HEAT EXCHANGER FOULING AND CLEANING EXPERIENCE IN ONTARIO HYDRO'S NUCLEAR GENERATION DIVISION

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Summary

The deposits encountered in Ontario Hydro's nuclear generating stations and the methods used to remove them are described. The results, experience, and future direction of heat exchanger cleaning are given.

INTRODUCTION

The Nuclear Generation Division (NGD) of Ontario Hydro presently supplies the province of Ontario with about 35% of its electrical needs. This power is generated by 10 reactor-turbine units of the CANDU-PHW type.

The CANDU-PHW type of nuclear-electric generating stations has exceeded the performance of any other type of nuclear station in the world. This outstanding performance depends in part on the following:

1. The CANDU-PHW concept was developed into reliable operation in three stages: (1) demonstration, (2) prototype, and (3) commercial operation through close co-operation of the two major partners; Atomic Energy of Canada Limited (AECL) and Ontario Hydro.

2. The comprehensive and coordinated nuclear program involves all scientific and engineering disciplines, and all life cycle functions (research and development, design, manufacturing, construction and operations).

3. The program is based upon in-depth development of science and technology of heavy water reactors over a period of 39 years, from 1942 to 1981. During this period, Canada was the first country in the world to operate a high flux reactor, and the first country to operate fuel in a high flux reactor at high pressure and high temperature conditions.

4. The program is based upon a systematic approach involving establishment of objectives, measurement of results, identification and resolution of problems, and continuous feedback of operating experience to researchers, designers and manufacturers.

The reliability performance of the eight commercial-sized Ontario Hydro CANDU-PHW's has been outstanding. Of the world reactors in the 500 MW(e) size and larger, to the end of 1980, the lifetime capacity factors (ratio of actual power produced to perfect output) achieved, put six of these units in the top eight in the world as follows:

Rank	Country		Gross Rating MW (e)	Years In-Service	Type	Capacity Factor %
1	Canada	Bruce 3	791	3	HWR	82.6
2	W. Germany	Stade 1	662	9	PWR	82.5
3	Canada	Pickering 2	542	9	HWR	81.5
4	Canada	Pickering 1	542	9	HWR	79.5
5	Canada	Pickering 4	542	7	HWR	78.1
6	USA	Point Beach 2	524	8	PWR	78.0
7	Canada	Bruce 4	791	2	HWR	77.6
8	Canada	Pickering 3	542	9	HWR	76.1

The prime reason for this outstanding performance is the on-power fuelling features characteristic of the CANDU-PHW.

An additional 8,600 MW(e) is under construction at Pickering NGS-B (PNGS-B), Bruce BNGS-B (BNGS-B) and Darlington NGS-A(DNGS).

The cost of nuclear generated electricity within Ontario's industrial infrastructure is approximately 40% less than that generated by a comparable coal-fired station. Nuclear stations are therefore used for base load. Because of the cost differential between nuclear generated electricity and thermal generated electricity, any incapability of nuclear units is associated with large economic penalties.

Because of the good performance of the heat exchangers in our nuclear stations, little attention, beyond minimum maintenance requirements, was given to this equipment. However, over the past 5 years, the incapability caused by heat exchangers has risen to 3%.[(1)]

The incapability of the heat exchangers was attributed to:

- loss of heat transfer capacity caused by fouling, and
- failure of the heat exchanger.

These failures of critical heat exchangers were caused by:

1. Flow-Induced Vibration
   - NPD NGS Steam Generator
   - PNGS-A Moderator Heat Exchanger
2. Random Manufacturing Defect
   - PNGS-A Unit 2 Steam Generator

3. Stress Corrosion Cracking
   - BNGS-A Bleed Coolers
   - BNGS-A Unit 2 Steam Generators (Unconfirmed).

4. Severe Pitting
   - PNGS-A Bleed Coolers

Many options are available to reduce the incidence of the causes of incapability.

Our initial response has been pragmatic and one of expediency. That is clean, where necessary, and then repair the heat exchanger so that we can return the unit to power.

The purpose of this paper is to:

1. Describe the types of fouling we encounter at our nuclear stations.

2. Discuss the cleaning techniques we have used to remove deposits from heat exchangers.

3. Outline our future program.

FOULING OF HEAT EXCHANGERS IN ONTARIO HYDRO'S NUCLEAR GENERATION DIVISION

Ontario Hydro's operating nuclear generating stations are located at three sites in southern Ontario. The sites border the Ottawa River (NPD NGS), Lake Huron (BNGS and DP NGS) and Lake Ontario (PNGS).

The major difference between the waters of the Ottawa River and Great Lakes is hardness. Typical chemical analyses of these waters are given in Table 1.

TABLE 1

CHEMICAL ANALYSES OF COOLING WATERS

Chemical (mg/kg)	Ottawa River	Lake Huron	Lake Ontario
Calcium	7	26	40
Magnesium	3	8	8
Sodium	4	3	15
Potassium	3	1	2
Bicarbonate	-	52	130
Carbonate	-	2	3
Sulphate	7	15	30
Chloride	2	5	30

The type of deposits expected and obtained in heat exchangers on once-through cooling water from these sources are:

Great Lakes - Calcium Carbonate
- Lake Silt
- Iron Oxide

Ottawa River - River Silt
- Iron Oxide

The heat exchangers that have fouled were mostly those subject to low coolant flows. Low flows were due almost entirely to where temperature sensors were used to control flow. Scale formation did occur but only when Lake Huron water was heated above 50°C. All these deposits lead to a loss of heat transfer and eventual failure of the heat exchanger. Fouling has occurred irrespective of whether the coolant was on the tube or shell side.

The location of the fouling together with heat exchanger design has dictated how each heat exchanger had to be cleaned.

TECHNIQUES FOR CLEANING HEAT EXCHANGERS

Two basic approaches are available for cleaning heat exchangers. These are on-line and shutdown.

The simplest example of the former usually uses a proprietary chemical, generally a polyelectrolyte. The normal application is to use the proprietary chemical to keep a clean heat exchanger deposit-free. These techniques could be used on all types of fouling encountered in our heat exchangers. However, proprietary chemicals are expensive and also are not always environmentally acceptable.

For shut-down periods, there are primarily two methods available for cleaning heat exchangers; physical and chemical.

One physical method uses jets of high pressure water. The jet is impinged on the deposit causing it to disintegrate and be washed away. Cleaning by high pressure jetting has many advantages:

- it is cheap,
- it is fast,
- you get instant results
- you can see what you are doing, and
- low effluent volumes are generated.

The disadvantages of this technique are:

- The heat exchanger to be cleaned must be partially stripped to expose the area to be cleaned; the tube sheet if the tube side is to be cleaned, or the shell if the shell side is to be cleaned.

- An aerosol is generated which, if not properly contained, can be messy.

- It is not applicable to all heat exchangers by virtue of construction and/or design. For example, triangular pitch tube bundles are not easily cleaned by high pressure water jetting. Nevertheless, this technique could be used to remove all the deposit we encounter.

Chemical cleaning methods are invaluable for cleaning those heat exchangers where water jetting is difficult.

The advantages of chemical cleaning are that the heat exchangers can be cleaned in situ with little area preparation. The disadvantages however are:

- it is expensive,
- pipework must be fabricated to allow circulation of the solvent,
- volumes are generally large,
- the solvent must be tested to ensure compatibility with system materials,
- solvent disposal, and
- corrosion.

All the deposits we encounter can be removed by chemical cleaning. However, when water jetting is feasible, it is the recommended procedure because of cost and time advantages.

EXPERIENCE IN NGD

On-Line Cleaning

This has been tried, however, with little success. A polyelectrolyte was used unsuccessfully to clean a heavily fouled heat exchanger. This application of a polyelectrolyte is unusual, and with hindsight, it is not surprising that it failed. As previously mentioned, polyelectrolytes are generally used to keep clean heat exchangers deposit-free.

SHUT-DOWN CLEANING

High Pressure Water Jetting (HPWJ)

The effectiveness of HPWJ is illustrated by comparing Figures 1 and 2. Figure 1 shows a turbine lubricating oil heat exchanger at PNGS-A prior to cleaning. Figure 2 shows the same heat exchanger after it had been cleaned by HPWJ; quite a difference! This heat exchanger contained 1,400 tubes of pure copper. It took about 12 hours to clean at a cost of under $1,000.

HPWJ is now routinely used at PNGS-A for cleaning the tube sides of heat exchangers on once-through cooling.

CHEMICAL CLEANING

Whenever possible, we use inhibited hydrochloric acid to clean heat exchangers. This is used routinely to clean instrument air compressors at PNGS and BNGS. If there is a material compatibility problem with hydrochloric acid, we use inhibited formic acid. With the exception of the chemical clean of the NPD NGS steam generator,(2) in which a mixture of citric acid and EDTA was used, we have used inhibited formic acid for all other chemical cleans. Formic acid was selected because it contains neither chlorine nor sulphur; both of these elements are known to be associated with failure mechanisms of stainless steel Inconel and Incoloy tubing materials.

The inhibitors used to date have been proprietory chemicals, sometimes with the addition of hydrazine. Hence, little corrosion has been experienced with formic acid solvent. Data is shown in Table 2.

TABLE 2

CORROSION OF MATERIALS IN 10% INHIBITED FORMIC ACID EXPOSED FOR 24 HOURS

Material	Metal Loss (m)
C Steel	12
304 SS	< 0.1
304 L SS	< 0.1
Inconel 600	< 0.1
Incoloy 800	< 0.1

These results were obtained in laboratory tests prior to the actual cleaning. There was no evidence of either stress corrosion cracking or intergranular penetration of any material.

Even though we have corrosion results for these materials, we always expose coupons of heat exchanger materials to the cleaning solvent. This extra data is used as the final guarantee for quality assurance of the process.

Figure 3 shows one heat exchanger we have cleaned. This is a BNGS-A bleed cooler prior to being chemically cleaned by formic acid. The calcium carbonate deposit can be seen in between the tubes. Unfortunately, there is no photograph of the clean heat exchanger as it was not reopened for inspection after the chemical cleaning. This heat exchanger was returned to service after repair with its heat exchanger capacity completely restored. However, because of the design and operating constraints imposed on the bleed cooler heat exchangers at BNGS-A, they will continue to foul. Because of this, they are presently routinely cleaned. The long-term solution being implemented is to place all these heat exchangers on a demineralized water recirculation system.

Figure 4 shows another fouled heat exchanger, the PNGS-A Irradiated Fuel Bay Heat Exchanger, and Figure 5 shows the same heat exchanger after cleaning with inhibited formic acid.

The duration of the cleaning was five days, and cost $9,000. Had we been able to use high pressure water jetting, this heat exchanger could have been cleaned for a third of the cost, and in one third of the time.

A list of the heat exchangers that have been cleaned in NGD is given as Table 4.

TABLE 3

HEAT EXCHANGERS CLEANED AT ONTARIO HYDRO NUCLEAR STATIONS

Heat Exchangers	Location	Solvents
Bleed Coolers	DP NGS	Proprietary Acid Solvent
Bleed Coolers	BNGS-A	Inhibited Formic Acid
Irradiated Fuel Storage Bay	PNGS-A BNGS-A	Inhibited Formic Acid
Turbine Lube Oil Cooler	PNGS-A	Water Jetting
Moderator	NPD NGS	Inhibited Formic Acid
Bleed Cooler	NPD NGS	Inhibited Formic Acid
Standby Cooler	NPD NGS	Inhibited Formic Acid
Recirculated Cooling Water	PNGS-A	Water Jetting
Moderator	PNGS-A	Air Sparging
Air Compressors	PNGS-A BNGS-A	Inhibited Hydro-chloric Acid

FUTURE PROGRAM

Activities are planned to compliment our current pragmatic approach to heat exchanger fouling.

Initially, we will concentrate our efforts at PNGS which has the highest silt burden. The program will consist of two parts; the first is to clean the heat exchangers in a systematic manner, and the second is to develop and apply techniques to minimize fouling.

In the first phase, cleaning procedures will be developed for the stations heat exchanger equipment. We will then monitor refouling using non-intrusive flow and temperature monitors. Calculated refouling rates will then be used to determine the cleaning frequency.

Results obtained concerning the nature of the deposits together with an evaluation of heat exchanger design and operation will form the basis for the second phase. A test program is envisaged to evaluate the impact of potential fouling minimization techniques such as:

- additions of biocides or dispersants to the cooling water, and
- modifications to the cooling water operation with a view to increasing cooling water flow and hence minimizing deposition potential.

CONCLUSION

Our initial response to the incapability caused by heat exchangers was pragmatic and expedient, such that we cleaned, where necessary, repaired then returned the unit to power. During this period, we have used both high pressure water jetting and chemical cleaning successfully.

Water jetting is invariably cheaper, less time consuming, and more effective than chemical cleaning. However, as water jetting is not universally applicable to all heat exchange equipment, chemical cleaning is also a necessary tool.

With these developed cleaning techniques available, we are reevaluating our approach to the problem. It is time to return to the systematic approach which has been the basis of CANDU development.

REFERENCES

(1) D. Dueck, "Major Heat Exchanger Performance in Ontario Hydro Operated CANDU Nuclear Generating Stations," presented at the Canadian Nuclear Association Seminar on Heat Exchanger Reliability, May 1981.

(2) C.R. Frost, P. Walmsley, P.V. Balakrishnan and P. McSweeney, "Chemical Clean of the NPD Steam Generator," to be published in Nuclear Technology, Special Issue on Materials Performance in Nuclear Steam Generators, October 1981.

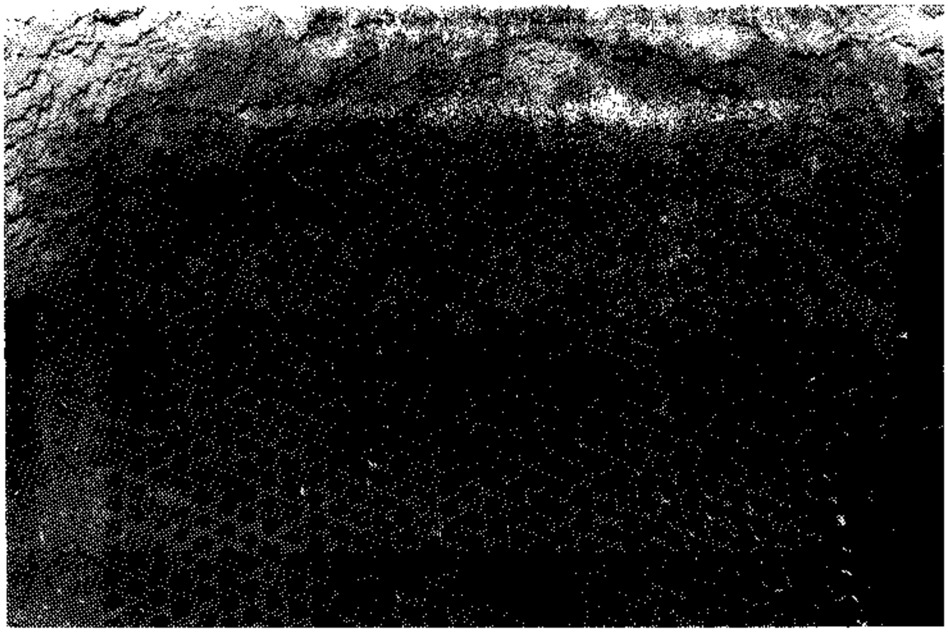

Figure 1

Lubricating Oil Heat Exchanger
Prior to Cleaning With Water Jets

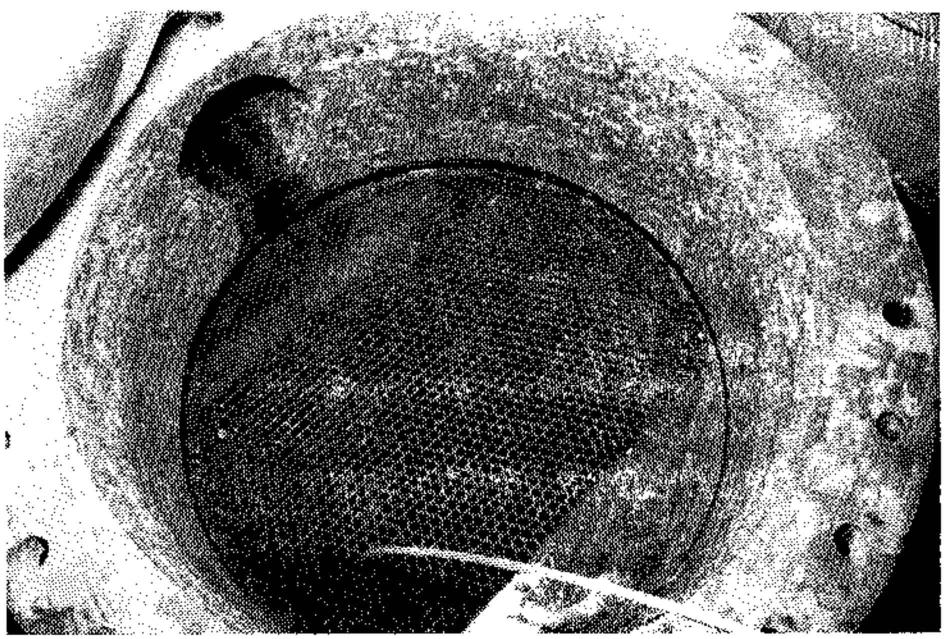

Figure 2

Lubricating Oil Heat Exchanger
After Cleaning With Water Jets

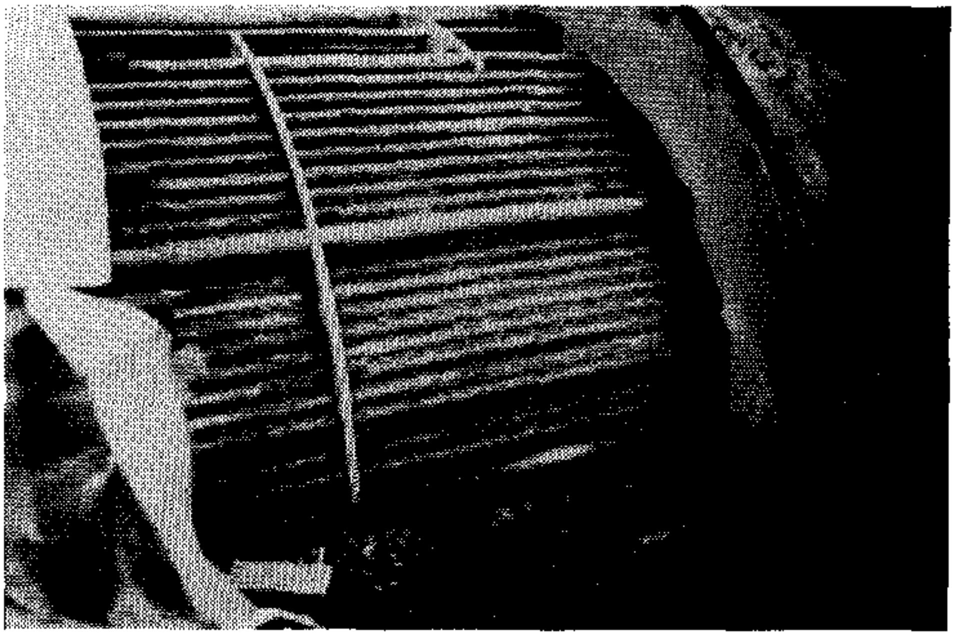

Figure 3

Bleed Cooler Before Chemical Cleaning

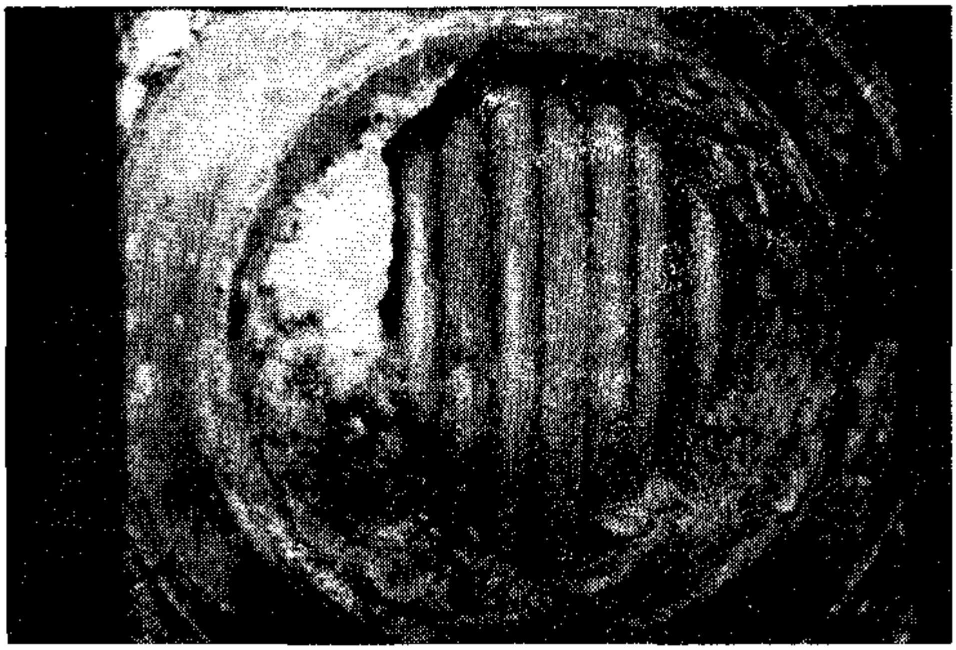

Figure 4

Irradiated Fuel Storage Bay Hea Exchanger
Bef re Chemical Cleani g

Figure 5

Irradiated Fuel Storage Bay Hea Exchanger
After Chemical Cleaning