A Simple Analytical Model For Heat Flow In Fractures – Application To Steam Enhanced Remediation Conducted In Fractured Rock

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Remediation of fractured rock sites contaminated by non-aqueous phase liquids has long been recognized as the most difficult undertaking of any site clean-up. Recent pilot studies conducted at the Edwards Air Force Base in California and the former Loring Air Force Base in Maine have provided valuable field data that can support the evaluation of Steam Enhanced Remediation (SER) for this setting. To aid in the interpretation of field temperature measurements collected during and after steam injection, a semi-analytical model was developed which can simulate radial convection and conduction of heat in a discrete fracture. The governing equations are formulated under the assumptions that the steam condensate boundary is stationary, that the rock is sparsely fractured, and that the aperture of the fractures are known. The boundary value problem was solved using the Laplace transform method and numerically inverted using the DeHoog algorithm. Generic simulations conducted using a range of steam injection pressures, fracture apertures, and thermal conductivities of the matrix show that the aperture size and the properties of the matrix act as the principal features governing the transport of heat in this setting. Comparison of the generic simulations to the temperature migration observed during the SER pilot study conducted at Loring shows general agreement. In this case, it was determined that the principal limiting factor in the propagation of heat was fracture aperture size. Smaller fracture apertures common to the Loring limestone bedrock led to limitations in the ability to inject steam. Consequently the steam condensed near the borehole and much of the heat was lost to the matrix. Based on these results, alternate scenarios are proposed for future pilot studies of SER in bedrock.