CONF-9606116--39

Plugging Temperature Indicator Computer Simulation

DeeEarl Vaden

Introduction

The Experimental Breeder Reactor II (EBR-II) is a sodium-cooled nuclear reactor with thermal and electrical outputs of 62 and 20 megawatts, respectivity. EBR-II has plugging temperature indicators[1] (PTIs) in the sodium coolant system to measure the temperature that impurities will precipitate from the coolant. High plugging temperatures are undesirable because impurities can precipitate in cold reactor piping and inhibit sodium flow. Reading a plugging temperature accurately from a typical plugging run (see Fig. 1) is important. A computer simulation program performs simulated plugging runs to optimize PTI operation. The simulation program also assisted electrical engineers in designing and testing a new PTI control system in their computer development laboratory[2].

PTI Simulation Program

The PTI computer simulation uses Bernoulli's equation with fluid friction[3],

$$\frac{p_a}{\rho}+\frac{gZ_a}{g_c}+\frac{u_a^2}{2g_c}=\frac{p_b}{\rho}+\frac{gZ_b}{g_c}+\frac{u_b^2}{2g_c}+h_f\,, \qquad 1$$

where,

p_a and p_b	=	pressure at inlet and outlet points, respectively,
ρ	=	fluid density,
Z_a and Z_b	=	elevation at inlet and outlet, respectively,
g	=	acceleration due to gravity,
g_c	=	Newton's-law proportionality factor,
u_a and u_b	=	fluid velocity at inlet and outlet, respectively,
h_f	=	energy loss due to friction,

MASTER

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

to determine the filter flow rate and bypass flow rate through the PTI. Because the total volumetric flow 'Q_T' separates into a filter flow stream 'Q_F' and a bypass flow stream 'Q_B' at the plugging element and the two streams combine downstream of the flowmeters, the filter and bypass streams have the same pressure drop. Applying Bernoulli's balance to both streams with point 'a' being where the streams separate and point 'b' where they combine produces produces two equations,

$$\left[4f\frac{L}{D}+\sum_i K_i\right]_F \frac{V_F^2}{2g_c}+\Delta P_E=\left[4f\frac{L}{D}+\sum_i K_i\right]_B \frac{V_B^2}{2g_c}, \qquad 2$$

$$Q_T = V_F A_F + V_B A_B , \qquad 3$$

where,

f	=	Fanning friction factor,
L	=	pipe length,
D	=	inside pipe diameter or hydraulic diameter,
K_i	=	form friction factor for situation 'i',
V_F and V_B	=	velocity in filter and bypass streams, respectively,
g_c	=	Newton's-law proportionality factor,
ΔP_E	=	pressure drop across filter element,
A_F and A_B	=	cross sectional area of filter and bypass streams, respectively,

having two unknowns V_F and V_B. The terms in brackets are losses due to skin friction and form friction. The ΔP_E term in equation 2 is the pressure drop across the filter element in the PTI. Impurities collecting on the filter change the pressure drop via filter cake resistance principles[4],

$$\Delta P_E = \frac{\mu u}{g_c}\left(\frac{m_c \alpha}{A}+R_m\right), \qquad 4$$

where,

μ	=	fluid viscosity,
u	=	linear fluid velocity through filter,
m_c	=	total mass of solids in the cake,
α	=	specific cake resistance,
A	=	filter surface area,
R_m	=	filter-medium resistance.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Calculating the temperature change with time utilizes an equation of thermal energy[5],

$$\rho \hat{C}_p \left[\frac{\partial T}{\partial t} + \mathbf{v} \bullet \nabla T \right] = k \nabla^2 T + H, \qquad 5$$

where,

C_p	=	constant pressure fluid heat capacity,
T	=	linear fluid velocity through filter,
t	=	time,
v	=	velocity vector,
k	=	thermal conductivity,
H	=	external heat source,

that assumes a Newtonian fluid at constant pressure, constant thermal conductivity, no viscous dissipation, and an external heat source. Using cylindrical coordinates and ignoring temperature gradients in the radial and angular directions, the energy equation simplifies to,

$$\rho \hat{C}_p \left[\frac{\partial T}{\partial t} + u_z \frac{\partial T}{\partial z} \right] = k \frac{\partial^2 T}{\partial z^2} + H. \qquad 6$$

In a numerical solution of equation 6, the parameters 'ρ', 'C_p', 'k', and 'H' are considered constant for small time increments. The external heat source is from heater input and losses from both natural and forced convection.

Results

After programming the equations needed to determine the temperature change with time, along with proportional-integral-derivative control techniques, and knowledge of the impurities in the sodium, simulated plugging runs look similar to real plugging runs (see Fig. 2). As a diagnostic tool, the simulation program can perform simulated plugging runs in minutes instead of hours and was useful in helping electrical engineers bench-check new control software without having to operate a real PTI.

Figure 1. Typical Plugging Run

REFERENCES

1 W.H. Olson and R.A. Washburn, "EBR-II Experience with Frit-Type Plugging Temperature Indicators," *Proc. 2nd Int. Conf. Liquid Metal Technology in Energy Production,* Richland, Washington, April 20-24, 1980, Vol. 2, p. 16-63 (1980).

2 R.B. Carlson and R.L. Gehrman, "EBR-II Secondary Sodium Loop Plugging Temperature Control System Upgrade", *9th Power Plant Dynamics Control and Testing Symposium,* Knoxville, Tennessee, May 24-26, 1995, Vol. 1, p. 18.01 (1995).

3 W.L. McCabe, J.C. Smith, "*Unit Operations of Chemical Engineering*", McGraw-Hill, 1976, p. 76.

4 W.L. McCabe, J.C. Smith, "*Unit Operations of Chemical Engineering*", McGraw-Hill, 1976, p. 937.

5 R.B. Bird, W.E. Stewart, E.N. Lightfoot, "*Transport Phenomena*", Wiley & Sons, 1960, p. 316.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

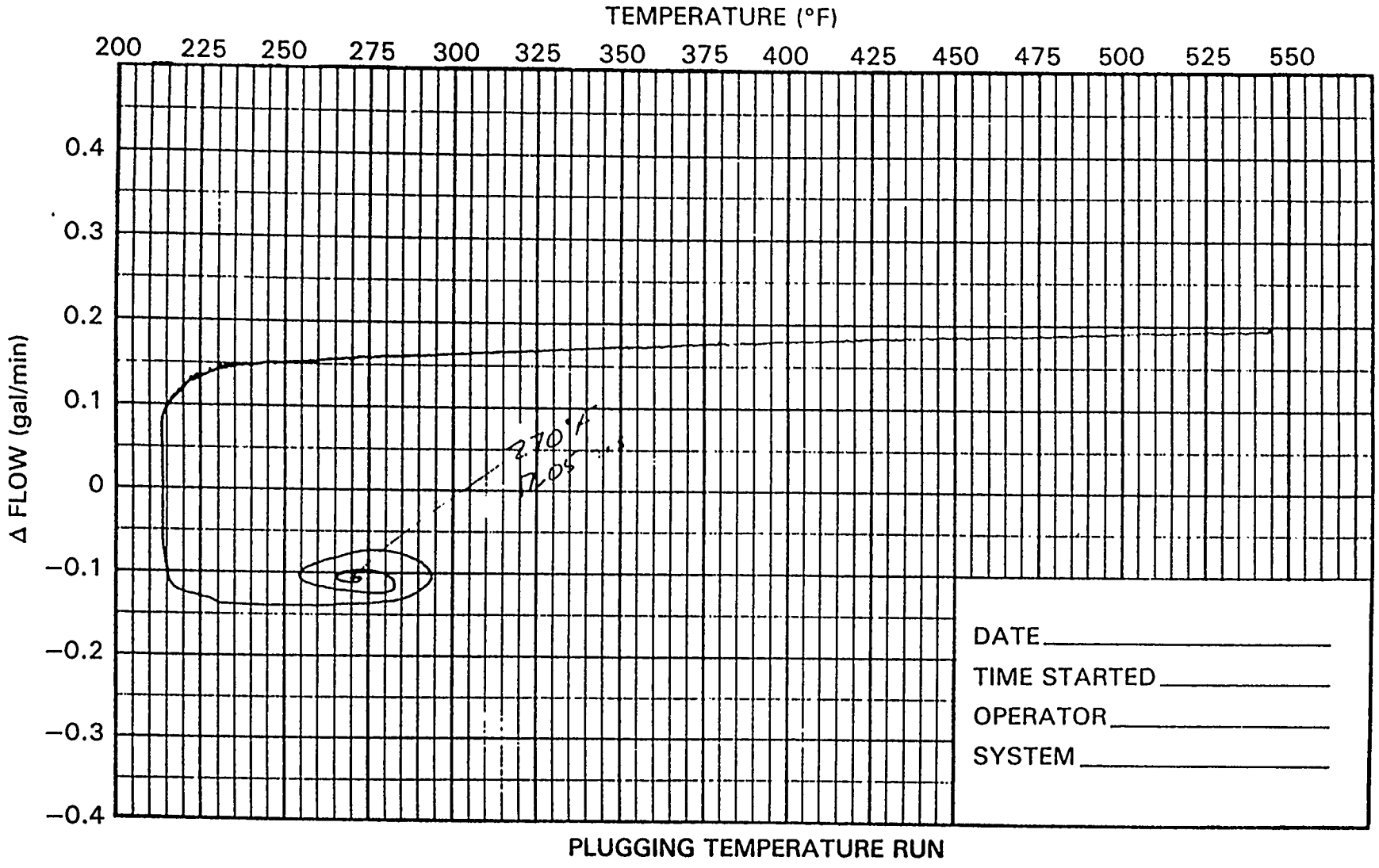

Figure 1. Typical Plugging Run

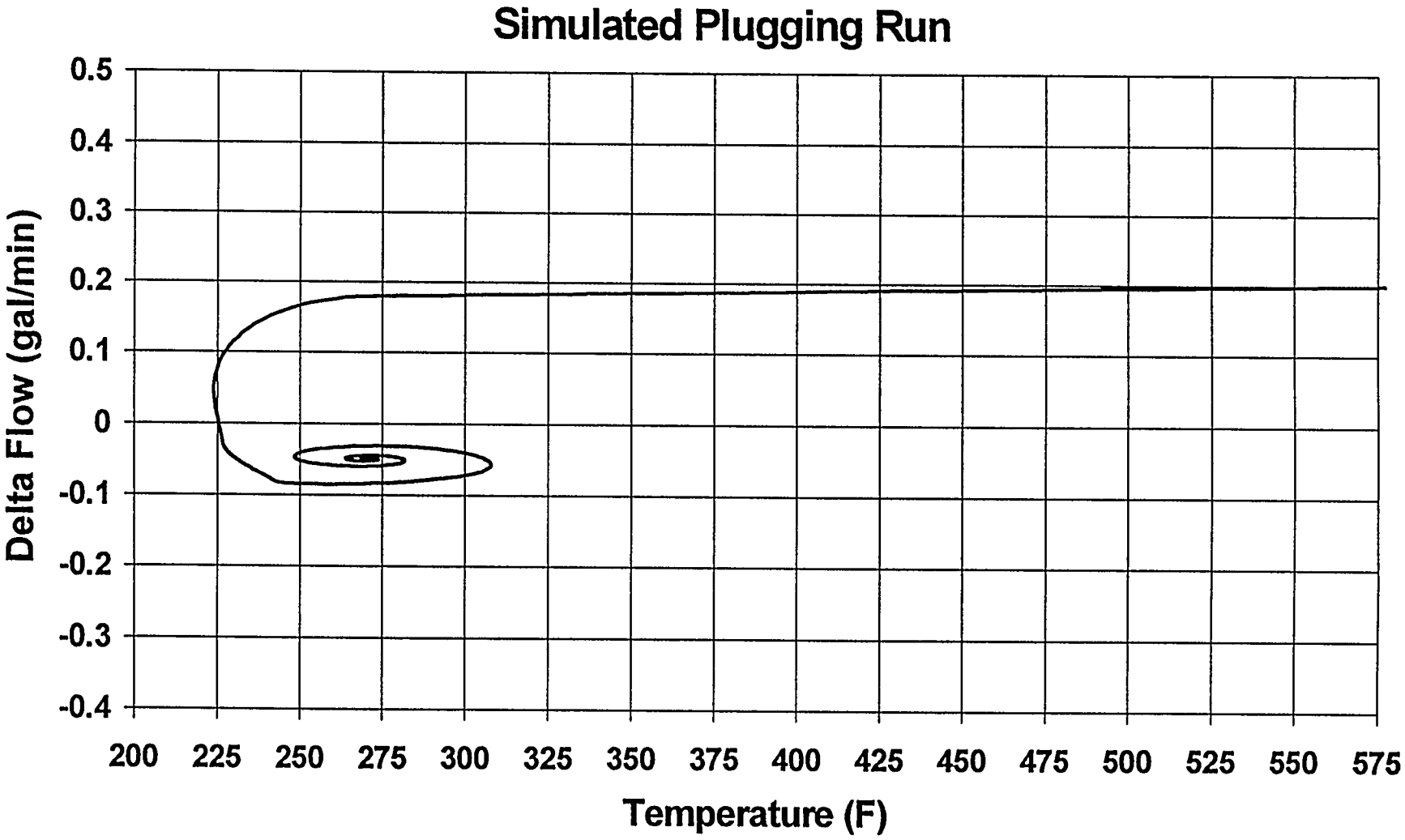

Figure 2. Simulated Plugging Run