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Transient combustion analysis for iron micro-particles in a gaseous media by weighted residual methods (WRMs)

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ABSTRACT

In this paper, combustion process for iron particles burning in the gaseous oxidizing medium due to radiation is investigated by three weighted residual methods (WRMs) called Galerkin method (GM), least square method (LSM) and collocation method (CM). The effect of thermal radiation from the external surface of burning particle and variations of density of iron particle with temperature are considered. The solutions obtained by WRMs techniques are compared with those of the fourth order Runge–Kutta numerical method. Results show that LSM has the most accurate results among other WRMs. Also, results show that by increasing the heat realized parameter (Ψ), combustion temperature increased and it faster reaches to its constant value.

1. Introduction

One of the most challenging in industries is combustion of metallic particles such as iron particles. In many of industrial applications, manufacture, process, generate, or use combustible dusts, an accurate knowledge of their explosion hazards is essential. Many researchers have worked on estimating and modeling the particle and dust combustion such as Haghiri and Bidbadi [1] which investigated the dynamic behavior of particles across flame propagation through a two-phase mixture consisting of micro-iron particles and air. They considered three zones for flame structure namely preheat, reaction, and post flame (burned) regions. Liu et al. [2] analyzed the flame propagation through hybrid mixture of coal dust and methane in a combustion chamber. A one-dimensional, steady-state theoretical analysis of flame propagation mechanism through micro-iron dust particles based on dust particles' behavior with special remark on the thermophoretic force in small Knudsen numbers is presented by Bidabadi et al. [3]. A mathematical model for analyzing the structure of flame propagating through a two-phase mixture consisting of organic fuel particles and air is performed by Haghiri and Bidabadi [4]. In contrast to previous analytical studies, they take thermal radiation effect in to consideration, which has not been attempted before. Recently, Hatami et al. [5] solved the nonlinear energy equation resulted from particle combustion modeling based on Bidabadi and Mafi's work [6] by using differential transformation method (DTM) and BPES and they presented equations for calculating the convective heat transfer coefficient and burning time for iron particles.

Polynomial expansion methods are extensively used in many mathematical and engineering fields to yield meaningful results for both numerical and analytical analysis. Among the most frequently used polynomials, weighted residual methods (WRMs)

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are one of the interesting tools due to their simplicity and high accuracy. Collocation, Galerkin and least square are examples of the WRMs. Stern and Rasmussen [7] used collocation method for solving a third order linear differential equation. Vaferi et al. [8] have studied the feasibility of applying of orthogonal collocation method to solve diffusivity equation in the radial transient flow system. Recently Hatami et al. [9] used collocation and Galerkin methods for heat transfer study through porous fins. Also least square method is introduced by Aziz and Bouaziz [10,11] for predicting the performance of longitudinal fins. They found that least squares method is simple compared with other analytical methods. Shaoqin and Huoyuan [12] developed and analyzed least-squares approximations for the incompressible magneto-hydrodynamic equations also Hatami et al. [13–15], Hatami and Ganji [16–18], Hatami and Domairry [19,20] and Ahmadi et al. [21] applied these analytical methods in different engineering problems.

Motivated by above mentioned works, this paper aims to introduce three analytical WRMs for obtaining the temperature of iron particle during combustion, so CM, GM and LSM are applied. These methods have an excellent agreement with numerical Runge–Kutta method; also they have very low errors without any needing to perturbation or discretization compared to previous analytical methods in the literature.

2. Problem description

As seen in Fig. 1a, consider an iron spherical particle which is combusted in the gaseous oxidizing medium due to high reaction with oxygen. The particle is considered to be isothermal and the Biot number is small ($Bi_H \ll 0.1$) due to high value of the thermal diffusivity of substance. In this study, a lumped system analysis is applied. When this condition is satisfied, the variation of temperature with particle's radius will be not sensible and can be approximated as a constant value, so the particle's temperature is just a function of time, $T = T(t)$, and it is not a function of radial coordinate, $T \neq T(r)$. The assumptions used in this modeling are [5,6]:

a) The spherical particle burns in a quiescent, infinite ambient medium.
b) There are no interactions with other particles.
c) The effects of forced convection are ignored.
d) Thermo-physical properties for the particle and ambient gaseous oxidizer are assumed to be constant.
e) The particle radiates as a gray surface to the surroundings without contribution of the intervening medium.
f) The surface reaction rate is treated as temperature independent and the surface reaction area is treated as a constant number. Also, the convection heat coefficient is assumed to be constant.

By considering the above assumptions and taking the particle into account as a thermo-dynamical system, and using the principle of conservation of energy or first law of thermodynamics, the energy balance equation for this particle can be written as

$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = \left(\frac{dE}{dt}\right)_p \tag{1}$$

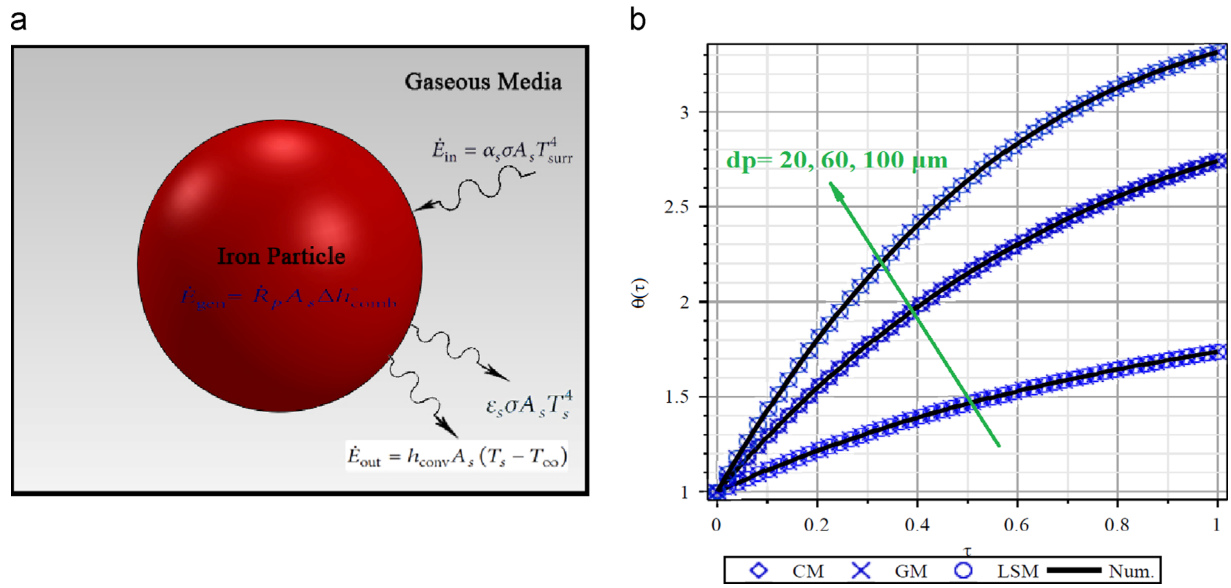

Fig. 1. (a) schematic of a combusted iron particle in gaseous media (b) the effect of particle diameter on temperature profile with WRMs.