Microwave-In-Drum-Drying

A new volume reduction process for radioactive and toxic liquid waste

A microwave-heated waste drying system can provide a tenfold reduction in liquid waste processing time.

Dipl.-Ing. Horst Linn, Dipl.-Phys. Roland Waitz, Dipl.-Ing. Hans Windsheimer, Linn High Therm GmbH, Eschenfelden, Germany

1. Introduction

Liquid radioactive waste, e. g. salt solutions or sawing slurry arising during the regular operation, downtime or decommissioning processes of a nuclear power plant or in medical dispositions, in research, in the defense industry etc. In most nuclear power plants these liquids are by standard enriched using a circulation evaporator to a dry substance content of up to 20 wt.-%. These concentrates must undergo an additional drying/concentration process prior to for final disposal.
The concentrates must be dried in a separate drying plant and placed in a receptacle (e.g., a 200 litre drum) for the final disposal. Common techniques include using a rotary film evaporator; other techniques include evaporation at reduced pressures by external heating etc. In case of drying up of salt solutions, the concentrates must be enriched up to a residual moisture content of approximately < 1 wt.-% to get a solid salt block for final disposal. The hardening of the hot waste product to a solid salt block occurs during the cooling process. At this time the salt solution (water content app. 20 wt.-%) which is contained in the drum builds a hard and crystalline salt block.
In addition it is more economic and safer to apply the drying procedure directly inside the final disposal container. The most common procedure is to heat up the wall of the drum from outside with strip heaters. However, heating the outside of the drum leads to a temperature gradient between the drum wall and the drum centre. The highest temperature is achieved at the wall of the drum, leading the solidification process to start there and resulting in the formation of a salt layer. This causes a reduced thermal conductivity from the outside to the inside (liquid solution) and corresponding by the thermal resistance increases. As a result, the solution in the centre of the drum generally does not completely crystallize, leading to longer process times and the need of considerable higher outside temperatures. The outside temperatures, however, are limited by the temperature resistance of the materials and process conditions. The typical time to dry a drum with the outside heating method is about 80 days. Furthermore - to guarantee the corrosion protection - the coating of the drums must not reach temperatures more than 120 °C.

2. A New Solution

As a result of a long term corporation with the german nuclear industry, Linn High Therm has patented a procedure using microwaves to reduce the liquid content in radioactive liquid wastes. This process, **M**icrowave-**I**n-**D**rum-**D**rying (MIDD), is an evaporation-driven crystallization process.
In cooperation with a partner of nuclear industry, Linn built a pilot MIDD plant. Several test runs with defined liquid waste (non radioactive simulated solutions) have been successfully performed.
The most important advantages of the MIDD process compared to resistive outside heating process include the following:

- microwaves generate the heat directly in the solution in the complete volume of liquid layer.
- minimal temperature gradients and homogeneous crystallization result.
- Process times that are 8 - 10 times shorter than the more common resistive heating methods (see Fig. 1).

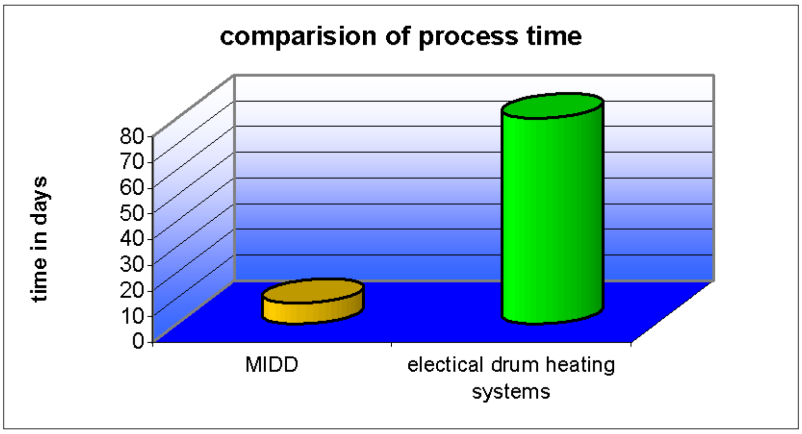


Fig. 1: Comparision of process times for the MIDD system and electrical drumheating systems

2.1 The MIDD Process

The MIDD process is semi-continuous and starts with feeding an initial amount of liquid waste into the final package (e.g. drum) while the drum bottom is preheated by induction heating. Then microwave heating is engaged and more liquid waste is continuously fed by a dosing pump. During evaporation the drum and the microwave applicator are kept under a slight vacuum – on a absolute pressure of 900 mbar. The exhaust steam is suctioned off by a fan. An aerosol separator removes entrained dust particles and liquid drops. The feed steam is condensed in a water cooled heat exchanger, and the condensate is collected in a separate vessel. At the end of the process the dosing pump is stopped, and the microwave heat evaporates the rest of the liquid inside the container. After cooldown of the drum and material the container is replaced by an empty one, and the cycle can begin again.
Generally, the condensate is discarded, and the solid waste in the container is ready for direct disposal. During the process, a closed circuit water cooling unit ensures a constant low temperature of the cold side of the heat exchanger, which guarantees that the exhaust steam is condensed completely.
To control the MIDD plant, a PLC system (Simatic S7) is used. All in- and outgoing mass-flows are measured, so that the mass balance of the evaporation process is ensured. In addition, the pressure, the temperature and the liquid level inside the container are measured continuously. Together with the other control parameters, the thickness of the liquid layer above the dry salt layer inside the container is determined, which is necessary for a controlled crystallization. All data are logged in a seperate unit. The data can either be shown at a 12“ touch-panel at the control unit or printed from a connected external personal computer and printer. The overall MIDD process is visualized at the touch-screen control panel.

2.2 Technical Details

The MIDD process is a semi continuous crystallization process (see Fig. 2). Before the start of the microwave heating, a certain amount of solution has to be pumped into the recipient drum.

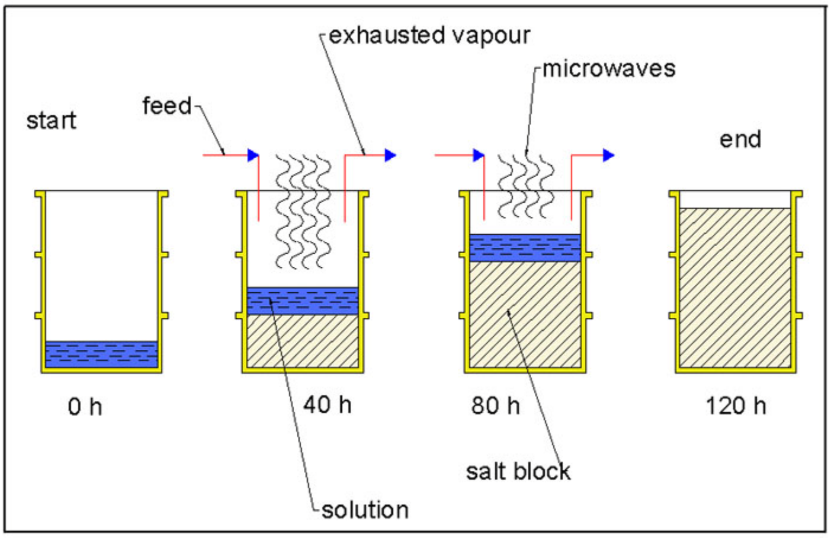


Fig. 2: Schematical construction of the MIDD Process

The solution is then heated by microwaves. In addition the drum floor can be preheated inductive. The microwave power has to be controlled with respect to the increasing boiling point of the liquid during the evaporation process because of the rising salt content. At a dry substance content of about 20 wt.-% the solution is oversaturated and the boiling point, as well as the concentration, stays constant. At this point, the content of the solid phase is steadily growing. The thermal balance is reached at approximately 105°C and a reduced pressure of around 950 mbar absolute pressure. After the liquid waste feed has been stopped, the homogeneous liquid surface over the solid product disappears. This causes the product surface to be heated too fast, because of the low thermal conductivity and heat capacity. To avoid this, the temperature of the product surface and the temperature of the drum wall are controlled by pyrometry. The temperature changes during the process is shown in Fig. 3.

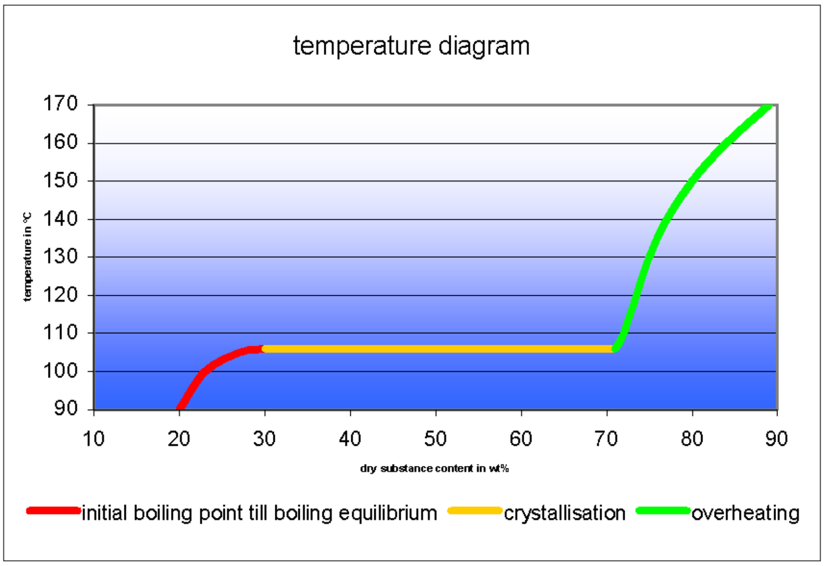


Fig. 3: Temperature diagram during the MIDD process

The maxium dry substance content of 70 wt.-% is calculated from the mass balance. The remaining weight percentage of water is being bound as crystal water. The residual moisture content of the salt block is 0.2 wt.-%.
The controlled and relevant process parameters are the microwave power and the feed flow. The degree of drying strongly depends on the exact process control. The liquid waste contains salts that form crystal complexes with water at low temperatures. Aqueous solution containing appr. 17 wt.-% sodium sulphate (Na_2SO_4) and other additives can be used as a reference solution. Sodium sulphate crystallizes in the hydrogenated complex (Glauber's salt, $Na_2SO_4 \cdot 10H_2O$) modification at low temperatures below approximately 32°C. To achieve better drying, the solution should not be cooled below this temperature during the process. The evaporation-driven crystallization continuous until the

drum is completely filled with dry waste product. The same is valid for sawing slurry which can contain the rests of the concrete, swarf, paint residues etc.

2.3 Pilot Test Results

With the MIDD pilot plant, various tests were conducted to optimize the process parameters. The most important tests were performed with defined concentrate surrogates (recipes originating from circulation evaporators of nuclear power plants). The main part of this solution is sodium sulphate. Some tests were performed with a microwave power of a 6-kW microwave generator, while other tests were performed with a 20-kW microwave generator. The composition of the solution was about 82 wt.-% H_2O, 16 wt.-% Na_2SO_4, 1 wt.-% $Fe_2(SO_4)_3$ and 1 wt.-% other additives.
With the 6-kW magnetron 1,750 kilograms of those aqueous concentrates are dried in about 200 hours, yielding 345 kg of dry salt and 1045 kg condensed water. The pilot plant was operated in 12-kg up to 25-kg batches without interruptions. With the 20 kW magnetron, 1280 kg of those concentrates were dried in 123 hours, yielding 363 kg dry salt and 917 kg condensed water (see Fig. 4).

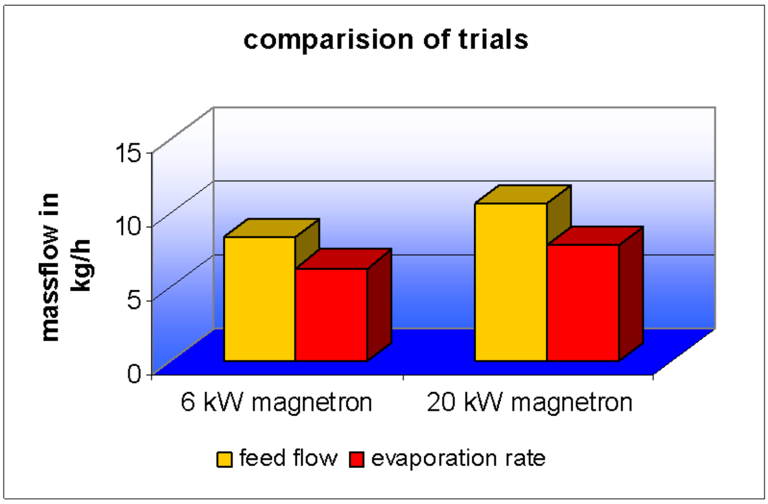


Fig. 4: Comparision of test runs with different microwave powers

The result of these tests shows, that the increase of the microwave power leads to a consequent increase of the evaporation rate and feed flow. The mean evaporation rate increased from 6.3 kg/h to 7.8 kg/h. The comparatively small increase is a result of high reflexions and due to the little volume of the 200 litre drum.
Other tests were conducted with discontinuous and semi continuous feed supply. These results show that semi continuous feed supply increases the feed flow and the mean evaporation rate by 20 percent.
The dry substance content of salt from 6-kW trials was higher than those from 20-kW tests, because the 20 kW-trials could not be operated continuously. Interruptions caused a temperature decrease to less than 32°C. Not evaporated water was bound as crystal water during these interruptions, and Glauber's salt was formed in the bulk. The 6-kW trials were operated without interruptions during the batches, and so a larger portion crystallized into sodium sulphate instead of Glauber's salt than in the 20-kW tests. Therefore, the 6-kW tests showed a larger dry substance content. In other short-term tests, a mean dry substance content of approximately 82 percent was almost always achieved.
All data depend on evaporation rate and applicator efficiency. These parameters were measured continuously during the crystallization of the defined liquid waste. The highest evaporation rate was at a temperature of approximately 105°C (boiling equilibrium) and absolute pressure of around 950 mbar. The best applicator efficiency was also at the boiling equilibrium. The applicator efficiency achieves a maximum of 77.3 percent at approximately 9 kW microwave power. The efficiency decreases below 69.8 percent when the microwave power was increased above 9 kW. The reason for this behaviour is the increased microwave reflection, which leads to a decreasing applicator efficiency of appr. 10 %. The dependence of the evaporation rate (stream of condensate) on applicator efficiency from the microwave power input is shown in Fig. 5.

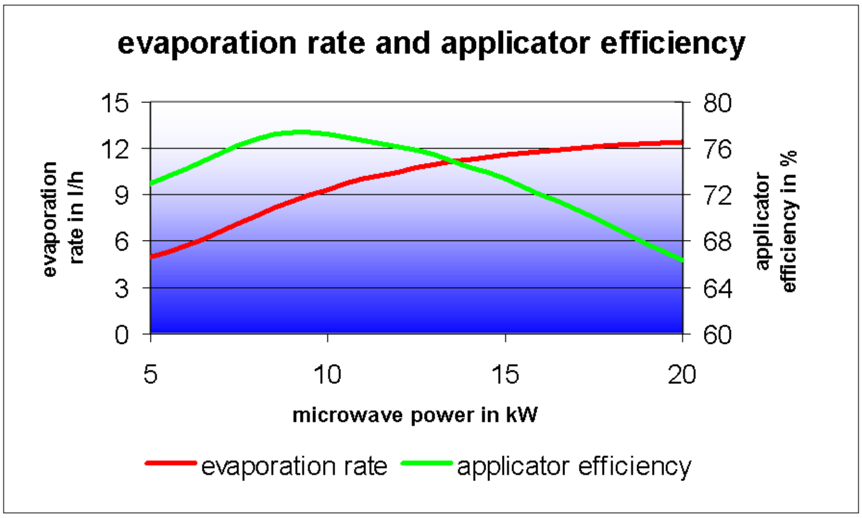


Fig. 5: Evaporation rate and applicator efficiency

Depending on the accuracy of the control of the MIDD process, the resulting waste can vary between a salt block and lose dry powder.

2.4 Commercial Development and Costs

As a result of the different tests and further developments to optimize the process, Linn High Therm has created a new MIDD plant model (see Fig. 6). This new prototype was designed and constructed for continuous industrial operation and will be ready for use in the nuclear industry. The MIDD prototype is adapted to nuclear safety regulations in cooperation with a partner from the german nuclear industry.

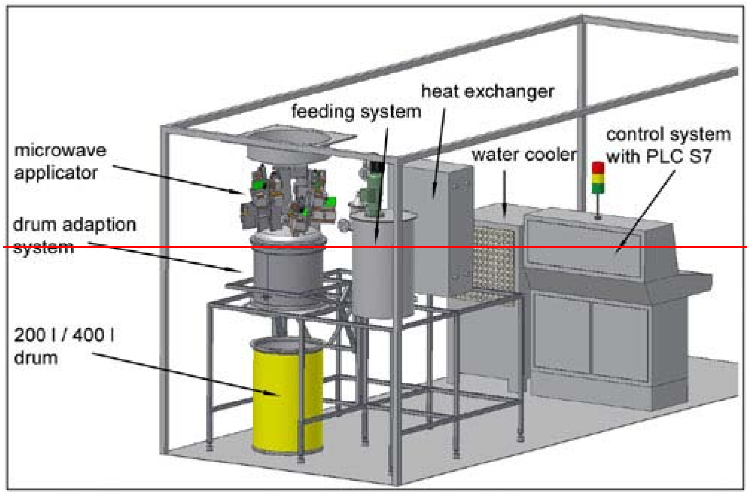


Fig. 6: The commercial MIDD system setup

From a technical point of view, it was important to achieve the best possible homogenous electromagnetic field and the best applicator efficiency. Therefore, in the commercial model, the single 20 kW magnetron was replaced by nine cheaper 900 W standard magnetrons. All parts of the new plant are made of stainless steel, polytetraflouroethylene, or silicone. The plant is designed to be cleaned and maintained easily, with quick connectors and short distances between the different components.

3. Technical data

- microwave power: 9 x 900 W
- inductive power: appr. 1,5 kW (bottom heating)
- microwave chamber: correlates to the container volume (e.g. 200 ltr. drum)
- microwave applicator
- evaporation rate: appr. 8 l/h

Further components:

- drum adapters (e.g., 200 litres drum, 400 litres drum)
- Remote control panel
- SPS system Simatic S7 for control the process
- Dosing adaptation systems (e.g., 200 litres drum)
- External power supply (optional).
- 20-feet housing container (optional).
- closed cool water circulation

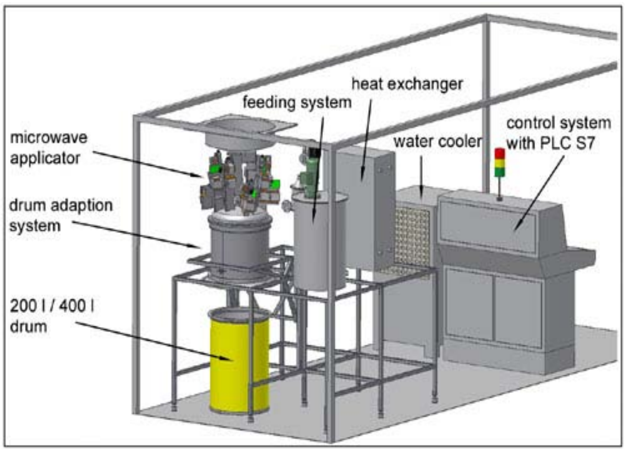
MICROWAVE-IN-DRUM-DRYING (MIDD)

An effective process for volume reduction of radioactive and toxic liquid wastes

The “microwave-in-drum-drying” process (MIDD) being a new patented concept for the evaporation of liquid wastes, combines the advantage of high efficiency, low energy consumption, universal applicability, mobility and self-contained operation. MIDD outperformes convential thermal processes as it yields the concentrated liquid, respectively the dried solid waste directly in the final package (e.g. 200 l drum, 400 l drum).

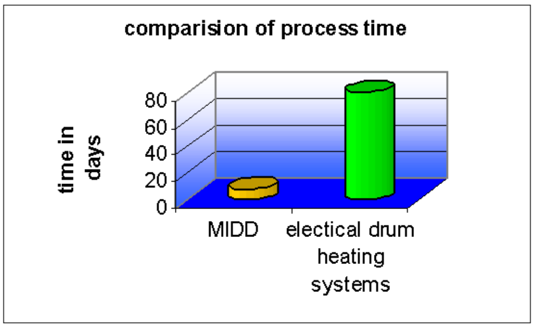
Technical Data:

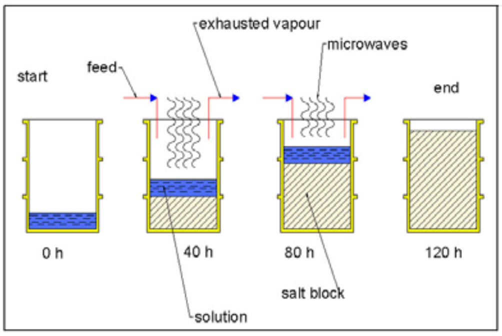
Microwave power:	9 x 900 W
Microwave chambervolume:	equal to drum volume
Induction power:	about 1,5 kW
Evaporation rate:	about 12 l/h



MIDD components:

- Microwave applicator
- Drum adaptations (e.g. 200 l drum, 400 l drum, rectangular packages, descrete packages)
- Remote control panel
- PLC system (Simatic S7)
- Closed water cooling circuit
- Dosing adaptation systems (e.g., 200 l drum, 400 l drum)
- External power supply (optional)
- 20”-housing container (optional)





The MIDD-process is a semi continuous process. It starts with feeding an initail amount of liquid waste into the final package (e.g. drum) while an induction system preheats the drum. Then microwave heating is engaged and more liquid waste is continously fed by a dosing pump. During evaporation, the drum and the applicator are kept under a slight vacuum. Vapours are sucked off by means of a fan. An aerosol separator removes entrained dust particles and liquid drops. The feed vapour is condensed in a customer-provided, water cooled heat exchanger and condensate is collected in a separate vessel. At the end of the process the dosing pump is stopped and the microwave treatment applied evaporates the rest of the liquid inside the package (e.g. drum). After cooling down of the drum and material, the full package is replaced by an empty one and the process can start again. Depending on the input liquid, the condensate is discarded or recycled in the case of valuable resource material. Solid waste in the package is ready for direct disposal.

www.linn.de • info@linn.de • Phone: +49 (0) 9665 9140 – 0

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