LUT–yliopisto
LUT School of Energy Systems
LUT Kone

# IMPROVING CURRENT SLUDGE TRANSFER SYSTEM BY MODIFYING SLUDGE PROPERTIES

# NYKYISTEN LIETTEEN SIIRTO MEKANIIKKOJEN KEHITTÄMINEN LIETTEEN OMINAISUUKSIA MUOKKAAMALLA

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**TIIVISTELMÄ**

LUT–yliopisto
LUT Energiajärjestelmät
LUT Kone

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**Nykyisten lietteen siirto mekaniikkojen kehittäminen lietteen ominaisuuksia muokkaamalla**

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Hakusanat: puhdistamoliete, ultraääni, puhdistamolietteen siirtäminen, kuivattu liete

Puhdistamoliete on jäteveden käsittelyssä syntyvä sivutuote, jonka hävittäminen on isossa roolissa vedenpuhdistamon toimintaa. Liete on usein myrkyllistä ja ympäristöä turmelevaa, joten sitä täytyy käsitellä erillaisilla monimutkaisilla prosesseilla sen hävittämisen mahdollistamiseksi. Lietteen käsittely on tärkeässä roolissa puhdistamon käyttö kustannuksissa, vaikka liete kattaa vain 1–2 % puhdistamon volyymistä vastaa se kuitenkin 20–60 % koko puhdistamon kustannuksista (Andreoli, Von Sperling, Fernandes 2007, p. 2). Tehokkaita tapoja lietteen hävittämiseen tarvitaan ja yksi lupaavista tavoista on lietteen polttaminen energian tuotannossa. Tämä sopii nykypäivän maailmaan, jossa ekologisuus on kasvava vaikuttaja teollisuuden päätösten teossa. Polttamista varten liete on kuivattava noin noin 70% kuiva–ainepitoisuuteen, tämä tapahtuu mekaanista- ja termistä kuivaamista hyödyntäen. Terminen kuivaus on kallis prosessi, mutta vaadittava päästäkseen tarvittavaan kuiva–ainepitoisuuteen. Nykyään on alettu kehittää mekaanista kuivausprosessia, jolla päästäisiin 30–50 % kuiva–ainepitoisuuksiin. Tällä saavutettaisiin termisen kuivaus osan käytön vähentäminen ja siitä seuraavat säästöt. Ongelmaksi tulee 30–50 % lietteen siirtäminen prosessien välillä, koska nykyisten siirto menetelmien tehokkuus laskee. Tässä työssä ehdotetaan konsepti siirtomekaniikkaa, jossa käytetään ultraääntä hyödyksi. Ultraäänellä hajoitetaan lietteen rakennetta ja saavutetaan voitelu ominaisuus, joka avulla entistä kuivemman lietteen siirtäminen on mahdollista epäkeskoruuvipumppuja käyttämällä.

**ABSTRACT**

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**Improving current sludge transfer system by modifying sludge properties**

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Sewage sludge is by–product generated in wastewater treatment plants, which disposal plays a major part of plant operation. Sludge is often toxic and hazardous to environment meaning it has to be treated with various processes before final disposal. 1–2 % of treatment plants volume is sludge but from total operating cost 20–60 % is generated by sludge handling (Andreoli, von Sperling, Fernandes 2007, p. 2). Effective methods for sludge disposal are needed and burning it for electricity is very promising use for it. Nowadays ecological operation are highly sort after. For burning sludge must be dried to 70 % Total solids(TS) which is achieved using mechanical and thermal drying processes. Thermal drying is costly process but necessary to reach needed TS %. Cost can be lower by using mechanical drying up to 30–50 % TS content. Problem will be that current conveying equipment start to lose efficiency. In this work concept conveyance system is proposed which uses ultrasonic technology. Ultrasonic treatment is used to generate sludge disintegration effect which improves lubrication effect allowing to use progressing cavity pumps for higher TS content sludge.

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**Symbols used**

Symbol

| | |
|---|---|
| $TS$ | Total solids % of total dry weight [%] |
| $s^{-1}$ | Shear rate [1/s] |
| $TS_{xyz}$ | dewatered concentration of residuals x, y, z [%] |
| $TS_x$ | TS content of residual x |
| $TS_y$ | TS content of residual x |
| $TS_z$ | TS content of residual x |

# 1 Introduction

## 1.1 Background of study

The mount of municipal waste water will increase as the world as population and world urbanization continues to grow. Wastewater treatment plants when operating generate by–product what is called sewage sludge. This sludge must be clear of contaminants before disposal. Sewage sludge management and disposal becomes more important as volume of sludge increase significantly. One promising solution is to use sludge to create electricity. Electricity is created by burning the dried sludge. For burning total solid (TS) content needs to be around 70%. Drying the sludge consist of two stages which are thermal drying and mechanical dewatering. Problem is that thermal drying consumes lot of energy and is expensive. Solution is to use mechanical dewatering methods to make sludge have 30–50% of TS content. This would make sludge require less drying which would save energy.

When sludge is dewatered it starts to act as semi–solid, so it has properties of liquids and solids. Meaning the sludge can support it's own weight and shape but when applied enough shear rate sludge starts to exhibit liquid like behaviour. This causes problems especially at pipelines because when shear rate drops below critical level sludge regains solid state causing blockages. Solid content rise causes sludge viscosity to increase and making the sludge behave more solid. Sludge composition doesn't remain constant even if sludge source stays same, which makes predicting sludge behaviour difficult.

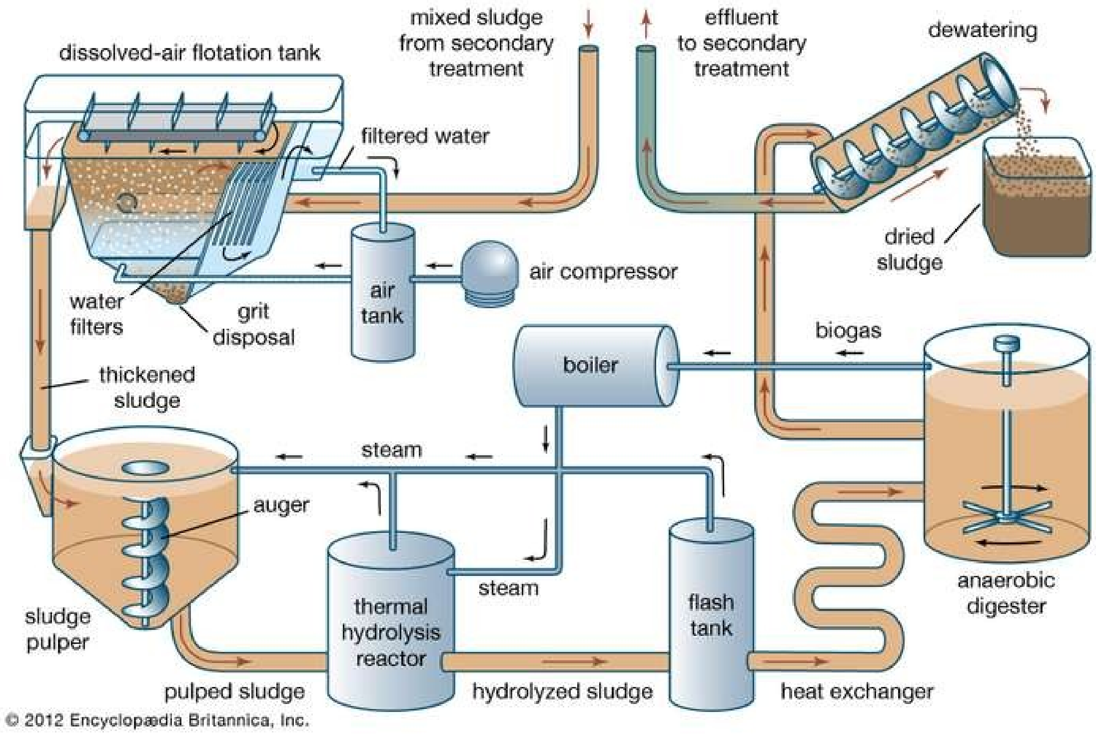


**Figure 1**. Sludge Treatment Process (Ambulkar. Nathason. 2020.)

1.2 Goal of study

This study focuses on improving current methods used for conveyance of residuals solids after mechanical drying. Current equipment start to lose efficiency when TS reaches more than 30%. Use sludge disintegration effect and diluting methods are examine in assisting the conveyance of sludge with high TS content. Conveyance method of the sludge needs to be efficient and reliable because it forms major portion of the cost to run treatment plant. Goal is to present a concept system using current conveyance methods in which by modifying sludge properties an increase in effectiveness for hole conveyance system achieved.

## 2 Theory

Sewage sludge is a term used for residual by–product material produced by wastewater treatment. Sludge treatment is multi–stage process as depict in figure 1 and this is only one option of sludge treatment process. Sludge can be solid, semi–solid or slurry like material and consist of various biological and non–biological suspended solids. 15–45% of the sludge is typically non–biological solids (Minerals Engineering 2010, pp. 359–360). Suspended amorphous solids contained in the sludge separate it from other types slurries. Sludge hydrous characteristic cause less predictable behaviour patterns. Composition of the sludge has major impact at its physical properties

Sludge also have different composition depending at the location of it's origin. Even if treated with same equipment sludge from two different origin might have extremely distinct characteristics. Likewise different waste water treatment processes (WTP) have impact at sludge characteristics and rheology. This makes accurate prediction of sludge characteristics and behaviour difficult.

Sludge can be divided to categories depending on their physical properties. These categories range from solid/water mixture to dust like material and can be used to roughly predict sludge properties at various points. Areas where classification overlaps generate problems when operating transport equipment as significant changes in sludge behaviour happens. That is why on site test are required after each different process to get accurate results. (ASCE 2000, pp. 2–5)

$$TS_{xyz} = \frac{(x+y+z)(100)}{\frac{(x)(100)}{\%TS_x} + \frac{(y)(100)}{\%TS_y} + \frac{(y)(100)}{\%TS_z}} \qquad (1)$$

In equation 1 $x$, $y$, $z$ are dry weight of residuals and $TS_x$, $TS_y$, $Ts_y$ are dewatered total solid percentage for chosen sludge type. $TS_{xyz}$ is concentration of dewatered residual x, y, z (ASCE 2000, p. 7). This equation can be used for rough estimates for maximum and minimum TS content for sludge with mix origin. In figure 2 values for x, y, z minimum and maximum TS for different types of sludge can be taken.

| | | | Thixotropic Solids | | Granular, Compactable | | |
|---|---|---|---|---|---|---|---|
| Solids Type | Temperature, °C | Thickened Solids (A), %TS | Low to Medium Viscosity ($B_1$), %TS | Medium to High Viscosity ($B_2$), %TS | Wet Solids ($C_1$), %TS | Dry Solids ($C_2$), %TS | Specific Gravity Equation, g/cc |
| Grit | 5–25 | 15–30 | — | — | 55–75 | — | 2 + 0.05 %TS |
| RPS | 10–25 | 5–10 | 20–26 | 24–40 | 35–65 | 65+ | 1 + 0.005 %TS |
| RWAS | 10–25 | 3–7 | 10–16 | 14–25 | 22–65 | 65+ | 1 + 0.0035 %TS |
| R(PS + WAS)[a] | 10–25 | 4–8 | 13–20 | 18–31 | 28–65 | 65+ | 1 + 0.0040 %TS |
| DPS | 20–30 | 5–10 | 20–28 | 24–40 | 35–65 | 65+ | 1 + 0.005 %TS |
| DWAS | 20–30 | 3–7 | 10–16 | 14–25 | 22–65 | 65+ | 1 + 0.0035 %TS |
| D(PS + WAS)[a] | 20–30 | 4–8 | 13–20 | 18–31 | 28–65 | 65+ | 1 + 0.0045 %TS |
| Alum [$Al(OH)_3$][b] | 5–25 | 3–7 | 8–15 | 13–30 | 25–60 | 65 | 1 + 0.004 %TS |
| Iron [$Fe(OH)_3$][b] | 5–25 | 3–7 | 8–15 | 15–35 | 30–60 | 65 | 1 + 0.0065 %TS |
| Lime ($CaCO_3$) | 5–25 | 15–30 | 25–50 | 45–70 | 70–80 | 80+ | 2 + 0.075 %TS |
| Pre-sed | 5–25 | 10–30 | 25–35 | 30–45 | 40–60 | 65+ | 2 + 0.050 %TS |
| HT(PS + WAS) | 25–35 | 8–15 | 25–35 | 30–50 | 40–60 | 65+ | 1 + 0.004 %TS |
| HDS | 75–85 | — | 30–45 | 40–60 | 60–70 | 65+ | 1 + 0.004 %TS |
| Ash[c] | 25–75 | 15–30 | 25–50 | 40–70 | 70–80 | 80+ | 2 + 0.070 %TSS |

[a] 50/50 mixture of PS and WAS
[b] $AlPO_4$ and $FePO_4$ will behave similarly to the hydroxide fraction.
[c] Fluid-bed combustion ash from gravity separation/dewatering

*Notes:* TS = total solids; TSS = total suspended solids; R = raw; PS = primary sludge; WAS = waste-activated sludge; D = digested; Pre-sed = water pre-sedimentation; HT = heat treated; HDS = heat-dried sludge

**Figure 2**. Slduge classification (ASCE. 2000. p.9)

## 2.1 Water distribution in sludge

Sludge has amorphous suspended solid which don't have definite size or shape and are hydrous in nature. This feature distinguish sludge from slurries. Solids will form flocs containing bacteria and other biological agents. Water can be divided to four category depending on their relation to floc structure and particle as seen in figure 3. Water that is not influenced by the suspended solids is called free water and it's the easily removed. Interstitial water is mostly water in the floc crevices, if floc structure is destroyed water trapped in them becomes free water. Microbial cells can contain interstitial water which needs the cell destroyed to became free water. Vicinal water or surface water is molecules that are held tightly at particle surface by hydrogen bonding. Bonding force is very strong and short range. Vicinal water adheres to suspended solids and is not free to move like interstitial water. Vicinal water that surrounds small particles acts as the particle resulting less particle density. Vicinal water have higher viscosity than bulk water and as it adheres to particles causes higher viscosity and adhesion effect. (ASCE 2000, pp.13–15)

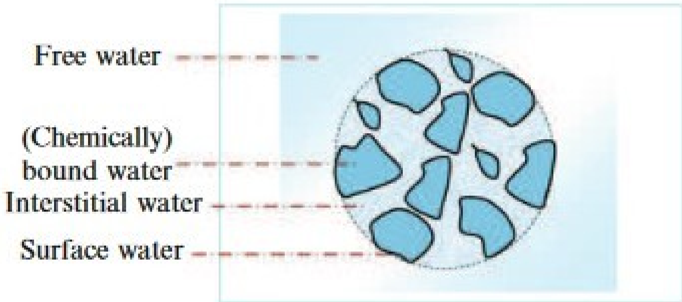


**Figure 3.** Water distripution in sludge (Mahmoud et al. 2013. p. 254)

2.2 Sludge physical state

Sludge can be divided to tree categories representing it physical state and it's tendency to flow under stress. In liquid state sludge flows continuously under gravity or certain pressure. Paste–like sludge will flow continuously when certain pressure thershold is reached but under that shear resistance won't flow. Solid state sludge cannot flow at all and shear resistance is prominent. (Spinosa, Wichmann 2008, p. 11) Threshold for the moment when sludge chance form one state to another is not clearly observable and test are needed for accuracy.

Sludge consist of different types of solids depending at the stage of dewatering processes. Each of these solid types have distinguishable behaviours and properties. Identification and understanding solid types is important to receive useful parameters for desing. Important points for desing are liquid limit and plastic limit. When solid content obtains certain value sludge state shifts from liquid to plastic state. Plastic limit means point where plastic state changes to solid from plastic. (Ruiz, Wisniewski 2008, pp. 204–205)

## 2.3 Liquid state

Only sludge that have very low total solids (TS) behave as Newtonian liquids. Above certain solid content sludge have non–Newtonian behaviour. Sludge flow properties are either plastic or pseudoplastic. Even as sludge is not Bingham liquid with shear rates of 250–1000 $s^{-1}$ sludge could be describe having Bingham plastic material behaviour. Shear rates less than 250 $s^{-1}$ sludge would have pseudo–plastic flow characteristics. Sludge flow in pipelines have shear rates of 5 to 200 $s^{-1}$, so pseudoplastic models should be used. Apparent viscosity decrease when shear rate and shear stress increases and at extreme shear rates pseudo–plastic fluids behave as Newtonian fluids. (ASCE 2000, pp. 21–27)

## 2.4 Paste–like state with thixotropic solids

When liquid limit is reached sludge begins to behave in thixotropic manner. In thixotropic sludge is paste like substance and forms massive flocculated flocs. Increase in shear rate decreases sludge cakes floc size until high enough shear rate is achieved were floc is enough destroyed. This causes decrease in viscosity as it is related to floc size. Addition to this decreasing viscosity water trapped in the floc is freed and acts as lubricant, which increases cakes possibility to be pumpable. When shear stress stops floc starts to rebuild and after finite time floc size returns to initially values. This causes viscosity to return to initial values after. If shear stress is applied again after short rest time viscosity starts from to decrease amount but will reach the same lowest value as before. Resting time is depended at the intensity of shear stress and time it was applied. (Barnes 1997, pp. 3–8)

Thixotropic sludge cakes are divided to own sub categories which are low to medium and medium to high viscosity. Categories are divided by viscosity rather than TS because pre treatments create different solid types witch have various viscosity at same TS levels. Viscosity at the higher range is usually determined by observation rather than calculated. (ASCE 2000, p. 5)

## 2.5 Paste–like state with wet granular solids

When TS concentration reaches the plastic limit the paste like sludge begins to transform to wet granual–like state. Removing water from the sludge causes flocculated flocs to be replaced by rigid and deformamble flocs. Where particles can not move without disturbing the position of adjacent particles unlike in thixotopic where the particles and flocs can move more freely. Key difference that separates wet granual material from fluids from thixotropic materials is the jamming property. Unlike at thixotropic systems where shear rate destroys the flocs causing structural damages, in granular systems this critical point doesn't result in large structural changes. When critical stress is applied wet granual material will have plastic flow but if stress drops below critical value the flow stops without delay. (Van Damme 2002, pp. 230–231)

## 2.6 Solid state

When high TS content is achieved behavior will start to resemble that of a solid material. High strear resistance and compression and other forces will permanently deform it. In this state sludge won't flow without extreme stress and can't be reasonable pumped. (Spinosa, Knut 2008, pp.12) Transition area from paste–like to solid is located between wet granual solids and dry granual solids. Complex nature of the sludge makes accurate prediction of this transition area impossible and only predictions can be made. When TS is 40–65 % this trasition should be consider as essential aspect in desing.

## 2.7 Adhesion and stickiness behaviour

Dewatered sludge has adhesion or sticky property where it sticks to surfaces it becames in contact with. This adhesion starts when thin layer of sludge sticks to surface and then rest of the sludge coheres to that layer to form thicker layer. Organic matter and dryness have a large factor in generating the sticky behaviour. Sludge with high water content sticky behaviour is not presented until the paste–like state is achieve will sticky behaviour start. As TS content rises stickiness increases until certain TS region were stickiness increase rate dramatically lowers. This region is called sticky phase, in it the stickiness value hae reached it maximun value. When TS content increases beyond the sticky phase there is sudden drop in stickiness. (Bart, Monsanto 2014, pp. 1–2)

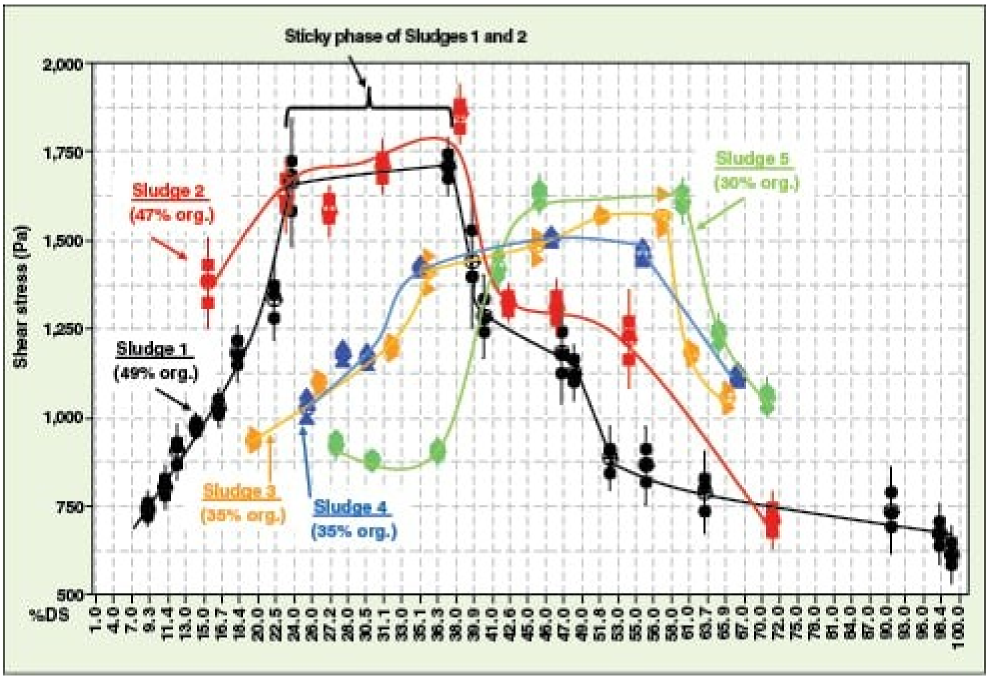


**Figure 4.** Stickyness curve (Bart, 2014, p. 3)

2.8 Methods to improve sludge conveyance

Highly used currently used method to assist progressing cavity pumps to convey high TS content materials is use manually added lubrication water. When pump itself cannot cause enough shear rate to destroy sludge structure to enable enough levels of lubrication water to exist. Water is added to dilute TS content of sludge to decrease it viscosity and making sure lubrication effect is at level where pumping is possible. Water polymer mix can also be used to further improve the lubrication effect and flow. (ASCE 2010, pp. 124–135) This is cheap process in itself if water and equipment to add will work for most TS levels as long as enough water is added. Usage of polymers do increase the cost. Problem is that part of the water will be absorbed by sludge resulting in lowered TS content. Use of maximum amount of mechanical dewatering is desired as the need for more expensive thermal drying is reduced. Modern improvements in mechanical dewatering enable higher TS content sludge to be made and by adding water to it this  improvement is partially mitigated.

Other method is using sludge property called disintegration were force is uded to break sludge structure increasing lubrication effect, reducing stickiness factor and decreasing viscosity. Disintegration is achieved with destruction of sludge floc and particle structure by mechanical or ultrasonic energy. Decrease in floc size and amount reduces drag caused by then in flow lowering viscosity and water released acts as lubricant. Paricle surfaces have vicinal water witch has highly adhesive properties and increase in viscosity. Limitations for this method is high TS content requires excessive mount of energy to completely disintegrate sludge. Sludge disintegration is also used to improve other than flow factor of sludge where full disintegration is needed. (Kampas et al 2007, pp. 1740–1743)

## 2.9 Currently used conveyance methods

In lower TS range there are multiple different conveying systems available which are mainly pumps. In this range wanted design criteria other than TS range might be main point when pump system is chosen. When high TS range of 30 % or above is reached number of available conveying systems is reduced and main criteria for chosen system will be TS content and sludge composition. Major challenge when designing pump system is determining the head loss in the pipes since sludge has complex characteristic.

## 2.10 Progressing cavity pumps

Progressing cavity pumps can be used for sludge with various TS content up to 45–50%. This is achieved with the rotor desing as seen in figure5. Capacity is greatly related to TS content and in ranges higher than 30% TS capacity is approximately between 1–70 $m^{3/}$/h. While being able to pump high solids progressing cavity pumps have higher wear and maintenance labour rates than other widely used pumps. Having also expensive and difficult to install replacement parts which commonly need to be change one a year. Flow is steady and smooth with discharge easily predictable making it good conveyance method between mechanical and thermal drying, where these characteristic are needed to better distribute sludge to drying machine. Progressing cavity pump has limited size for solids that can pass through the pump so sludge controlling to filter out large solids must exist. Sludge containing grit or abrasives increases already high wear causing even more frequent maintenance and lowers plants productivity. These pumps can not operate dry needing lubrication either provided sludge itself or added water is needed. (Anderson, Hanna 2008, p. 19.11)

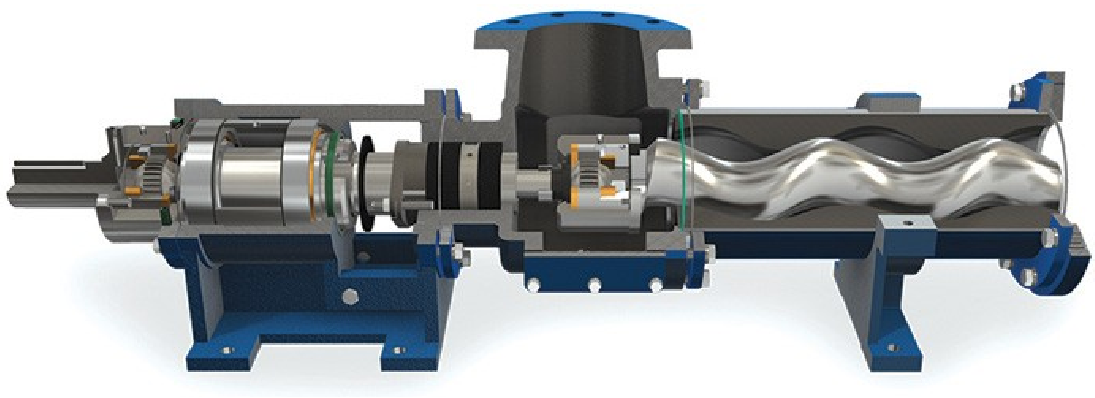

**Figure 5.** Progressing cavity pump (Elsey 2017)

## 2.11 Screw conveyors

Used for sludge when TS content reaches high enough value where progressing cavity pumps start to fail. This point is usally around the moment when sludge transforms from thixotropic solids to wet granular solids. Screw conveyors can be used as alternative for progressing cavity pumps for short range application because of cheaper price and less costly maintenance. Another limitation is conveyance being only one directional meaning if conveyance direction needs to be changed another screw conveyor is needed.  Screw conveyors also have limited length making long range conveyance ineffective.

## 2.12 Belt conveyors

Used for highly dewatered sludge similar to screw conveyors but also long transfer distance is possible without use of multiple devices. Transfer in vertical direction is possible but limited to certain angles depending at sludge and used belt. This method requires much space especially for large height changes. Special belt conveyor that only moves in vertical direction is useful for large height and is more compact in size but costs are increased. Belt scrapers are needed to clean the belt as sludge sticks to the surface because of it’s adhesion property. Using open belt conveyors odour and hazardous dust particles become a problem and closed conveyors should be considered.

## 3 Results

Sludge disintegration have many useful aspects in when it comes to improving sludge conveyance by it's lubrication effect and lesser stickininess factor. It also won't decrease the TS content of the sludge like adding water polymer mix as all the lubrication materials come from the sludge itself. By passing the energy requiments for high TS content sludge disintegration is done by using high power local ultrasonic energy to only disintegrate thin sludge surface layer. Ultrasonic disintegration gives higher local concentration of energy than mechanical method. High local energy is recuired to cause the disintegration effect at all. There is no need to disintigrate the sludge thourgh out as we only need minimum amout of water to couse the lubrication effect. This would enable use of progressing cavity pumps throughout the wanted TS range achieving smooth, steady and reliable flow unlike screw and belt conveyors. Progressing cavity pumps are compact in size and verical transfer is easy to do. Reduced maintenance will not be achieved because ultrasonic system brings more even if pump maintenance is reduced by lessen stickiness. Belt and screw conveyors won't benefit as much from lubrication effec and also won't provide smooth and steady flow. Over all usage of ultrasonic treatment and progressing cavity pump fullfils most of the requiment in table 1.

*Table 1. Requirement list for conveyance system*

| R/H | Requirements (Requirements=R, H=Hope) |
|---|---|
| R | Reliable conveyance of sludge |
| R | Ability to convey sludge with TS range 30–50% |
| R | Multiple sludge types are conveyable |
| R | Capacity of 1–50 $m^3$/h |
| R | Not increase in sludge moisture content |
| H | Reduced maintenance |

*Table 1. continues. Requirement list for conveyance system*

| R/H | Requirements (Requirements=R, H=Hope) |
|---|---|
| H | Compact size |
| H | Easy vertical transfer possibility |
| H | Steady and smooth flow |

3.1 Ultrasound effects causing sludge disintegration

Ultrasound when applied to sludge causes effect called disintegration. Sludge disintegration is were flocs and cell structure itself is damaged releasing water trapped in those areas. Primary causes for disintegration are the cavitation, sonochemical degradation and hydromechanical shear forces. (Tyagi et al 2014. p. 1225–1226) Disintegration caused by hydromechanical forces and cavitation is more important sonochemical (Show et al. p. 53–73)

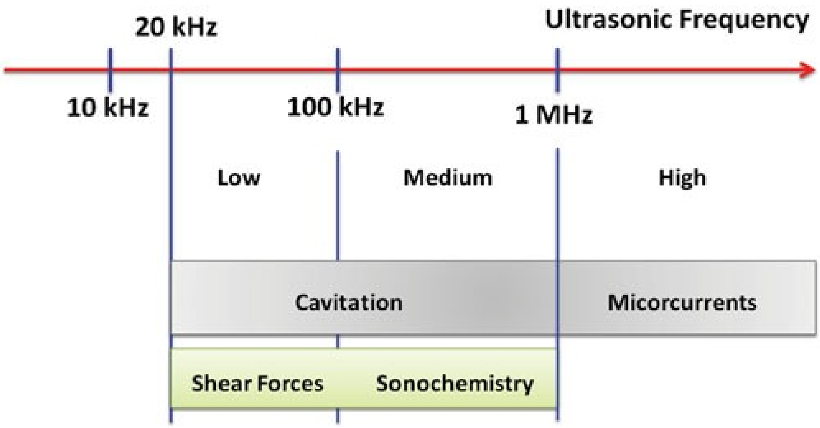


**Figure 6.** Ultrasonic frequencies and cavitation area (Kumar Tyagi 2014, p. 1223)

Ultrasound is a cyclic pressure wave with frequency starting from – kHz all the way to limit of human hearing. Ultrasound is divided to low (20–100 kHz), medium (100 kHz–1 MHz) and high (1 MHz–10 MHz) categories depending the frequency.

Ultrasonic treatment of sludge have been studied in improving dewaterability and same effects that occur there could assist sludge conveyance. Ultrasound like any sound wave consist of compression cycles with positive pressure and rarefaction cycles with negative pressure. This affects the molecules in the liquid and with high enough negative pressure attractive forces holding the molecules together will be overcome causing voids or cavities. Vapour from surrounding liquid fills the void to prevent structural collapse when compression cycle continues the void grows forming acoustic cavitation bubble. Voids size became unstably large with many cycles leading to severe collapse in the end emitting shock waves that damage surrounding near by materials. (Tyagi et al 2014, pp. 1223–1225). Frequencies higher than 1MHz cavitation effect is hard to achieve and optimal Frequencies range for cavitation is 20–40 kHz (Mark et al 1998, pp. 41–42).

Sonochemical effect or generation of active free radicals is an other major result from sludge exposure to ultrasound. Bubbles form in cavitation phase when imploding can release energy to generate chemical reactions. Free radiacals H, OH are generated by the implosion energy. These radicals cause oxidations and other reactions that degrade and weaken the sludge flocs (Ruikun et al 2014, p. 95). Frequencys 20 kHz–1 MHz sonochemical effect is possible but efficient range is 200–1000 kHz (Tyagi et al. 2014, p. 1226).

Hydromechanical shear forces are caused by high local pressures and shock waves that occur from implosion of cavitation bubbles. When bubble is located near a cell surface liquid jet may travel through the bubble hitting cells and causing damage. Implosion also generate strong shear forces in the bulk liquid around the bubble rupturing cells.

### 3.2 Use of ultrasonic methods to increase lubricant effect of sludge

Using ultrasound to cause sludge disintegration can be used to increase the lubrication effect. This is possible by the structural damage caused by ultrasound to flocs and cells in the sludge. The destruction of sludge flocs releases the interstitial water from floc crevices. This water will then act as a lubricant reducing the friction between sludge particles and contacting surface such as pipe. Other source for interstitial water are microbial cells witch contain water inside them and ultrasound can break those cell realising the water in them.

TS content has negative effect for ultrasonic treatment as higher TS concentration absorbs the acoustic energy so no cavitation will happen (Tyagi et al. 2014, p. 1229). Conventional ultrasonic treatment of sludge with TS content of 30–50% where sludge disintegration throughout sludge is wanted would not be very effective. If only lubrication effect is wanted you would only need part of the sludge disintegrate to release enough water to cause lubrication. Sludge exposed to ultrasonic waves should be thin layer so absorbs effect will be minimize as waves don't need to travel long distance in side the sludge. Specific energy input should be around 16000 kJ/kg TS which is the maximum range for reported optimal disintegration. High power input leads with short sonification time gives better disintegration than low power with long sonification. (Tyagi et al. 2014, pp. 1228–1229)

## 3.3 Ultrasonic progressing cavity pump system

System consist of 4 devices that are grinder ultrasonic treatment, screw feeder and progressing cavity pump. Grinders purpose is to shred solids smaller size chunks so when ultrasonic can be applied smaller layer of sludge to reduce the absorb effect. Smaller chunks also help to lower temperature caused by ultrasonic energy applied as there is more surface area to emanate heat away. Screw feeder is used to feed ground sludge to pump and is also place where the ultrasound transmitter are located. Feeders screw is were cooling element is mounted so heated sludge won't reach the pump were heat rotor is already a problem. When transmitters are located inside the feeder there needs to be extra space made for them meaning that special feeder must be manufactured. Screw feeder needs to be longer and than normal so multiple transmitters can be installed and transfer speed lower to maximize. More transmitters that are used longer the sonification time will be but cost will increase. Sonification times to reach local disintegration are short so exposure will be achieved in feeder Feeder must collect the water coming from the sludge and transfer it to pump so increase lubrication effect from ultrasonic treatment is achieved.

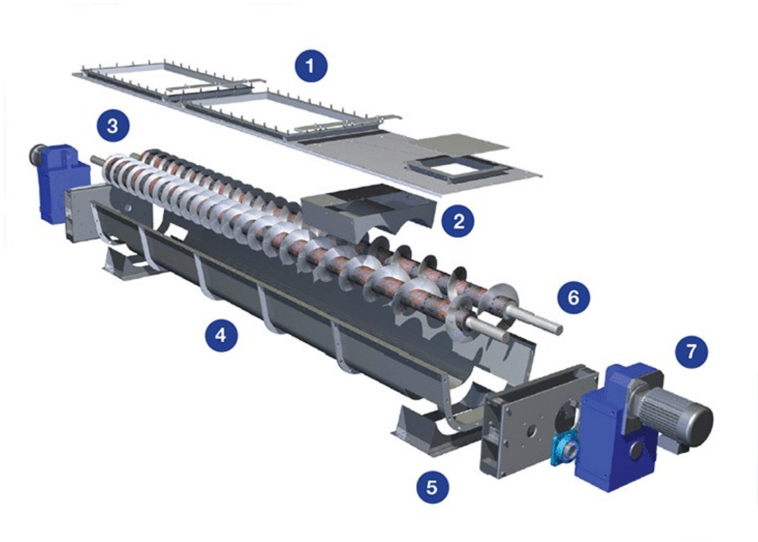


**Figure 7.** Regular screw feeder (KWS Manufacturing Company. p. 9)

Other variant to this configuration is to have ultrasonic treatment in a separate phase after grinder. Now separate storage is needed for ground sludge from where it's feeded to ultrasonic. Simple belt conveyor can be used to transfer sludge from storage to ultrasonic transmitters and then to screw feeder. This enables longer sonifiction times as sludge transfer can be stop for ultrasonic treatment easily.

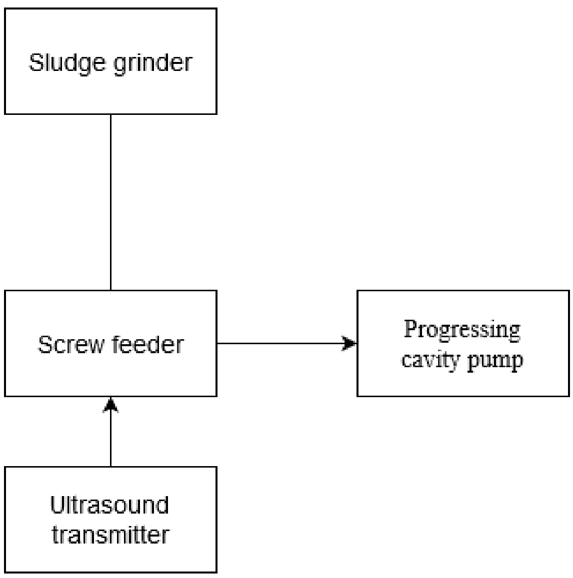


**Figure 8.** System with ultrasonic transmitters inside the screw feeder

## 4 Analysis

If local disintegration with considerable lubrication are achievable with practical energy requirements use of ultrasonic will be feasible method for sludge in thixotropic phase. In thixotropic phase there exist enough flocs to be destroyed and release water to act as lubricant. When transform to wet granular phase completely done there won’t be any flocculated flocs to destroy so released amount of water will be substantially reduced. Ultrasonic treatment can also rupture cell but that requires lot longer sonification times and even then not enough water probably will release to cause lubrication at required level. If sonification time will be higher than 1 min that would slower the conveyance too much and storage areas will be needed then. Sludge in these storage areas start to rebuild their structure and achieved benefits would be reversed. So if high sonification times are needed benefits from this system are low. Border line area where progressing cavity pumps failed should transfer to higher TS content by disintegration effect. In this transform area sludge has properties of both thixotropic and wet granular phase flocs still exist to release water but how large is this increase is depends on the actual disintegration effect. Sludge type has massive impact on effectiveness of ultrasonic disintegration meaning some types increase in lubrication and stickiness will be dramatically lower. Sludge with transition area between thixotropic and wet granular phase is in lower end of the 30–50% TS range, there is no possibility even in best case of increase in lubrication cannot be pump with this system. System fails to convey all kind of sludge and if disintegration effect is not achievable failure is inevitable in that case.

Research should be made on disintegration effects on high TS content sludge and it potential to improve conveyance methods Particular focus should be made to determine if using local disintegration is possible and does it generate enough lubrication. Especially can it be used to increase the lubrication effect that is in especially high priority in sludge pumping. Research done to determine if ultrasonic treatment or any other method can get disintegration at levels were it can increases conveyability. If found this method can be used should optimal TS content levels and sludge types determine to ease design process.

## 4.1 Conclusions

Without extensive studies to high TS sludge disintegration effects this proposed concept system should not be heavily futher investigated. 30–50% TS content sludge conveyance and properties link to that sould receive futher reasearch as sludge disposal and dewatering importance will continue to increase. Sludge quantity keeps rising enormous speeds as living standard and urbanization grow if sludge disposal won't keep up the hazrdous sludge will end up spoiling environment.

# 5 Summary

Difficulty when predicting sludge flow and conveyance properties makes optimal desing of conveyance methods hard. Sludge volume will keep increase with accelerated speeds as living standards and urbanization in developing countries increases. More effective sludge treatment and specialy conveyance methods need to be developed so cost of sludge handling is at the level where even developing countries are encourage to do so. Conservation of the environment is more inportant than ever and untreated sludge poses high risk for the enviroment. Concept system in this work is just one possibility and step to achieving that efficent sludge handling. There is still long way to go for the point where all the world sludge will be appropriate dispose of.

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