International Journal of Heat and Mass Transfer 123 (2018) 805–814

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Internal flow and air core dynamics in Simplex and Spill-return pressure-swirl atomizers

Milan Maly [a,*], Jan Jedelsky [a], Jaroslav Slama [b], Lada Janackova [a], Marcel Sapik [a], Graham Wigley [c], Miroslav Jicha [a]

[a] *Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic*
[b] *Provyko s.r.o, Czech Republic*
[c] *Loughborough University, United Kingdom*

ARTICLE INFO

Article history:
Received 21 December 2017
Received in revised form 22 February 2018
Accepted 22 February 2018

Keywords:
Internal flow dynamics
Pressure-swirl
Transparent nozzle
CFD
Spill return atomizer
Air core

ABSTRACT

Spill-return (SR) atomizers enhance the construction of Simplex atomizers by addition of a passage in the rear wall of the swirl chamber through which the liquid can be spilled away. It allows to discharge the liquid always at a high pressure and to spray well over a wide flow rate range. The spray characteristics of pressure-swirl atomizers are strongly linked to the internal flow, and the air-core dynamics affect the spray stability. The SR atomizers are rarely investigated and their internal flow is not studied at all. Therefore, in this paper, the Simplex and SR atomizers with a central SR orifice were examined comparatively.

Transparent polymethyl methacrylate (PMMA) models of both atomizers scaled 10:1 were manufactured for the visualization and velocity measurements of the flow inside the swirl chamber. The atomizers were examined by means of high-speed imaging, laser-Doppler anemometry and computational fluid dynamics tools. The experimental and numerical results were analysed and compared in terms of the spray cone angle (SCA), discharge coefficient (C_D), and the morphology and temporal stability of the air core. The internal flow characteristics between the original and the model atomizer were matched using the Reynolds, Swirl and Froude numbers. The test conditions were limited to inlet Reynolds numbers from 750 to 1750.

The results show that the addition of the spill passage strongly affects the internal flow even when the spill-line is closed. The air core in the Simplex atomizer is fully developed and stable for all flow regimes. The SR atomizer behaves differently; with the closed spill-line (spill-to-feed ratio, SFR = 0), the air core does not form at all; therefore, the spray is unstable. The reason is that the liquid, contained in the spill-line, is drained back into the swirl chamber due to a recirculation zone found inside the spill-line. Increasing the SFR stabilizes the internal flow, and the spray becomes stable if SFR > 0.15. The air core begins to form for SFR > 0.4. The results suggest that the axially positioned spill orifice is inappropriate and its placing off-axis would improve the spray stability. The results of the 2D numerical simulation matched closely with the experiments in terms of SCA, C_D, velocity profiles, and air core morphology which proved its prediction capabilities.

1. Introduction

Pressure-swirl (PS) atomizers are used in many applications where a large surface area of droplets is needed, or a surface must be coated with a liquid, e.g. combustion, fire suspension or air conditioning. PS atomizers are easy to manufacture, reliable and provide a good atomization quality. They convert the pressure energy of the pumped liquid into kinetic and surface energy of the resulting droplets. The liquid is injected via tangential ports into a swirl chamber where it gains a swirl motion under which it leaves the exit orifice as a conical liquid sheet. The centrifugal motion of the swirling liquid creates a low-pressure zone in the centre of the swirl chamber and generates an air core along the centreline. The flow inside the atomizer is rather complex; it is two-phase with secondary flow effects. There is a strong link between internal flow conditions and the resulting spray characteristics. However, not all aspects of the internal flow are well understood. A drawback of the Simplex atomizer is that the droplet size depends on the inlet pressure, hence on the liquid flow rate.

* Corresponding author.
E-mail address: milan.maly@vutbr.cz (M. Maly).

https://doi.org/10.1016/j.ijheatmasstransfer.2018.02.090
0017-9310/

Nomenclature

A	area [mm^2]
b	width [mm]
C_D	discharge coefficient [–]
d	diameter [m]
f	frequency [–]
g	gravitational acceleration [m/s^2]
k	atomizer constant [–]
k_{vel}	correction factor [–]
Fr	Froude number [–]
h	height [mm]
$\dot{m}$	mass flow rate [kg/s]
n_1	refractive index of PMMA [–]
n_2	refractive index of the liquid [–]
Q	volumetric flow rate [–]
r	radial distance [mm]
R	radius of the swirl chamber at the measurement plane [mm]
Re	Reynolds number [–]
SCA	spray cone angle [deg]
SFR	Spill-to-Feed ratio [–]
S_1	virtual distance of the measurement volume from the atomizer wall [mm]
S_2	real distance of the measurement volume from the atomizer wall [mm]
S_o	Swirl number [–]
w	velocity [m/s]

Greek characters

Δp	pressure drop at the nozzle [MPa]
μ	dynamic viscosity [kg/(m·s)]
ρ	density [kg/m^3]
ν	kinematic viscosity [m^2/s]
σ	liquid/gas surface tension [kg/s^2]

Subscripts and superscripts

l	atomized liquid
o	exit orifice
s	swirl chamber
p	inlet port
a	air core

The flow rate varies as the square root of the injection pressure. Thus, doubling the flow rate demands a fourfold increase in injection pressure, which means that the range of applicable flow rates is limited and thus the turn-down ratio (defined as the ratio of maximum liquid flow rate to minimum liquid flow rate), which satisfies the requirement of atomization quality, is usually low [1]. This disadvantage can be eliminated using a Spill-return (SR) atomizer which is basically a Simplex type with a passage added in the rear wall of the swirl chamber, see Fig. 1. When the spill-line is closed, the atomizer operates as a standard Simplex type. When a low injection flow rate is required, the liquid is spilled away through the spill orifice while the inlet pressure and the swirl momentum keep high, and the atomization quality remains such as previously. However, an increase in spilled flow rate causes a reduction in the axial momentum of the discharged liquid; this consequently leads to a change in the spray cone angle (SCA), as the SCA is determined by the ratio of the swirl momentum to the axial momentum. Other drawbacks are the requirement for increased pump power and complicated flow metering. For these reasons, the interest in SR atomizers for aircraft combustors has declined. However, if the aromatic content of gas turbine fuels rises, a gum formation in the small sized atomizers could pose serious problems in terms of the atomizer blockage [2,3]. The SR atomizers are virtually free of this defect as they have no small passages. Beside the aircraft combustors, the SR atomizers were used in stationary gas turbines [4] and industrial burners [5]. Also, the above-mentioned advantages of SR atomizers are crucial for special applications that require a fine spray at very low flow rate, e.g. decontamination devices [6], or for atomization of waste fuels and liquids containing impurities where large dimensions of flow cross-sections are necessary to prevent the atomizer from clogging, or for applications where pneumatic atomizers are not allowed

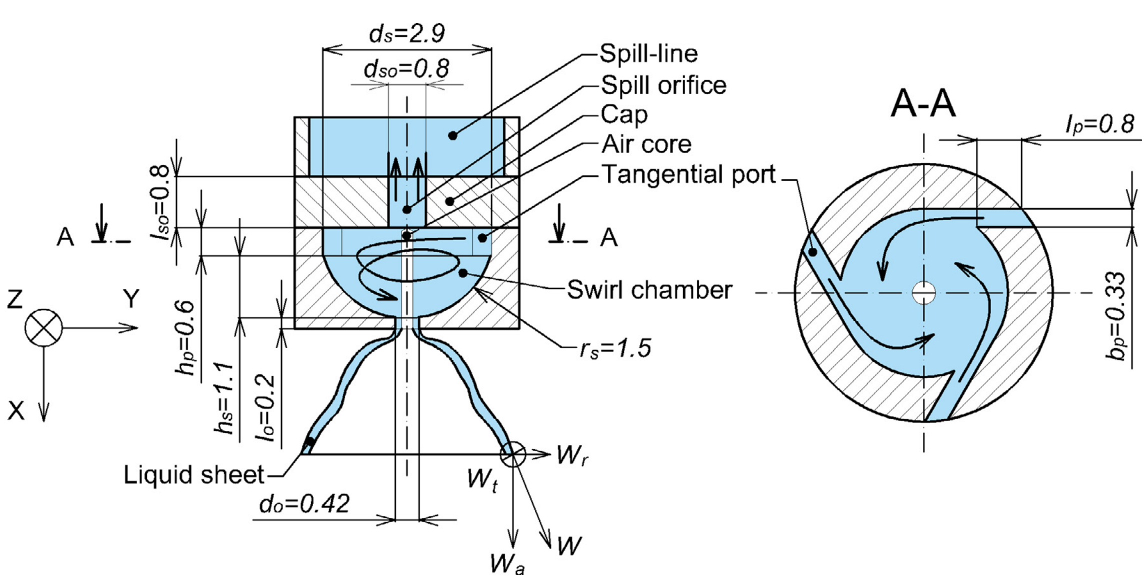

Fig. 1. A sketch of the original SR atomizer with the main dimensions in millimetres. The Simplex atomizer has the same geometry and size, but the spill-line orifice is missing. The transparent atomizer has the same shape, and all dimensions are 10 times larger.