CLOSED-CYCLE THERMAL TREATMENT OF TANNING SLUDGE TO ENHANCE ENERGY VALUE

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ABSTRACT
The sludge drying system envisages treating the wastewater from tanning water treatment plants, downstream of mechanical dewatering. The sludge has a dry matter of 20÷25%, so it is mainly composed of water.
This wastewater is taken to landfills located far away, with consequent landfills overloading and trucks movement.
Water evaporation from the sludge allows to:
- Reduce sludge quantities (78% weight reduction, from 80% down to 10% moisture)
- Reduce transports
- Stabilise the sludge with subsequent energy recovery (dried sludge has a PCI of 2.800 kcal/kg).
The process consists of two phases: product extrusion (to increase heat exchange surface and limit the dust) and extruded product drying (by passing it over modules with air at low temperature - 80°C). The system is supplied with hot water (85-90°C) from thermal waste or cogeneration processes. The efficiency of the heat exchange is guaranteed by special conveyor systems that shoot the air over the sludge at high speed (10m/s).
The plant works in closed circuit, the evaporated water is condensed through an integrated condenser, the safety of the operation is guaranteed by a continuous renewal of air (about 1% of total process air) that is cleaned through a two-stage scrubber, acid and basic oxidative, with continuous monitoring of the concentrations of potentially dangerous substances through PID (ammonia and related compounds) and IR (hydrocarbons) sensors.
This process allows the reduction of sludge in closed cycle, with zero emissions and low consumption, aimed at creating a by-product (fuel for energy plants) from waste

1. Introduction

Machine type: Hot air belt dryer

Intended use: Drying of sewage sludge or similar in a dehydrated state with input moisture up to 85% and final output moisture at 10%.

Heating source: the system is designed to operate using hot water: 70 ° ≤ T ≤ 110 °C Foreword: in a hot air dryer, heat is transmitted mainly by convection, the heat power transmitted between the air and the solid product to be dried is given by the following formula:

$q = \alpha \cdot A \cdot (T_a - T_p)$

where:

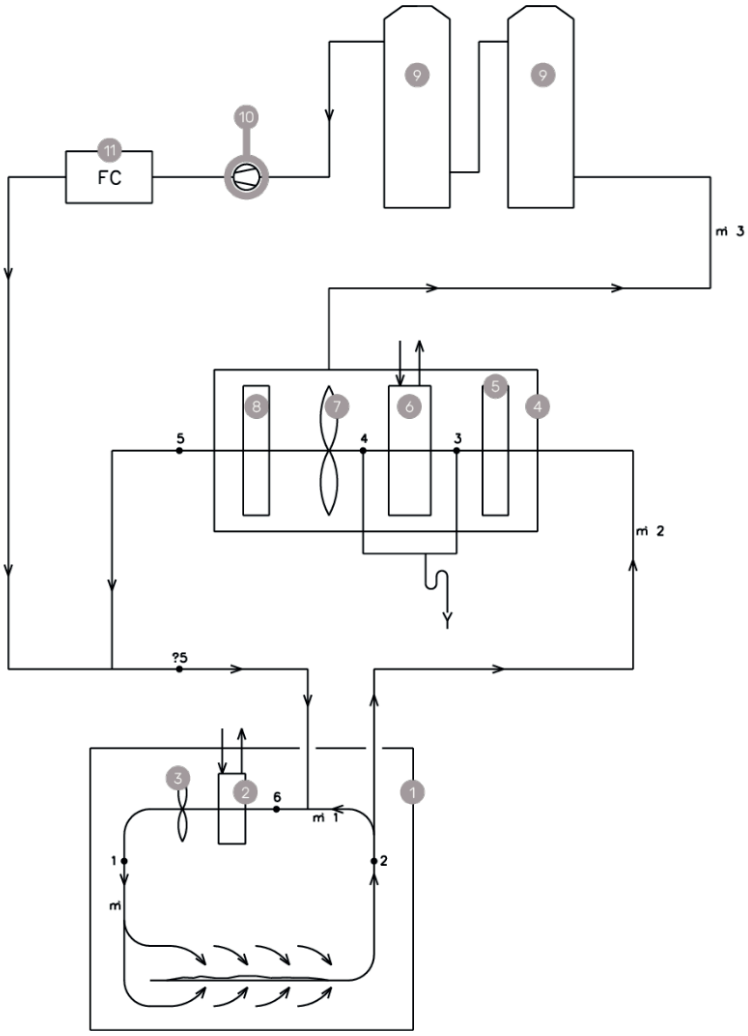
• q= heat power transmitted

• A= exchange surface area

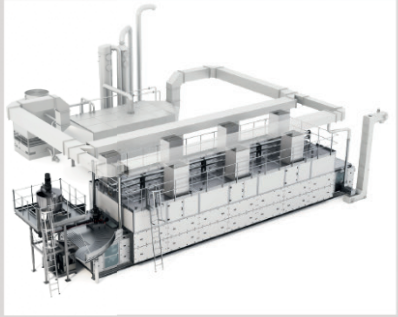
• $(T_a - T_p)$= ΔT between air and product

Prerequisite: For a given exchange surface area A, if the factor ΔT is limited by the temperature of the heat source, in order to increase the heat power exchanged and therefore the efficiency of the machine, the coefficient α has been adjusted by increasing its value to give the air flowing over the product an adequate speed compatible with the permissible electrical consumption. The machine has therefore been equipped with suitably shaped shrouds/

diffusers with openings that enable air to flow over the product at an average speed of 40 km/h.
The machine is modular to provide the flexibility required by the market.
Operating principle: the thermodynamic cycle used for drying the product is described in the following schematic section:



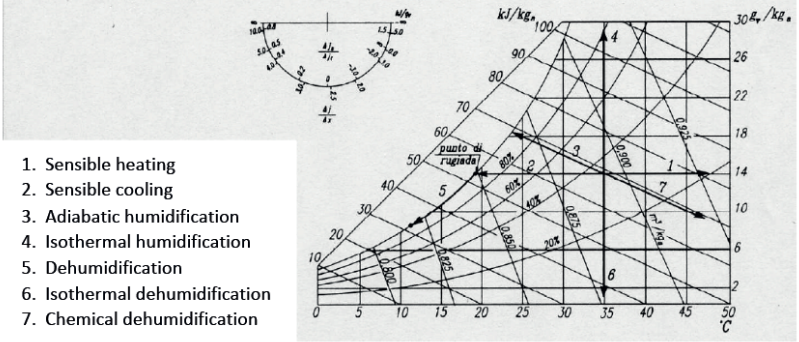
1- EFT module
2- EFT module heating coil
3- EFT module fan
4- ATU
5- ATU heat recovery coil
6- Condensing coil ATU
7- ATU fa
8- ATU heat recovery coil
9- Scrubber
10- Scrubber fan
11- Carbon filter



During product drying, the air passes from state 1) to state 2) and undergoes a Cooling + Humidification transformation, transformation (3) in the following diagram:

4. THE PSYCHROMETRIC DIAGRAM

The psychrometric diagram is used to calculate the transformations that mixtures of air and water vapour undergo and refers to standard atmospheric pressure (approx. 1.013 bar). The physical state of a mixture (temperature, humidity, enthalpy) is recorded on the diagram once any two parameters are known.



1. Sensible heating
2. Sensible cooling
3. Adiabatic humidification
4. Isothermal humidification
5. Dehumidification
6. Isothermal dehumidification
7. Chemical dehumidification

To ensure the effectiveness of the drying action, the following respective permissible temperature and relative humidity limit values are assigned for the air in state (1) and state (2):

- $T_P \geq 60°C$
- $RH_L \leq 30\%$

1.1 Technical and design data:

- Fan air flow rate per single module	25,000 m^3/h (constant)
- Condenser air flow rate per single module:	4,000 m^3/h max
- Air flow rate to scrubber circuit + carbon filter per module	150 m^3/h
- Coil hot water supply temperature:	80 °C ≤ T ≤ 110 °C
- Condenser cold water supply temperature:	T ≤ 32 °C
- Air temperature after product:	T ≥ 50 °C
- Air humidity after product:	RH ≤ 30%
- ΔUa through the product:	max $8g_{H2O}/kg_{dry\ air}$
- Dwell time at first lap:	min 25min
- Total dwell time inside the dryer:	min 90min

1.2 Operating logic:

With reference to the previous diagram:

- The air temperature before the sludge is normally set to the theoretical maximum value equal to the hot water supply temperature value: $T_P = T_{hot\ water\ IN}$
- The air humidity before the sludge is normally set to the theoretical minimum value: 5%
- The fan flow rate *m* [m^3/h] is constant and equal to the maximum value
- The actual air temperature before the sludge T_1 will be equal to the temperature of the incoming hot water minus approx. 5°C (air/water exchange efficiency)
- The flow rate of humid air sent to the condensing unit is regulated by the speed of the fan inside the unit itself, regulated by an inverter and controlled by the T1 value: the system must operate with the fan of the condensing unit regulated to 50Hz as per the design; if temperature T1 drops from the initial value measured at no load, this means that the air arriving from the condensing unit is colder than the design conditions and therefore the flow rate can be reduced. The relative humidity follows the temperature trend, so it will only be a practical measurement value.
- The flow rate to the safety circuit (scrubber and carbon filter) is 0.6% of the drying flow rate, so its influence on the thermodynamic process cycle is negligible.

1.3 Note on the safety circuit

The drying system treats sludge that may contain residues of organic compounds and nitrogen compounds that can essentially be traced back to ammonia or otherwise derived from it. These compounds may present a risk of building up hazardous concentrations in the sense of explosiveness. In order to dilute the substances released below the safety thresholds, the dryer provides for purification of a suitable flow rate of process air, through the safety circuit, by means of wet abatement columns and activated carbon scrubbers, with subsequent reintroduction into the machinery. To avoid any danger in the event of failure or malfunction of the abatement system, the dryer is equipped with a system for sampling and measuring the substances inside. The air flows taken from inside the system each pass through two different sensors that analyse and measure the concentration of hazardous substances:

• 1 electrochemical cell sensor that detects the presence of ammonia

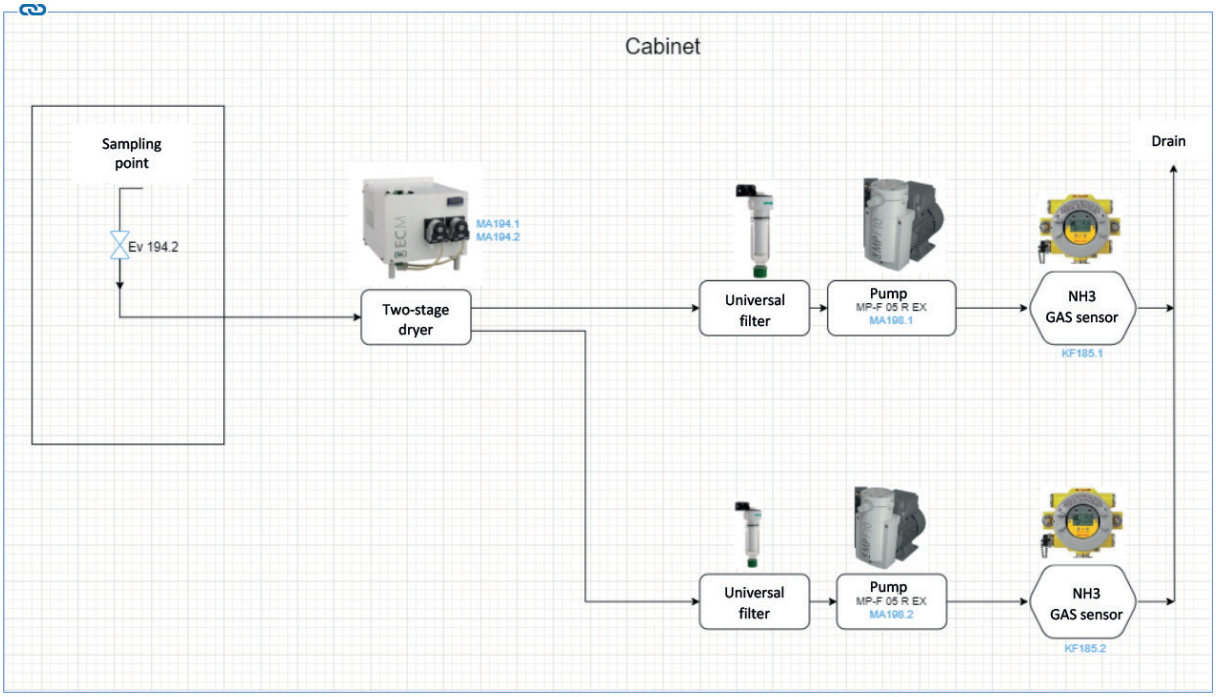
• 1 catalytic cell sensor that detects broad-spectrum flammable gases

The sensor system is calibrated on dual-threshold logic: the first threshold triggers an alarm and feedbacks that try to lower the concentration of hazardous substances present (reduction of operating speed, replenishment of external air etc.) The second threshold commands the immediate stop of the machine.

When the machine restarts, a "scouring" cycle of the drying chamber and intake ducts is carried out in order to remove any residues of accumulated hazardous substances.

In addition, any failure of the systems that affect the safety of the machine (mainly faults in the air extraction and abatement system) triggers a safe shutdown of the entire system.

ll monitoring and control systems that affect the safety of the system are implemented by means of reliable systems and circuits under safety logic or in electromechanical circuits.



1.4 Dryer characteristics

The EFT Cartigliano is a modular low-temperature dryer powered by hot water (hot air at 70-80°C) with material transport on a belt.

Inlet extruder

The patented extruder can process different types of palatable sludge with a wide range of moisture content (50-85%) and forms the material into a cylindrical shape, with the following advantages:

- It increases the heat exchange surface and thus the efficiency of the process
- It makes drying uniform and continuous
- It minimises formation of dust

Modularity of the system:

- each module has 2 fans; in the event of a decrease in the sludge flow rate, the system can be adapted to the new loads by switching off one or more modules and/or fans. Therefore, the system can work with partial loads, optimizing energy consumption.
- in the event of future productivity increases, the system can be adapted to treat the new flow rate by adding

intermediate modules.

- when maintenance is carried out, it is not necessary to shut down the entire system since it is possible to disconnect only the module undergoing maintenance.

Air diffuser boxes

Inside the drying modules there are slotted, stainless steel shroud systems that are able to blast the moist material with hot air at high speed over a short distance. This system eliminates the formation of dust.

Flexibility

- Possibility of working with partial loads while maintaining maximum efficiency
- Possibility of processing different types of wet material (chemical-physical sludge, biological sludge, digestate, etc.)
- Modularity of the system:
- Possibility of using hot water heating sources with different origins (co-generator, waste heat flow, thermal waste)

2. Materials and Methods

2.1 Sludge collection hopper after mechanical dewatering

1. Continuous feeding to the dryer;
2. Mixing of the sludge to homogenise it;
3. Filling level control to synchronize the inflow of sludge to be treated with the dwell time in the dryer in line with the set production output.

The hopper is equipped with:

- a continuous level gauge with:
  - a low level threshold that gives a signal to the loading system to start loading the material, but does not cause any consequences on the machine;
  - a high level threshold that gives a signal to the loading system when material loading stops.
- a redundant paddle level sensor to prevent the high level threshold from being reached
- Automatic tank flushing system via multi-stage pump.
- Electric motors controlled by VFD

2.2 Extruder loading system

The extruder is composed primarily of the following:

- a swivel joint, which allows the hopper to be connected to the reciprocating distribution feed screw
- a system of dosing feed screws and lump breakers;
- a horizontal feed screw that conveys the material to the extrusion head;
- an extrusion head equipped with a special vertical screw with a grind end that presses onto the perforated extrusion plate. There is also a pressure sensor with low and high pressure thresholds. High pressure signals a die plate blockage, with an alarm and locking of the extruder (the belts continue to run).
- Arc track on which the extruder moves, which allows even distribution of the product on the dryer belt

The extruder is flushed automatically by a circuit equipped with a multi-stage vertical pump.

2.3 Dryer

The dryer is of the belt type with direct heating on the product by means of hot air. It has a variable flow rate depending on the modular configuration in question.

In this type of dryer, heat transfer occurs by convection, with a high-speed air current (therefore with high flow-rate fans) and relatively low temperature. It is therefore possible to use low exergy primary energy, making the dryer versatile for already available heat supply sources such as:

- Thermal waste
- Flows from a cogeneration plant
- Residual hot steam from other processes
- Residual hot water flows from other processes
- Other carriers

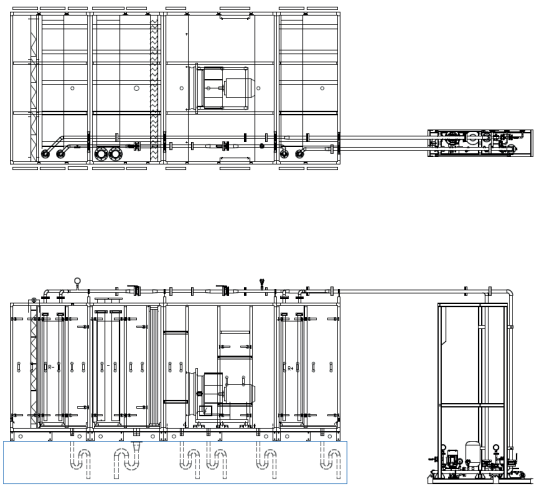
The material advances longitudinally with respect to the system, completing 3 or 5 laps depending on the configuration chosen during the design phase. Transition from upper to lower belt is by gravity.

The belt motors are equipped with VFDs with a setting defined during commissioning. The dried sludge is extracted from an additional conveyor.

The system consists of modules that can be juxtaposed to achieve the required treatment capacity. Each module is functionally independent, since it is equipped with:

• Upper ATU for air treatment consisting of:
  - 2 fans for air movement
  - 1 hot water heating coil
  - 1 filtering station
  - lower air conveying unit consisting of:
  - side air passage channels
  - air distribution shrouds
  - special slotted boxes for air distribution over the sludge deposited on the belts

2.4 External condensing unit and heat recovery unit



The condenser unit is unique and its positioning is not binding. The condenser operates with cooled water from an evaporative tower or other cooling systems..

A heat recovery system consisting of air/water exchangers connected in series on the water side is installed between upstream and downstream of the condenser. The exchanger at the condenser inlet removes heat from the

inflowing air by heating the water, which is sent to the outlet exchanger. Here, the water is cooled by preheating the air leaving the condenser.

Temperature and relative humidity measurements are taken on the air flows in and out of the single condenser to monitor the status of the flows.

The fan serving the condenser is equipped with a VFD and its speed is automatically varied by a PID function in relation to the average temperature/humidity value measured on the incoming air flow. The measurement is carried out - as in the integrated system - on three modules.

2.5 Construction materials and surface finishes

The following is a list of materials for each individual item:

• Extruder:

- Loading hopper: AISI 304 stainless steel with hot-dip galvanised structural steel balcony in accordance with UNI EN ISO 1461
- Support structure: AISI 304 stainless steel;
- Reciprocating distribution structure: Epoxy coated S235 industrial steel;
- Cover bellows: AISI 304 stainless steel
- Horizontal feed screw jacket: AISI 304 stainless steel;
- Horizontal feed screw: AISI 304 stainless steel;
- Extruder screw jacket: AISI 304 stainless steel;
- Extruder screw: AISI 304 stainless steel;
- Die: K110 tool steel;

• Inlet/outlet modules:

- Structure: epoxy coated S275JR structural steel;
- Drive rollers: AISI 304 stainless steel;
- Relay rollers: AISI 304 stainless steel;
- Supports: cast iron with anti-corrosion surface treatment
- Belt guidance system actuator: painted steel
- Side infill panels: anodised Al and polycarbonate profiles
- Upper infill panel: sandwich panels in pre-painted Al with polyurethane foam insulation
- Lower infill panel: AISI 304 stainless steel;

• Lower intermediate modules:

- Structure: epoxy coated S275JR structural steel;
- Air diffuser boxes AISI 304 stainless steel;
- Supporting rollers: AISI 304 stainless steel;
- Shrouds/deflectors: AISI 304 stainless steel;
- Upper infill panel: sandwich panels in pre-painted Al with polyurethane foam insulation
- Lower infill panel: sandwich panels with pre-painted Al and polycarbonate “Isobox” sheet metal

• Upper ATU modules

- Structure: 20 μM anodised Al with painted die-cast Al joints;
- Infill panel: sandwich panels in pre-painted Al with polyurethane foam insulation
- Double inlet centrifugal fans with backward facing blades: epoxy coated S275JR structural steel
- Flow control dampers: AISI 304 stainless steel;
- Pre-coil filter: AISI 304 class G2 stainless steel

- Water/air heating coil AISI 30 stainless steel frame, Cu tubes, Al fins, fully lined with Heresite P-413 C thermosetting phenolic resin protective treatment

• Conveyor belts: PET mesh, mesh opening 2.2x2.2 mm colour blue;

• Last lap conveyor belt: PET closed mesh (permeability at 2 mbar 7920 $m^3/m^2/h$

• Hot water supply and return manifolds: Painted and insulated S235 steel;

• Air-conditioned electrical panel: 1.5 mm thick steel sheet painted with thermosetting powders

2.6 Electrical systems

The supply includes an electrical power and control panel that controls the accessories serving the dryer. The cable ways located on the package up to the package edge are supplied and assembled.

Some characteristics of the electrical components are listed below:

- The electrical panels are equipped with all the necessary safety and switching devices.
- The inverter-controlled electric motors are suitable for variable speed operation.
- An adequate earthing system for the system is provided.
- The motors are powered at 400 V three-phase at 50Hz.
- The instrumentation is powered at 24 VDC.

The motors are controlled by: remote control switches, soft-starters, inverters The electrical panel is equipped with:

• Siemens ET200SP series PLC

• Schneider electromechanics

• Schneider inverters controlled in Profinet

• Panel PC for drying system management

2.7 Automation

The PLC acquires all the signals (digital, analogue, bus) from the system to process them and control all the system's utilities.

The PLC communicates with inverters, encoders, etc. via PROFINET bus

It controls remote control switches, contactors and interface relays via wired signals.

The electromechanics manage the power part of motors and signals outside the dryer electrical panel. Inverters regulate the speed of the motors that require accurate control for the process.

There is a Panel-PC on which supervision software (SCADA) is installed to display, control and record the parameters of the entire system.

The dryer's PLC can be integrated with dedicated devices to interchange signals with your DCS system for display/ control of the dryer's slave parts.

The slave devices of the dryer are connected and managed directly or partly by the PLC of the dryer itself via field bus (Profinet) or via wired signals.

There is a device for remote assistance with connection to your network via network cable or WiFi, so that problems can be resolved and upgrades can be carried out.

3. Results and Discussions

Thanks to the system, we were able to reduce the amount of water in the sludge and wet residues from 80% to 10% (approximately). Ensure that there is continuous monitoring by the operators of the chemical agents that are hazardous to safety during the processing phase of the system.

4. Conclusions

We succeeded in designing and building a low-temperature (80°C) and zero-emission belt drying system. Continuous monitoring and control of agents hazardous to the safety of people working in the drying plant.