Outotec (Sweden) AB

SludgeIsBioFuel (LIFE12 ENV/SE/000359)

LIFE Deliverable,

Evaluation Report, Test Run 2 (Action C2)

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Summary

Evaluation report, Test Run 2 is a part of a development project run by Outotec (Sweden) AB and funded by the EU Commission via the LIFE programme and also co-funded by KIC Innoenergy GmbH.

Evaluation report, Test Run 1, described the first results and conclusions of operating the Demonstrator Steam Dryer with digested sewage sludge. After the first test campaign there were three areas that needed improvement before reaching an operative plant:

- Inlet area; Sludge from the inlet nozzle forms accretions inside of the tube wall close to the inlet nozzle.
- Outlet area; The dried produced material exiting the drying loop get stuck in the outlet pipe.
- Circulation fan sealing box; The sealing box is only a standard component needed for the operation of the circulation fan but needs to be improved/restored.

The second test campaign (test run 2) was initiated after rebuilding and improving the design of the three areas mentioned above. In addition, also a cleaning device and nozzle puncher was implemented. The following conclusions summarize test run 2:

- Drying; the dryer could dry the material to a dryness level of 80-99% i.e. reduce the water content from 75% water content in the raw sludge entering the dryer to only 20-1% water content for the dried material, fulfilling the requirements for drying.
- The sludge pump worked well during all times.
- The pneumatic transport of the sludge through the loop worked well.
- The cyclone could easily separate the dried material from the circulating steam.
- The outlet area was working well, after a small improvement, with the dried sewage sludge being collected in steel drums or a big-bags.
- The superheater could heat the circulating steam and did not show any signs of fouling.
- The condenser did not show any signs of blocking and the condensate was rather clean, which is an indication of good material separation in the cyclone.
- The inlet area still needs some improvement before it can be implemented into a full size plant.

The demonstrator is now considered operational and hot commissioning tests have been replaced by scientific work and proving design concepts for a full size plant.

Our overall conclusion is that the process developed has much potential to solve one key issue for a circular economy where nutrients must be recycled due to the limited fossil sources. Outotec is determined to continue commercializing the process and design a full size plant that is expected to be recognized as the best available technology when presented to the market.
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1. Introduction

Evaluation report, Test Run 2 is a part of a development project run by Outotec (Sweden) AB and funded by the EU commission via the LIFE programme and is also co-funded by KIC Innoenergy GmbH.

The project is for LIFE called SludgeIsBiofuel and has the LIFE reference LIFE12 ENV/SE/000359.

The overall aim of the project is to achieve phosphorous and energy recovery by drying and high temperature oxidation, according to Figure 1.

Figure 1: Phosphate Recovery according to Outotec’s approach.

The main missing process step in the suggested process is an energy efficient drying step (III), which is proposed to be a Closed Loop Steam Dryer without recycling, not normally used for sludge drying.

Evaluation Report, Test Run 2 is the second report describing the results and conclusions of operating the Demonstrator Steam Dryer with digested sewage sludge.
2. **Background**

Today's industrial process chains in minerals thermal raw materials processing and metallurgy mainly rely on fossil fuels for energy supply. On the other hand, there exist established thermal conversion routes (often being based on combustion) to treat residual biomass streams, waste streams or sewage sludge.

Facing changes in the legal framework for the thermal processing of nutrient containing feedstock and disposal of residual streams and taking into account fluctuations of oil and gas prices and increasing interest in more sustainable processes with lower CO2 emissions and use of renewable or residual feedstock as fuels, Outotec has derived a comprehensive concept for thermal conversion of such feedstock to provide heat and electricity or fuel gas to downstream industrial processes.

Based on its existent process and technology portfolio, new processes required to complement the concept (drying and treatment of residual streams to recover nutrient components) were developed and demonstrated during the last years.

The organic waste flows containing high concentrations of nutrients and thus targeted by the concept are:

- Municipal sewage sludge
- Sludge from food and beverage production
- Processed animal by-products (meat and bone meal)
- Farmyard manure, chicken litter and effluents of anaerobic digestion.

A schematic block flow diagram of the concept is shown in Figure 2. Major Process steps include pre-treatment of the feedstock by dewatering and drying, thermal conversion of the fuel by gasification, an adoptable gas purification process chain to meet downstream processes fuel gas requirements and legal emission limits, and a phosphor-recovery stage to treat the ash being a residual stream after gasification.
Typical industrial applications addressed by the concept include for example waste-to-energy plants, cement kilns or calcination plants. Some of these processes with internal combustion of the fuel, in particular calcination and metallurgical processes, often have specific requirements to the quality of the fuel – mainly the content of mineral matter or maximum concentrations of elements like sulfur, to avoid contamination or pollution of the final product. Gasification with gas purification enables efficient conversion even of difficult feedstocks into a fuel gas and separate recovery and processing of residual streams being advantageous from technological point of view and with regards to legal requirements to nutrients recovery if the indicated fuels are used. Moreover, elements of the process chain can also be applied and retro-fitted to conventional and existent thermal conversion plants.

Outotec has overtaken the IP ownership of a drying process from Skellefteå Kraft AB. The process was developed for drying of wood and peat and has been in operation for more than 15 years. Outotec has reviewed the process and developed a concept for its industrial implementation on drying of biomass sludge’s. However, pilot testing is necessary prior to commercializing. Today’s state of the art practice is to firstly produce biogas from sewage sludge and manure. Then the remaining digestion residues, sludge which still contains >50% of available energy, can be dried and incinerated/gasified. A practice mostly applied on sewage sludge in Europe’s bigger cities. The resulting ash after incineration could be used for phosphor recovery through existing processes.

Almost all waste biomass contains large amounts of water, up to 97%. Energy generation by anaerobic digestion does not require dewatering. But prior to incineration the water has to be removed and the state of the art drying methods consume more energy than what is available in the sludge’s i.e. input of energy is needed.

The steam drying process, which the project want to test in a pilot unit, uses <400 kWh to evaporate one ton of water in comparison to 850 kWh for energetically optimized systems for traditional processes and, hence, will give a surplus of energy.

The technical challenge and the reason why pilot tests has to be performed is the physical properties of manure and sludge before and during the drying process. Sludge is entering into a sticky state at a certain stage during drying. This has always been a challenge to sludge dryers.
3. Process description

The process flow diagram is shown below in Figure 3.

Figure 3 Flow sheet for biomass closed loop steam dryer Demonstrator

Wet sludge is pumped to the inlet feed device and distributed in the loop pipe through a nozzle. The wet material is then pneumatically conveyed and directly dried by the circulating superheated steam in the drying loop between the inlet feed device and the cyclone. The sludge is heated and the water evaporated by the pressurized steam atmosphere inside the drying loop. After considering the sludge physical properties, residence time and superheating is set so that the sludge is dried to a specific dry matter content depending on customer requirements. The circulating steam in the drying loop is entirely made up of water from the sludge, no need to add water after start-up.

The circulating steam and the now dried sludge are separated in the cyclone. The material is ejected from the pressurized cyclone via a sluice with knife valves. The dried sludge is discharged from the plant and filled into big bags or 220L steel drums.

The steam in the pipe loop is reheated by fresh steam from the boiler which indirectly heats the circulating steam via the heat exchanger. The condensate from the heat exchanger is collected in a condensate tank and taken back to the boiler. The steam in the loop is circulated by a fan.

There is increasingly more circulating steam as the water from the wet material evaporates. The excess steam is taken out from the pipe loop after the cyclone at a point where it is low in dust. The excess steam is condensed in a heat exchanger cooled by cooling water and taken back to the sewage treatment plant.

The excess steam would in a full size plant be taken directly to heat recovery system or to a steam regenerator where it would be condensed producing fresh steam from boiler water. The fresh steam would then be taken to the second turbine step.
Steam and gases from the raw material silo ventilation and the exhaust from the discharge sluice are taken to a scrubber to keep emissions to a minimum.

The aim of the overall process is to keep it as simple as possible using a minimum of equipment to minimize both CAPEX and OPEX.

4. The Demonstrator

The Demonstrator (see Figure 4) is placed at the Tuvan Sewage Treatment Plant in Skellefteå. The plant is able to operate within the environmental permits of the Tuvan plant. The Sludge can easily be taken from the sewage plant to the pilot plant. The dried material and condensate can be returned to the sewage plant. Any cleaning water can also be returned to the sewage plant in the occasion that the dryer needs to be cleaned for inspection or maintenance.

The pilot plant consist of a number of functions, some of them are critical to get a full size plant to operate correctly and some are merely there to allow the plant to be run. An example of such a function is the steam generator which “merely” provides steam to the plant. Steam would be provided in another manner for a full size plant.

A number of other functions are however critical for a full size plant, and will therefore be evaluated during the test work. These are (numbers according to Figure 3):

1. Drying

   The pilot plant must be able to dry the sludge to the drying level needed (i.e. approx. 80-99% dry matter). This can be evaluated by moisture measurement of the incoming wet sludge and the produced dried sludge.

2. Sludge pump

   Must be able to provide a constant flow of sludge to the sludge inlet. Important that the sludge can be pressurised enough and that sludge in the piping can block the pressurised steam from the loop.

3. Sludge inlet

   Must be able to insert the sludge into the drying loop, without accretions forming around the inlet area, so that the sludge is carried away by the steam flow in small enough parts so it is completely dried.
Figure 4: The Demonstrator placed at Tuvan, Skellefteå
4 First loop bends

Important that sludge does not stick to any of the first bends as the sludge may still be in the “sticky” phase.

5 Pneumatic transport

Must transport the (dried and partly dried) sludge all the way through the loop without material settling in bends or pipes.

6 Cyclone

Must separate the dried material from the circulating steam with high efficiency (non-separated material can cause dust build-up on the fan impeller or cause fouling of the superheater).

7 Sluice valves

Must release the separated dried material to the Big-Bag at atmosphere pressure, also considering ATEX regulations (explosive dust atmosphere).

8 Circulating fan

Must circulate the steam in the drying loop with high efficiency and without increasing vibrations (vibration of fan can be measured during the test run) due to dust build-up on the impeller.

9 Superheater

Must transfer heat to the circulating steam without decreasing performance due to blocking of tubes or fouling of heat transfer surfaces.

10 Condensor

Must condense the excess steam in the loop without blocking due to dust in the steam. Cleanliness of the condensate is a good indication of the risk for fouling in the condenser (and a good indication of the efficiency of the cyclone).

11 Big-Bag

Must collect the produced material considering ATEX regulations (explosive dust atmosphere). Function gives indications for how the produced material can be handled.
5. Results and discussion

Over 20 tests have been performed during the last year to continue developing the process and operating procedures based from the state described in the report “Evaluation Report, Test Run 1”.

Improvements in the DCS together with increased experience and expertise now means that the plant can be operated with only two persons and two tests can be performed each week increasing the development pace substantially. Every test has a specific test description and test report to track the progress. Standardized test and sampling routines has also been prepared for external customer sludges.

Information gathering for the development and design of the full size plant is ongoing and new concepts are continuously proven in the pilot plant.

Below more detailed results for the various parts to be evaluated (numbers according to Figure 3):

1. Drying

The drying process is now quite well understood and processing parameters can be set to achieve a suitable dry substance content in the discharged product depending on the sludge physical properties. 83-98% dry matter content has been tested so far using sewage sludge.

The dried product has a very consistent quality with regards to particle size, physical properties and dry matter content.

The drying time is also shorter compared to more known wood based biofuel materials indicating that a short loop can be used.

2. Sludge pump

The sludge pump, eccentric screw feed pump, which is a standard pump used for sewage sludge, has proven both functional and reliable.

3. Sludge inlet

The inlet is capable of inserting the sludge into the flow of steam to achieve the drying needed.

Five new feeding nozzles types have been evaluated in the pilot plant during 2016 with increasing reliability and performance. It is by now obvious that a reliable wet sludge injection is critical for the function but the nozzle alone cannot solve the issue with accretions forming on the inside of the tube wall (as mentioned as one of the main problems in “Evaluation Report, Test Run 1”) when drying it past the “sticky phase”. An advanced CFD calculation model has been developed to analyse and simulate a new concept that will be proven in the demonstrator during 2017 before installation in a full size plant.

To allow the demonstrator plant to operate longer without stopping due to wall accretions a cleaning device has been installed to remove the symptoms of the accretions forming on
the inside of the tube walls in the loop. Thanks to the possibility to occasionally clean the walls we have achieved a material balance in-out and have operated the plant for up to two days without any need to stop due to accretions.

4 First loop bends

The first loop bends have generally not shown any signs of blockage at the later part of the tests.

When operating the cleaning device in the loop some sludge can form accretions in the bends under certain operating conditions but this can easily be detected and a steady state is normally reached.

5 Pneumatic Transport

The produced material is a relatively “fluffy” material (see figure 5), which have a low specific weight (0.25-0.3kg/dm3) at the same time as it is holding together relatively well. This seems like an easy material for pneumatic transporting. The pneumatic transporting in the dryer loop has proved to be quite powerful by transporting relatively wet and solid material through the loop.

Figure 5: Two of many 220 litre barrels produced at the plant, ready to be sent to high temperature oxidation tests.
6 Cyclone

The cyclone has proved both efficient and reliable. The cyclone has during inspections always been clean inside. The condensate water sampled from the condenser has only shown minor dust content indicating a proper design and function of the cyclone.

7 Sluice valves

Sluice valves were not working well at the beginning yet better than cell feeders. Some of the problems could be related to condensation in the outlet area causing the condensate and the dried material forming sludge and blocking the lower parts of the outlet.

After a small revamp on the demonstrator in the beginning of 2016 (increasing of the outlet pipe diameter), the discharge of the fluffy dried sewage sludge is working acceptable most of the time.

The existing heat tracing has been improved to solve the condensation issue but there are still some issues that need to be solved during the winter maintenance stop to further improve reliability.

8 Circulating Fan

The circulating fan has worked well as for circulating the steam in the loop. Vibration levels have always been within allowed limits.

The effect of steam flow speed in the loop has been evaluated to find the most energy efficient and reliable process parameters. Steam speed has also a big impact on the dried materials physical properties.

9 Superheater

The superheater has worked well and have not had any problems with heat transfer to the loop. It has during inspections not been dirty/blocked indicating a proper design and proper function of the cyclone.

10 Condensor

The condenser has worked well. It has not during inspections been dirt/blocked and the condensate has been relatively clean indicating a proper function of the cyclone.

11 Big-Bag

In the later stage of test work, after improving the sluice valves (see above), the collecting of dried sewage sludge has been working without problems.

The big-bags has been replaced by 220l steel barrels to increase storage life of the produced material and ease handling and freight, see figure 6.
Figure 6 Eight full Steel barrels used for dried material storage cooling down after a successful test.
6. Conclusions

After the first test campaign it was concluded that there were three areas that needed improvement before an operative plant can be reached:

- Inlet area; Sludge from the inlet nozzle forms accretions close to the inlet nozzle.
- Outlet area; The dried produced material that should exit the drying loop into the Big-Bag gets stuck in the outlet pipe.
- Circulation fan sealing box; The sealing box is a standard component needed for the operation of the Demonstrator and not an equipment planned to be tested. Still the sealing box has to be improved/restore.

The seal box was renovated and improved steam supply together with better control parameters solved the issue.

The outlet area has been improved both technically and through how it is operated. The function is now acceptable. The behaviour and requirements for the outlet are however now well known. This is also a less critical areas for a full size plant as the outlet will not be made as a sluice arrangement.

It is clear that the sludge inlet still is a critical function and that the design will require some further development before any installation in full size process plant can be made.

The other areas to be evaluated, mentioned in Chapter 4 and 5, has continued to work well.

One further area noticed is that the drying time is short indicating that a short loop can be used.

After the latest minor rebuilding of the demonstrator and redesign of the DSC control philosophy the plant is now considered operational and the hot commissioning test runs are being replaced by scientific test work and proving design concepts for a full scale plant.

- Evaluation of the drying process for new types of customer sludges in bigger quantities (several tons) is now possible.
- Production of bigger quantities of dried sludge for combustion tests.
- Evaluation of design concepts for the full scale plant can now be performed.
7. Future work

The design is almost ready for commercial use, but some future steps need to be taken first:

- To increase throughput to reach full capacity by improving the reliability of the sludge feed. For this the inlet feed device would need to take a technical step forward.
- Long term operation (weeks) as compared to days is also necessary to prove component wear and suitability in a production plant.
- Process parameters and best operating practice needs to be further optimized to be better adapted to a full size operation.
- The DCS control loops and control philosophy needs to be further analysed to improve plant performance and usability. The operator interface (HMI) is acceptable for a test bench but unnecessarily complex for a production plant and need to be developed and proven in the demonstrator.
- Instrumentation needs to be revaluated to reduce complexity and cost.

8. Future full size production plant

The base for using the Steam Dryer for sludge drying is that is has a number of advantages compared to other types of dryers.

- Energy efficient
- Completely closed process (no fugitive emissions)
- Other substances/nutrients available in the separated condensate
- No need for a gas cleaning stage (odour, emissions)
- Low internal energy consumption
- Mechanically few components that are easily scalable to the necessary capacity
- ATEX safe (steam environment)
- Able to dry to high levels (>90%)

As the recycling of phosphates only will generate a modest income for the operator, likely from a gate fee, energy production and sales of phosphate containing ashes, it is clear that the plant must be simple, reliable and energy efficient with a low internal energy consumption to be successful. The Steam Dryer has the potential to achieve those criteria.

A likely reduction in the drying loop length would also reduce the CAPEX investment needed as the shorter loop, besides being less costly, would also save cost by reducing the footprint and the needed steel structure. A new optimized layout could be beneficial based on these findings.
Figure 6 Flow sheet for an full size plant

One further advantage is that the Steam Dryer is also well adapted to the next gasification process step as that process step benefits from having the gasification in a steam environment, something that could easily be supplied from the Steam Dryer.

As always, the Steam Dryer needs integration into the infrastructure to achieve the full potential of energy efficiency, the surplus steam must be put to good use as for example process heating, district heating or as electric production in a steam turbine.