the force varying with distance from the axis and there is a general lack of parallel directions of the centrifugal forces acting on sludge particles that are not positioned on the same radii. These reasons have precluded the development of theoretical or even empirical design basis. Thus the centrifuge installation has to be designed based on pilot and full scale runs since no scale-up procedures have so far been developed. A direct evaluation of centrifuge efficiency is expressed as centrifuging factor, which is determined by a transformed Froude number, which includes the centrifugal force.

Of the three cetrifuges used for sludge dewatering: vertical disc and basket type, and horizontal solid bowl type, only the latter has found wide application to dewatering coagulation sludges. Modern centrifuge installation consists of continuous sedimentation centrifuges equipped with helical screws (scrolls) for moving the consolidated solids to the discharge port which facilitates their further dewatering on the beach.

The effects of some of the process and machine variables on dewatering efficiency expressed as solids recovery from the incoming sludge into the cake and concentration of solids in the cake are presented in table 2. The usual cake concentrations achieved amount to 6–40% d. w. solids, with solids recoveries from 50–90% without conditioning, and over 95% with preconditioning.

The compilation in table 2 does not indicate which of the variables plays the leading role in centrifugation. The quality of centrate i. e. solids recovery is affected most by: the participation of difficult chemical sludges, throughput rate and bowl speed. Cake solids contents is significantly influenced by scroll speed and polyelectrolytes dose.

Table 2

Factors affecting the efficiency of centrifugation of chemical coagulation sludges

Varied parameter of:	Effect of the increase of variable parameter on the improvement (+) or deterioration (—) of:	
	Solids recovery and centrate quality	Cake solids content
The centrifuge:		
Bowl speed	(+) Q_{opt}	(+) Q_{opt}
Conveyor (scroll) speed	(—)	(—)
Pool depth	(+) Q_{opt}	(—)
The feed sludge:		
Feed solids contents	(—)	(+)
Participation of Al^{+3} or Fe^{+3} sludges	(—)	(—) Q
Participation of untreated biological sludges	(—)	(—)
Acid pretreatment	(+) Q_{opt}	(+) Q_{opt}
Temperature	(+) Q_{opt}	(+)
The process:		
Flow rate	(—)	(+)
Polymer or inorganic coagulant dose	(+) Q_{opt}	(+)

Note: Q — denotes that the effect of given variable may sometimes be diametrally different.
Q opt — denotes that there is an optimum and the sign may be reversed.

In order to illustrate the influence of the most important variable — the centrifugation factor, fig. 14 illustrates our results of dewatering alum sludge from water coagulation at various centrifugation times, bowl speeds and initial sludge solids contents. The effect of

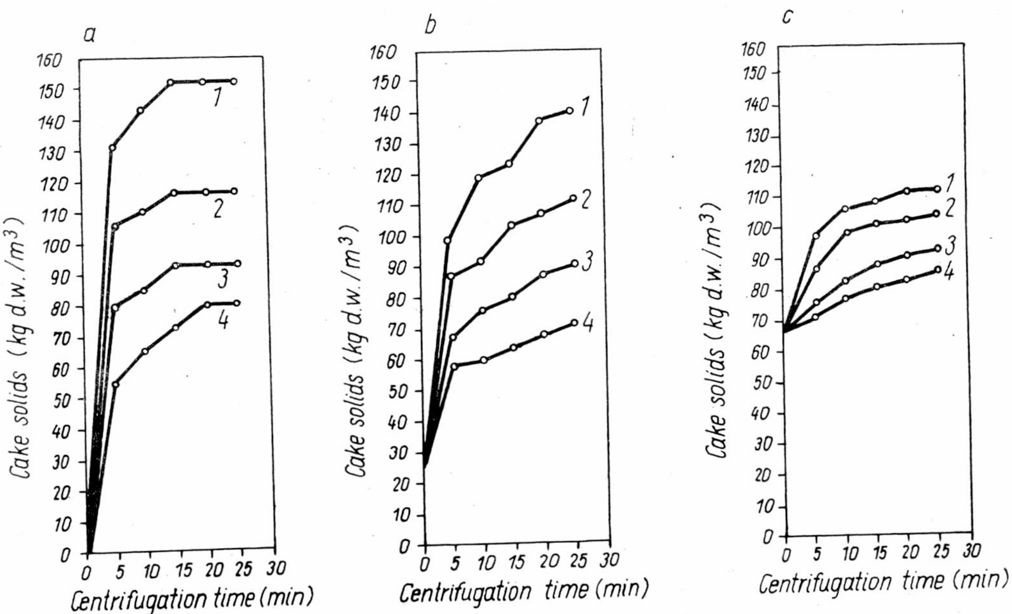

Fig. 14. Cake solids versus various centrifugation factors:

1 — 2010, *2* — 975, *3* — 352, *4* — 156, at different initial water content of Tomaszów waterwork sludge: a) 98.80%; b) 97.45%; c) 93.44%

Rys. 14. Efekty odwadniania osadu pokoagulacyjnego z Tomaszowa Mazowieckiego w zależności od różnych współczynników wirowania (WW)

varying polymer dose is illustrated (fig. 15) by the results obtained by the authors during centrifugation of raw primary sewage sludge precipitated with aluminum and ferric hydroxides (23]. Effects of polyelectrolyte conditioning of alum sludge from water coagulation, on solids recovery are presented in fig. 16 for various centrifugation factors [3].

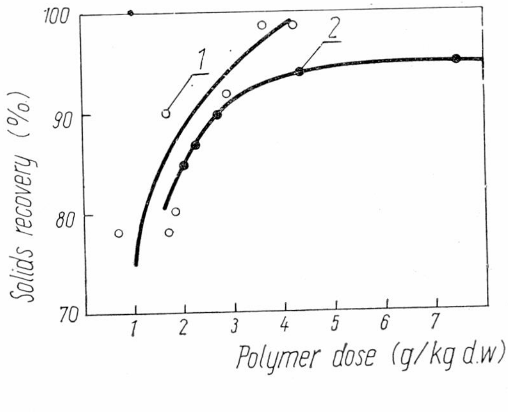

Fig. 15. Effect of polymer dose on efficiency of centrifugation of raw sewage sludge precipitated with:

1 — ferric hydroxide, *2* — aluminium hydroxide

Rys. 15. Wpływ dawki polimeru na stopień odzysku ciał stałych w placku osadowym surowych ścieków komunalnych

1 — osad żelazowy, *2* — osad glinowy

Due to the ease and simplicity of operation horizontal solid bowl sedimentation centrifuges are finding more frequent use in dewatering chemical sludges. The basic problem still remaining is the scale-up which very infrequently follows existing empirical formulation

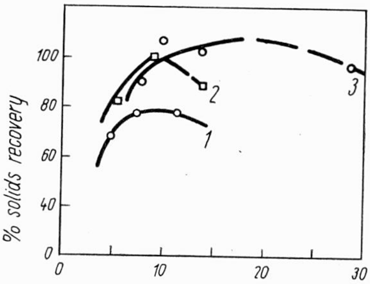

Fig. 16. Influence dose and centrifugation factor on solids recovery from alum sludge:

1 — CF = 1500; cake 11.4–11.8% d. w.
2 — CF = 2100; cake 15.5–17.4% d. w.
3 — CF = 3200; cake 16.1–17.1% d. w.

Rys. 16. Wpływ polielektrolitu i wyróżnika wirowania na odzysk ciał stałych w osadzie glinowym

1 — W.W — 1500, s.m. placka — 11,4–11,8%,
2 — W.W — 2100, s.m. placka — 15,5–17,4%,
3 — W.W — 3200, s.m. placka — 16,1–17,1%.

for contrifugation efficiency. At the present high level of technology of vacuum filtration the centrifuge will become competitive only after the improvement of centrate quality (solids recovery) and low cake solids attained usually with sludges from chemical coagulation.

7. COAGULANT RECOVERY

The recovery of coagulant from the sludge is considered here as a method of sludge dewatering improvement regardless of economic effects. Recovery cf three valence coagulants is gaining wider recognition since it significantly improves the filterability of chemical sludges and facilitates competitive asset in comparison with the less expensive two-valence coagulants such as lime.

The improvement of specific resistance to filtration through acidification of ferric hydroxide sludges is presented in fig. 17 (note also fig. 7). The hydrochloric acid treatment yielded some 66% recovery of Fe^{+3} ion with simultaneous improvement in the cake solids contents, decrease of the dewatering time and increase in filter yields [20]. In case of aluminum sulphate precipitation sludge, acidification yields similarly rewarding improvement in dewatering efficiency, even though the aluminum ion concentrations in the sludges taken from four waterworks, were several times those of ferric sludges in fig. 17a and amounted to 1383–3480 g Al^{+3}/m^3. Figure 17 b illustrates the improvement in specific resistance of sludge versus the amount of recovered aluminum taken from the studies of Chen et al. [4].

In conditioning by acidification and coagulant recovery there is always an optimum obtained for the amount of recovered coagulant and anticipated improvement of dewaterability.

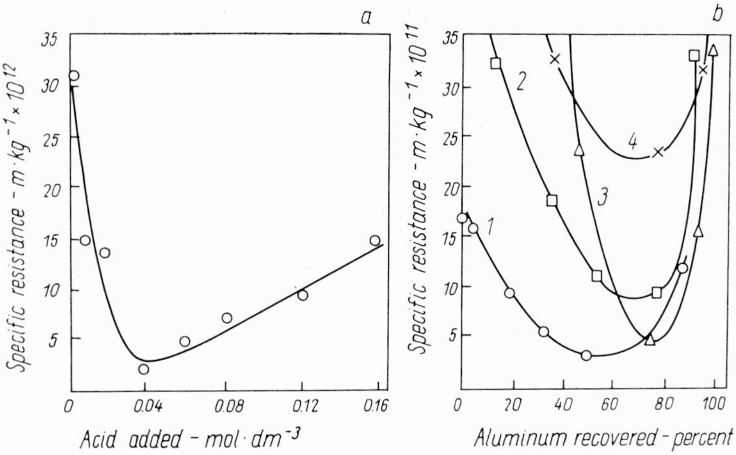

Fig. 17. Effects of acidification and subsequent coagulant recovery on the filterability of waterworks chemical sludges:

a) ferric chloride coagulation; b) alum coagulation and recovery at 1) Radford, 2) Blacksburg, 3) Harrisonburg, 4) Timbersville

Rys. 17. Wpływ zakwaszania i odzysku koagulanta na zdolność do odwadniania się osadów chemicznych z oczyszczalni wody

a) koagulacja chlorkiem żelaza; b) koagulacja siarczanem glinu i jego odzysk w 1) Radford, 2) Blacksburg, 3) Harrisonburg, 4) Timbersville

8. SUMMARY AND CONCLUSIONS

Practically used methods of dewatering chemical sludges were presented in the paper. Based on our own work and other authors research selected factors influencing the dewaterability of chemical sludges were discussed. The selection was made from the standpoint of magnitude of influence of a given factor on improvement of dewatering characteristics of these sludges. The paper allows for formulation of the following conclusionss:

1. The properties of sludges from chemical coagulation of water and wastewater are best characterized by the moisture contents, temperature, degree of dispersion and contents of metal hydroxides. These factors have the most profound influence on the kinetics of coagulation sludge dewatering.

2. Water contents of raw chemical sludge is perhaps the single most important factor and an indicator for selection of apropriate dewatering technique.

3. Temperature of dilute sludges has significant effect on dewatering which is the result of the viscosity changes and phenomena occurring at the interfaces.

4. Several properties of chemical coagulation sludges and their dewatering characteristics are strictly related to the level of dispersion of the solid phase. Intensification of dewaterability is attained through the decrease of this dispersion. The latter, when effected through the polyelectrolyte conditioning, results in the increase of size and uniformity as well as rigidness of the sludge flocs; heating under pressure destroys the colloidal struc-

ture; while freezing may be regarded as a specific form of flocculation facilating thickening and dewatering.

5. The problems of dewatering chemical sludges from water and wastewater treatment are very complex and as yet are not amenable to theoretical treatment and predictions. The knowledge of these problems calls for elaboration of uniform principles for pilot research and data interpretation — which in turn would facilitate comparison of results and allow for definition of independent influence of factors affecting a given unit dewatering process.

6. Basic studies should incorporate the general laws governing the physicochemistry of colloids, and be directed at:

- classification of water in chemical sludges based on physical and chemical properties, affinity for solid phase and energies required for its removal;
- phenomena of coagulation, agglomeration (flocculation) and their influence on the improvement of sludge structures when such conditioning methods are applied as chemical thickening and dewatering aids, temperature increase, freezing, etc.

7. Development and applicability studies should be aimed at optimization of the coagulation process of water and wastewater pollutants against the economically feasible methods of subsequent sludge conditioning, dewatering and final disposal. This could be effected primarily through:

- introduction of different primary coagulants (e. g. lime) and polymers combinations that yield easiely dewatered sludges;
- recycle of coagulation sludge to the water or wastewater treatment train which facilitates both full utilization of sludge sorption properties in the basic treatment stream and improves its filterability;
- introduction of conditioning methods that do not require additional chemical use such as freezing tied with natural climatic conditions.

8. Studies on development, kinetics and efficiency of mechanical dewatering processes should always include pilot installations. The complexity of dewatering coagulation sludges suggests the need for introduction of dimensionless criteria for scale-up, which would include the most important parameters of sludge, machine and the dewatering process.

CZYNNIKI WPŁYWAJĄCE NA EFEKTYWNOŚĆ ODWADNIANIA OSADÓW CHEMICZNYCH

Znaczny wzrost ilości osadów pokoagulacyjnych w ostatnich latach spowodował, że ich odwadnianie stało się pierwszoplanowym problemem w oczyszczalniach wody i ścieków. W pracy omówiono czynniki wpływające na poprawę efektu odwadniania osadów pochodzących z koagulacji wody i ścieków w procesach zagęszczania, wirowania, filtracji próżniowej i ciśnieniowej, wymrażania oraz w trakcie odzysku koagulanta i łączenia osadów z oczyszczalni wody z osadami ściekowymi. Stwierdzono, że oprócz nowych metod odwadniania osadów, nie wykorzystano dotychczas możliwości poprawy ekonomiki procesu koagulacji przez zmniejszenie dawek koagulanta podstawowego, zastosowanie koagulantów wspomagających, usprawnienie pracy istniejących urządzeń do odwadniania, powtórne wykorzystanie osadów w stanie niezmienionym, odzysk koagulanta.

Stwierdzono, na podstawie własnych badań i innych autorów korzystny wpływ łączenia osadów z procesów oczyszczania wody i ścieków w przypadku stosowania zasady obowiązującej przy kondycjonowaniu osadów; zakwaszaniu osadów z koagulacji wodorotlenkiem glinu lub żelaza dla odzysku koagulantów oraz kondycjonowania termicznego i chemicznego.

W pracy omówiono zasady prowadzenia badań nad odwadnianiem osadów przypominając o konieczności każdorazowych badań laboratoryjnych lub pilotowych.

BEEINFLUSSUNG DER ENTWÄSSERUNG CHEMISCHER SCHLÄMME DURCH VERSCHIEDENE FAKTOREN

In letzten Jahren hat die Menge von chemischen Schlämmen enorm zugenommen. So ist die Entwässerung dieser Schlämme — sei es in Wasserwerken, sei es in Kläranlagen — ein ernstes Problem geworden. Im Bericht werden die Faktoren, die eine Verbesserung der Entwässerungseigenschaften der Schlämme bewirken, eingehend besprochen. Es handelt sich sowohl um Eindickung, wie um Filtration, Frierverfahren; um gemeinsame Behandlung von Schlämmen aus der und Wasseraufbereitung und Abwasserreinigung.

Es wird festgestellt, daß neben neuen Verfahren auch andere, bisher wenig genutzte Möglichkeiten bestehen. Zu diesen gehören u. a.: eine Senkung der Fällmittelzugabe bei paralleler Anwendung organischer Flockungmitteln, Verbesserung von bestehenden Entwässerungsanlagen, die Wiederverwendung von Schlämmen in der anfallenden Form, die Rückgewinnung von Fällmitteln usw.

Anhand eigener und anderer Verfasser Versuche, hat sich die Vermischung von Schlämmen aus der Wasseraufbereitung mit denen aus der Abwasserreinigung als günstig erwiesen — bei Beibehaltung der Regeln einer Schlammkonditionierung. Es besteht auch die Möglichkeit einer Azidifikation (Säuerung) von Al- und Fe-Hydroxydschlämmen zwecks Rückgewinnung sowie die thermische und chemische Konditionierung.

Formuliert werden die Regeln der Entwässerungsversuche, wobei auf obligatorische Versuche im Labor- bzw. im Pilotmaßstab mit Nachdruck hingewiesen wird.

ФАКТОРЫ, ВЛИЯЮЩИЕ НА ЭФФЕКТИВНОСТЬ ОБЕЗВОЖИВАНИЯ ХИМИЧЕСКИХ ОСАДКОВ

Значительный рост количества коагуляционных осадков привел в последние годы к тому, что обезвоживание их стало первостепенной проблемой на водоочистных станциях и станциях очистки сточных вод. В работе обсуждены факторы, влияющие на повышение эффективности обезвоживания осадков с коагуляцией воды и сточных вод в процессах обогащения, центрифугирования, вакуумной фильтрации и фильтрации под давлением, вымораживания, а также в ходе регенерирования коагулянта и соединения осадков с водоочистных станций с осадками из сточных вод. Обнаружено, что кроме новых методов обезвоживания осадков пока не использовалась возможность улучшения экономики процессов коагуляции путем умаления доз основного коагулянта, применения вспомогательных коагулянтов, усовершенствования работы существующих установок для обезвоживания, повторного использования осадков в неизмененном состоянии, регенерации коагулянта и т. п.

На основе собственных результатов и результатов, полученных другими авторами, установлено положительное влияние соединения осадков от процессов водоочистки с осадками из сточных вод в случае применения принципа, который должен соблюдаться при кондиционировании осадков. Подкисление осадков от коагуляции гидроокисями алюминия или железа для регенерирования коагулянтов, а также термического и химического кондиционирования.

В работе обсуждены принципы проведения исследований по обезвоживанию осадков и подчеркивается необходимость производить каждый раз лабораторные испытания и испытания в полузаодском масштабе.

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