SELECTION AND USE OF MATERIALS FOR GEOTHERMAL ENERGY APPLICATIONS USING COMPUTER BASED TECHNOLOGY

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Abstract - Advice on the selection and use of materials for new and existing geothermal energy applications in New Zealand is based on knowledge and experience gained over several years of field testing and research on materials exposure to geothermal fluids. Some of this knowledge has been captured in computer based systems, these include: a database of metal corrosion results, a listing of archived publications and reports, a modelling programme which describes corrosion processes (potential-pH diagrams) and an expen system which provides interpreted materials advice for typical plant applications. The resultant computer programmes are combined under a Windows based user interface to permit free movement between the programmes throughout a materials consultation.

1. INTRODUCTION

The use of computers for transfer of corrosion control technology began with abstract storage and searching programmes in the 1960's and 1970's. The use of computers in more direct corrosion control applications also increased dramatically over this same time period and into the 1980's. Table 1 lists applications-oriented computer systems for data logging, database tabulation and modelling of corrosion data which have become standard tools for many corrosion control technologists. Expert systems, neural networks and hypertext systems which are applications of Artificial Intelligence research are also being used for corrosion control technology. (Lichti and Wilson, 1990)

Table 1: Computer applications for transfer of corrosion control technology.

- Abstracts and Text Searching
  - corrosion and materials information
- Dam Logging
  - corrosion measurements and calculations
- Database Information Systems
  - data storage, manipulation and reporting
- Modelling
  - corrosion process modelling
- Expert Systems
  - materials selection and performance advice
- Neural Networks
  - data evaluation and modelling
- Hypertext and Integrated Advisory Systems
  - combined text (book) searching, case histories, databases, and expen systems

The capture of geothermal corrosion expertise using computer based technology can involve many of the applications listed in Table 1. The specification of materials and limitations on their use for geothermal energy applications is a mature technology. Procedures for assessing corrosiveness and data on which to judge the suitability of materials are available for many situations. Where a corrosiveness assessment has been completed and the environment is judged to be outside the range of well understood parameters, corrosion tenting will also typically involve the use of computers for insvument control, datu logging and data modelling.

An essential premise for capture of corrosion control technology is the need for data evaluation. (Lichti and Wilson, 1990) The process of "evaluating" data involves (Anderson, 1989):

- assessing accuracy and reliability
- assessing experimental techniques and associated errors
- comparison with other experimental or theoretical values
- recalculating derived results and accepted models
- comparison with service experience
- comparison with current industry practice
- selective acceptance and statistical manipulation
- assignment of probable error or reliability.

Information and raw data collections require evaluated data whereas computer based systems which give advice must be bared on data which has not only been evaluated but also interpreted and placed in context for a particular application.

In addition, successful development and application of computer based systems for corrosion technology transfer must include:

- formal models for capturing corrosion expertise
- quality assurance systems for assessing the validity of any computer model results and any provided advice for a defined application
- a suitable procedural modcl for the use of the technology
- a suitable user interface to provide access to the technology and to generate the required reports.

This paper describes the current status of a methodology for providing advice on selection and use of materials for geothermal energy applications using computer based systems.

2. STRUCTURE OF GEOTHERMAL CORROSION AND MATERIALS KNOWLEDGE

Domain knowledge for materials in geothermal energy systems must be drawn from differing types of data and expertise. Figure 1 illustrates the structure of materials knowledge relating to geothermal corrosion with the central region representing that which may be captured using computer based technology.

2.1 Corrosion Results

Geothermal corrosion results are available in published papers and reports and also in many private company archives. Published results will have had a degree of data evaluation but the use of such results for provision of advice for new applications generally requires added interpretation. Company archives can include:

- listings and collections of published papers and conference proceedings dealing with geothermal corrosion results
- listings and collections of confidential reports and communications on geothermal materials selection.

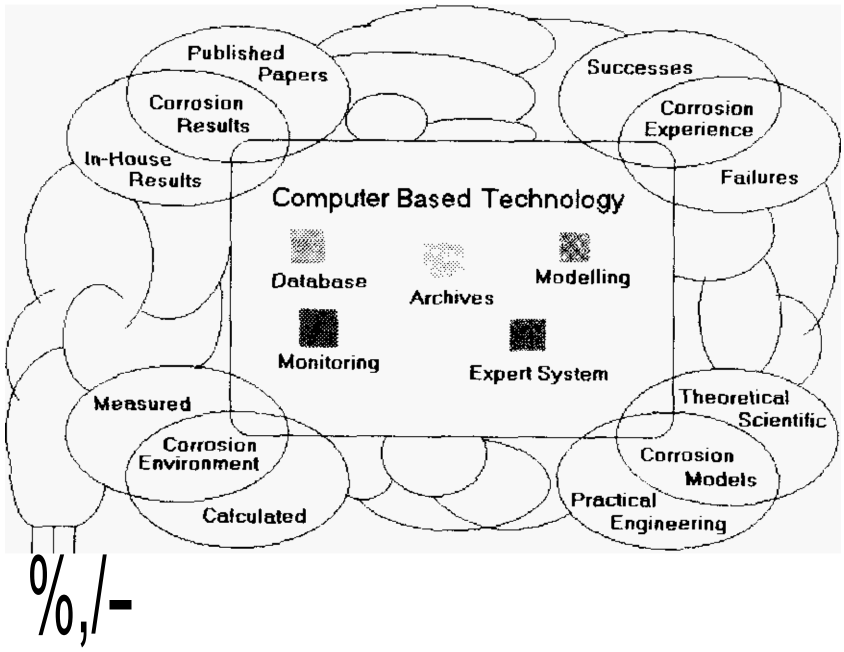

Figure 1: Structure of gmthermal corrusion knowledge which can be captured using computer based technology.

In-house results from corrosion experiments can be critically reviewed by a formal evaluation process and tabulated in simple spreadsheets or they may be assembled into a computer searchable database. Knowledge gained from the collected and evaluated results may be incorporated in advisory systems, but again, only after it is interpreted for a particular situation.

2.2 Corrosion Experience

Geothcrmal corrosion experience includes both successes and failures. Materials performance within an operating plant will depend on aspects of environment. plant design and operation practicer such as startup, shutdown and standby procedures. The practical extension of this experience to new situations also requires the application of critical evaluation and interpretation practices to assure reliability. Collecting and archiving materials experience in power stations is not a trivial exercise hut can he simplified by the application of a realistic life extension programme such as that outlined by Lichti et al (1993).

Corrosion experience for individual plant items can he captured in a database or the knowledge gained can be funher interpreted for more general application using an expen system.

2.3 Corrosion Environments

Knowledge of the environment experienced in geothermal plant and equipment and also the environment present in vessels used to test materials performance is critical to the extrapolation of corrosion results and corrosion experience to new environments. In many situations the measured environmental parameters such as non-condensible gas content of steam cannot be directly related to corrosion processes and calculation of theoretical corrosion chemistry is required. Direct measurement of corrosion parameters such as condensate pH and corrosion potential in pressurised systems are also difficult. New techniques are being developed to provide more direct measurement of corrosion parameters to reduce reliance on theoretical models. (Inman et al, 1992 and 1993)

Calculation of high temperature corrosion chemisuy is based on chemisuy models which can be automated using computers. Models may be implemented in stand alone applications or incorporated into other programmes such as expert systems. (Lichti and Wilson, 1990) The results of these models can be used to compare differing geothermal systems and plant environments with the proviso that some means of independently verifying the validity of the results is available. (Lichti and Wilson, 1993)

2.4 Corrosion Models

A large range of practical engineering models have been developed for describing materials performance in geothermal energy systems. lhese models are based on corrosion results gained from historical types ofcorrosion experiments which give a snapshot of the progress of corrosion over a period of exposure as wcll as results from on-line corrosion probes which follow the progress of corrosion. (Lichti et al, 1981, Lichti and Wilson, 1993, Lichti et al, 1995)

Theoretical models of corrosion processes such an potential-pH (Pourbaix) type diagrams are also available for characterising the reactions expected to occur on carbon steels exposcd to a geothermal environment. (Wilson and Lichti, 1982) The production of these diagrams can be automated using a computer. The diagrams provide a useful means of summarising equilibrium chemistry of significance for corrosion reactions; for the equilibrium Fe-H_2S-H_2O system the thermodynamically stable solid specics are illustrated in Figure 2. The formation or reprecipitation of solid species (such as those Seen on the diagram in the near neutral pH range below the H_2/H^+ equilibrium line) next to the corrading metal surface provides the passivating mechanism which limits corrosion. (Borshevska et al, 1982. Wilson and Lichti, 1982)

3. GeoMats™ SYSTEM

A computer based system has been developed as an in-house aid for the provision of materiais performance advice for geothermal energy applications. The **GeoMats™** system consists of the fallowing: an expert system for provision of interpreted advice on selection and use of materials, a fortran programme for calculating data for potential-pH diagrams and a database of surface corrosion results obtained in tests at Broadlands well BR22. Access is also provided to listings of company archived reports and published papers. These programmes are accessed via a Windows™ user interface, which provides selection buttons for the programmes in a single window and gives help and guidance on the use of the programmes. The screen design for **GeoMats™** is shown in Appendix I. (The **GeoMats™** system has not been developed for sale but as a research and consulting aid.)

™ GeoMats, Industrial Research Limited, New Zealand

™ Windows, Microsofr Corporation, USA

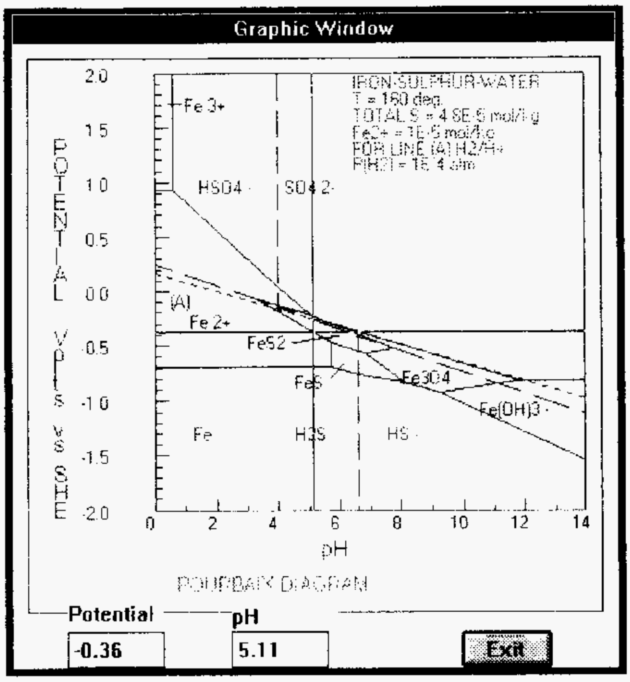

Figure 2: Pourbaix diagram of Fe-H_2S-H_2O system at T = 160°C: total sulphur = 4.8x10^{-5} mol/kg (calculated condensate pH = 6.5).

3.1 GeoMats™ Expert System

The expert system was programmed using the SNAP™ Object Module software development shell and a purpose built user interface. The system contains (Lichti and Wilson, 1990):

- rules to focus the user on the power station area of interest
- rules which calculate the corrosion chemistry of geothermal condensate in equilibrium with steam
- formatted reports for summarising the calculations
- rules to access graphic presentations of Pourbaix diagrams for calculated steam chemistries
- rules which access advice files to provide guidance on the selection and use of materials for the identified conditions
- formatted reports of advice given for the identified conditions.

The expert system uses a question and answer method of obtaining information from the user. The questions being asked are dependent on the answers to previous questions with the sequence being defined by a logic tree which includes all areas of interest in a geothermal energy development. The question and answer system is used to focus the consultation to the specific area of interest for which the user is seeking advice.

Additional features built into the user interface include:

- customising options for addition of:
  - NOTES when a question is being asked
  - GRAPHICS when a question is being asked
  - NOTES on advice at the end of a consultation
- a glossary of corrosion related terms
- a listing of references used for provision of advice
- options to view the system rules and the system logic
- explanation of system questions
- a comprehensive on-line help facility.

Advice information is kept in separate files outside the expert system shell and the required files are displayed by the user interface when required by the expert system.

™ SNAP, Template Software, USA

™ Paintbrush, ZSoft Corporation. USA

™ Paradox, Borland International Inc, USA

3.2 Potential-pH Puurbaix Prugramme

A programme developed by Chen et al (1983) for calculating potential-pH Pourbaix diagrams has bcen adapted for use in this system. The programme uses a data input file which contains the calculation temperature, total sulphur concentration, a listing of the solid and dissolved spccics to be cansidered together with their thermodynamic data. The input data files are unique for each combination of conditions which is to he considered. Thermodynamic data for species normally encountered in geothermal applications have k e n researched, tabulated and reviewed. (Johnson, 1993) The programme generates two output files; one containing a listing of all the reactions considered with those having the lowest free energy highlighted, the second provides a set of coordinates for drawing the Pourbaix diagram.

A developed programme, PBpaint reads the Pourbaix programme output files and gencrater a bitmap graphic of the Pourbaix diagram on the computer screen. This bitmap is captured using the Windows™ programme, Paintbrush™ and can be further processed to providc a report quality diagram.

3.3 Relational Database Fur Corrosion Data

Corrosion testing results are available in New Zealand for geothermal fluids derived from Wairakei, Ohaaki/Broadlands, Rotorua, Kawcrau and for a simulated high gas environment typical of the Ngawha geothermal field. Corrosion chemistries have k e n calculated for these and other fields. Much of this data has k e n incorporated into engineering and theoretical models which allow interpretation of the results and extrapolation to new applications.

The basic building blocks for these model, is the raw data. It is essential that this data be evaluated and archived in a formal manner which permits other scientists to review the data and allows new data to be added without revision of the bare system.

A database systcm has been developed using Paradox™ 4.5 far Windows™. The original DOS-based user interface (Mcllhone and Lichti, 1991) was been abandoned in favour of the Windows basCd system with a small set of searching and reponing options. The base system has been loaded with surface corrosion results for ASTM type coupons exposed at Broadlands BR22. Facilities for capturing historical corrosion results from an-hne corrosion monitors have not been added to date.

3.4 Archived Publications and Reports

Published literature describing New Zealand research and experience on materials selection has been collated and catalogued as a "Corrosion File". (Marshall and Lichti, 1991) A listing of authors and titles is available for simple word searching. Copies of the papers are bound to provide ready access for system users.

Reports generated in the course of providing advice an materials selection and use for geothermal energy applications provide a valuable history of problems and solutions. The "corporate" information contained in company records of this type is seldom collated, summarised and published because of its confidential nature. In this instance a separate collection of these confidential reports has been made, however, access has of necessity k e n restricted.

3.5 Knowledge and Computers

Selection of a computer based technology for capture and transfer of knowledge will depcnd on (Lichti et al, 1993):

- the nature of the technology
- the available expertise
- the needs of the users
- the time and budget available for development
- the versatility and complexity of the software
- the cost of the software
- the hardware requirements for development and delivery.

No single method provided the scope of knowledge capture required for the GeoMats™ system and a combination of products has evolved to meet the needs of the application.

The pmesses used for the capture of knowledge in computer based systems differ for differing applications. Procedures for developing databases (Mcllhone and Lichti, 1991) and knowledge capture models for the development of expert systems are available. (Lichti and Cradwick, 1991)(Lichti et al, 1992) The use of Windows™ based systems aids users through pmvision of graphical user interfaces which simplify access to the programmes.

The systems described here were developed using a team approach. Team contributions are required from domain experts, (Lichti and Page, 1994) system developers/knowledge engineers, (Lichti, 1994) and programmers (Cmdwick and Lichti, 1994). In this instance the principal developers are also the system users but systems developed for use by non-experts would require user input throughout the development.

4. PROCEDURES FOR PROVIDING ADVICE

A philosophy for provision of advice on materials in geothermal energy systems has been documented and used in practice for a number of applications. (Wilson and Lichti, 1982) The procedures followed to assess new environments and to evaluate the validity of current knowledge for new applications have been partially automated using the computer based systems described above. Appendix 1 describes these in greater detail with reference to the programmes being used, The procedure is based on a knowledge of common materials selection and usage practices such as one would find in a materials standard as well as an extensive database of results and models of corrosion developed to describe the mechanisms of corrosion. (Lichti and Wilson, 1993) The computer programmes have becn developed to assist experienced corrosion engineers to provide the required the advice. (Attempts to promote the development of a materials standard for geothermal energy applications have not been successful. (Wilson et al, 1987))

Firstly, a theoretical assessment of the likely corrosion chemistry in the proposed energy utilisation system is advocated, with corrosion testing being undertaken only where the new environment is significantly different from those for which corrosion data is available. Secondly a critical review of the existing knowledge base is required to define the materials advice which can be recommended as well as any additional caveats which apply to the new field.

4.1 Assess corrosiveness

Initial assessment of corrosiveness of a geothermal field can be based on the reported geochemistry and on the corrosion chemisny calculated or derived from the geochemistry. Comparison of corrosion chemistries of new fields with those of existing fields for which corrosion data is available, can permit an estimate of the corrosiveness of the new system. ***The chemistry calculations and comparison of corrosiveness are done*** using ***rhe GeoMats™ expert sysrem.*** In many instances the corrosion data available for previously tested geothermal environments can be applied to the new environments, with suitable caveats, and additional corrosion testing is not required. ***The experr system provides a series of known caveats.*** where significant differences exist there may be justification in conducting tests which aid in determining the caveats which must be applied to the existing knowledge base.

The GeoMats™ experr system is based on the following:

- calculated steam chemisnies
  - condensate pH
  - total H_2S+HS^- in solution
- separated water chemistry
  - high temperature pH
  - Cl^- and SiO_2
- predicted corrosion product stability on carbon steels
  - corrosion product type
  - properties of corrosion products
- description of planned engineering plant
  - anticipated utilisation environments.

When differences exist which are beyond the scope of the current knowledge, corrosion testing or examination of existing plant is required before advice can be provided.

4.2 Consider knowledge base

The knowledge base for geothermal materials selection and use is extensive. Published and unpublished results can be searched for relevant data, ***The corrosion results from Broadlands well BR22 are accessible from the GeoMats™ user inrerface window as a searchable listing of geothermal publications and reports.*** Existing models describing corrosion mechanisms can be reviewed to establish their relevance. ***Theoretical potential-pH Pourbaix diagram are included in rhe expert system bur where rhe conditions have not been previously defined the user can action rhe software for calculating and drawing another diagram from the GeoMats™ user inrerface window.*** Practical experience gained in solving similar in-plant metallurgical and corrosion problems provide "rules of thumb" which can be applied to the new problem. ***Rules of rhumb and derived advice for many situations are captured in the expert system.*** Whenever possible existing corrosion models and mechanism are used to describe the new environment. ***The experr system provides hisrorical listings of planr and marerials as well as caveats on rhe use of rhe materials or on the control of rhe environment.*** The work of providing some means of quality assurance for the advice provided by the expert system and making an initial lifetime prediction must he made by the system user by for example consulting all referenced documents contained in the "Corrosion File" archives. (Lichti et al, 1993) In theory, all of the information used by the system will be accessible for the user to independently review if any aspects are in doubt.

Recommendations must of necessity be based on the best available information at the time of the consultation. In those instances where this is of a questionable quality then it may be necessary to monitor the progress of corrosion in full size plant or to conduct additional field or laboratory research to further define the corrosion mechanisms.

5. CONCLUSIONS

A series of computer based aids for selection and use of materials for geothermal energy systems, **GeoMats™** have been brought together in a single Windows based user interface:

- **GeoMats™** expert system for chemistry calculations, corrosiveness assessment and historical materials advice
- potential-pH Pourbaix diagram programme for modelling corrosion processes and programmes to draw the diagram
- Paradox™ database of evaluated surface corrosion results
- searchable listings of corrosion publications and reports relating to selection and use of materials for geothermal energy applications.

The custom user interface provides ready access to the required programmes and gives guidance on their use. Experienced corrosion engineers can use the system without the need to be intimately familiar with the large database of materials results and knowledge available for geothermal energy applications.

6. ACKNOWLEDGEMENT

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7. REFERENCES

Anderson, D.B. (1989). Computerisation of corrosion data. ASTM Symposium on Corrosion Testing and Evaluation.

Borshevska, M., Lichti, K.A. and Wilson, P.T. (1982). The relationship between corrosion products and corrosion rates in geothermal steam. in Proc of Pacific Geothermal Conference incorporating 4th New Zealand Geothermal Workshop, Geothermal Institute, U of Auckland, pp 191-197.

Chen, C.M., Aral, K. and Theus, G.J. (1983). *Computer-calculated potential-pH diagram to 300°C*. Electric Power Research Institute Repon Prepared by Babcock and Wilcox Co, EPRI-NP-3137, June.

Cradwick, P.D. and Lichti, K.A. (1994). The role of the programmer in expen systems development. Corrosion/94 Paper No 379 in Computers in Corrosion Control - Knowledge Based Systems, eds P.R. Roberge, P. Mayer and W.F. Bogaerts, NACE International.

Inman, M.E., Sharp, R.M., Wright, G.A. and Wilson, P.T. (1992). Development of an erosion-corrosion test facility for geothermal steam condensate. in Proc 14th New Zealand Geothermal Workshop. Geothermal Institute, U of Auckland, pp 165-170.

Inman, M.E., Sharp, R.M., Wright, G.A. and Wilson, P.T. (1993). Predicting protective film behaviour on low carbon steels. in Proc 15th New Zealand Geothermal Workshop. Geothermal Institute, U of Auckland. pp 75-80.

Johnson, C.A. (1993). *User guide to programme 'Pourbaix' for calculating and plotting Pourbaix diagrams*. Industrial Research Ltd Internal Repon 18013.31.

Lichti, K.A., Soylemezoglu, S. and Cunliffe, K.D. (1981). Geothermal corrosion and corrosion products. in Proc New Zealand Geothermal Workshop, Geothermal Institute. U of Auckland, pp 103-108.

Lichti, K.A. and Wilson, P.T. (1983). Materials testing in geothermal steam. in Proc of Int Symp on Solving Corrosion and Scaling Problems in Geothermal Systems, San Francisco, USA, NACE International, pp 269-284.

Lichti, K.A. and Wilson, P.T. (1990). Geothermal materials advisory system. Proc 12th New Zealand Geothermal Workshoo. Geothermal Institute, U of Auckland, pp 17-22.

Lichti, K.A. and Cradwick. P.D. (1991). Expen systems for materials technology transfer. Proc of 7th Asian-Pacific Corrosion Control Conference, International Academic Pub, Beijing China, pp 1370-1379.

Lichti, K.A.. McIlhone, P.G.H., Cradwick, P.D. and Page. G.G. (1992). Expert system for materials performance advice. Corrosion/92 Paper No 276 in Computers in Corrosion Control. Volume 3, NACE International.

Lichti, K.A., Cmdwick, P.D. and Aldous, K.J. (1993). Guidelines for the selection of applications for expen systems. 5th New Zealand Materials Symposium. Engineering Materials Group, IPENZ. Lower Hutt, New Zealand, paper no 41.

Lichti. K.A., Firth, D.M. and Wilson, P.T. (1993). Lifetime predictions for critical plant in geothermal energy systems. in Proc of 15th New Zealand Geothermal Workshop, U of Auckland, pp 81-86.

Lichti, K.A. and Page, G.G. (1994). The role of the expen in devrlopment of materials performance expen systems. Corrosion/94 Paper No 369 in Computers in Corrosion Control - Knowledge Based Systems, eds P.R. Roberge. P. Mayer and W.F. Bogaens. NACE International.

Lichti, K.A. (1994). The role of the system developer/knowledge engineer in the development of materials performance expen systems. Corrosion/94 Paper No 383 in Computers in Corrosion Control - Knowledge Based Systems, edn P.R. Roberge. P. Mayer and W.F. Bogaens, NACE International.

Lichti, K.A., Johnson. C.A., Mcllhone, P.G.H. and Wilson, P.T. (1995). Corrosion of iron-nickel base and titanium alloys in aerated geothermal fluids. submined to World Geothermal Congress, Florence, Italy, May.

Marshall, A.N. and Lichti, K.A. (1991). *Geothermal Corrosion File, Revision 4.* Confidential DSIR Industrial Development P3896, Repon No R13370, June.

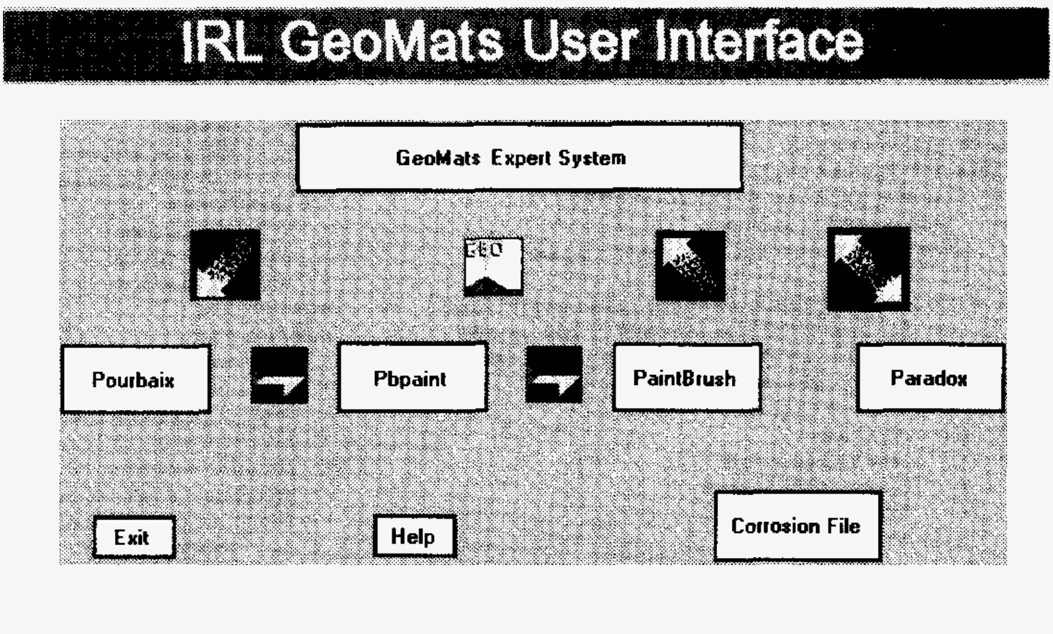
McIlhone, P.G.H. and Lichti, K.A. (1991). Database for materials performance in geothermal fluids. 13th New Zealand Geothermal Workshop, Geothermal Institute, U of Auckland, pp 233-238.

Wilson, P.T. and Lichti. K.A. (1982). Assessment of corrosion Performance of construction materials. in Proc of Pacific Geothermal Conference incorporating 4th New Zealand Geothermal Workshop, Geothermal Institute, U of Auckland, pp 185-190.

Wilson, P.T., Lichti, K.A. and Wells, D.B. (1987). Materials selection for geothermal developments, the need for a materials standard. in Proc 9th New Zealand Geothermal Workshop, Geothermal Institute, U of Auckland, pp 229-234.

Appendix I: GeoMat™ System Consultation Procedure

Screen Appearance



System Consultation

1. Known Chemistry

Experienced users of rhe GeoMats™ system will know rhar besr resulrs are obtained if the georhermal steam phase gas chemistry is known. If the gas phase chemistry is not known, the expert system will accept qualitative estimates of corrosion characteristics.

- Steam Phase Gas Chemistry(mmol/100 mol steam(water free))
  - CO_2, H_2S, NH_3, H_2, H_3BO_3, HCI, Residual gases ie CH_4, and N_2, O_2 to judge the risk of the sample having been exposed to air
- Temperature (°C)
- Pressure (kPa(a))

2. Expert system operation

Clicking rhe expert system burton starts the expert system user inrerface programme. Loading of the knowledge base requires security access. Expert system asks questions of the User.

- User enters area and plant of interest
- User enters physical conditions
- User enters gas phase chemistry

Expert system uses a chemistry model to determine chemical composition of steam condensate in equilibrium wirh the steam phase. Interim output of steam condensate chemisrry and all parameters used to determine the chemistry Required paramerers are automatically displayed on the screen.

- Summary Output Of All Parameters On Request
- Required Parameters: Total S, T, pH

The above required parameters are used to assess rhe tendency of rhe high temperature condensate to firm stable corrosion products on carbon steel through an examination of a poienrial-pH diagram. Sir diagrams which describr New Zealand geothermal systems are available within rhe experr sysrem.

If the chemistry is similar to one of rhese, the appropriate diagram is presented to the user on the screen. If the conditions are outside the range of those built into rhe system then the user must note the chemistry values and exit rhe experr system to run the Pourbaix programme to generare the required diagram.

- Potentid-pH diagram built into expert system or
- Potential-pH diagram generated for the conditions (see Step 3 below)

Diagrams built into the expert system are provided wirh a set of mouse operated cross hairs to assist the user in determining the theoretical corrosion potential for the calculated pH and to read. from rhe diagram, the pH of the interface between solid corrosion products and the free corrosion (Fe^{2+}) region at the theoretical corrosion potential (see Figure 2 in text). The expert system requires this detail to approximate the stability of corrosion products and the tendency for erosion-corrosion.

- Input from Pourbaix diagram
  - Corrosion potential at the calculated pH
  - Corrosion product stability
  - pH of free corrosion area at corrosion potential

The risk of corrosion is defined by the experr system and relevanr advice files are displayed to rhe user. The user is able to enter custom advice which will be displayed after rhe system advice whenever the same set of rules are consulted.

- Output Options and Displays
  - **Summary** Option
    - User entered Values
    - System inferred values
    - Internal calculations
    - Model outputs
    - Definition of corrosiveness
- Advice Displays
  - Risk of corrosion
  - Materials options
  - Historical Plant/Materials listing
  - An indication of the need for more expertise

3. Potential-pH Pourbaix Diagram Programme

The input data file must be selected and evaluated for rhe desired analysis conditions. The solid and dissolved species io be considered must be specified and the input file completed.

- Input Data File
  - Total S, T, pH
  - Thermodynamic Data (he-Evaluated)

While the Pourbaix programme is running the generared output file is displayed on rhe screen.

- Output Data Files
  - List of equations and co-ordinates for lines on the diagram
  - A separate listing of co-ordinates for lines on the diagram

5. PBpaint

This programme takes the output files from the Pourbaix programme, generates a birmnr graphic of the diagram and sends the bitmap to Windows"' Clipboard so that it can be picked up by Paintbrush™.

- Input from Pourbaix output files
- Output diagram in bitmap capture window on screen
- Transfer diagram to Clipboard

6. Paintbrush™

The user is offered the opportunity to use Paintbrush™ to add comments and to change the location and font of the species labels.

- Retrieve diagram from Cliphoard
- Add *comments* and *revise* text labels
- Print the diagram (see Figurc 2 in text)

The generated bitmap can be added to the expert system using rhe expert system customising options.

7. Paradox™ Database

The Paradox™ database can be accessed at any time throughout the consultation.

Surface corrosion of metals and alloys tested at Broadlands BR22

- materials tested
  - standard alloy composition
  - exposed allay analysis
- test type descriptions
  - surface corrosion
    - coupons
    - electrical resistance probes
    - Linear Polarisation Resistance
- test environments
  - vessel designations
  - physical conditions
  - chemical conditions
- exposure times
- corrosion results
  - description of corroded samples
  - corrosion product analysis
  - material gain due to scale or corrosion product formation
  - material loss due to corrosion
  - corrosion rates based on linear extrapolations
  - description of form of corrosion
  - pitting and crevice corrosion depth of attack
    - maximum depth
    - mean of 5 deepest pits