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This Week's Citation Classic

McNabb A & Foster P K. A new analysis of the diffusion of hydrogen in iron and ferritic steels. *Trans. Met. Soc. AIME* **227**:618-27, 1963. [Applied Mathematics Lab. and Dominion Lab., Dept. Scientific and Industrial Research, Wellington, New Zealand]

The diffusion of hydrogen in steel is described in terms of two phases in the metal, a mobile diffusing phase interacting with a trapped component. Approximate and exact solutions of the nonlinear equations describing the system are derived for simple geometric shapes. [The *SCI*® indicates that this paper has been cited in over 115 publications since 1963.]

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"At the time this paper was being prepared, Peter Foster was working at Dominion Laboratory, the chemistry division of the Department of Scientific and Industrial Research (DSIR), and Alex McNabb was at the Applied Mathematics Laboratory of the same department. A major scientific effort, coordinated by Ian Dick, was under way to understand our geothermal fields and discover how they might be used to generate electrical power. Peter was working on the potential hazards of passing geothermal steam contaminated with hydrogen sulphide through steel turbine blades. It was surmised that the hydrogen liberated by anaerobic corrosion of the metal might embrittle the blades.

"Alex had been working on various heat and mass transfer problems, and since all the chemists, physicists, geologists, and hangers-on were called together every two or three months at a coordination meeting to give an account of problems and report progress, it was almost inevitable that we would collaborate on this problem. I must say that this was a very stimulating environment for an applied mathematician.

"Peter had some experimental results, and a lot of material from a literature search (perhaps an unusual starting point), and had come to the conclusion that theory and experiment didn't match up. There was a general inconsistency of about four orders of magnitude! Surely there were some missing variables to take into account.

"Over a period of many months we tried theories involving trapped atoms, trapped molecule hydrogen, surface interactions, and so forth, but found great difficulty in experimentally validating any of these possibilities. There seemed to be no technique available to discriminate between the different populations of hydrogen atoms we were postulating.

"There was no problem in fitting the data; we just needed to be able to measure one more variable to clinch the validation problem.

"Eventually we decided in frustration to publish the more appropriate theory and write a second paper on the validation aspect when we had it sorted out. Two years later we did publish some experimental results[1] interpreted in terms of the theory of this paper, but had really made little further progress. It was a very difficult problem.

"Why is the paper so frequently cited? I'm reminded of a comment by Richard Bellman on authorship —'Don't be afraid to leave something for somebody else to do; the readers like that.' The fact that the paper is still frequently cited suggests we offered a viable alternative theory. The problem is an industrially and commercially significant one and the validation problem is still unsolved.[2]

"In the geothermal power context, Peter was able to show that certain suitable steels formed a coherent protective oxide-sulphide coating which protected them from further corrosion. Under these conditions, susceptibility to hydrogen embrittlement was transitory and a cautious initiation regime was recommended for the turbines. They survived and at one stage were producing a quarter of the power consumed in the North Island."

1. **Foster P K, McNabb A & Payne G M.** On the rate of loss of hydrogen from cylinders of iron and steel. *Trans. Met. Soc. AIME* **233**:1022-31, 1965.
2. **Hirth J P.** 1980 Institute of Metals Lecture of the Metallurgical Society of AIME: effects of hydrogen on the properties of iron and steel. *Met. Trans. A—Phys. Met. Mater. Sc.* **11**:861-90, 1980.