CHECWORKS™ INTEGRATED SOFTWARE FOR CORROSION CONTROL*

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Abstract

CHECWORKS™, a comprehensive software package for managing Flow-Accelerated Corrosion (FAC, also called erosion-corrosion and flow-assisted corrosion) concerns, is expanding to include other systems and other aspects of corrosion control in CANDU reactors. This paper will outline CHECWORKS™ applications at various CANDU stations and further plans for CHECWORKS™ to become a code for comprehensive corrosion control management.

AECL is currently introducing all facets of CHECWORKS™ into the CANDU stations. Point Lepreau, Pickering, and Darlington have all benefited from CHECWORKS™ predictive analysis of FAC on the primary and secondary sides. Darlington and Bruce A have both incorporated CHECWORKS™ into their ongoing UT data management and analysis on the secondary side.

Current plans for CHECWORKS™ include various aspects of corrosion control management as follows:

1) Proposed work in Ontario Hydro stations to model major secondary side systems for predicting FAC.

2) Integration of CHECWORKS™ and new inspection technology developed by NTS.

3) CHECWORKS™ incorporation into the automated chemistry control system planned for CANDU stations.

4) New modules presently being introduced into CHECWORKS™ with co-operation from EPRI (Electric Power Research Institute). These modules will manage corrosion concerns in Service Water systems, iron transport in the secondary side, and cavitation.

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5) A CHECWORKS™ application to predict FAC rate and rank components in the primary side. The application will be based on extensive R&D undertaken recently.

Feedback from station staff on the current plans for integration of Ontario Hydro equipment and systems into CHECWORKS™ is both timely and invaluable.

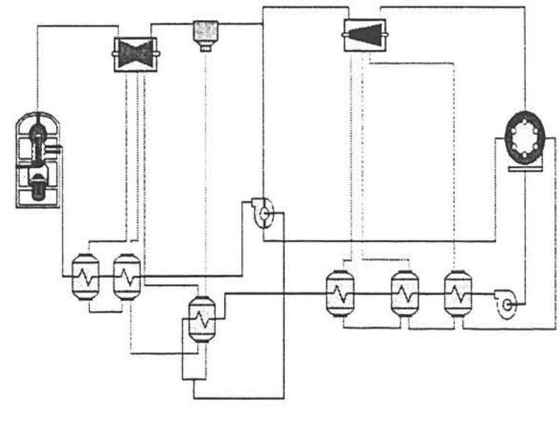
Current Work In CANDU Stations

CHECWORKS™ uses an empirical model to predict the rate of FAC on a component-by -component basis. The model is based on alloy composition, fluid pH level and control amine, dissolved oxygen, fluid bulk velocity, component geometry and upstream influences, fluid temperature, and steam quality. It is not possible to periodically inspect all susceptible locations. Therefore, a predictive analysis is required to assess piping networks and determine susceptible locations. In addition, the cost is approximately $4,000/inspection/ inspection location. Additional cost savings will result from a reduction in forced outages or unit derating.

Currently, the primary and secondary sides of Pickering Nuclear Generating Station are being modeled by CHECWORKS™. This predictive modeling consists of analyzing the outlet feeders on the primary side and the major systems in the secondary side systems. This predictive analysis will provide assurance that the current inspection program has included all the locations that should be inspected for FAC wall thinning. Darlington ND is continuing to use CHECWORKS™ for the analysis of their UT data as the UT data is generated from their inspection program. The station has incorporated CHECWORKS™ predictive capabilities into its FAC program for both the primary and secondary sides. Bruce is in the process of putting all their UT data into CHECWORKS™ for analysis and for documentation purposes. Using CHECWORKS™, the stations can choose from a number of its capabilities, some of which are described below.

Plant Modeling

To use the FAC Application, it is convenient to make a graphical representation of the plant's power generation loop.

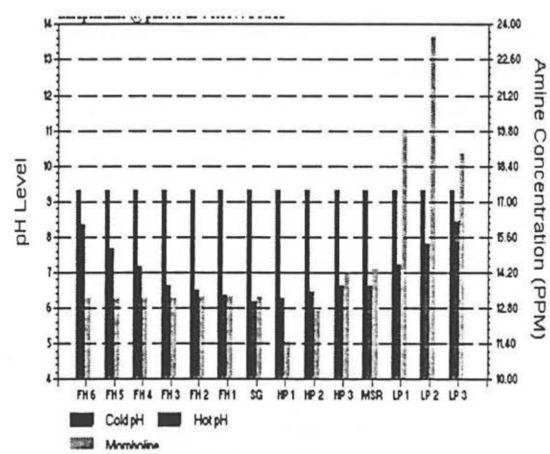


Power generation model

Water Chemistry Analysis

Dissolved oxygen level and operating pH of typical nuclear plants around the steam cycle can be determined using the power generation model. It takes into account line and equipment operating conditions and the effects of pH control amines. The volatility of the amines as they partition in wet steam lines is also modeled. CHECWORKS™

- models virtually all configurations of power plants
- provides built-in properties of all common amines
- specifies amine concentrations in several different ways



Results of Water Chemistry Analysis

Network Flow Analysis

An analysis of network flow will determine any unknown local operating conditions (flow rate, temperature, pressure or steam quality) that are needed for FAC predictions. It accounts for source and sink conditions, pipe routing,

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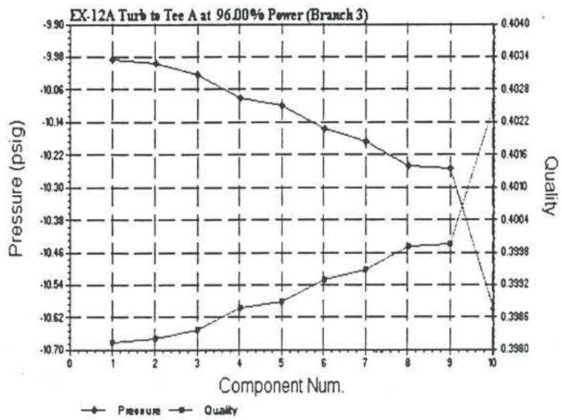
elevation changes, pipe insulation, in-line equipment, and valve type and position. Capabilities include

- modelling of all types of header and tee configurations
- checks for single and multiple flashing and choking
- including surface roughness effects using user specified or default values



Results of Network Flow Analyses

Wear Rate Analysis

A wear rate analysis determines the total amount of wall thinning, the rate of thinning, and remaining lifetime of piping components degraded by FAC. Capabilities include

- predictions for both single-phase (water) and two-phase (wet steam) lines.
- built-in geometry factors representing 64 of the most common piping configurations
- various ways of reporting results to aid in outage planning
- using results of past piping inspections to refine predictions
- factoring component replacements into remaining life predictions
- component specific trace alloy measurements
- predictions at multiple power levels and for part-time line operation
- historical and planned changes to water chemistry and operation
- access to component database with generated or scanned isometrics

UT Data Analysis

The UT data analysis allows users to import, manage, display, store, and evaluate data from the ultrasonic inspection of piping components. The program is capable of

- importing data from popular makes of dataloggers
- displaying inspected components using colors to represent local thickness or wear since a previous inspection
- viewing a cross-sectional and longitudinal image of the component
- editing and displaying thickness readings using a color-coded spreadsheet
- evaluating thickness readings using user selected methods to determine the amount of measured wear over time
- evaluating thickness data using statistical methods
- making separate wear evaluations of all parts of components
- tracking wall thickness data
- scanning photographs to store in the database.

FACTRAK

FACTRAK is a spreadsheet that may be used to help plan and manage outage activities associated with FAC inspections. FACTRACK can

- create views to help manage outage activities such as scaffolding, insulation removal, marking of grids, and the taking of inspection data
- summarize data such as temperature and pressure, initial thickness, material, past inspection results, and acceptable thickness
- sort views by, for example, components previously inspected or components scheduled for inspection
- determine the structural acceptance of thinned piping components using user specified criteria.

Integration of CHECWORKS™ and Tomoscan

Tomoscan is an automated ultrasonic instrument that the SIM Department is using for Periodic and In-Service Inspections of station components. A pair of these systems were purchased in February as a replacement for the much older Sonomatic 'ZIPSCAN' unit. These systems are faster, smaller, lighter, easier to use, and more powerful and flexible than the system they replace.

Tomoscan is produced in Quebec City by RD Tech. The system is widely accepted internationally and may be considered as an

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advanced ultrasonic data acquisition, processing and display system.

The Tomoscan unit is a multichannel unit, i.e., it has several pulser and receiver channels that can be configured in a number of ways via software. The instrument is capable of being configured to operate in several ultrasonic modes such as conventional pulse echo (angled beam shear and zero degree which are used by Periodic Inspection), tip diffraction techniques, tandem techniques, through transmission and the TOFD technique. The Tomoscan can record all information on a number of channels during the inspection for later playback and analysis. Data may be recorded in free running mode or with encoded position information or with robotic probe manipulators. Each of these recording modes increases the level of sophistication in the set up, but also yields more information upon subsequent processing.

There are a greater number of variables that must be controlled with automated systems over conventional manual pulse echo techniques; however, Tomoscan records all variables and once these variables are set they can be recalled and analyzed.

There are a number of reasons that justify the application of automated UT over manual UT. They may be summarized as substantial reduction in dose exposure to the inspectors, increased repeatablility of the inspection results, a hardcopy output of the inspection data, quicker inspections, and most significantly, increase in inspection accuracy by an order of magnitude. Properly set up, the techniques are capable of repeatable sizing indications down to a fraction of a millimetre.[1]

Ideas are being discussed to use CHECWORKS™ for analyzing the data from the new Tomoscan technology. This will allow the data from Tomoscan units to be imported directly into the CHECWORKS™ code for analysis and data management.

<u>Integration of CHECWORKS™ and COMPAS</u>

There are future plans that CHECWORKS™ will be integrated with online chemistry input of the CANDU reactor with the use of the COMPAS (Corrosion Monitor and Prediction Analysis Systems). COMPAS will provide reliable and efficient operation of steam generators while minimizing corrosion in the balance of plant, crud transport into the steam generators, and corrosion inside the steam generators. The goals are to prevent performance degradation, and reduce the cost associated with unplanned outages or extended plant outages due to repairs or maintenance of the steam generators. COMPAS will provide plant chemists with information such as

- on-line chemistry and process monitoring information to assess compliance with the station chemistry guidelines,
- early detection and diagnostic capabilities to allow for quick response to chemistry excursions, and
- corrosion and fouling predictive capabilities to optimize secondary chemistry conditions.[2]

By incorporating this on-line chemistry capability into the CHECWORKS™ platform, instant analysis of wear rates due to FAC are possible. This technology will also allow accurate documentation of past water chemistry and its effect on wear on the secondary side.

<u>New Modules in CHECWORKS™</u>

The service water (SW) systems of operating nuclear and fossil plants are being degraded by a variety of mechanisms. These include microbiologically induced corrosion (MIC), pitting, underdeposit corrosion, galvanic corrosion, crevice corrosion, cavitation, solid particle erosion, erosion-corrosion, and general corrosion. In addition, piping and heat exchangers are subject to sedimentation and fouling from several sources.

Work necessary to keep the system operable include inspections, cleaning, repairs and replacements of piping and equipment, coating application and maintenance, performance trending, selection and application of water treatment, and associated engineering support. Related O&M costs can be quite high–several million dollars per fuel cycle in many cases.

The objective of the CHECWORKS™ SW Application is to transfer technology for controlling the various forms of degradation that are affecting the service water system. This has been achieved by developing predictive models for the most common forms of degradation and installing the models on CHECWORKS™ in a way that the SW systems can

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be easily evaluated. The output of the calculations is component-by-component predictions for each form of degradation as a function of system line-up and season.

Models have been developed to predict the most common forms of degradation as a function of local conditions. These models include microbiologically-induced corrosion, sedimentation, pitting, galvanic corrosion, underdeposit corrosion, crevice corrosion, cavitation, erosion-corrosion, and solid particle erosion.

Iron Transport

Significant amounts of corrosion products are being formed in the power generation loop of operating nuclear and fossil power plants. Most of the corrosion products result from FAC during power generation and during shut down and startup periods. The corrosion products are mostly iron oxides and hydroxides–primarily magnetite and hematite. When released from the parent metal, the products are transported around the steam loop and tend to deposit in the steam generators, condensate polishers, feedwater heaters, and the condenser. Products deposited in the steam generators act to accelerate corrosion of the tubes, tube support plates, and tube sheet; degrade its heat transfer capability; and increase the pressure drop across the generator. Products deposited in the condensate polishers require them to be more frequent regenerated.

FAC tends to produce and release iron oxides during power generation at a constant rate with time. General corrosion tends to produce iron oxides as a function of time and conditions during plant shut-downs, but release them in a highly transient manner after plant restart (a crud burst). The condensate polishers remove some of the oxides during regeneration of the resins, but can also act as a capacitor–sometimes storing and sometimes releasing the oxides into the condensate.

Most power plants are now monitoring the levels of iron found in the final feedwater (the concentration just prior to entering the steam generator). Some plants also monitor iron levels in other locations such as condensate and heater drains. Depending on water chemistry, lay-up strategy during outages, design, and materials and time when measured, final feedwater iron levels are typically in the range of 0.5 to 20 ppb. It is generally agreed that the ideal level of iron is essentially zero.

The objective of the Iron Transport Application is to deliver technology to the operating plants to help reduce the levels of iron oxides in the power generation loop. This is being achieved by developing predictive models for the generation of iron oxides resulting from FAC during power generation and general corrosion during outages. The models are being installed on CHECWORKS™ in a way that the sources of the iron can be easily identified. The source predictions are quantitative on a component-by-component and line-by-line basis. The first release of the Iron Transport Application assumes steady state conditions. A later release will predict the transient effects of iron transport around the loop (e. g., include crud bursts, deposition, and re-entrainment), and include an interface with THIRST and SLUDGE programs for steam generator sludge prediction.

Cavitation

This module will predict the location and intensity of any cavitation that may occur in the power generation loop. The predictions are based on an empirical model, developed from an extensive set of laboratory and plant data. The empirical formulae take into account geometry, flow conditions, upstream pressure, downstream pressure, and component size. The code has four levels of cavitation: incipient cavitation, critical cavitation, incipient damage cavitation, and choking cavitation. Sufficient information exists to analyze orifices, bends, and valves: butterfly, globe, cone, ball, and gate. Release of CHECWORKS™ with this module is planned for 1998.

Primary Side Application

The current version of CHECWORKS™ does not cover ranges of some parameters that exist in the primary side of CANDU reactors. To extend the range of applicability of the code to cover the CANDU primary side, a lot of R&D projects have been undertaken. The results will be included into CHECWORKS™, which will be the tool for dealing with primary side FAC concerns for the stations and designers. To achieve that, a model predicting FAC rate for the components in the

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primary side is needed. The model can be based on experimental evidence, mechanistic approach, or both. It can also use elements of the current formula in CHECWORKS™.

A model for primary side FAC will include the following correlations and effects:

- pH. The CHECWORKS current range does not cover pH > 10.0. A relationship for pH > 10.0 will be based on published data in the literature and a mechanistic approach, and will be validated by experiments.
- geometry. Experiments at room temperature will be done to find CANDU-specific geometry factors, for example for non-standard elbows and reducers attached to end fittings. Other geometries will use factors that are now in CHECWORKS™.
- pH-controlling agent (lithium hydroxide)
- Cr effect. Experiments are under way to validate the current knowledge.
- void fraction.
- temperature affecting material properties and reaction kinetics.
- hydrogen concentration.
- oxygen concentration. The CHECWORKS correlation will probably be used.
- velocity. The CHECWORKS™ correlation will probably be used with heavy water properties.
- iron concentration. It can be calculated from solubility curves and simple balance equations within the circuit and does not need to be input.

The code will model both the outlet and inlet feeders to have a capability for a complete analysis of the circuit. Steam generator tubes can be treated as a black box, or on FAC rate can be assumed. The application will use heavy water properties.

Industry Acceptance

CHECWORKS™ (and its predecessor CHECMATE™) is being used by all US nuclear utilities, many US fossil plants, and utilities in Canada, the Czech Republic, Japan, Korea, Slovenia, and Taiwan to help predict FAC in their piping systems, and assist in managing their overall program to control it.

User Support

CHECWORKS™ is supported by a full-time technical team with specialties in materials, chemistry, corrosion, nondestructive evaluation, plant operations, stress analysis, and computer science. The CHECWORKS™ User Group (CHUG) includes 54 members worldwide.

Summary

The benefits of using CHECWORKS™ to predict FAC in nuclear and fossil plants include:

- Capability to identify problem areas long before a leak or rupture might occur.
- Need to inspect far fewer locations than is required using a less accurate methodology.
- Ability to establish a remaining service life for inspected and non-inspected components.
- Allow the plant to optimize water chemistry and evaluate other options to select the most cost effective way of controlling FAC on a line-by-line basis.
- Reduce the number of personhours needed to manage, evaluate, and store piping inspection data.
- Provide a useful tool to help manage FAC inspection activities.

Acknowledgements

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