Waterlancing for CANDU Steam Generators

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Introduction

Steam generators, which are critical to the availability of nuclear plants, are very sensitive to corrosion induced by chemical attack, and particularly to attack from deposits left by the concentration of boiler water contaminants. Since steam generators around the world have suffered severely in this regard, high priority has been given to removal of deposits – especially those in the tube sheet area.

A typical CANDU steam generator is shown in Figure 1. This unit, a Darlington SG incorporates 4,550 U-tubes of 16 mm diameter on 24.5 mm triangular pitch. The recirculating boiler water flow enters the hot leg (primary inlet side) just above the tube sheet, whence it penetrates the tube bundle and then flows upward toward the steam drum. CANDU steam generators have special design features to enhance this flow (i.e., high circulation). Nevertheless, the centre of the bundle is inherently an area of weak flow, as well as high heat flux.

These characteristics create an environment that encourages the deposition of any boiler water contaminants onto the tube sheet, and also provides an environment where such a deposit can become highly aggressive in the event of an excursion of feedwater chemistry. Figure 2 shows a typical tube sheet sludge deposit as observed in a Pickering A steam generator.

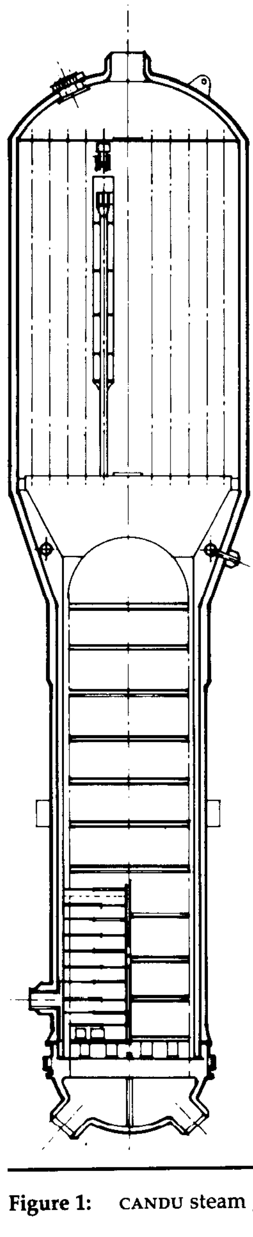

Figure 1: CANDU steam generator (Darlington).

The Waterlancing Process

Waterlancing is a process for removing sludge deposits by means of high-pressure water jets. The primary application has been in the tube sheet region; however, it can be applied to other areas, such as U-bends and steam separators.

The active component of the system is high-purity water issuing as a coherent, focused jet into the inter-tube gaps of the steam generator tube bundle. The jet impinges on the surface of the deposit, breaking it up and sweeping it out of the bundle. The effectiveness of the jet on deposits is determined by its pressure and the degree of focus that it sustains at the point of impact.

The specific process described in this paper is that used at Pickering 'A', Unit 1, SG No. 3, which is the

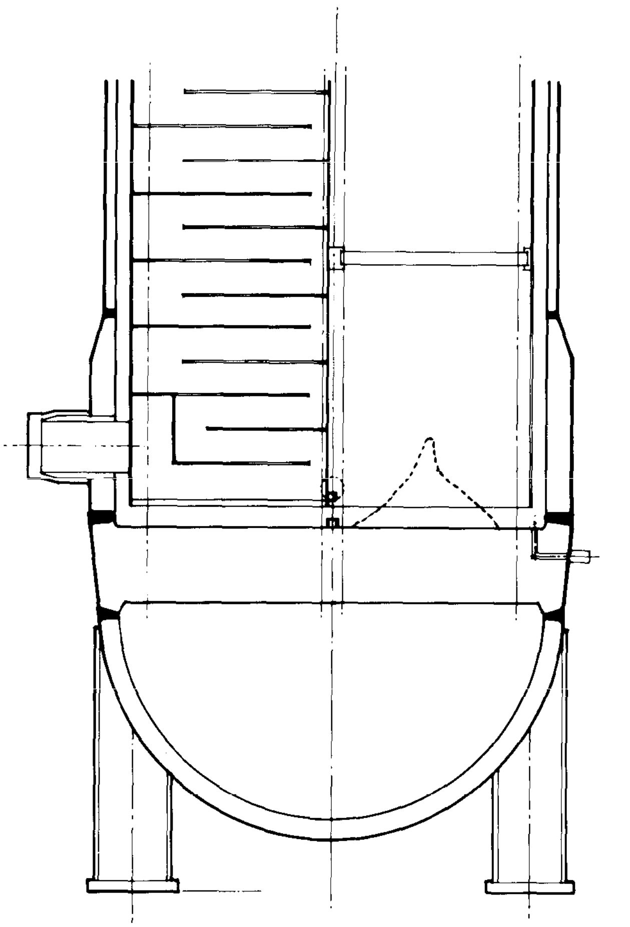

Figure 2: Sludge deposit (Pickering A).

only CANDU application of tubesheet waterlancing at time of writing. This project was carried out using the process of the Booyclean Company of Rotterdam, working together with B&W Canada.

A typical waterlancing setup is shown in Figure 3, and includes a mobile waterlancing unit, control console, lance and drive, and interconnecting hoses. The self-contained mobile unit shown in Figure 4 contains the demineralized water reservoir, the booster and high-pressure (hp) pump, return suction pumps, filters, and system controls. The hp pump is a diesel-driven reciprocating pump that is fed by a centrifugal booster pump and has a pressure control at its outlet, to control pressure at the lance tip. The suction pumps are high-volume, lift-and-force diaphragm pumps designed for air / water service. Their function, along with smaller suction pumps at the SG, is to evacuate the water / sludge mixture from the tube sheet and return it to the mobile unit for filtering. The filtering system incorporates three filter trains in parallel – each with 10.0 micron, 5.0 micron, and 0.5 micron filter elements in series.

The mobile unit also houses the control system, which includes the pump controls, safety shut-downs, and a video monitor for the in-containment cameras.

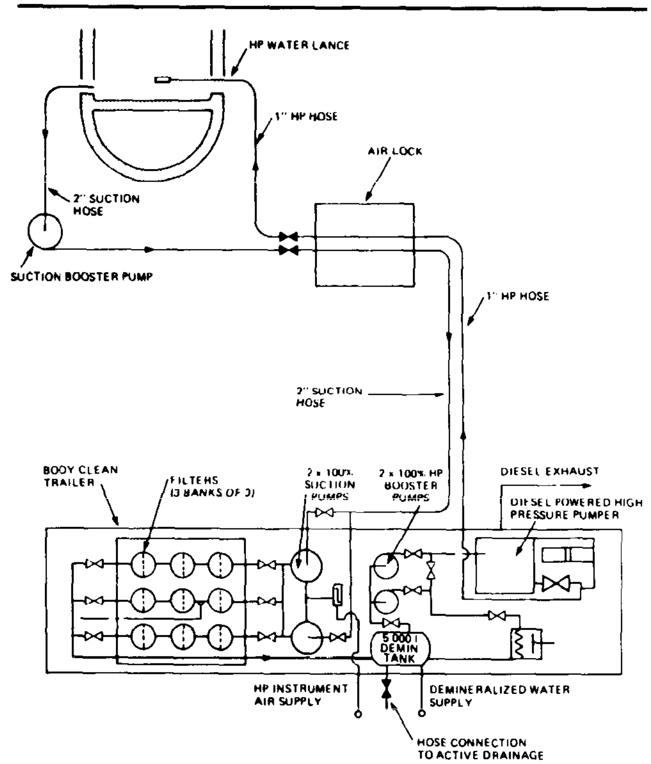

Figure 3: System configuration.

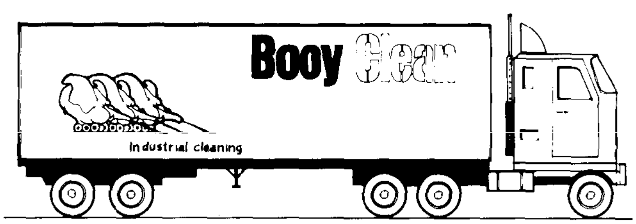

Figure 4: Waterlancing mobile unit.

The lancing equipment at the SG includes the lance and drive, the suction system, and the video cameras to monitor the above. Figure 5 shows a typical lance and drive. The lance is a long tube (usually segmented) with a number of nozzles at an angle of 90° to the lance axis, positioned so that several adjacent lanes may be lanced simultaneously. In operation, the tube rotates about its axis, so that the jets sweep up and down over the surface of the deposit within the inter-tube gap. The lance drive, which indexes and rotates the lance (in / out motion and forward / reverse rotation, respectively), is built onto a flange, which in turn mounts to a handhole at the SG no-tube lane (NTL) at the centre of the bundle.

The above lance and drive is the type used on a SG with inter-tube gaps at an angle of 90° to the NTL. At Pickering 'A', these gaps were at 60° and 120°, necessitating a special lance, as described below.

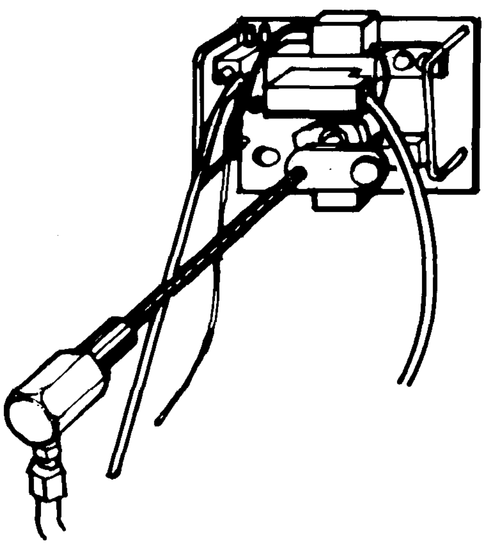

Figure 5: Waterlance with lance drive.

The control console, which is situated in a low-activity area near the SG, contains the indexing controls as well as safety shut-off controls, and a monitor to observe the video from the SG camera.

International Experience

Waterlancing, as a steam generator cleaning technique, began in the 1970's, and has since gained wide acceptance in the U.S. and Europe. In 1986, 45 SG's in Europe and 19 SG's in North America were lanced by the Booyclean process alone.

In many plants, it is now an established practice to waterlance all steam generators at regular intervals and, in some cases, as often as yearly. As noted during the discussions at the EPRI-sponsored conference on SG cleaning [2], SG waterlancing is a matter of routine for many plants.

Technical Issues

The technical issues related to the use of the waterlancing process basically involve: a) The ability to cut hard sludge; b) the ability to totally flush loose material from the SG; and c) the concern of tube erosion.

The ability to cut hard sludge is a function of pressure at the jet tip, the degree of focus of the jet at the point of impingement, and the jet motion as it affects the fracturing of deposits.

It is also a function of the hardness of the sludge, and the amount of fractures and fissures within the deposit. Selection of pressure is a compromise determined by the need to avoid erosion.

A pressure of 200 bar (3,000 psi) has been a widely accepted value and was used at the Pickering 'A' project. The jet focus and sweeping aspects relate to the design of the equipment and the process.

Tube damage is to be avoided at all costs, particularly in CANDU units such as Pickering 'A', in which the 125,000 tubes operating since 1971–3 have had only one in-service failure and, to date, show no sign of deterioration. Erosion testing was a key part of the initial qualifications of the process. Testing was conducted by a number of companies, including Electricité de France, Ontario Hydro, B&W, and others. While some erosion was observed during certain conditions, the tests generally support SG lancing at the normal 200 bar (3,000 psi) operating pressure.

Regarding field experience, there have been no reports of tube damage due to erosion during the years of waterlancing.

The Pickering 'A' Demonstration Project

Ontario Hydro has been pursuing waterlancing as well as chemical cleaning for several years. While it has numerous steam generators of different designs and in-service dates, the units of prime interest were those at Pickering 'A'. The main reason was that inspections had shown that Pickering 'A' SG's had up to 400 mm of sludge on the tube sheets (which have a bundle radius of only about 760 mm). Also, Units 1 and 2 were in an extended shut-down and were available for worthwhile upgrade measures. While these units clearly would benefit from waterlancing, they are also the most difficult to deal with because, as noted below, access is very difficult, and the sludge is extremely hard.

The excellent tube reliability of these SG's provided an unusual constraint. Since there has been only one in-service tube failure and no apparent degradation, it was particularly important that lancing avoid even the slightest effect on the tubes. Additionally, since Pickering 'A' tubes went into service in the as-drawn (not surface ground) condition, it seemed possible that their good fortune night relate to some protective feature built into the outer skin of the tube or the oxide layer. Therefore, these areas also had to remain undamaged.

On 30 September 1986, Ontario Hydro issued instructions to proceed with the design and development of the necessary lancing equipment, and with the demonstration lancing of one steam generator at Pickering 'A' (Unit 1, Boiler 3). The entire program was completed on 7 February 1986, meeting a very tight schedule, considering the uniqueness of the devices required.

The Pickering 'A' Lance Design

The Pickering 'A' steam generator lancing system employed a standard mobile unit, with control console, which was already stationed and in use in North America. However, as already noted, it required a very special lance head and drive because the tube pattern was rotated at 60° and 120° to the NTL, and because the NTL access space allowed a lance head which was only about 31 mm square in cross section. The lance design had to be small enough for the NTL space, and it had to provide jets which would sweep up and down in the 60° and 120° planes. This required the use of a stationary lance shaft, but with articulated nozzle blocks mounted in the head of the lance. Furthermore, the lance jets had to accurately align with inter-tube gaps of only 3.8 mm (0.15 inch).

The Pickering lance design incorporates a standard lance drive with indexing capability, but without rotation. The lance itself is a tube with five passages. At the inboard end of this tube, there is a non-rotating lance head with two nozzle blocks that sweep up and down and contain the nozzle tips. The sweeping is performed by a special drive at the outboard end of the lance. Alignment of the jet with the inter-tube gaps is confirmed by an infrared eye transmitting the location from the lance head via a fibre optic cable. This device allows initial lance alignment and confirmation of indexing accuracy by the pre-set lance drive indexing system.

Two lances were used at site. The majority of the work was performed by one lance with two jets operating on adjacent lanes at an angle of 120° to the NTL (120° from the NTL handhole onto which the lance drive was mounted). A second lance had two jets – one at a 60° angle and one at a 120° angle. These lances were totally new in concept, as well as being quite intricate. Some mechanical difficulties were encountered during the mock-up testing and during the early part of the site work. Ultimately, however, the equipment performed its function.

Unit 1 Boiler 3 Demonstration

The demonstration waterlancing of this single steam generator at Pickering Unit 1 followed a step-by-step program that was arranged to demonstrate the process with minimum exposure to tube damage. The areas lanced are shown in Figure 6.

Three-Lane Trial

The initial lancing trials were performed on three lanes (designated A, B, C) located at about 120° from the NTL handhole. These lanes were in line with a second handhole, so that extensive inspection was possible. The lancing proceeded in seven steps, with the pressure and time at position increasing up to 3,000 psi, and 50 jet rotations of 30 seconds, respectively. All subsequent jetting was at 3,000 psi – the normal lancing pressure. During this stage, the sludge pile was cut back about 75 mm (measured horizontally from the NTL), with the progress becoming poorer with time. This was attributed to the jet being 'choked' by a buildup of water in the restricted space in the middle rows of the deep pile.

Visual inspection showed no sign of tube erosion or even of loss of the surface layer. It was then decided to try a larger area near the edge of the tube bundle

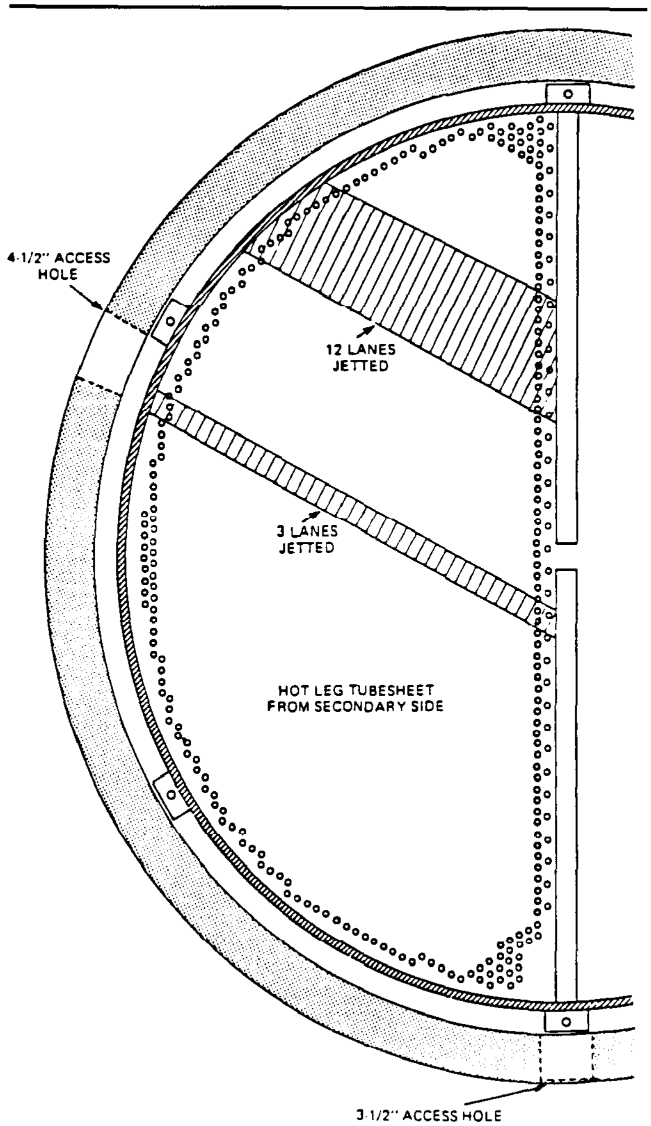

Figure 6: Areas lanced at Pickering Unit 1.

where the pile was less deep and the flow less restricted.

Twelve-Lane Trial

In the twelve-lane area shown in Figure 6, the outer and inner six lanes were jetted for 30 and 60 rotations, respectively. During this stage, the cutting was a bit faster.

With this trial completed, a temporary hold was imposed, while Ontario Hydro removed two tubes for examination (one from the three-lane and one from the twelve-lane area). Visual examination showed no loss of either base metal or of the tubes' protective layer. It was then decided to lance the full hot leg on a 24-hour-per-day basis.

During the earlier part of this program, equipment difficulties were experienced with the prototype lances developed specifically for Pickering. However, there was no problem with the proven equipment. The

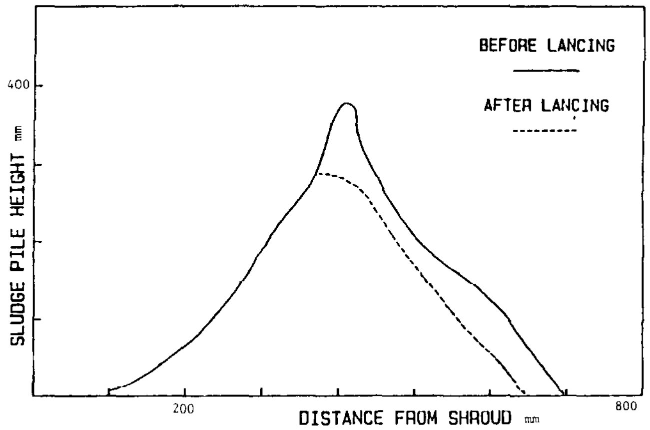

Figure 7: Pickering sludge profile.

difficulties involved design details in the intricate articulated head, and with the initial use of an infrared eye to indicate tube gap location. The need for these particular design features relates to the small NTL space and the rotated pitch orientation of these SG's.

Complete Hot Leg Waterlancing

During this operation, the complete hot leg was lanced in four passes, with each lane undergoing about 120 minutes of jetting at the normal 3,000 psi pressure. This operation altogether took three and a half days, working on a 24-hour-per-day basis.

The result was a steady but slow removal of the very steep face of the bundle on the NTL side. At no time was the lance able to work on the outboard side of the pile, which was initially about 250 mm above the lance axis. By the end of this activity, about 50 mm (measured horizontally) or 100 mm (measured vertically) had been removed from the NTL side of the pile. The 'before' and 'after' profiles are shown in Figure 7 [1].

Overall Results

The overall result of the operation based on the physical measurements was removal of 35–45 kg of deposit, or 12–15% of the total initial deposit. Considering that earlier microanalysis had indicated the sludge to be as hard as 16,000 psi concrete, it is not a bad result; nevertheless, it is clearly necessary to progress faster if the process is to be viable on these particular units.

These results indicate a need for some optimization of the process, to enhance removal rates for this very hard sludge. Some promising possibilities exist in this regard. Optimization would include operation of the system closer to its capacity, i.e., in a normal setup, two to four lances, with up to nine jets each, would operate simultaneously. This compares to the two jets used in this demonstration program.

Examination of the tubes after the twelve-lane trials and after the full hot leg operation showed no tube damage or loss of protective oxide layer.

The recommendation to other plants is to recognize the importance of early lancing in avoiding, as much as possible, hardness. For the same reason, the sludge should not be allowed to air-dry.

Other CANDU SG's

While CANDU SG's in general have had excellent tube reliability experience, they also, in many cases, have deep sludge piles, which can become aggressive at any time. Therefore, the following comments and recommendations are made regarding other CANDU SG's:

The situation at Point Lepreau is different from that at Pickering. The Point Lepreau plant has started up and is operating on phosphate water chemistry – a condition which is known to have caused phosphate wastage attack at a European plant with similar stabilized I800 tubing. Even though no general attack has been observed to date, sludge removal is a high priority – either to reduce the potential for under-deposit attack, or ultimately to allow a change to all-volatile (AVT) water chemistry. At time of writing, instructions have been provided by the utility to proceed with development of special lancing devices, to demonstrate them in a specially constructed mock-up, and to perform full-scale lancing on the four SG's during the May 1987 outage.

The 600 MWe units at Gentilly 2 and Embalse are identical to Point Lepreau in this regard and are waterlanceable with identical equipment. Clearly, such lancing should be planned for and carried out in the near future. The other 600 series SG's are also similar and amenable to similar treatment.

The Pickering 'B' SG's are somewhat easier to lance than the 'A' units, in that they are newer, have small handholes, and have tube gaps at 90° angles to the NTL. These would be amenable to lancing with a variation of the Point Lepreau equipment.

The Bruce 'A' and 'B' SG's with I600 tube material have deposits, and are therefore in need of cleaning. Their physical location makes access exceedingly awkward. Nevertheless, the possibility of some type of lancing should not be dismissed. Even if they are cleaned chemically, some type of lancing is desirable to remove the 15% or so of deposit which is not soluble in the cleaning agents.

The Darlington SG's clearly should be lanced routinely right from the start. While they are carefully designed to minimize deposit, some will undoubtedly occur. Fortunately, these units are well designed for lancing. External access is very good and internally the arrangement for lancing is also very good, and similar to Point Lepreau.

Conclusions

Waterlancing is a very important means of reducing tube sheet deposit accumulation and, in turn, the potential for under-deposit-attack on the critically important steam generator tubing. This conclusion is supported by practice in Europe and in the U.S., where such lancing is now, in many cases, done at routine intervals.

The Pickering 'A' development and demonstration project has shown that lancing is a viable process, even with the physically difficult and hard deposit conditions of those SG's. It has also been shown that tube erosion is not the concern that many had feared, as evidenced by a variety of tests.

The current Point Lepreau project will provide full-scale lancing of those steam generators. They are newer and have physically easier access, but contain sludge deposits which are very hard.

Sludge lancing should be considered as a routine cleaning measure for all CANDU steam generators, including those which are just in the process of starting up.

Acknowledgements

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