1 Introduction to Industrial Sprays

1.1 Why Use a Spray?

It is often stated that the primary reason for breaking-up liquid into droplets is the advantage gained, for various processes, by the resulting increase in the surface area of the liquid; see, for example, Lefebvre[†]. This is certainly the case for many processes, particularly those where rapid vaporization of the liquid is required. For example in the combustion of liquid fuels the utilization of sprays is often the only real choice available. However, in other applications this increase in surface area may be either one of several benefits, or an incidental and irrelevant result of the main process. For example, in spray painting the formation of an even surface coating takes advantage of the dispersion of droplets into a nearly homogeneous spatial pattern, which is made possible with several types of spraying nozzles. With suitable choices of droplet sizes and momentum, coatings of the required thickness are achieved with minimal splashing and unevenness. In many industrial applications outside the combustion field, the choice of spraying, as opposed to other unit processes, is not always an obvious one and it requires careful balancing of the pros and cons. As an example, although metal powder production by spraying molten metal is a major industry[‡], there are still cases where use of conventional mechanical communition is preferred. As a further example, although fine water sprays are ideal for rapid vaporization there are cases where they are not the automatic choice. For example, in the UK electrical power generation industry using steam turbines, the use of large cooling towers, within which the hot water falls under gravity and is not sprayed, is the norm, presumably because calculations for capital and running costs favour these designs over more compact spraying chambers.

It is often the case that the successful utilization of a spraying process in industry requires careful design and monitoring of the process, the use of reliable pumping systems and possibly the use of quite complex control technology. Also specialized processes, such as metal atomization and spray drying of foodstuffs, demand scientific insight into the physico-chemical processes and fluid mechanics that are involved, and they often require skilled operators and strict safety or hygiene procedures.

[†] Lefebvre, A.H.
[‡] Yule, A.J. and Dunkley, J.J.

For these reasons the utilization of spraying processes, as opposed to "conventional" alternatives, during most of the 20th century was marked by a steady growth as understanding increased and problems were overcome.

In recent years, however, dramatic advances in computing, materials and opto-electronics have contributed to corresponding advances in several fields relevant to industrial spraying. These fields include computational fluid dynamics (CFD) and spray measurement techniques. Thus it is only comparatively recently that the designs of industrial spraying systems have been improved via a combination of diagnostic techniques, principally measurements of droplet sizes, and computer-aided design, principally using CFD computer modelling codes.

Figure 1.1 gives some features of sprays that may be utilized in industrial processes and provides examples of processes which use one or more of these features and which are covered in detail within this book.

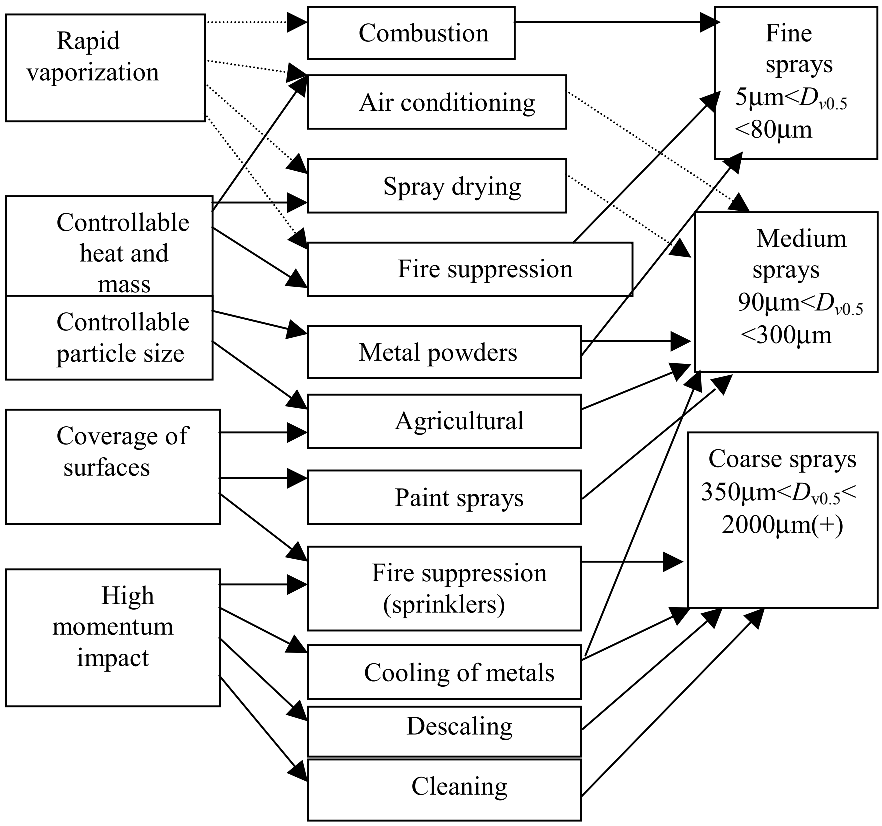

Figure 1.1 Properties of sprays and examples of their uses

1.2 Scope of this Book

1.2.1 Brief Glossary of Terms

It is useful to define some of the terms and expressions as they are commonly used throughout the book. The word “atomizer” is used to refer to the nozzle, or other device, through which the liquid flows, and downstream of which a spray is formed. The word “spray” is used to refer to a droplet-laden flow of gas, or droplets moving through essentially ambient gas, where a jet-like momentum is assumed for the flow. The words “drop” and “droplet” tend to be used interchangeably in the literature. Here we use “droplet” to refer to small liquid particles, e.g. D<500 μm, and the word is also used to indicate a near-spherical shape. The word “drop” is used more generally to refer to any size or shape of liquid particle, although “ligament” is used to refer to the fibrous-shaped liquid particles that occur at some stage in most atomization processes.

1.2.2 When is a Spray an “Industrial Spray”?

The authors have found it necessary to define the expression “Industrial Sprays”. In spite of its common occurrence in the literature, there is a lack of precision in the received meaning of the term. Here it has been decided, somewhat arbitrarily, that the usual requirement for a spray to be considered an “Industrial Spray” is that it should be used in a process that has a tangible end product. With this definition we can omit fuel sprays used in transport, for example in gas turbines in aircraft or in gasoline and diesel injection systems in vehicles. On the other hand, we do cover fixed plant such as industrial gas turbines and diesel generator systems, where the end product is electrical power. Similarly medical sprays, such as inhalers and nebulizers used for health treatments, are not included, although consideration is given to spraying processes utilized in the manufacture of pharmaceuticals. In spite of this definition there occur cases where the occurrence of a tangible end product is debatable. In these cases the authors have used their subjective judgment, for example we include consideration of spray cleaning processes for buildings and use in inkjet printing. Fire suppression spraying is also covered, due to its importance in the industrial environment.

1.2.3 Layout of this Book

Before addressing the various industrial spraying processes it is necessary to provide background coverage of the basics of droplet behaviour, spray structure, measurement techniques, modelling methods and to describe atomization techniques. This is done in Chapter 2, which also includes information on basic spray processes such as vaporization and wall impaction.

The subsequent Chapters 3-8 address the range of applications of sprays in industry and in these chapters more information on the atomizer designs and performances is provided, with emphasis on their operating conditions for each application. These chapters group industrial spraying processes according to a common theme or a particular industry. Thus in Chapter 3 the wide range of unit manufacturing spray processes are described, with emphasis on the chemical and food processing industries. Chapter 4 groups those industrial applications together, which use sprays for "treatment" of gases. Included in this context are the suppression of fires, and the cooling and cleaning of gases. Chapter 5 describes applications where the key process is the deposition of droplets on a surface, where agricultural and paint spraying are obviously important processes. Chapter 6 covers fuel spray utilization for industrial combustion processes including the use of fuel spray burners for boiler, furnace and kiln plant, and the use of liquid fuel injectors in industrial diesel engines and gas turbines, for electrical or combined heat and power generation. Sprays may be used in several ways during the manufacture of metal alloys, metal powders and during cooling and descaling in downstream metal manufacturing processes, particularly in the steel industry. These applications of sprays in metal manufacturing and processing industries are grouped together in chapter 7 and 8. Inevitably some spraying processes could be included within more than one of the above chapter headings, for example surface cooling processes can occur in both of Chapters 5 and 7. Also the same type of atomizer may be utilized for several different applications so that similar atomizers occur in several chapters. As this is a process-orientated, rather than an atomizer-orientated book, this is inevitable. Thus in order to avoid duplicating information, the text in each chapter is cross-referenced with the rest of the book and a comprehensive index is provided at the end of the book.

1.2.4 The Approach to Information Provision on Each Process

Within Chapters 3-8, where the industrial spraying processes are described, a consistent approach is used to the provision of information on each process. This involves, first, a description of the process itself, the role of the spray in the process and thus the requirements that the process enforces on the ideal spray properties. Then a comparative description is given of the atomizers currently used in the process, their normal operating conditions and spray properties, and the experimental techniques used in diagnosing the spray performance as part of the process. A discussion is then given of problems and possible future developments for the process and the implications for future needs for atomizers and operating conditions.

In order to convey understanding, the processes are extensively illustrated and for readers who wish to pursue a topic in more detail references to key publications in journals and conference proceedings are given.

1.3 Scope and Scale of Industrial Spraying

The development, construction and supply of atomizers and their associated spraying equipment tend to form a distinct industry. That is, for example, manufacturers of diesel engines, gas turbines, boilers (all combustion), vehicles (paint spraying), steel, etc. would normally purchase the spraying equipment used in their products (or in plant making their products) from specialist manufacturers. There are perhaps less than one dozen international companies worldwide who each manufacture a wide range of atomizer types for use in a wide range of processes and some of these companies are listed in Table 1.1. Even so, none of these companies attempts to produce off-the-shelf atomizers suitable for every process, although generally atomizers and associated spraying equipment can be designed and constructed to order by such firms. There is a larger number of atomizer and spraying equipment manufacturers who concentrate on only one field, for example agricultural or paint spraying, molten metal atomizers, gas turbine or diesel injectors, etc. Again, a selection of these manufacturers is listed in Table 1.1. Atomizers are manufactured and sold either for new plant and equipment, or as replacement parts, the ratio of the two markets depending greatly on the particular spraying process. There is a tremendous price range depending upon the complexity of the atomizer and the volume of the market. For example, a relatively straightforward two-fluid atomizer designed for a relatively low volume market, such as a specialized spray drying application, may be several times the cost of a high volume, more complex injector, for the relatively high volume diesel engine market. The catalogues of these various manufacturers are generally valuable sources of information and, increasingly, these catalogues contain useful information an atomizer performance, such as droplet sizes, which are essential when selecting atomizers for particular applications.

There are many materials and methods of manufacture of atomizers, and a selection of these is given in Table 1.2. As well as this selection of relatively mass-produced equipment, there is an increasing interest in the utilization of micro-machining technology. This may be particularly applicable where precise very small orifices and channels are required which may be the case in, for example, medical applications. Finally mention should be made of the scope for using rapid-prototyping techniques when developing atomizers. This is particularly relevant because atomizer performance cannot generally be predicted with reliability for new designs, so that a rapid build-and-test procedure is of great value.

Table 1.1 Examples of atomizer and spraying equipment manufacturers

Company	Country	Applications
Lechler GmbH	Germany and international	Wide range
Spraying Systems Co.	USA and international	Wide range
Delavan	USA/UK	Gas turbine, Wide range
Bosch GmbH	Germany	Fuel injection
Hamworthy Combustion Engineering Ltd	UK	Combustion
Delphi/Lucas	USA/UK	Fuel injection
DeVilbiss	UK and international	Paint, Medical and Others
Lurmark Ltd	UK	Agriculture
Parker Hannifin	USA	Combustion
Niro Atomizer	Denmark	Spray drying
Precision Valve	USA and international	Household aerosols
Schlick GmbH	Germany	Wide range

Table 1.2 Nozzles, materials and production methods

Nozzle Type	Application	Material	Manufacturing Method
Metal nozzle: (all types)	General industry, agriculture	Brass, stainless steel, other metals	Machining (drilling, turning, cutting)
Plastic nozzles: flat jet, full cone, hollow cone, accessories	Agriculture, surface treatment, general industry	Plastic (PP,POM, PVC, PVDF)	Injection moulding
Ceramic nozzles, small sizes: flat jet, hollow cone	Agriculture, spray drying, general industry	Oxide ceramics, Aluminium oxide, Zircon oxide ($Al_2 O_3$, ZrO)	Powder injection Moulding (PIM, CIM)
Ceramic nozzles, large sizes: helix hollow cone, full cone	FGD plants, process engineering, chemical industry	Silicon carbide (SiC, S-SiC), reaction or nitrude bonded	Casting, slip casting
Hard metal nozzles: flat jet, solid jet, hollow cone	Descaling high Pressure applications, spray drying	Tungsten carbide	Isostatic pressing, grinding eroding

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