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Full Length Article

Flash boiling in a multihole G-DI injector – Effects of the fuel distillation curve

Lucio Araneo [a,b], Roberto Donde' [a,*]

[a] CNR-ICMATE, via Cozzi 53, 20125 Milano, Italy

[b] Politecnico di Milano, Dipartimento di Energia, via Lambruschini 4A, 20156 Milano, Italy

HIGHLIGHTS

- n-hexane has a behavior closer to gasoline than n-heptane and isooctane.
- The near field spray angle has an opposite behavior respect to the far field angle.
- Spray angle data can be related to reduced pressure, overheat or Jacob number.
- The saturation pressure curve can be obtained from the fuel distillation curve.
- The saturation pressure curve can be obtained from the experimental spray angle.

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ABSTRACT

The effects of fuel temperature and chamber pressure on the spray of a multi-hole G-DI injector were analyzed in a quiescent test chamber. The analysis was focused on the behavior of the global spray angles both close and far from the injector. Three pure hydrocarbons (*n*-hexane, *n*-heptane, and isooctane), three gasolines of known distillation curve and a commercial 95 RON gasoline from a gas station were utilized. The tests were performed at four chamber pressures (atmospheric, 80 kPa, 60 kPa and 40 kPa) and the fuel temperature was varied from 30 °C to 110 °C.

The results for *n*-hexane and gasolines were very similar, while *n*-heptane and isooctane showed a different behavior. The ratio between the fuel saturation pressure at the operating temperature and the air pressure (p_s/p_a) is confirmed as a fundamental parameter for spray angle data reduction. The near field spray angle data for pure hydrocarbon fuels merge to a unique curve when plotted in function of p_s/p_a. An approximated method to deduce the gasoline saturation pressure curves starting from the distillation curve is presented. Using the calculated saturation pressures for the reduction of near field spray angle data for the gasolines, a unique curve is obtained, coincident with that of the tested pure hydrocarbons. In alternative, from the results obtained for a fuel of known saturation pressure curve, it is possible to obtain a direct correlation between near field spray angle and saturation pressure. From this relationship, an approximated saturation pressure curve from the experimental angle measurements obtained on the same injector for an unknown fuel can be derived.

1. Introduction

It is well known that rapid evaporation occurs when a liquid is injected in an ambient at pressure below its saturation pressure. The sensible heat of the fuel provides the latent vaporization heat for a fraction of the liquid mass. After the pioneering work by Brown and York [1], numerous studies on the phenomenon in pools, ducts, jets, films and sprays were published. Although the physical bases are the same, the practical effects of interest in the various configurations could be different. Many studies were focused on transition from Rayleigh jet regime to spray regime by flash boiling. The aim was to obtain a good atomization with low pressure atomizers. An overview of the state of the art on this aspect of flash boiling is given in Sher et al. [2]. Different is the scope of the present work. In this case the effects of the phenomenon on a real G-DI injector at real injection pressure are studied. It means that a fully developed breakup regime is considered even in absence of flash boiling.

* Corresponding author.
E-mail address: roberto.donde@cnr.it (R. Donde').

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Nomenclature

c_p	specific heat
p_a	air pressure
p_s	saturation pressure
T_f	fuel temperature
T_s	saturation temperature
ΔH_v	latent heat of evaporation
ρ_l	liquid density
ρ_v	vapor density

Abbreviations

ASOI	After Start Of Injection
ASTM	American Society for Testing and Materials
DIPPR	Design Institute for Physical Properties
G-DI	Gasoline Direct Injection
NIST	National Institute of Standards and Technology
RON	Research Octane Number
SAE	Society of Automotive Engineers
TBP	True Boiling Point

As the G-DI technology developed, the behavior of different injector types was reported in literature. From the first studies devoted to swirl injectors [3–9], the attention lately moved to other injector types [10–24], however the studies on swirl injectors were not abandoned [25]. From the experimental results reported in the cited literature, a clear effect of flash boiling both on the spray shape and on the droplet diameters was noticed both for swirl and for multi-hole atomizers. The effects on both types of atomizers are similar. In particular, flash boiling causes an increase of the spray angle at the nozzle exit [4,5,9,10,12,13,16,19,24], that is followed by a contraction of the angle as the distance from the nozzle increases [5,10,12–14,18].

It is evident that the choice of the position where the spray angle is measured strongly affects the results, so quantitative comparison of works from different origins with different processing criteria cannot be immediately performed. In some cases, the angle definition gives as a consequence a behavior apparently opposite to the actual one. It would be desirable to define some standard procedures to measure the spray angles in order to obtain a comparable description of the actual spray behavior.

The SAE J2715 [26] Recommended Practice has some limitations when applied to a flashing spray. Depending on the injector design, the recommended measurement range from 5 mm to 15 mm could interest a region where the transition between angle increase and angle decrease occurs.

The spray penetration is affected both by the degree of overheating and by the ambient pressure [12,19,21,24]. The mean droplet size was observed to decrease in presence of flash boiling [4,6,11,14,16,21]. These effects could be either favorable or detrimental depending on the applications, from this fact follows the importance of the studies about this topic. For this reason the authors carried up in the past studies on a G-DI swirl injector using simple fuels [9]. The results, reported in Fig. 1, demonstrated that the angle at the exit of the injector was greatly influenced by flash boiling. Infact as soon as the phenomenon starts to occur the spray angle increases. Testing mixtures of *n*-pentane and isooctane in different percentage at atmospheric pressure, the angle increase starts to occur at higher temperature as the percentage of the higher boiling component (isooctane) is increased (Fig. 1a). Plotting the same results in terms of the ratio between saturation pressure and ambient pressure (p_s/p_a) instead of temperature, the experimental curves merge in a unique curve as shown in Fig. 1b. When the value of p_s/p_a becomes greater than one the spray angle starts to increase and for values greater than 1.5 the data can be fitted by a logarithmic curve. Furthermore, the saturation pressure to be considered resulted to be the average saturation pressure of the mix, with no dominant effects of the lighter element. Considering these previous results, the authors decided to extend the investigation to a new generation multi-hole injector and different distillation gasolines. The examined results regard mainly the effects of flash boiling on the near field global angle of the injector spray.

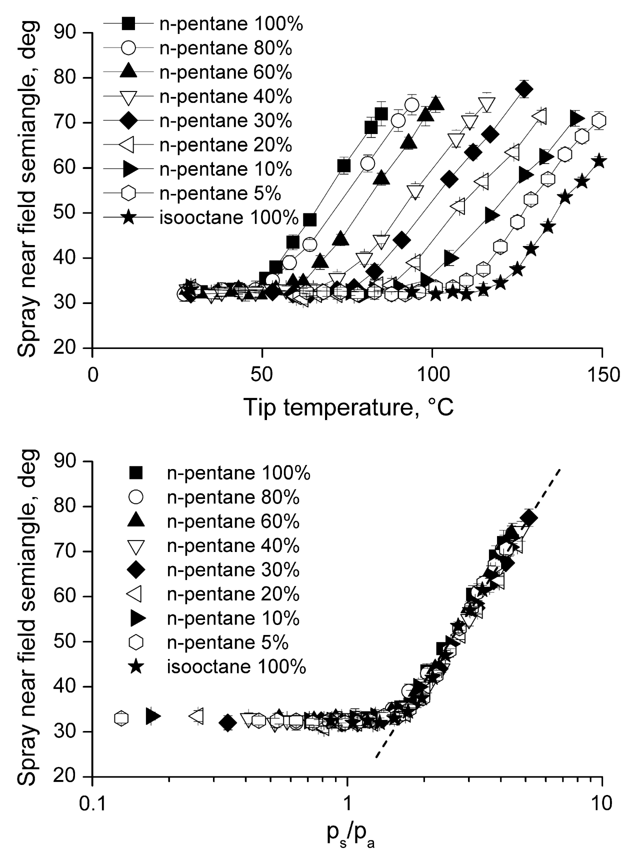

Fig. 1. Swirl injector near field spray semiangle variation with fuel temperature for different *n*-pentane/isooctane mixtures (a) and the same data plotted in terms of normalized pressure (saturation pressure/air pressure) [9].

The main scope of the work is the setup of a procedure to study the effect of different distillation curve gasolines on the behavior of the injector spray in flash boiling conditions.

2. Experimental setup and procedure

A six holes G-DI injector was tested in a constant volume chamber. The spatial distribution of the injector jets at 30 mm distance from the tip is reported in Fig. 2, where the arrow indicates the line of sight of the camera. Four of the six jets are nearly aligned in the visualized image plane, while the other two are aligned along the line of sight.

The nominal value of the spray angle in the image plane is 72° and the nominal single beam angle is 19°. The nominal static mass