Study of Shock Ignition via Applying Different models of Deuterium Equation of State (EOS)

M. J. Jafari[1], S. Rezaei[1], A. H. Farahbod[1]

[1] *Laser and Optics Research School, Tehran, Iran*

Shock ignition scheme is proposed as a high gain approach for laser direct-driven inertial confinement fusion (ICF). Target performance and timing of ignitor in shock ignition depend on the equation of state (EOS) model used in numerical simulations. In the current work, the results of applying deuterium material equation of state generated by ideal gas EOS, BADGER and MPQeos codes are compared with the SESAME equation of state. 1D simulations on the HiPER target by means of MULTI code show that areal density and maximum target gain change by using different EOS models. While using ideal gas EOS maximum gain is achieved, EOS table of MPQeos code results minimum gain.

1. INTRODUCTION

Inertial confinement fusion (ICF) based on heating a pellet of fusion fuel above 5 KeV and compressing it to densities of about 1000 times solid density [1]. Thus, knowledge of the properties of the matter at high densities and high temperatures, especially equation of state (EOS) are important to calculate thermodynamic functions, radiation and shock propagation into pellet. Using for instance the Thomas-Fermi model or ideal gas model, the amount of energy needed to compress the pellet to high density is different [2]. Performing simulation of laser fusion, pressure and internal energy as a function of density (ρ) and temperature (T), as well as their derivatives are essential input Ingredients for hydrodynamic codes. During heating and compression of pellet, target material passes through the wide regime of ρ and T which are analysed with different EOS models. For example, at the sufficiently high temperature and/or low density of corona, ideal gas EOS is a good approximation. However, because of strong coulomb interactions at the compressed fuel, T-F-D model for electronic and Deby-Grunsitin for the ion EOS are described as the realistic condition [2].

According to crucial role of ρ and T, one could see changing EOS model has an effect on the implosion dynamic [3]. Since for different ICF schemes, output energy depends on areal density (ρR) and temperature; therefore, target gain may depend on the availability and quality of EOS data [4]. In this article, the effect of different EOS models on the shock ignition is investigated using hydrodynamic simulations. To better understand of dependence of shock ignition characteristics on the EOS model, changes of areal density, shock timing and target gain are illustrated.

2. Different EOS models for D2 and numerical simulations

Hydrodynamic codes perform inertial confinement fusion require the use of EOS data which describe the thermodynamic functions of both electrons and ions. Most of the inertial fusion codes use SESAME tables. SESAME libraries are a collection of tabulated data generated from a variety of sources, including phenomenological and theoretical models and fits to experimental data [5]. In addition to SESAME there are some computer programs for calculating EOS data, such as MPQeos and BADGER, which are developed recently for hot dense matter. MPQeos has been developed at MPQ Garching and is publicly available which generates material EOS based on QEOS model [6]. The QEOS model describes the equation of state of any material in a wide range of densities and temperatures by means of the Thomas-Fermi equation of state for the electrons, plus a semi-empirical part for the ions [7]. Accurate calculation of EOS in the high density and low temperature regime could be obtained by BADGER library. It applies quotidian equation of state with scaled binding energies for ions and an adaptation of the screened hydrogenic model with l-splitting for electron equation of state data [8]. BADGER takes advantage of multiple options for electron, ion and ionization model.

Table 1. Simulation main parameters for different EOS models.

Type of EOS	Ideal gas	SESAME	MPQeos
Driver energy (kj)	140	140	140
$<\alpha>$ (in-flight adiabat)	1.0	1.17	1.11
ρR at maximum of spike power (mgcm^{-2})	79	42	35
Thermonuclear energy (MJ)	24.5	19.7	15.6

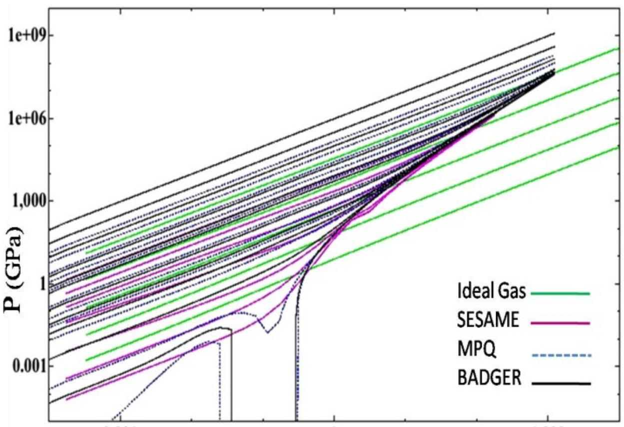

Figure 1. Comparison of ideal gas EOS, MPQeos, BADGER and SESAME pressure curves of D2 at constant temperatures.

Figure 1 shows isotherm curves of deuterium total pressure as a function of density using different equation of state models. The pressure for ideal gas EOS is lower than that for the SESAME, MPQeos and BADGER in a high density and low temperature regime. There is a difference even between SESAME and MPQeos in low temperature and near the solid density regime, however, BADGER and MPQeos have the same behavior.

Having explained variety of EOS models, here, the results of different models inclusion into shock ignited target performance are given. To obtain results of using ideal gas and SESAME EOS, 1D radiation hydrodynamic code, MULTI is used. MULTI [9] is a Lagrangian code which included electron and ion hydrodynamic, radiative transport, laser deposition and option of ideal EOS or tabulated SESAME tables. Simulations were performed with HiPER baseline target and laser pulse [10]. The thickness and radius of the shell are 211 μ and 1.044 mm with the vapor DT density and solid DT density are 0.1 mg/cm^3 and 0.25 g/cm^3, respectively. SESAME input table used in MULTI is total pressure and temperature of electron and ion, whereas data obtained from MPQeos code are for electron and ion separately. To compare the results we use MPQeos data in MULTI-fs code. Table 1 gives the main parameters of the simulation results in different use of EOS models. Incident laser energy is the same for all cases, while thermonuclear energy evolves between 15 and 24 MJ. The shell ρR when the spike is launched are also given in table1.

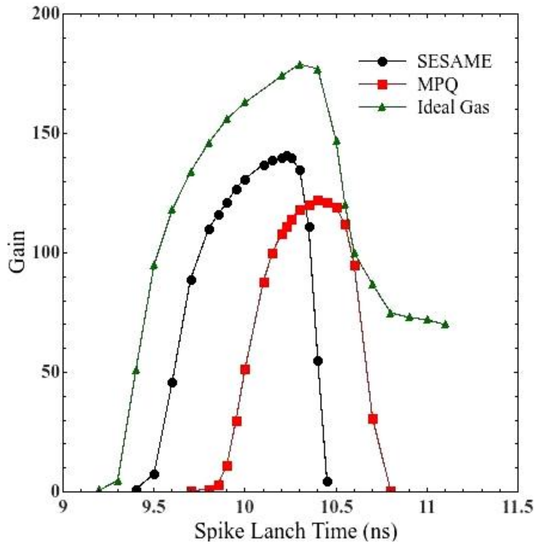

Figure 2. Gain versus spike launch time, for three different EOS models.

4. Discussion

Figure 2 shows the gain curve versus shock ignitor launch time for different EOS models used in simulation. The results indicate that without considering repulsive forces in ideal gas EOS, compressing the DT gas is easy and therefore an unrealistically large value for ρR is obtained which leads to incorrectly high gain. Considering the same peak power duration Δt_s =700 ps for all cases, Figure 2 shows a time window that shifts few hundred picoseconds using different EOS models. Shock time window is duration of spike launch time which leads to appropriate gain. Figure 3 shows fuel areal density during spike obtained by numerical simulation for ideal gas, SESAME and MPQeos. The peak areal density depends on the in-flight adiabat which in turn depends on EOS model used in simulations. The in-flight adiabat is the ratio of the plasma pressure to the Fermi pressure of a degenerate electron gas. The maximum areal density achieved with the ideal gas EOS is 0.37 g/cm^2 and with the SESAME and MPQeos model are 0.11, 0.08 g/cm^2 respectively.

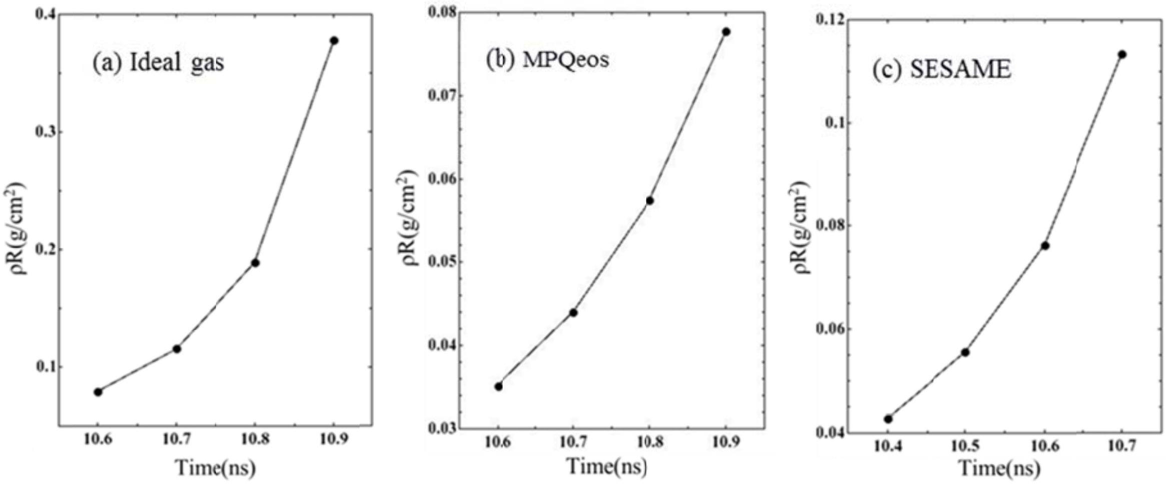

Figure 3. Fuel areal density during spike pulse for three different EOS models:(a) Ideal gas EOS, (b) MPQeos and (c) SESAME EOS

5. Conclusion

Different pressure-density properties affect the achievable areal density and maximum target gain. We investigated shock ignited target performance by using MULTI code. Appropriate timing of spike for obtaining optimum gain changes with SESAME and MPQeos models and widens while using ideal gas EOS. Areal density of ideal gas modeled fuel during the spike pulse reaches to an unrealistic large value and gives higher gain than using SESAME and MPQeos models.

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