Are Sprays an Answer to Global Warming?

D.R. Guildenbecher[†], E.D. Hirleman, Jr. and P.E. Sojka[*]
School of Mechanical Engineering
Purdue University
West Lafayette, IN 47907 USA
[†]Institut für Thermische Strömungsmaschinen
Karlsruher Institut für Technologie 76131 Karlsruhe, Germany

Abstract

Global climate change is a serious problem for which there may be dire consequences. This presentation discusses a novel application for sprays to fight global climate change. This is revealed to be an area where more research and development is needed. In particular more work is necessary to produce a spray device which can achieve D_{30} in the μm range at flow rates of kg/s. Energy analyses for some current classes of spray devices are provided, along with an assessment of their viability for this application.

Introduction

Improved atomization and spray devices are critical to combating global climate change. For example, enhancing the efficiency of hydrocarbon combustion requires greater control of the fuel distribution via advanced injection. However, despite significant progress in this and other technologies, many climate change experts are concerned that the reduction in greenhouse gas emissions has not advanced fast enough. This has led some to propose environmental engineering (geo-engineering) schemes which could be used if the worst predictions of global climate change become a reality. Here too sprays and atomization play a crucial role.

In this presentation we consider one such geo-engineering proposal and discuss the engineering requirements and challenges facing the spray designers.

Salter *et al*. [1] outline a novel scheme to increase the reflectivity of stratocumulus clouds over the oceans. Seawater drops are to be injected into the turbulent boundary layer, after which natural circulation will transport them to the cloud layer. At that point evaporation will have reduced the drops to salt crystals. These crystals will serve as initiation sites which redistribute the moisture already contained in the cloud, thereby reducing the mean water drop size and increasing drop concentration. Twomey [2] has shown that increasing drop concentration leads to dramatically increased cloud reflectivity. As a consequence the device proposed by Salter *et al.* [2] will reduce the solar radiation reaching the earth surface thereby reducing the mean global temperature.

The current design (Figure 1) proposes a fleet of approximately 1000 ocean vessels to create the spray plume. These vessels are to be autonomous and completely powered by the wind. Consequently, the power available for spray formation is exceedingly limited. Furthermore, the requirements of small drop sizes and high flow rate present exceptional challenges.

Table 1 summarizes the engineering requirements for a single atomizer (three per ship), which according to the calculations of Salter *et al*. [1] is capable of offsetting the global warming effects of doubling pre-industrial CO_2 levels. It should be understood that these requirements are tentative and more testing is needed. For example, it is unknown exactly what drop sizes and size distribution are acceptable.

As already mentioned, the cloud reflectivity is a function of the drop concentration. Therefore, as suggested by Salter *et al*. [1], the controlling parameter for cloud reflectivity is the total number of drops and not their sizes. Nevertheless, drops larger than a certain size are unlikely to reach the stratocumulus layer due to the effects of gravity, while drops below a certain size may be too small to serve as effective nucleation sites. Consequently, the acceptable range of drop sizes is likely to be limited. Table 1 provides an initial approximation.

In addition to the requirements given above, the device should be low cost, technically feasible, and provide many months of continuous, maintenance free operation while operating on sea water that is not treated in any way. Currently no spray technology is known which meets all of these requirements and a new design is needed.

Any atomizer that can meet all of these requirements would be a great leap forward in spray technology and would have numerous applications beyond the one considered here. From our initial design work it is clear that meeting the energy requirement will be exceptionally challenging, and the remainder of this presentation focuses on this issue.

[*] Corresponding author: sojka@ecn.purdue.edu

Analysis methodology

Evaluation of proposed atomizer designs requires consistent analysis techniques. In this section, we discuss the techniques most appropriate for the current problem.

Practical atomizers produce drops whose sizes can be described by a probability density function, $f_0(D)$. Here we are most interested in the total number of drops which fall within the acceptable size range given in Table 1. This can be written as:

$$n/Q_{liq} = \int_{D_{\min}}^{D_{\max}} f_0(D)\,dD \Big/ \int_{D_{\min}}^{D_{\max}} \frac{\pi}{6} D^3 f_0(D)\,dD \tag{1}$$

where n is the number of drops per unit time, Q_{liq} is the volumetric flow rate, $D_{\max}$ is the maximum acceptable drop size, and $D_{\min}$ is the minimum acceptable drop size (Table 1).

If all drops fall within the acceptable size range then Eq. (1) becomes:

$$n/Q_{liq} = 6/\pi {D_{30}}^3 \tag{2}$$

where D_{30} is the diameter whose volume multiplied by the total number of drops is the spray volume [3].

Most spray techniques rely on pressurization of a liquid or gas to supply the energy necessary to cause atomization. Isentropic, reversible pump work for a liquid is given by:

$$W_{pump} = Q_{liq} \cdot \Delta p \tag{3}$$

where Δp is the pressure rise. Note that the power required scales with spray volume. This further justifies the selection of D_{30} as the most relevant mean diameter, as it represents the number of drops produced per unit spray volume.

Isentropic, reversible compression work for an ideal gas is:

$$W_{gas} = m_{gas} \frac{kRT_1}{(k-1)} \left[\left(\frac{p_2}{p_1} \right)^{(k-1)/k} - 1 \right] \tag{4}$$

where m_{gas} is the mass flow rate, k is the specific heat ratio, R is the gas constant, T is temperature, p is pressure, and the subscripts 1 and 2 denote the inlet and outlet respectively.

To minimize the energy required, the above indicates that an ideal atomizer should operate at the lowest pressure possible while minimizing D_{30} (thereby decreasing the required flow rates of liquid and gas).

This analysis methodology is directly applied to several classes of atomizers, including internal and external mix twin-fluid atomizers, while additional terms are necessary to analyze energy consumption for rotary, electrostatic and piezoelectric atomizers.

References

[1] Salter, S., Sortino, G., and Latham, J. Sea-going hardware for cloud albedo method of reversing global warming. *Philosophical Transactions of the Royal Society of London Series A*. 366: 3989-4006 (2008).

[2] Twomey, S. The Influence of Pollution on the Shortwave Albedo of Clouds. *Journal of the Atmospheric Sciences* 34(7): 1149-1152 (1977).

[3] Lefebvre, A.H. *Atomization and Sprays*. New York: Hemisphere, 1989.

Table 1. Requirements of spray system (Salter *et al.*, 2008)

spray rate, n	$4\text{x}10^{16}$	drops/s
drop diameter, D	< 2.5	µm
power consumption	30	kW

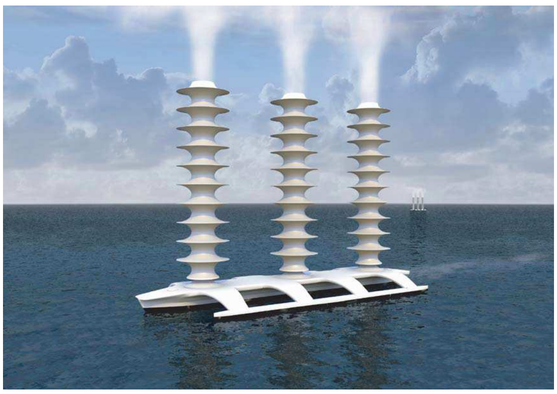

Figure 1. Artist rendition of a geo-engineering spray vessel [1].