Int. J. Heat Mass Transfer. Vol. 21, p. 79. Pergamon Press 1978. Printed in Great Britain

LETTERS TO THE EDITORS

COMMENT ON "PREDICTIONS OF VIGOROUS IGNITION DYNAMICS FOR A PACKED BED OF SOLID PROPELLANT GRAINS"

(*Received* 19 *August* 1976 *and in revised form* 8 *October* 1976)

THE NUMERICAL results of Krier and Gokhale [1] reveal serious deficiencies in the analysis of a two-phase flow. The Appendix of the article presents computed values that are inconsistent with a physical conception of the process being modeled.

Predicted gas temperatures are unrealistic in the first two inches of the bed. For the one time step shown in the printed appendix the gas temperature of 8000*R* is about 1.5 times the adiabatic flame temperature of M30 propellant of about 5400*R*. Using the authors' input data and allowing an ideal gas simplification, the temperature of the gas introduced by the combustion should be

$$\frac{E_w}{C_v} = \frac{EM_w(\gamma-1)}{R} = 5470R$$

where E is the chemical energy released in burning, M the gas molecular weight, R the universal gas constant, and γ the ratio of specific heats.

In the actual code operation only 90% of the chemical energy goes into the gas and the predicted temperature should be less than 5000*R*. Although not shown in the cited article, the predicted gas temperatures for this case exceeded 20000*R* later in the calculation. With no external compression of the chamber such temperatures are unrealistic.

At the front of the compression wave in the bed interior the predicted gas temperatures and heat transfer violate thermodynamic principles. The initial physical condition is a quiescent gas in thermal equilibrium with solid particles. Hot gas entering at the aft portion forms a compression front driving gas and particles forward. In the forward portion of the bed the gas should be heated by the combination of compression by particle compaction and mixing with the hot combustion gas. As the gas temperatures rise, heat is transferred by convection (only mode allowed) to the particles.

What the code predicts however is a cooling of the gas from 550*R* to about 250*R* while the solid phase is being simultaneously heated from 550 to 560*R*. Heat transfer from a cold gas to a hot particle is inadmissable. Although the printed output in the Appendix shows only one time step, the full results show the minimum temperature region propagating through the bed but never any particle cooling. Neither the low gas temperature nor the particle heating can be justified by quantitative arguments.

Particle temperatures at the aft end of the bed are shown below the ignition temperature. A self-sustaining combustion of the solid propellant requires a heat feedback from the flame which means that the solid phase temperature cannot decrease. The surface temperature of the burning solid must be greater than the ignition temperature and heat transfer from the solid to gas is not allowed.

Porosity in the bed center is computed as 0.250 when the initial porosity of the "packed" bed is 0.470. Such a compression cannot be computed with a model which assumes the bed is always fluidized with no particle interaction. As the bed becomes "more packed" the propagation of disturbances proceeds through the bed as though it were true solid. Propagation rates are probably inversely proportional to porosity. Resistance to particle motion increases as packing increases. The drag function must account for such increased friction. The authors have used 0.250 as an arbitrary lower limit to compaction. They have not recognized that the model is probably not valid below porosities of about 0.40. Instead of merely overriding the computation of porosity, the computation should have stopped altogether. Imposing a lower limit on porosity has the effect of creating arbitrary gradients that affect the coupled equations. It effectively converts solid to gas without combustion.

A minor error was made in computing *DP/DX* in that the printed value should be divided by the chamber length, in this case 8 in. The input value for energy of M30 propellant is incorrect, a value of 1132 kcal/kg is more appropriate. The authors have acknowledged these minor errors and will submit an appropriate correction.

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REFERENCE

1. H. Krier and S. S. Gokhale, Predictions of vigorous ignition dynamics for a packed bed of solid propellant grains, *Int. J. Heat Mass Transfer* **19**, 915–923 (1976).

Int. J. Heat Mass Transfer. Vol. 21, pp. 79–80. Pergamon Press 1978. Printed in Great Britain

REPLY TO COMMENT BY C. W. NELSON

(*Received* 14 *June* 1977 *and in revised form* 25 *July* 1977)

THE COMMENT recently prepared by Nelson [1] regarding the paper by Krier and Gokhale [2] brings out some interesting points regarding the predictions presented in [2]. But at the same time some hasty conclusions were arrived at, possibly due to a lack of understanding of the basic theme of the work.

The first item deals with the fact Nelson thinks that during the unsteady compression process in the closed chamber (while an ignitor source is issuing hot gases) the predicted gas temperatures cannot exceed the adiabatic flame temperature of the propellant or ignitor gases. Of course this is not so, since one can show from the simplest