Numerical Investigation of the Effects of Fuel Injection Diameter on the Main Working Characteristics of a Power Plant Boiler

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Abstract
Particle size is a crucial property of fuels which effects combustion efficiency, combustion stability and pollutant formation of conventional energy generation systems. Present study investigates the relationship between fuel particle diameter and the main working parameters of a power plant boiler. The boiler of 600^{MW} power plant was investigated through a numerical simulation with real dimensions and real working conditions. Also, Rosin-Rammler method was utilized for the distribution of fuel droplet diameter. Results show that by increasing droplet mean diameter, the maximum temperature of the boiler decreased, maximum temperature peak approached rear wall and combustion efficiency of the boiler decreased too. From environmental point of view, increase of droplet mean diameter resulted in decrease of NO_x, soot and other pollutants but in order to maintain power plant working parameters like main steam temperature, fuel consumption must be increased that makes more pollutants.

Keywords: Numerical simulation, Boiler, Fuel, Combustion, Rosin-Rammler distribution, Droplet diameter.

Introduction
According to the increasing importance of energy phenomena through the world and undeniable significance of conventional power plants as the main consumers of fossil fuels, many investigations and endeavors have been conducted in order to optimize power plant boilers. This study investigates the relationship between fuel particle diameter and the main working parameters of a power plant boiler. There is no doubt that particle size is one of the most important physical characteristics of the injection of liquid fuels. This property influences not only the combustion process but also the total efficiency of fuel based energy conversion devices like industrial furnaces and boilers. It also effects the flow characteristics of granular materials, the compacting and sintering behavior of metallurgical powders, setting time of cements, spray drying, etc. [1].
Many distribution functions have been proposed to predict particle diameter and characterize the fraction of materials as a function of the particle size [2]. In 1933 P. Rosin and E. Rammler proposed use of an empirical distribution for description of particle sizes, which they obtained from data describing the crushing of coal and other materials. In 1939 W. Weibull proposed the same distribution, which he obtained from the study of fracture of materials under repetitive stress. Proposed distribution had been strictly empirical until Austin

et al. derived it to describe batch grinding in 1972. Later, Peterson, Brown, Wohletz *et al.* independently derived the distribution. Astin, Peterson and Brown each derived the distribution from a somewhat different point of view, but they all used a simple but nonetheless empirical power law to describe the breakup of a single particle into smaller ones [3].

The most famous distribution functions are the traditional log-normal, Rosin-Rammler and the more recently developed log-hyperbolic distribution. The log-normal distribution is frequently used to represent the size of solid particles while the Rosin-Rammler distribution is frequently used for representing droplet size in sprays [4]. As it was said, classic models to predict diameter and velocity distribution of droplets were derived mainly from experimental data. In this procedure, a curve is fitted on different data obtained from various conditions of nozzle operations [5]. The Rosin-Rammler distribution function is based on the assumption that an exponential relationship exists between the droplet diameter, *d*, and the mass fraction of droplets with diameter greater than *d*, Y_d:

$$Y_d = e^{-(d/\bar{d})^n} \tag{1}$$

Where $\bar{d}$ and *n* are two empirical constants which are referred as the Mean Diameter and the Spread Parameter respectively [6]. The values for the spread parameter are chosen from past modeling experience and from a review of experimental observations. The larger the value of the spread parameter, the narrower the droplet size distribution [6].

The case of this investigation is 600^{MW} Mashhad Tousss Power Plant, one of the biggest power plants through the world which use Air Cool Condensers. The boiler of unit 4 of this power plant was considered in real dimensions and nominal load. There are 9 burners in 3 rows in each of this power plant's boilers which use Fuel-Oil ($C_{19}H_{30}$) as the main consumable fuel [7].

In this study, OpenFOAM, free, open source computational fluid dynamics (CFD) software was utilized under Linux Operating System to simulate the boiler of unit 4 of this power plant. The numerical grid was generated with about 1,000, 000 tetrahedral cells in graphical environment of SALOME. Also, Rosin-Rammler diameter distribution method was used for burners' fuel injection.

Results and Discussion

After a time consuming procedure of about 200,000 iterations and experimenting more than 10 droplet size under various conditions, the following results were obtained:

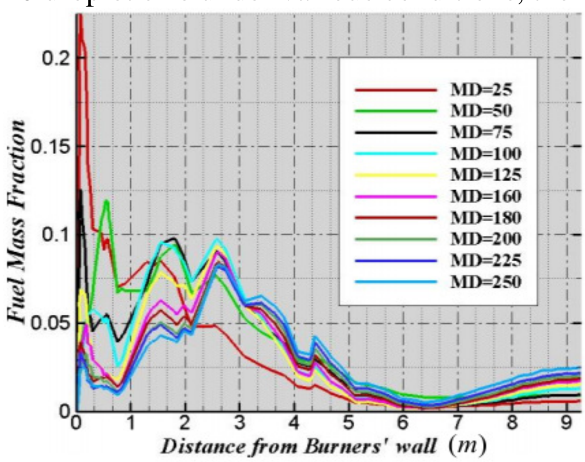

Figure 1: Fuel mass fraction along the central burner's axis line

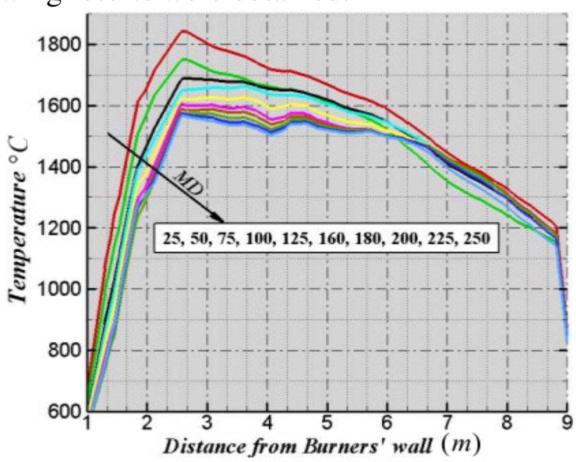

Figure 2: Temperature distribution along the central burner's axis line

As it was obvious in Fig.2, by increasing droplet mean diameter, temperature decreased and maximum temperature peak approached rear wall. Needless to say, increase of droplet diameter causes increase of droplet mass and because of this, droplet injection velocity decreases. So, as diameter increases, droplet can't survive in long distances and evaporates closer to injection point and participates in combustion process.

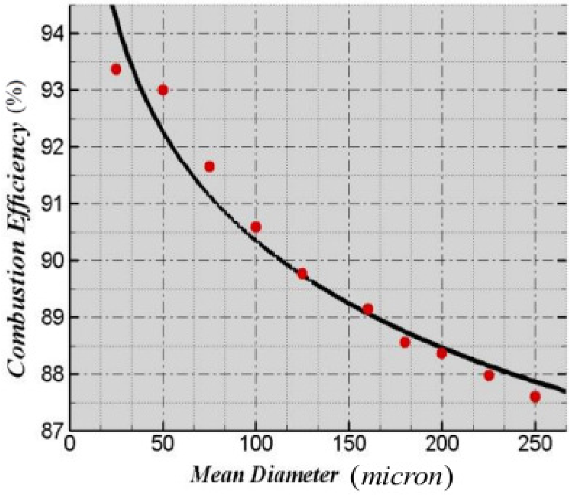

Figure 3: Effect of droplet diameter on combustion efficiency

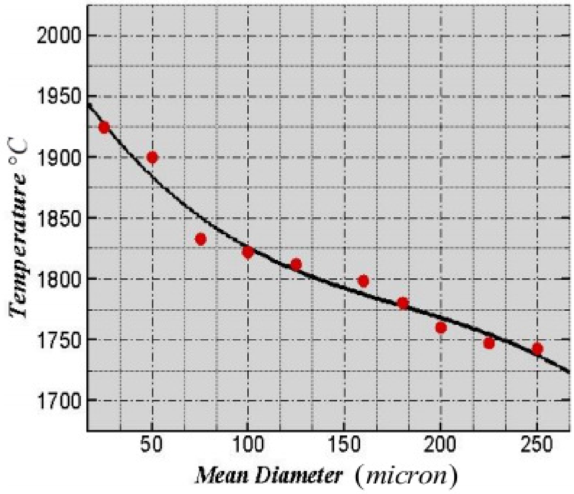

Figure 4: Effect of droplet diameter on maximum temperature

It was observed that mean diameter increase resulted in decrease of combustion efficiency of boiler, Fig.3. This decrease of combustion efficiency brings lower boiler temperature and there are more amounts of unburned fuel vapor at larger distances from burners. These results can be seen in Fig.4 and Fig.1 respectively.

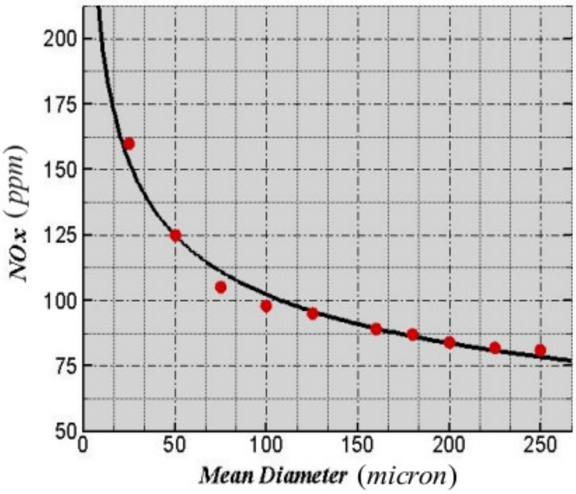

Figure 5: Effect of droplet diameter on NO_x at outlet

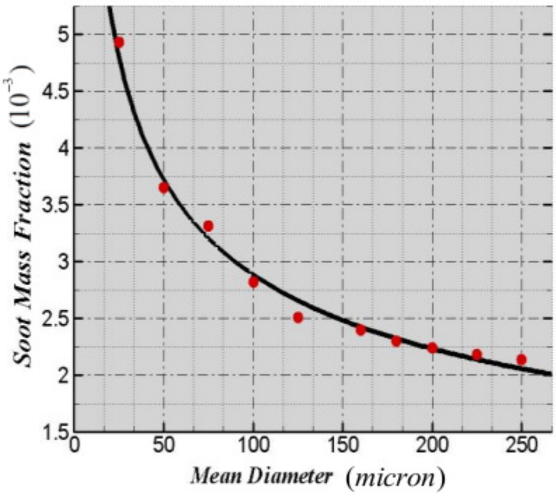

Figure 6: Effect of droplet diameter on soot mass fraction at outlet

As it was seen in Fig.5 and Fig.6, increase of droplet diameter causes decrease of formation of soot and NO_x and their amounts at the boiler's stack entrance. During combustion process and NO_x formation, the great portion belongs to the thermal NO_x. As it was seen in Fig.4, the bigger droplet size, the lower boiler temperature. This reduction in temperature results in decrease of thermal NO_x and formation of general NO_x decreases correspondingly. Also, other pollutants like SO_x, CO etc. were decreased as droplet mean diameter increased. But decrease of temperature and combustion efficiency results in increase of fuel consumption in order to maintain power plant working parameters like main steam temperature. This increased fuel makes more pollutants and is not acceptable from economical point of view.

Conclusions

The effects of fuel injection diameter on the main working characteristics of a boiler of Mashhad Touss Power Plant was investigated through numerical simulation and Rosin-Rammler diameter distribution method was used for burners' fuel injection. It was shown that by increasing droplet mean diameter, the maximum temperature of the boiler decreased, maximum temperature peak approached rear wall and combustion efficiency of the boiler decreased too. From environmental point of view, increase of droplet mean diameter resulted in decrease of NO_x, soot and other pollutants but in order to maintain power plant working parameters like main steam temperature, fuel consumption must be increased that makes more pollutants.

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