UGU, A VERSATILE EVAPORATOR IN NUCLEAR INDUSTRY

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ABSTRACT

This paper describes a versatile system for the concentration of light water reactor (LWR) evaporator bottoms. In nuclear industry a variety of evaporator systems is used for concentration of radioactive aqueous liquids. The UGU evaporator system allows to super-concentrate as well as to dry radioactive evaporator concentrates and is deployed as a super-concentrator with high throughput upstream a cementation line to minimise final cemented waste volume, or alternatively as a concentrate dryer to produce a final solid waste form without additional matrix material (salt block). The UGU evaporator is composed of several U-shaped units. Each unit consists of one U-shaped tubular shell containing evaporator pipe sections. Pipes are heated by steam from outside. A cyclone separator separates the waste vapours streaming out from the evaporator into the water vapour and the super-concentrate phase. UGU units easily can be coupled together to give even higher throughput rates on request.

The benefits of this versatile system are obvious: simple system, no moving parts, easy to control, high throughput, low internal volume and thus low activity inventory, option for operation on series, minimum maintenance.

Technical information about both system variants is given in the paper.

INTRODUCTION

One main liquid radioactive waste stream generated during the operation of light water nuclear power plants (NPP) consists of evaporator concentrates produced in the central evaporator of the plant. The quantity of that kind of waste can be in the range of 30 m^3/year to 300 m^3/year, depending on the reactor type (BWR, PWR) and on the waste water treatment technology. The composition may vary as shown in table I.

Table I. Composition of Evaporator Concentrates

Characteristics	Range	Typical
Total salts concentration (g/dm^3)	200 to 500	300
Total salts content (% by weight)	20 to 38	25
BO_3^{3}- concentration (g/dm^3)[a]	80 to 180	120
Density (g/dm^3)	1150 to 1340	1200
Total activity concentration (Bq/dm^3)	$3 \cdot 10^6$ to $2 \cdot 10^8$	$5.5 \cdot 10^7$

[a] Not relevant in the case of boiling water reactor.

Depending on the storage requirements, the chemical composition and the activity concentration of the final product, and based on economical considerations, the treatment method of the evaporator concentrates can follow different processes, for example:

- concentration to obtain a super-concentrate which can be cemented or bituminized
- concentration to obtain a product suitable for vitrification
- concentration to obtain a salt block which can be stored in approved containers (the formation of salt blocks is possible if the content of salts with crystal-water, e.g. borates, is higher than 20 % by weight)
- concentration to obtain a dry granular product that can be stored in acceptable container.

The selection of the one or the other process technology, each having particular advantages, depends on the waste characteristics and on specific local requirements of the NPP.

RWE NUKEM provides necessary technologies and meanwhile can rely on extended practical experience from active evaporator operation with also the UGU system. In the following, the UGU process and its application to borate salt-containing evaporator effluents is described for super-concentrate production in brief, and for salt block production in more detail.

UGU CONCENTRATION FACILITY FOR SUPER-CONCENTRATE PRODUCTION

The UGU technology was developed in Russia (UGU: from the Russian **U**stanovka **G**lubokogo **U**parivanija, which means facility for enhanced concentration).

The UGU evaporator provided by RWE NUKEM is an improved design from the Russian AEP Institute in Moscow. It is composed of several U-shaped units. Each unit consists of one U-shaped tubular shell containing evaporator pipe sections. Pipe diameter increases steadily from inlet to outlet to guarantee avoidance of clogging. The evaporation is carried out by a multi-tube hairpin heat exchanger. All welds of the UGU 500 are easily accessible for repair and survey.

The simplified process flowsheet for the concentration process with an UGU can be depicted from figure 1.

A submerged pump in the feed tank produces the required flow for the concentrate to the one-pass UGU evaporator. Before entering the UGU evaporator, the solutions are pre-heated in a heat exchanger using the heat of the condensate flowing from the steam-heated evaporator.

A cyclone separator is used to segregate the hot salt concentrate from vapor streaming out from the evaporator. The steam vapor rises from the central pipe of the cyclone and enters the condenser. The concentrated liquid waste flows downwards through the cyclone into the UGU-product collection and adjustment.

The steam vapor is condensed in the water-cooled condenser, which is a horizontal shell-and-tube heat exchanger. The exhaust ventilator system produces a unidirectional stream from the product collection equipment via the cyclone separator, preventing steam vapor from entering the collection equipment. Once condensed, the liquid flows into the distillate collection tank. The collected distillate can be used for flushing the system or as clean condensate in other areas.

The concentrated liquid waste flowing from the cyclone separator is directed into a recycling tank first until the temperature of the mixed phase leaving the evaporator has reached a predetermined set point. Once this is reached, the liquid flow is switched to the end product collection equipment where the product starts to cool.

The super-concentrate's final temperature is adjusted to meet the requirements of subsequent processing. In case the subsequent processing is cementation and if the super-concentrate contains significant concentration of borate, it is necessary to add calcium hydroxide. The final temperature of the concentrated waste has to be in the range of 40°C by this adjustment. The agitator in the collection tank ensures a good heat transfer between concentrated waste and the heat exchanger thermostatic medium, and good mixing of the various constituents.

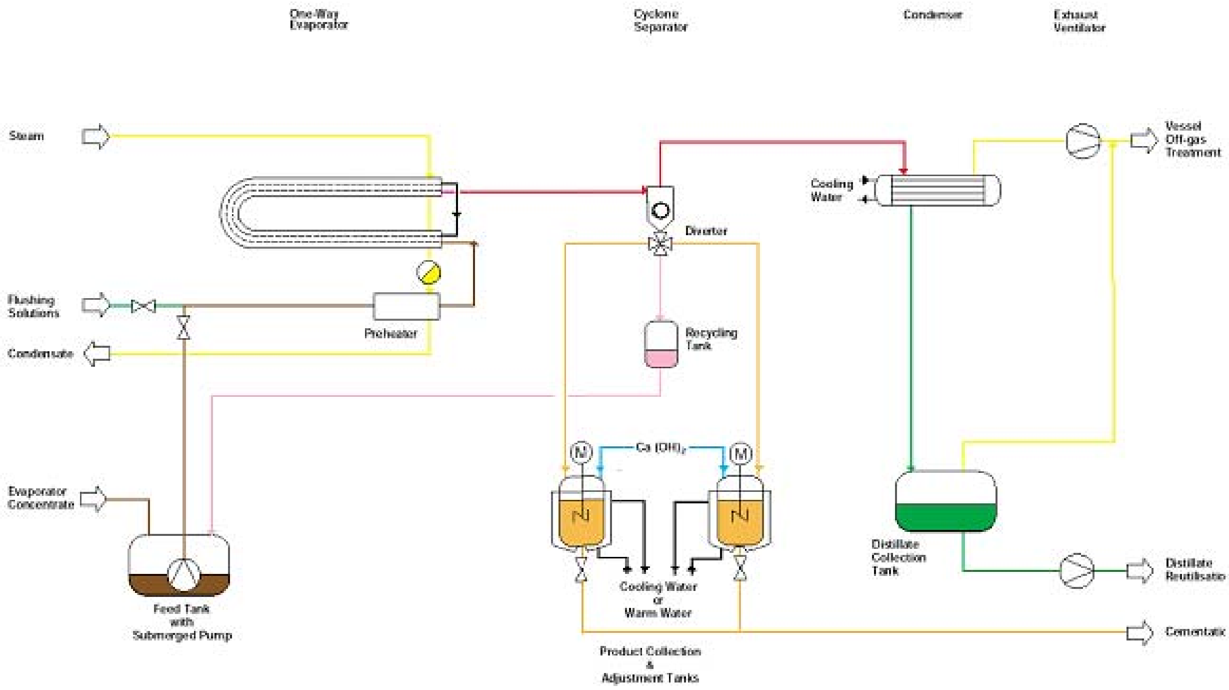

Fig. 1. UGU simplified process flowsheet
(exemplary option for the production of borate-rich super-concentrates)

The solutions collected in the recycling tank during the first stage of the evaporation or during flushing the evaporator are transferred to the UGU feed tank. These solutions are processed together with the next batch of evaporator concentrates. Once the operating temperature has been reached, operation of the facility occurs almost automatically.

During the concentration process, some deposits settle on the internal walls of the evaporator pipes. After a time, these deposits slow down the facility processing rate. This undesirable situation is automatically detected and the control unit switches the facility into flushing mode. The flushing of the UGU evaporator with recycled distillate cleans the piping. After the cleaning cycles the evaporator concentrates are once again fed to the evaporator.

The salt concentration (between 500 and 700 g/dm^3) of the concentrated waste is set up and controlled by the temperature at the outlet of the evaporator.

Figure 2 shows the arrangement of an UGU evaporator system in operation at the Bohunice NPP, Slovakia.

Fig. 2. UGU multi-tube hairpin heat exchanger (left) and cyclone separator (front right)

There the UGU concentration plant with subsequent cementation of the concentrated evaporator waste is successfully in operation since 2000. Main features of the UGU concentration plant at Bohunice NPP are shown in table II [1].

Table II. Main features of the UGU concentration plant at Bohunice NPP

Issue	Data
Evaporation plant type	through-flow
Operation mode	continuous / campaign
Heating medium	Steam, Pressure ~ 0.5 MPa
Heating temperature	105 - 108°C
Heat exchange surface	9.6 m^2
Input	220-250 dm^3/hour
Treated waste	Liquid radioactive concentrate (Salt 200 g/l)
Product	Concentrate (Salt 400-500 g/l)
Way of further treatment of product	Cementation

Secondary product	Waste vapour distillate						
Way of further treatment of secondary product	Final purification by filters						
Thickening	max. 500 g/dm³						
Decontamination factor	10,000						
Concentration by UGU	year	2000	2001	2002	2003	2004	total
	m^3	30	220	323	356	370	1299

UGU 500 CONCENTRATION FACILITY FOR SALT BLOCK PRODUCTION

Besides the use of the UGU system for the concentration of evaporator bottoms with subsequent cementation of the concentrated product the UGU system is used elsewhere for the production of final product in form of salt blocks. Details for such a system are given exemplary in the following.

Evaporator Concentrate Intake Subsystem

The subsystem comprises three stainless steel tanks of 16-m³ volumetric capacity each. Each tank is equipped with vertical pump, jet mixer array, heat tracing, sampler, and instruments to control temperature and level.

One of the tanks, preferably used as evaporator feed tank, is equipped with an additional redundant vertical pump to ensure continuous operation of the evaporator plant.

The content of each tank can be transferred into each other tank.

This design provides for carrying out operations independently as filling a tank, radiochemical analysis of the content of other tank, and feeding the evaporator from a properly analyzed tank.

Any crystallization in the tanks is prevented by the jet mixer array in each tank that also ensures quick homogenization while pH adjustment. The heat tracing and the insulation of the tanks keep the temperature of received materials constant all time. Thus, all material that was dissolved in previous process stage will remain in solution until fed for evaporation.

Evaporation Subsystem

The subsystem comprises the pre-heaters as well as the evaporator elements. The evaporator subsystem is equipped with instruments and a programmable logic controller, PLC, to automatically control the evaporation process.

Four small hairpin shaped double tubes, serve as pre-heater. The hot steam condensate from evaporator elements above flows through the shell and heats up the material to be evaporated in the pipe. The pre-heater is a true countercurrent flow design.

The pre-heated material enters the tubes of the evaporator elements for flash-like evaporation. The evaporator elements are formed by multi-tube hairpin heat exchangers. The evaporator tube loops five times through the shell. Condensing steam of max. 0.8 MPa in the shell provides for the heat to evaporate the water from salt solutions routed through the tube. Flash-like evaporation on the entrance of the tube and high efficiency further heating by steam condensation causes an extreme turbulent flow. Thus, all materials as vapor, high concentrated salt solution, and even melted and solid salt particles are blown through the loops and eventually into the cyclone separator for segregation.

The steam pressure in the shell of the evaporator elements controls the evaporation rate and by this means the final concentration of the salt residue. Pre-heater and evaporator elements are completely insulated.

Salt Separation System

The salt separation system is formed by cyclone separator, three-way valve, connector, turntable, and the waste water routing tank with vertical pump and jet mixer array.

The outlets of the evaporator elements are connected to the tangential inlet of the cyclone separator. The material consisting of vapor, high concentrated salt solution and melted salt is blown through this connection. Due to the centrifugal forces resulting from helical way the superheated material is forced into, it segregates in two phases. The light phase, the vapor is collected in the central tube of cyclone and routed to the condenser. The denser, liquid phase flows down the cone and goes into the steel barrel for cooling and disposal or into the wastewater tank. In order to avoid any crystallization all equipment of the salt separation system is heat traced. In addition several nozzles for water flushing are arranged at equipment. The final decision on the location of those rinsing means will be made according to the final equipment layout.
The hot salt residue runs down the connector and is collected in steel barrels. The steel barrels are arranged on a turntable to facilitate their handling. The turntable can hold six steel barrels. One of them is at the filling spot, the next four are cooling down to allow the salt residue to crystallize and at the sixth spot the completely cooled steel barrel will be replaced by a new, empty one. The discharge of the steel barrel as well as the introduction of the new one is done e.g. by a crane. The filling spot is equipped with instruments to determine weight and density of salt residue and to prevent the steel barrels from overfilling. Thus, its number and the corresponding data as weight and density can be recorded. By means of an optional database connection, the recording can be fully automated.

During start up and shut down of the evaporator as well as by periodic flushing a few liters of wastewater and non-spec product arise. Those fluids are collected in the small wastewater tank made of stainless steel. The wastewater tank is equipped with the vertical pump, the jet mixer array, heat tracing as well as with temperature and level instruments. The contents of wastewater tank can be returned to each of the intake tanks.

Secondary Steam Condensation System

The subsystem is comprised of the condenser, the distillate tank, the distillate pump, and the air-jet fan. The subsystem is equipped with all instruments to automatically control its operation and to fulfill safety requirements.

The condenser, attached as close as possible to the vapor outlet of cyclone separator, is designed for inert gas condensation. It is an in-shell condenser. The wide vapor inlet is arranged at the centerline of the horizontal TEMA-style shell-and-tube heat exchanger. This arrangement and the wide empty space across the vapor inlet allow the current to “laminarize” as necessary for good segregation of vapor and air. While the vapor condenses, the air is vented through a nozzle on back of the condenser. The air-jet fan drives the venting.

The distillate tank stocks up the distillate running down the siphon. The magnetic driven distillate pump transfers the distillate to its destination determined by the user.

Technical Data

Type:	continuously operated evaporator, UGU 500
Feed composition:	borate containing evaporator concentrate

Density of crystallized:

Salt residue:	n. 1700 kg/m³
Capacity:	3,600 m³/a
Heat source:	0.8 MPa steam
Operation mode:	fully automated

Fig. 3. UGU concentration facility (exemplary)

UGU 500 OPERATING DESCRIPTION

Evaporator Concentrate Intake Subsystem

A batch of up to 16 m³ of evaporator concentrate is transferred to one of the intake tanks. While one of the intake tanks is filled with evaporator concentrate the other one is waiting for release for concentration. The release will be granted when the radiochemical analysis is in accordance with regulatory stipulation.

The third tank in this subsystem is the UGU feed tank. It is equipped with two vertical pumps to ensure continuous operation of the UGU. The UGU feed tank is refilled from the released intake tank.
The vertical pumps and the jet mixer arrays of the tanks should be operated all time when they are filled to avoid settling of solids and crystallization of borates.
Regardless that the tank is the preferred UGU feed tank each of the intake tanks can be used as UGU feed tanks as well.
If necessary or wanted all contents of the intake tanks and the UGU feed tank can be returned to the previous process stage at the NPP.

Evaporation System

The temperature of the superheated material at the outlet of the evaporator elements determines the final concentration of salt residue to crystallize in the steel barrels. To manage this temperature the steam pressure in the evaporator element shells is controlled. The instruments the evaporation system is equipped with allow the automated precise control of this essential parameter.
Despite of the high velocity of current in the evaporator element tubes as well as its careful design it is unavoidable that a few solid particles build up on the inner walls of those tubes. Thus, during the course of operation a growing steam pressure is needed to keep the set outlet temperature. The increase is recognized by the instrumentation and evaluated in the PLC. When the ratio of steam pressure, outlet temperature and flow rate into the evaporator have reached a certain value the salt crust in the evaporator tubes will be flushed off automatically.
To flush the evaporator tubes the regular feed is stopped, the heating steam is shut and distillate from distillate tank is routed through pre-heater and evaporator with approximately 50 l/hr. If the distillate tank does not hold enough water pure condensate from NPP can be used for flush. The flush takes about 10 minutes.
If the first flush wasn’t successful the PLC is programmed to carry out two more flushes of the same kind.

Salt Separation Subsystem

As already described the hot salt residue flows down into the steel barrel for final cooling, crystallization and disposal. When the facility is started up a new steel barrel is lowered onto the turntable. By pressing the related command button the turntable rotates 60° towards the connector and the connector attaches the steel barrel automatically to the salt separation subsystem. Once the steel barrel is properly attached the evaporation process is started or restarted while normal operation by PLC. At time of startup the three-way valve is adjusted to direct the evaporated material to the wastewater tank. After a few minutes the appropriate temperature at the outlet of the evaporator elements will be reached. Then the current is redirected to the attached steel barrel by the tree-way valve. Now the weight scale integrated in the turntable and the thermal level sensor takes control of filling process. Redundant instruments and a dual watch program, on weight and level, of PLC prevent the steel barrel from overfilling. The density of salt residue is calculated from weight and volume of in the steel barrel. This feature of the facility provides additional safety to keep the required minimum density of 1700 kg/m³.

The small wastewater tank will be emptied as necessary into one of the intake tanks. Of course, the content of wastewater tank can be transferred to the evaporator feed tank as well. The vertical pump arranged in the wastewater tank carries out the transfer.

Secondary Steam Condensation Subsystem

Condensation of vapor, stock, and transfer of distillate and venting of the system are the processes performed by this subsystem.
The condensed vapor (the distillate) from condenser is collected in the distillate tank. During normal operation a stock of distillate is hold in the distillate tank for routine flushing. The excess distillate is either returned to evaporator concentrates storage for dissolution of crystallized salt or transferred to the special sewage of the NPP. All transfers which have to be manually initiated are safely controlled by level instruments.
In order to maintain proper operation of the salt separation subsystem and to reduce the risk of airborne contamination around the steel barrels certain airflow from connector or waste water tank through the cyclone separator is necessary. The airflow is provided by the air-driven fan.

Manual Operation

The UGU 500 concentration system works automatically. The following work, however, must be carried out manually:

- Transfers and sampling of liquid radwaste (LRW) in the evaporator concentrate intake subsystem.
- Startup and shutdown of the facility.
- Cleaning of the evaporator with chemicals (NaOH or HNO_3 solutions) if routine flushes fail.
- Transportation of filled and new steel barrels from and to the UGU facility.

CONCLUSION

Under a Russian license RWE NUKEM has modified the UGU evaporator and has implemented this versatile system within several Waste Treatment Centers in the near past. Installation of more systems, including the UGU concentration facility for salt block production, are in planning.
With the UGU, being a technically simple and continuously operating evaporator, there is available an interesting and competitive system, particularly for LWR liquid waste treatment.

REFERENCES

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