Finite Element Software for Estimation of Unknown Boundary Heat Flux – InverseSOLVER

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1. Introduction:

In solving dynamic heat transfer problems, many impediments may arise in specifying accurate boundary conditions. The surface conditions may not be known a-priory. The physical situation at the surface may be unsuitable for attaching a sensor or the accuracy of a surface measurement may be seriously impaired by the presence of the sensor. In such cases, the boundary condition(s) in the form of specified heat flux / heat transfer coefficient / surface temperature may be determined from transient temperature measurement at one or more interior locations. This type of problem is known as Inverse Heat Conduction Problem (IHCP).

IHCP is one of many mathematically 'ill posed' problems. It is much more difficult to solve the IHCP than the direct problem. However, its solution depends on the temperature history at an interior location which is easy to measure accurately. On the other hand, solution to the direct heat conduction problem, although easier, depends on the measurement/specification of accurate boundary conditions, which is far more difficult to achieve. Thus there is a choice between relatively inaccurate measurements or a difficult analytical problem. An accurate and tractable inverse problem solution thus minimizes both disadvantages simultaneously.

2. About InverseSOLVER:

InverseSOLVER is a finite element based software which can be used to estimate the boundary heat flux, surface heat transfer coefficient and the boundary temperature in a solid from the knowledge of a measured thermal history at one or more interior locations. The software is based on a serial algorithm for the Inverse Heat Conduction Problem (IHCP) and is developed to estimate the time and space varying heat flux components at the unknown boundary. InverseSOLVER is a module of a suite of software, TmmFE (Thermo-mechanical-metallurgical Finite Elements), which run on a common finite element platform. InverseSOLVER can be seamlessly integrated to solve related engineering problems like thermal stress analysis, alloy solidification, heat treatment etc.

3. Applications of InverseSOLVER:

InverseSOLVER has been applied successfully for estimating the spatial and temporal distribution of boundary heat flux components (i) on the heat shields of re-entry of space vehicles (ii) along the metal-mold interface during net shape casting of steel (iii) at the metal-mold interface during mold filling in aluminum die casting (iv) during die casting of cast iron in cast iron moulds (v) due to the welding arc during TIG welding (vi) during quenching of alloy steel specimens (vii) at the metal-mold interface corners of solidifying aluminum bars and slabs (viii) on the plasma facing components in the Tokomak etc. InverseSOLVER may be used for estimating heat transfer in free convection, forced convection, boiling and condensation heat transfer also. InverseSOLVER may also be used for the estimation of maximum temperatures in electronic cooling systems and the estimation of thermal conductivities of new materials of unknown composition.

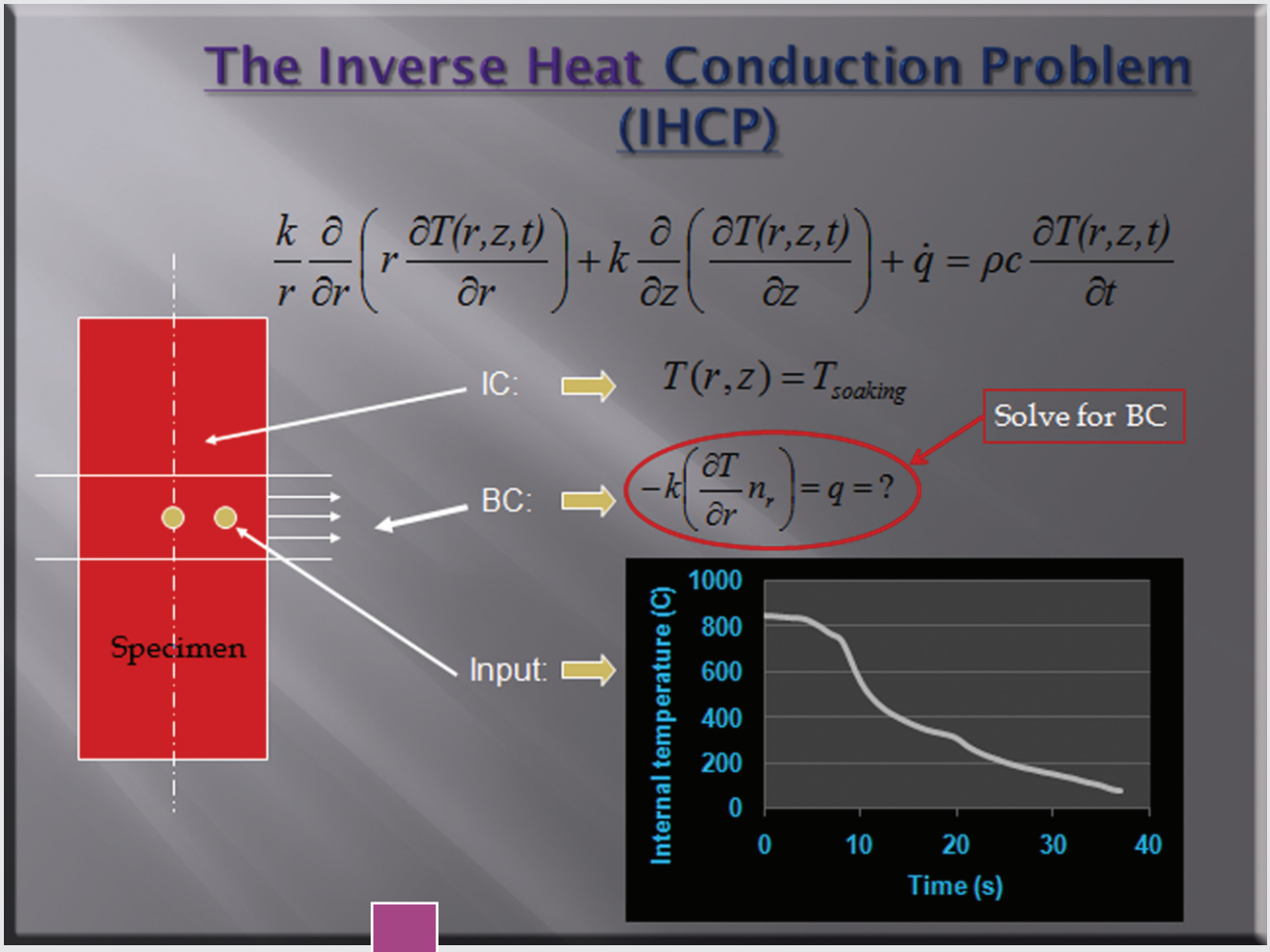
4. About the Company:

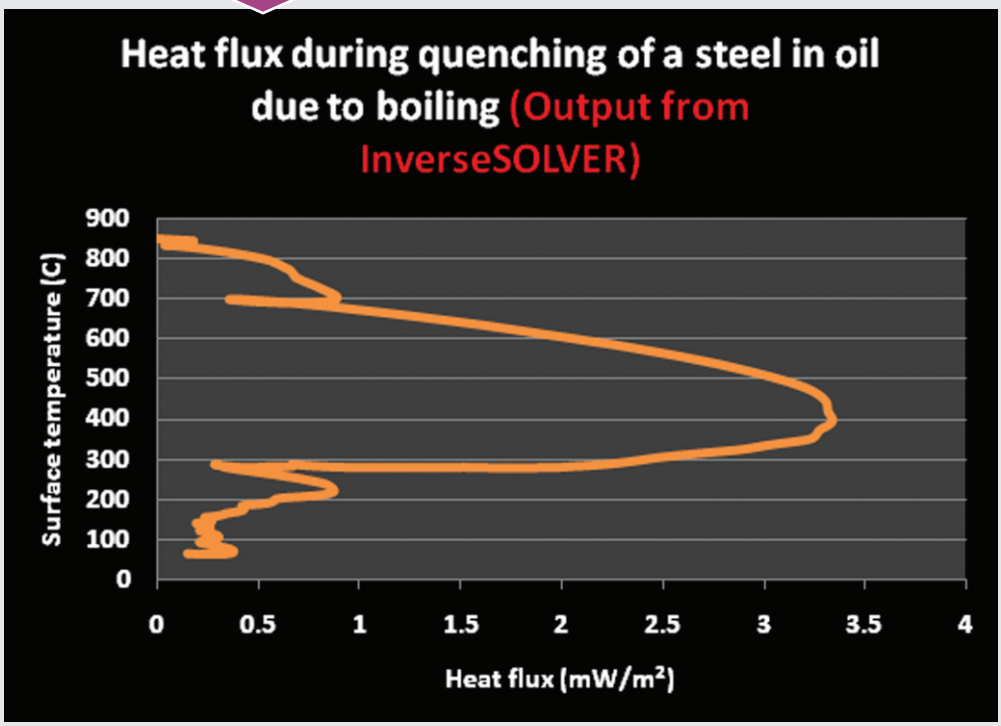
InverseSOLVER, which is a module of TmmFE (Thermo-mechanical-metallurgical Finite Elements), is a proprietary software of TherMet Solutions. It has been under development over the last 30 years. Realizing the potential for global application of the software, the Company was registered in Bangalore in the year 2010 for commercializing the software for promoting the use of this software. So far, the software has been used by researchers in (i) Universidad Nacional Autónoma de México, (ii) National Institute of Technology Karnataka, Surathkal (iii) Sri Venkateshwara College of Engineering, Chennai and (iv) Siddaganga Institute of Technology, Tumkur. The software has been used successfully in many industries for process monitoring during alloy steel quenching. Six research theses; four research projects (sponsored by the Indian Space and Fusion Energy Projects and others) ; eight International Refereed Journal papers; eighteen International and National Conference / Symposium / Workshop papers related to the applications of InverseSOLVER have been published so far.

5. Selected Publications on InverseSOLVER

- T.S.Prasanna Kumar "A serial solution for the 2-D inverse heat conduction problem for estimating multiple heat flux components"- **Numerical Heat Transfer Part B-Fundamentals,** Vol 45, n 6, June 2004, pp 541-563
- T.S.Prasanna Kumar and H.C.Kamath "Estimation of Multiple Heat Flux Components at the Metal/Mold Interface in Bar and Plate Aluminum Alloy Castings"- **Metallurgical and Materials Transactions B,** Vol 35 B, June 2004, pp 575-585
- Kun Xu & T.S.Prsanna Kumar, "Coupled Heat Transfer Optimization Calculation of ABAQUS and DOT for Beam Blank Mold", **Mathematical Models of Continuous Casting of Steel,** Annual Report 2206, Continuous Casting Consortium, Dept. of Mechanical and Industrial Eng., University of Illinois at Urbana-Champaign, Urbana, IL, USA, June 2006
- K.Babu and T.S.Prasanna Kumar, "Effect opf CNT Concentration and Agitation on Heat Transfer during Quenching in CNT Nano-Fluids", **Intl J of Heat and Mass Transfer,** v 545, 2011, pp 106-117

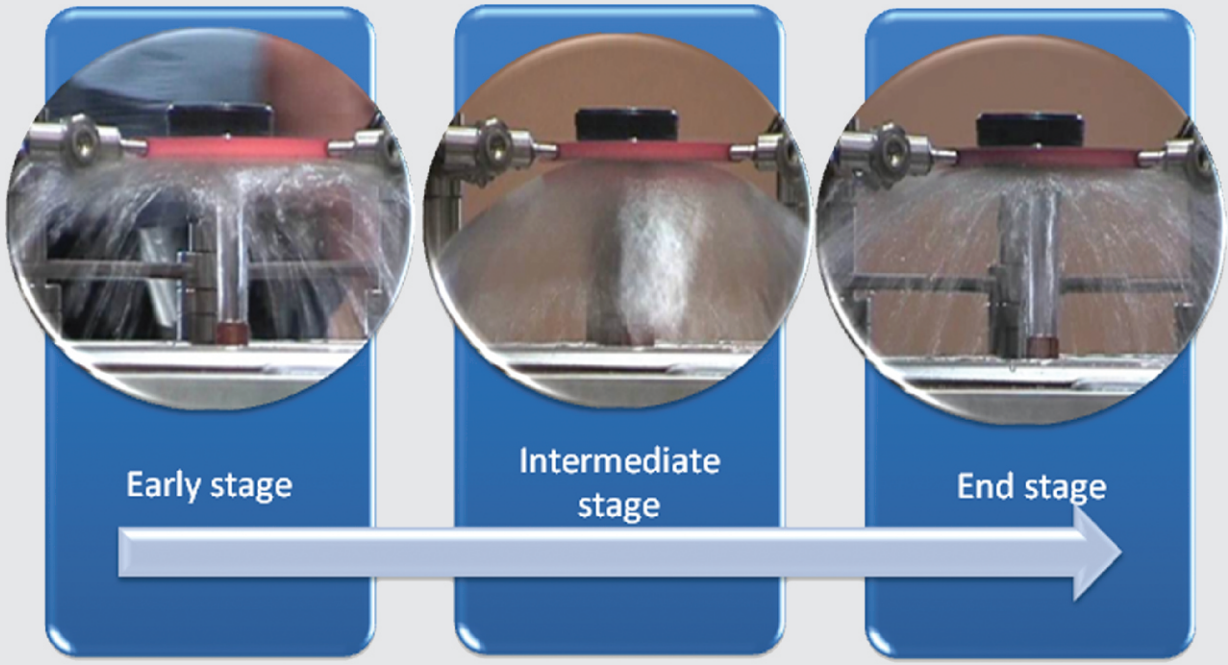
- K.Babu and T.S.Prasanna Kumar, "Mathematical Modeling of Surface Heat Flux during Quenching", **Metall. And Materials Trans. B,** 41, 214-224
- S. Arunkumar, K.V. Sreenivas Rao, T.S. Prasanna Kumar," Spatial variation of heat flux at the metal–mold interface due to mold filling effects in gravity die-casting", **Intl J of Heat and Mass Transfer** 51 (2008) 2676–2685
- T. S. Prasanna Kumar, Coupled Analysis of Surface Heat Flux, Microstructure Evolution, and Hardness during Immersion Quenching of a Medium Carbon Steel in Plant Conditions", **Materials Performance and Characterization,** Vol. 1, No. 1,Paper ID MPC104477, www.astm.org

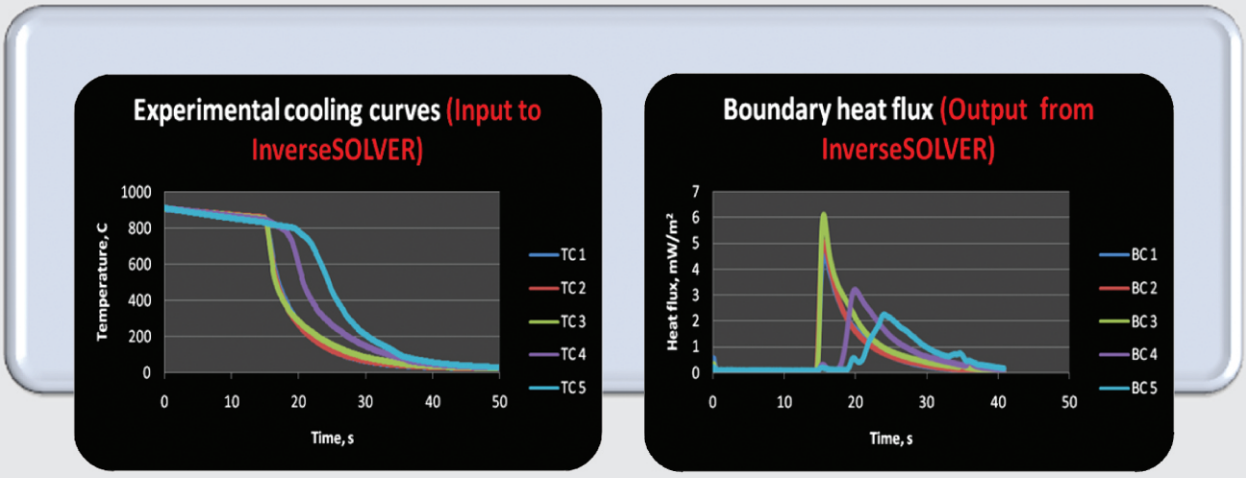




Videograph of water column impinging on a heated steel disc*

*B. Hernández-Morales, J.S. Téllez-Martínez, T.S. Prasanna Kumar, “Benchmarking of mathematical models for quenching operations: a proposal”, 5th **International Conference on Thermal Process Modeling and Computer Simulation June 16 – 18, 2014, USA**





Input to InverseSOLVER

- Experimental cooling curves

Output from InverseSOLVER

- Boundary heat flux distribution