TNO EXPERIENCE ON SODIUM CLEANING OF LARGE PLANT COMPONENTS BY VACUUM DISTILLATION

C. Ch. SMIT
MT-TNO Dept. 50-MW Sodium Component Test Facility,
Hengelo,
Netherlands

1. Introduction

The Intermediate Heat Exchanger and Steam generators developed within the framework of the SNR-program are being tested in the 50 MW Test facility at Hengelo - The Netherlands.
The facility was designed and built by Neratoom, and is operated by TNO, the Dutch Organisation for Applied Scientific Research. Sodium technology work, such as reported in this paper, is done in close cooperation with Neratoom and with TNO-laboratories at Apeldoorn, where several smaller sodium rigs and other facilities are available.

The operation and maintenance of a large sodium test facility and sodium rigs lead to frequent cleaning of small plant components, test sections and sampling devices. The choice of method usually depends on the size of the component and the cleaning quality needed. The results are predictable and satisfactory.

For large components, however, the situation is different. Although the basic cleaning methods using alcohol and moist gas are well-known, and procedures for the cleaning of small components are available, complete cleaning of tight crevices and threaded bolds cannot be guaranteed, and consequently the requalification procedure needs to include a complete disassembly and inspection of the cleaned component.
For large components this policy cannot always be followed. In those cases for instance where an in-between internal inspection is required, or where only small modifications of the test object are necessary, other possibilities have to be considered.

For this reason some work has been done to develop reliable vacuum distillation procedures for large components, based on the cleaning experience with small plant components.
The results of these procedures applied to large plant components are reported in this paper.

Basic description of the vacuum distillation process

The vacuum distillation process is similar to well-known processes where a vapour flows from a boiler to a cooled condenser. Usually a vacuum pump is connected to the coldest spot of the condenser to suck off the non-condensable gases. Provided the partial pressure of these non-condensable gases is sufficiently low, the driving force of the vapour transport is equal to the difference between the boiler pressure and the saturation pressure corresponding to the condenser temperature.

During the vapour distillation process the condenser vacuum is usually maintained at 0.1 to 10 Pa, and the component to be cleaned is kept at a temperature of 400 ^{o}C. At these conditions the influence of non-condensable gases may be neglected and the maximum mass flow can be calculated using well-known fluid-flow equations.

The time necessary to evaporate sodium pools or amounts of sodium adhering to the walls and tubes of the component to be cleaned may be influenced by the flow resistance between the evaporating sodium and the condenser.
Because of the very low density of the sodium vapour the mass flow may be surprisingly low, even when acoustic velocity is reached.
During the vacuum-distillation cleaning of the 28 MW straight tube evaporator in Hengelo the 40 mm piping connecting component and condenser limited the sodium-vapour flow to 250 grams/24 hours.
Another limiting factor is the heat transfer to the evaporating sodium. In a sodium pool the sodium temperature will drop to a level where an equilibrium exists between the evaporation heat and the heat supply by convection or radiation.
During actual cleaning operations a temperature drop in the range of 40 to 70 ^{o}C., was measured.

After the evaporation of sodium in pools and adhering to the walls and tubes has been completed, some residual sodium will be left in crevices. The cleaning of such spots, especially sodium pockets underneath long narrow gaps, may take much longer than the evaporation of open pools. The sodium mass transfer, however, is in principal defined by the same flow equations, and in most cases acoustic velocity may be assumed. Only in very narrow cracks molecular or Knudsen flow may be expected.

Since calculation is difficult, the cleaning time of crevices has to be determined by experiments, using models of the worst configurations existing in the component.
During the cleaning of the 50 MW helical-tube steam generator in Hengelo the time necessary to clean the worst crevices proved to be 2 - 3 days, while the undrained sodium pool at the bottom of the component was evaporated in 2 - 3 hours.

During the time when the crevices are cleaned the pressure difference between the component and the condenser may be very small and the sodium transfer to the condenser will be diffusion instead of flow. In this situation the cleaning process might be accellerated by the injection of very small amounts of inert gas ("sweeping-gas"), the pressure in the component, however, should be kept below the sodium-boiling pressure.

During the initial phase of the distillation process sodium vapour may condensate on colder spots in the components. Normally when the cold-spot temperature is not lower than 300° C, the condensation heat will tend to equalize the temperature and does not slow down the cleaning process. Difficulties may arise when the sodium vapour condensed on a cold spot (for instance a length of unheated piping) is allowed to flow back to the component. Experiments have showed that in such cases the time necessary to evaporate a sodium pool can be 100 times as long as under normal circumstances.

3. Component cleaning case histories

3.1. Cleaning of a 380 m3/h sodium pump

A small prototype of mechanical sodium pump of Dutch design was been tested in a special test rig in the TNO-laboratories at Apeldoorn. Repeated removal and disassembly of the pump was necessary to facilitate modifications and maintenance work. The easiest, cheapest and shortest cleaning method proved an in-situ vacuum distillation pre-cleaning followed by alcohol rinsing.
The pump was heated up to 560°C using the available electrical trace heating. The test rig is cooled to ambient temperature and maintained at a vacuum of 10 Pa for about 60 hours.

After the distillation process had been completed, the lower part of the pump including bearings, shaft, bolts and tapped holes was found to be completely free from sodium.
On the upper part of the pump, where the maximum temperature was limited because of the oil-cooled mechanical seal, some sodium had to be removed by hand using brushes and alcohol-wetted cloth.
The pump was cleaned by this method six times. No damage was observed.

3.2. Cleaning of a 12-inch sodium valve

A 12-inch prototype sodium valve was cleaned after a series of tests in a by-pass of the main sodium circuit of the 50 MW Test Facility at Hengelo. To protect the Stainless Steel bellows an in-situ vacuum distillation method was applied instead of the alcohol method normally used for sodium valves.
The distillation procedure took 30 hours at 400° C and 0.3 Pa.
Cleaning was completely successful, not only the valve but also the by-pass piping was free from sodium residues.

3.3. Cleaning of a 28 MW prototype straight-tube evaporator

After a testing period of 3000 hours, the ferritic straight-tube evaporator had to be dismantled for internal inspection.
To gain practical experience with the application to a full-sized component, the vacuum distillation method was chosen to clean the steam generator.
The sodium piping was disconnected and closed by welded caps, and bagging techniques were used to prevent the intrusion of air.
The component was heated to 400 to 500°C using normal electrical trace-heating reinforced with extra heaters to compensate heat losses through mechanical supports.

Calculations proved that the inexpected slow evaporation was caused by the high vapour-flow resistance in the piping connecting the component to the condenser.
Further the experiment indicated that a reliable method to determine the end-point of the evaporating process is indispensable.

The component was maintained at a vacuum of about 10 Pa for 10 days. During this period 18 kg sodium was removed by the distillation process. The procedure was not a complete success. After dismantling about 2 kg of sodium had to be removed from the lower thermal-shield area.

The tube bundle showed a thin gray deposit indentified as sodium carbonate. The total amount of sodium present at the tube surface was about 140 $\mu g/cm^2$.

3.4. Cleaning of a 50 MW prototype helical-tube steam generator

After 3000 hours of testing at the Hengelo Test Facility an in-between internal inspection was required, which made sodium cleaning necessary. The helical-tube steam generator is a highly complex component containing a large number of deep narrow crevices and bolted joints. Complete dis-assembly would be extremely difficult if at all possible. Because requalification for test operation was an essential requirement, vacuum distillation was preferred to other available methods. A modified vacuum distillation method was developed based on the evaluation of the results of the cleaning operation previously used with the 28 MW straight tube evaporator.

Preparations

The cleaning operation was performed in-situ, the component was drained at a temperature of 450°C and was maintained at this temperature by the electrical trace heating. The trace heating and insulation were especially designed and tested for use at distillation conditions.

To create a vacuum-tight compartment the two 12-inch isolation valves were frozen-in, drain and vent lines were disconnected, and caps were welded on.

A mechanical vacuum pump unit protected by a vapour trap was connected to both drainlines (fig. 1).
Vacuummeters were connected to the highest and lowest part of the component using the hydrogen detection systems.
To condensate the sodium evaporated in the component the 30 meter long 12-inch sodium piping connected to the sodium inlet and outlet was used. The trace-heating of the piping was switched off and some of the insulation was removed to create the necessary cold spot.

Distillation process

The distillation process was performed at a temperature of 450°C and a vacuum of 0.3 Pa was maintained. During the whole operation a small amount of argon leaked into the evacuated system, but this did not influence the process.
At the moment the vacuum reached the boiling pressure corresponding to the existing temperature, one of the thermocouples in an undrained sodium pool showed a distinct temperature drop caused by the evaporation heat drawn from the pool (fig. 2).
After about three hours this temperature slowly approached the original value, indicating the end-point of the evaporation of the sodium from the open surfaces in the component.

Determination of end-point of distillation process

As was known from preliminary tests, the rate-limiting parameter of the vacuum-distillation cleaning process is the removal of sodium from tight crevices and threaded bolts. Although the theoretical evaporation rate at the prevailing conditions (450°C, 0.3 Pa) should ensure a very rapid cleaning, the presence of sodium impurities might slow down the evaporation process considerably. Therefore an empirical method was used to verify the results of the cleaning process.
A small model simulating the most unfavourable bolted connection wetted and filled with sodium was inserted in a sample harp connected to the component, and the temperature of the harp was maintained at a value equal to the lowest temperature measured in the component.
The model was removed for inspection after three days and was found to be

completely cleaned; no trace of sodium could be detected.
Although the component was considered clean, the preparations necesssary to remove the steam generator made it possible to continue the evaporation for a total of 15 days.

Inspection and requalification

After a controlled cooling-down the steam generator was disconnected and transported to the manufacturer's workshop for internal inspection.
The results of the inspection were highly positive; all bolts, nuts and crevices that could be inspected proved to be free from sodium.
On the ferritic tubes a dark gray deposit was found that turned into light gray as air was admitted; no deposit was detected on austenitic and on all machined ferritic parts.
Some of the deposit was analysed. It contained a small amount of sodium in the form of sodium carbonate and sodium hydrocarbonate.

The total amount of sodium present on the ferritic tubes was about 40 $\mu g/cm^2$.
After inspection and requalification tests the steam generator was reinstalled and returned to service. To date more than 7000 operating hours have been made since the cleaning operation.

4. Conclusions.

- Several successful cleaning operations with large components have proved that vacuum distillation is a very attractive cleaning process for large and complex LMFBR components.
- The process is particulary suitable for the removal of sodium from components which are not polluted with sodium reaction products.
- The process is much faster than typically chemical cleaning processes, especially in those cases where the operation is performed in-situ and, consequently the time for mechanical preparations and heating is short.
- No reliable measuring technique is available to determine the end point of the evaporative process. However, test models simulating the worst crevices present in the component can be used to determine the evaporation rate in advance or to verify the results before the cleaning operation is terminated.
- The main limiting factor for in-situ cleaning seems the problem to create a suitable vacuum-tight compartment. Further investigations are necessary to explore applications in practical LMFBR-situations, especially where no sodium-side isolation valves are available.
- The vacuum-distillation method would gain in value if it could also be applied to components that are slightly polluted with sodium reaction products.
  More investigations are necessary to determine the corrosive effects of these reaction products on structural materials in a 200 to 500 °C temperature range and to determine the influence on the cleaning time.

Acknowledgements.

The work described here forms part of a goverment financed activity in the frame of the Dutch contribution to the development for the DEBENE SNR-300 project.

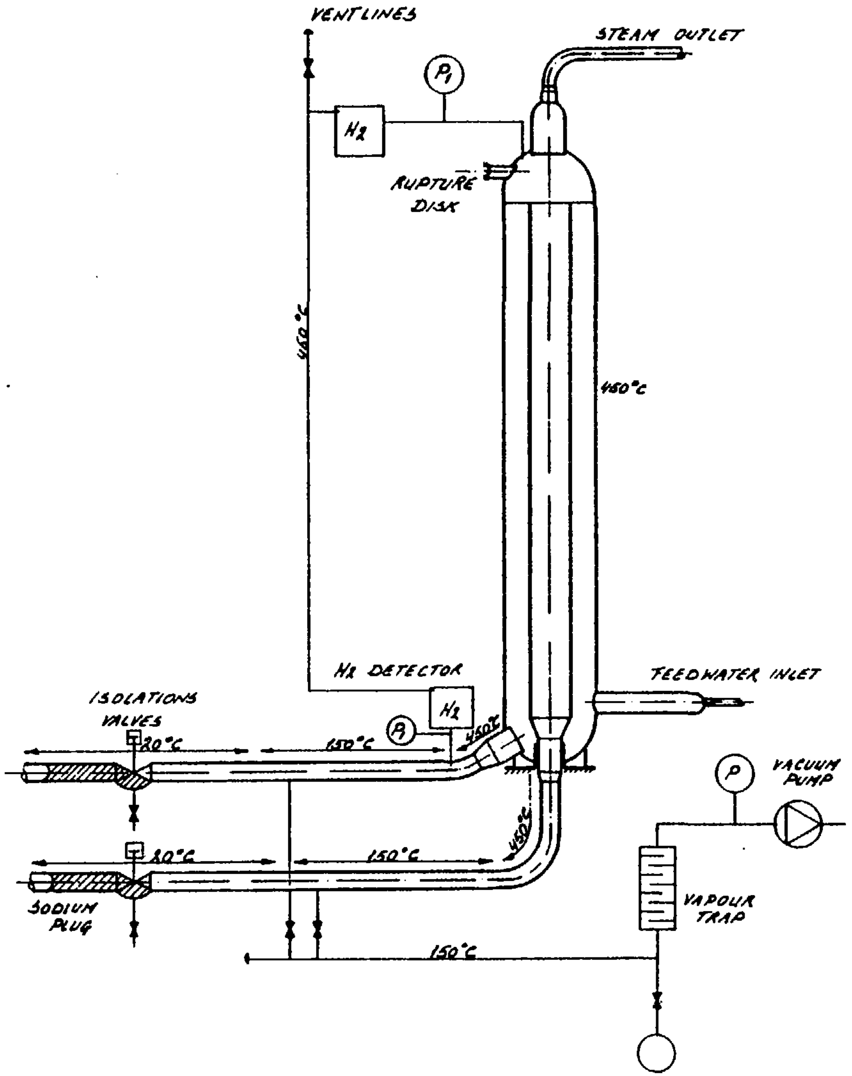

FIG 1 IN-SITU VACUUM DISTILLATION OF A 50 MW STEAMGENERATOR

MT-TNO
DEPT 50 MW
HENGELO

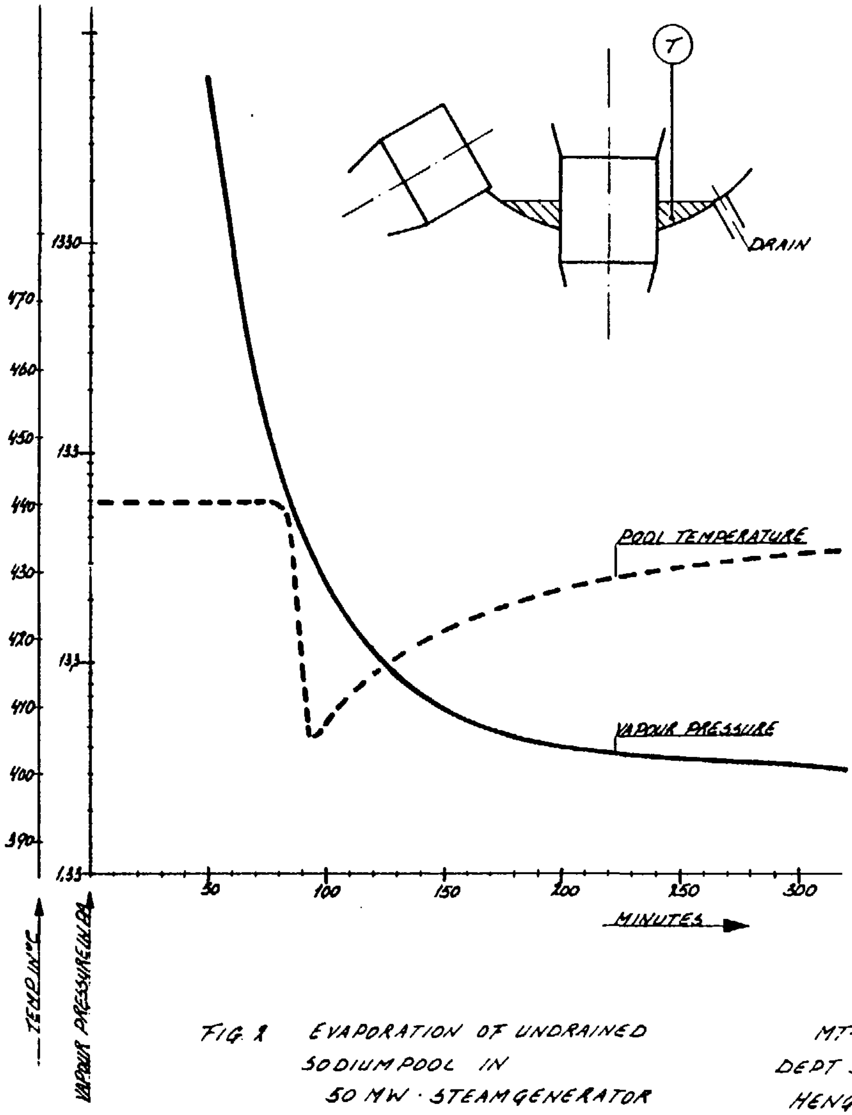

FIG. 2 EVAPORATION OF UNDRAINED SODIUMPOOL IN 50 MW · STEAMGENERATOR

MT-TNO
DEPT 50 MW
HENGELO