VERSATILE CEMENT SOLIDIFICATION OF LOW- AND INTERMEDIATE LEVEL RADWASTE WITH THE MOSS SYSTEM

by

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ABSTRACT

The MOSS system, a mobile cement solidification system, has been in successful operation since the early nineties at the Borssele nuclear power plant in the Netherlands. Extensive experience has been gained which serves as the basis for the development and construction of the second generation of the MOSS system during 1997-1998.

The MOSS system is a complete, remotely controlled system for cement solidification of liquid radioactive waste. The system is compactly installed in a framework with the size of a standard 20-ft transport container. The system uses the "lost stirrer" technique to immobilize different kinds of waste such as ion exchange resins, sludge and evaporator concentrate in standard 200 or 400 liter drums. The container together with the separate control module can be transported from one site to another for different tasks.

Different additional modules have been tested in combination with the MOSS unit in order to add functions and to provide a more complete treatment service. One is a dewatering module that utilizes a settling process to adjust the water content of a slurry to a suitable level for cement mixing. The module then feeds the dewatered slurry directly into the drum positioned in the MOSS unit. The dewatering unit has been tested with good results both for bead resin and perlite filtering aid.

During year 2000 the new MOSS system will be used for a cementation campaign for intermediate-level waste at the research center at Rossendorf, Germany. Due to the relatively high activity concentration it is of utmost importance that no activity is spread during processing so that the solidification unit easily could be transported away from the site after the campaign. In this case, the cleanliness of the "lost stirrer" system is a great advantage. The whole MOSS unit is designed to reduce the risk of contamination of the unit itself.

Thus, it has been demonstrated that the mobile MOSS system could be a versatile method for clean and reliable solidification of most applications with liquid radwaste. With precise process control the properties of the final cemented product are optimized and will satisfy the highest demands.

INTRODUCTION

The use of cement for the solidification of radioactive waste offers the advantage of optimization of the properties of the final waste package. The solidification systems can be "taylored" for special waste products and special requirements on the final product. The ABB Atom MOSS System for mobile cement solidification of liquid waste is developed to meet customer and authority requirements in various applications for nuclear reactors, research centers and other nuclear facilities.

A MOSS 200 system, a mobile cement solidification system for 200-liter drums, has been in successful operation since the early nineties at the Borssele nuclear power plant in the Netherlands. Extensive experience has been gained which served as the basis for the development and construction of the second generation of the MOSS system during 1997-1998. The design also relies on more than 25 years of experience from several cement solidification systems delivered as fixed installations in nuclear power plants.

The MOSS system is a complete, remotely controlled system which is compactly installed in a framework with the size of a standard 20-ft transport container. The system uses the "lost stirrer" technique to immobilize different kinds of waste, such as ion exchange resins, sludge and evaporator concentrate in standard 200- or 400-liter drums. The container together with the separate control module can be transported from one site to another and can be adapted for different tasks.

One of the improvements that has been incorporated in the new version is the technique to top-fill the drums. This has been achieved by utilizing a precise weighing technique. The drums can now be filled up with a well-mixed slurry to a level about 5 cm (and with a special adapter up to about only 1 cm) from the top.

Different additional modules have been tested in combination with the MOSS unit in order to add functions and be able to perform a more complete treatment service. One is a dewatering module that utilizes a settling process to adjust the water content of a slurry to a suitable level for cement mixing.

Another additional module is e.g. a unit for chemical pretreatment of the liquid waste prior to feeding the liquid into the MOSS unit for solidification.

In summary the main features of the MOSS system are:

- Compact installation & simple operation based on proven technology
- Remote operation from a separate control unit
- Automatic control of parameters influencing the final waste product quality
- High filling factor for waste drums
- Fulfills extensive ALARA requirements;
  - a "lost stirrer", resulting in a clean process with a minimum of secondary waste
  - few components exposed to the radioactive waste
  - controlled ventilation air flow in order to prevent airborne contamination
- Additional modules for process optimization for special requirements

WASTE PROJECTS FEASIBLE FOR THE MOSS

The mobile cement solidification system "MOSS" has a wide variety of applications. It can be designed for installation in new waste treatment facilities and offers special advantage with respect to a compact installation based on proven technology. In retrofit cases the MOSS can easily be adapted to the locations available at the power plant for receiving of the waste from the liquid waste storage tanks or by emptying old drums e.g. with dewatered resins, which have been in storage at the plant. Different additional modules for accommodation to various types of waste have been tested and can be easily connected to the MOSS.

The MOSS can be provided to a power plant or a nuclear facility on a short term basis for the treatment of small amounts of waste (few cubic meters) as well as for longer periods of continuous production.

Waste Categories Handled by the MOSS System

The MOSS system is designed for the solidification of all liquid radioactive waste types from the operation of nuclear power plants or other nuclear facilities. Powdered resin, bead resin, evaporator concentrates, sludges, filter aid material such as perlite, etc; all types of waste that can be pumped as a liquid slurry can be solidified in cement in the MOSS.

DESIGN FEATURES AND OPERATION OF THE SYSTEM

The main system

The MOSS system is, with exception for the control unit, built into a modified 20 ft container frame. The container bottom is equipped with a stainless steel spillage plate to avoid contamination of the building floor due to possible spillage or dripping during operation and the subsequent decontamination of the MOSS unit. Furthermore, the container is equipped with dismountable wall panels to facilitate transport or storage. A trolley is used to transport the waste storage drum between the different workstations of the system. The trolley has a lifting device for docking the drums and a weighing scale for precise control of the amounts of medium to be dosed to the drum. In addition to the loading position there are three main workstations as follows: the lid handling station, the wet waste dosing station and the dry dosing station for cement.

Ventilation equipment is installed to ensure directed ventilation of the dosing positions during filling of the drum to avoid spreading of cement dust and possible aerosols. The ventilation equipment consists of a self rinsing dust filter, an absolute filter and a fan. (cf Figures 1 and 2)

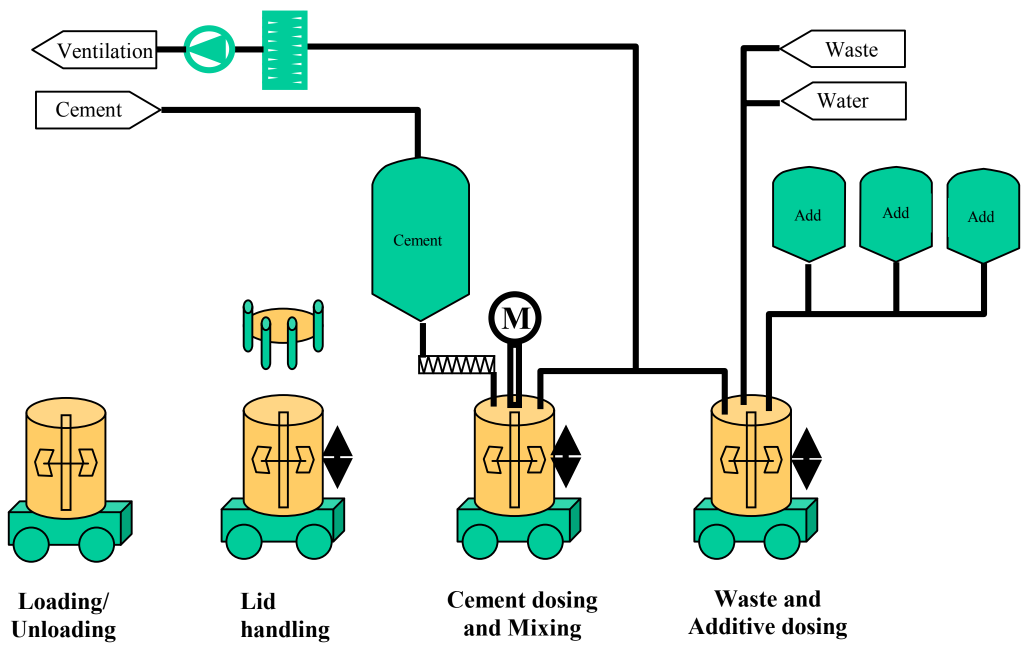

Figure 1: Principle flow diagram for the MOSS cement solidification system

Types of waste containers

The MOSS system can be adapted for various drum sizes, normally either 200-liter or 400-liter drums are used. The different drum designs are supplied with various types of lids. Various lid sealing principles can be accommodated in the MOSS system, such as the type of lid which will be sealed by a folding over the top edge with a special tool or the bolted lid which will require a multi bolt tensioner tool for simultaneous engaging of up to ten bolts. Other types of containers may be accommodated as well depending, however, on the amount of modification necessary.

Process supervision

The MOSS 200 system is remotely controlled from a separate control desk. The process is controlled by sequence programs. In the process control system, up to 10 different recipes can be stored. Operator communication is performed via a video screen. The control desk also contains a monitor for CCTV for visual process control. During operation the control desk is located within a radiation protected area at some distance from the MOSS unit.

All vital recipe parameters for each individual drum are stored in a database connected to the process control equipment. The stored data for each drum facilitates conclusions about end product properties, e.g. for confirmation that the individual package meets the national requirements. The data can be fed into the power station information network or stored on disc or printed on hardcopy.

System operation

An empty drum with a specially designed built-in "lost" stirrer is loaded onto the trolley in the loading position. The drum lid is placed on the drum but not fixed. The trolley moves the drum to the lid handling position where the lid is removed and placed in a waiting position for later use.

The trolley then moves to the "wet dosing position" for dosing of liquid waste and wet cement additives. The spillage protection plate is removed and the drum is lifted to allow the lower part of the dosing adapter to enter the drum. The amount of waste prescribed by the recipe is dosed to the drum. The amount is controlled by the weighing scale in the trolley. After dosing of waste to the drum, wet additives and extra water if needed, are dosed as prescribed by the recipe.

After finalized dosing of waste and wet additives, the drum is lowered, the spillage protection plate is replaced and the trolley is moved to the "dry dosing position" for dosing and mixing of cement, and in special cases dry additives. The process of locking of the trolley, removal of the spillage protection device and lifting and docking of the drum is repeated. When the drum is docked in this position a stirrer drive shaft is engaged to the stirrer. The stirring is started and cement and, if prescribed, dry additives are dosed to the drum via a dosing screw. The amount of cement is controlled by the trolley scale. Stirring continues a certain time after finalized dosing of additives to ensure a homogeneous matrix.

Once mixing is completed, the drum is transferred to the lid capping position where the lid is replaced by means of a pneumatic manipulator and is sealed by the proper sealing tool. Finally the trolley with the completed drum is transferred to the unloading position; which is the same as the loading position. The drum is unloaded from the MOSS unit the same way as it was loaded.

Figure 2: Photo of the MOSS 200 unit delivered to the Borssele Nuclear Power Plant

Top filling technique

One of the improvements that has been incorporated in the new version is the technique to top-fill the drums. The top filling technique has been developed and patented by ABB Atom in order to meet the requirement of a high filling factor for the waste drums. A special adapter is mounted in the upper part of the drum in order to increase the necessary available volume during the mixing process. The special adapter will then be disposed of directly into the filled waste drum. Another important factor is the precise weighing technique that also takes the axial forces during the stirring process into account. The drums can thus be filled with cement waste slurry up to a level of only about 1 cm from the top edge.

Production capacity

The production capacity is dependent on the type of waste to be solidified and the selected solidification formula. As an order of magnitude, the normal capacity is about 5 up to a maximum of 8 drums per 8 hours working shift.

Dewatering unit

When MOSS is used for immobilization of waste types such as ion exchange resins or filter aids, the waste is normally pumped from storage tanks to the cementation plant together with water at a relatively low dry substance content. To optimize waste load and cement matrix properties a dewatering step is normally needed prior to the cementation process. In customer tailored applications MOSS can be combined with different types of dewatering units such as sedimentation tanks, dewatering screw feeders or decanter centrifuges depending on what is the most efficient technical solution in each application.

The dewatering screw feeder is in principle built up of a settling volume with an upwards directed screw feeder. After settling of the waste at the bottom and decanting of freestanding water, the waste is transported upwards to the cementation system while the remaining water is gradually drained. A combination of MOSS and a dewatering screw feeder unit has been succesfully demonstrated for dewatering and cementation of bead type ion exchange resin mixed with filter-aid.

PROPERTIES OF THE CEMENT SOLIDIFIED WASTE

With a precise process control and robust mixing equipment it has proved to be possible to optimize the product quality. The additives can be dosed accurately so that the composition is well known and repeatable. The mixing technique makes it possible to produce a relatively stiff solution of waste, cement and additives so that the content of waste can be maximized. Ten different recipes can be stored in the process control system. The operator chooses the suitable recipe for the type of waste to be treated and the amounts of waste, cement and additives are dosed automatically. Thus, the composition in each drum and the predetermined product quality are assured.

End product characteristics
The most important end product characteristics are:

- Homogeneity
- Compressive strength
- Leachability
- Water and sulphate resistance

During the last few years formulas have been developed for customers in Germany, Holland, Sweden and Switzerland. The various national requirements and the combination of requirements reflect the situation as regards the intended route towards final disposal - or the availability of a final repository for disposal - of the radioactive waste in the respective areas. This will influence upon the optimization of the solidification recipe and it will certainly result in differences in the total waste volumes to be produced in the respective countries.

Some examples of typical requirements are given in the succeeding:

<u>Compressive strength:</u>
Alt.1) >45 MPa after 12 weeks for waste packages without overpack
Alt 2) >10 MPa after 28 days hardening

<u>Leachability:</u>

Alt.1) amount	$<1*10^{-4}$ g/cm^2*day for Cs
	$<4*10^{-5}$ g/cm^2*day for Co
Alt 2) diffusivity	$<5*10^{-6}$ m/day for the most significant nuclides (e.g. Cs and Co)

<u>Water and sulphate resistance:</u>

Alt.1)	≥85% of the original compressive strength after 8 weeks
Alt 2)	≥70% of the original compressive strength after 150 days

After submersion both in deionized water and in sulphate saturated water for the given period (normally 150 days).

For the Borssele NPP in Holland, formulas were initially developed for evaporator concentrate and bead resin. Later, also optimized formulas for bead resin/concentrate and powder resin/concentrate mixtures have been developed. Local Hochofen cement was used as the binding compound. The final products meet all requirements.

For the Mühleberg NPP in Switzerland, formulas for: powdered resin, bead resin, sludges, evaporator concentrate and mixtures of these were developed. The average compressive strength is about 20 MPa. The final products meet all requirements.

The diagrams below are examples of the qualifications performed in order to verify the end product properties for each type of recipe.

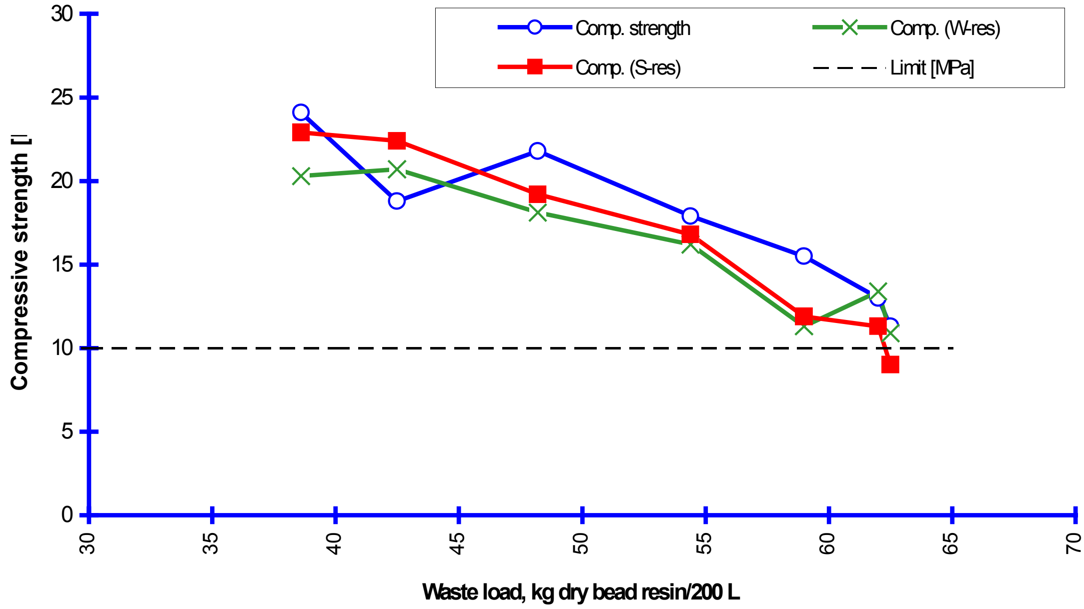

Diagram 1: Compressive strength versus waste load

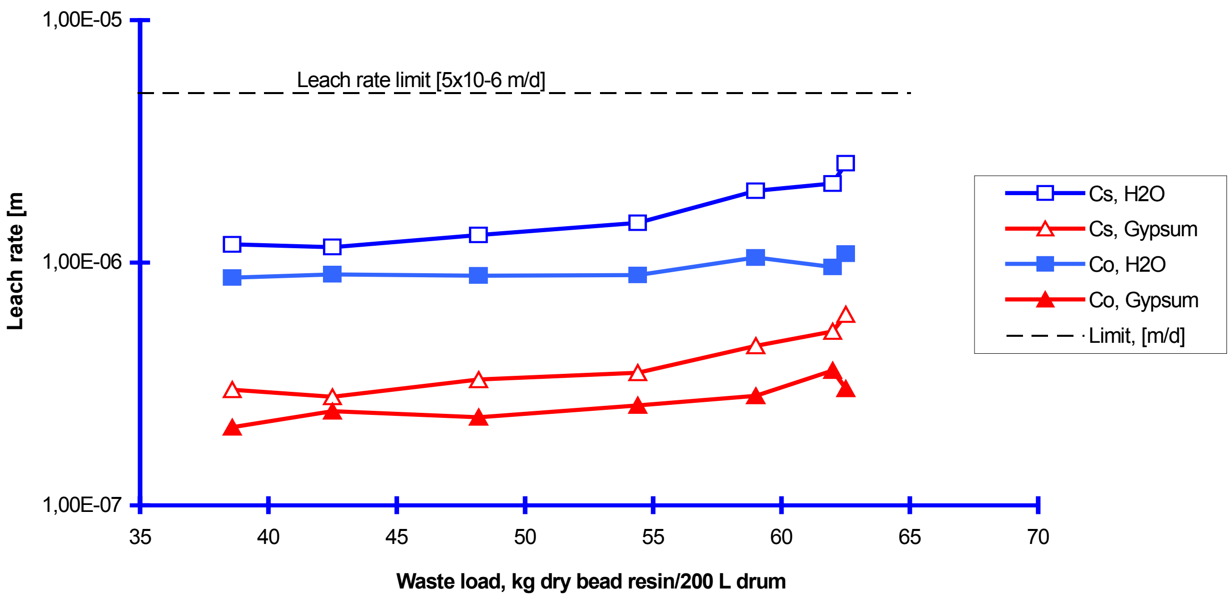

Diagram 2: Leach rate versus waste load

These two diagrams represent the solidification of bead resins. The high waste load is achieved in the CVRS-system (Cement Volume Reduction Solidification) installed in the Mühleberg NPP, which utilizes a thermal pretreatment before solidification (cf Ref. 2). With *e.g.* a 50% safety margin, a waste load of 55–56 kg heat-treated bead resin (representing ca 60–65 kg non-pretreated resin) could be recommended. In the MOSS system without utilizing the pretreatment step a waste load of about 40–45 kg bead resin would be feasible.

End product verification program

An end product qualification normally comprises the following steps:

Test in laboratory scale. Laboratory tests are performed with inactive products. Normally, several formulas and different cement types are tested. The qualification covers mixing properties, homogeneity, hardening process, water and sulphate resistance and compressive strength.

Full scale solidification tests. In the test facility for 200-liter drums the test products are produced with non-radioactive waste. The full scale mixing properties, viscosity and homogeneity are studied. To be able to test the homogeneity of the waste product after hardening the drums are cut vertically. By using a "Schmidt hammer" the compressive strength of the end product can be tested over the entire exposed surface. Results from the full scale tests are shown in Figure 3.

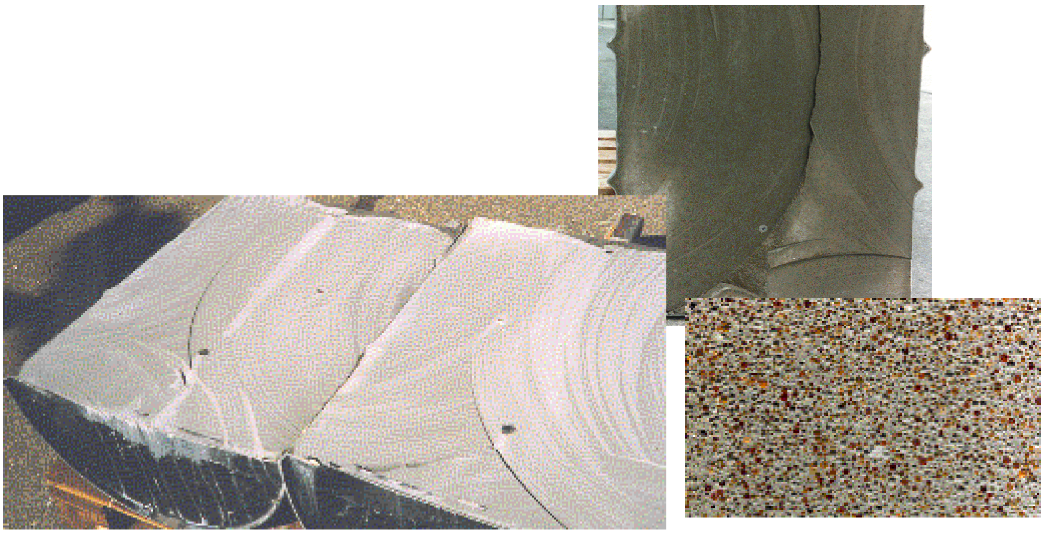

Figure 3: Cut away picture of 200-liter drums with cement solidified sludge (to the left) and bead resin (to the right with magnification)

Types of cement

Customers usually require the use of local cement in order to obtain the lowest possible cost for the bulk supply of this ingredient. In order to be able to meet such a requirement the cement solidification recipes have to be tested, optimized and qualified for the available local cement. In addition to the parameters mentioned above a number of different cement types have been tested, e.g. ordinary standard Portland cement, synthetic Portland cement, special high strength cement and slag cement.

MOSS FOR RESEARCH CENTER ROSSENDORF

Solidification of medium level radioactive liquid waste in Rossendorf
The Rossendorf Research Center has initiated a program for the solidification of liquid wastes. One waste category is a strongly acidic waste solution, containing mostly Sr-90 and Cs-137 and some alpha emitters, which is currently stored in underground tanks. ABB has been awarded a contract by the customer VKTA for solidifying this waste solution. The project includes the following parts:

1. Development of a solidification formula, end product with verified properties and process qualification
2. Preparation of a MOSS 200 plant and erection of a building
3. Solidification in Rossendorf

The first part was successfully completed in Autumn 1996. Thus, the solidification process and formula have been approved by the German BfS (Bundesamt für Strahlenschutz). The second part is now (Autumn –99) in its final stages. The MOSS unit and the pretreatment modules (cf Figure 4) are ready and on standby at ABB Atom. The solidification operations are scheduled to commence during the first half of year 2000.

Figure 4: Photo of the MOSS unit to be utilized at Rossendorf

OTHER REFERENCE PLANTS WITH THE "LOST STIRRER" TECHNIQUE

The ABB Atom experience with the "lost stirrer" technique dates back to the delivery of the Oskarshamn, Unit 1, in 1972. This technique has been verified for the cubical concrete moulds with inner cubical volumes of 0,3 m^3 and 1 m^3 as well as for drums of various sizes, e.g. 200- and 400-liter drums. Permanently installed systems with the cubical concrete moulds have been built for the Oskarshamn 1, Ringhals 1 and the CLAB Facility (the Swedish Interim Spent Fuel Storage Facility at Oskarshamn). Systems utilizing the 200 liter drum technique have been permanently installed in Oskarshamn 3, Forsmark 3 and Mühleberg Nuclear Power Plants. This thorough background experience serves as a basis for the successful application of the "lost stirrer" technique in the mobile MOSS system.

CONCLUSIONS

Cement solidification is generally known to be a reliable and robust method for conditioning of liquid radwaste. Recent development has now also shown that with a thorough process control and with optimized formulations of radwaste, cement and additives, the final result will be solidified products that fulfills the highest demands on product properties and quality as well as a process that is clean and repeatable. The high product quality is achievable for a large variety of different waste slurries.

Thus, it has been demonstrated that solidification with the mobile MOSS system could be a versatile method for clean and reliable solidification of most applications with liquid radwaste. The findings are:

- Most types of radwaste could be treated.
- The process will be clean with no spillage, no secondary waste and low doses to the personnel.
- The drums can be completely filled.
- The waste load in each drum can be high.
- The product quality will meet any national requirement.
- The reproducibility of the process meets any QA requirement.

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