5.
The Physics of Application

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PESTICIDE APPLICATION - HOW CAN WE IMPROVE OUR UNDERSTANDING AND CONTROL OF THE PROCESS?

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ABSTRACT

Some of the continuing problems of the spray application process are discussed, to illustrate both its complexity and the need for a greater understanding and control. New techniques for both applying pesticides and studying the application process continue to be developed - frequently faster than the accompanying theoretical or practical understanding of such techniques. This can lead to problems that may distract from - or offset - their original benefit. This is discussed in relation to some laser-based droplet sizing equipment. The problems of droplet distribution and canopy penetration, and the apparent limitations of some new application techniques are discussed in an attempt to identify some of the physical factors affecting the process. A novel device is described for the controlled production and placement of individual droplets. Fundamental studies with such a device can give valuable insight to aspects of the overall application process.

INTRODUCTION

It is obvious from the content of this symposium that spraying continues to be a major method of applying pesticides - though it is not, nor should it be, the only method. New technologies and concepts can equally well be applied to other methods; for example seed dressing or soil incorporation. However it is clear that the main issue of this symposium, and the theme of this introductory paper, is that tremendously involved process conveniently embraced by the simple word "spraying". This paper is not intended to be a review of the current situation - that has been ably accomplished by others recently, (Mathews, 1983; Combellack, 1984). In this paper I hope to be able to illustrate a number of areas of ignorance, concern, or progress in our understanding of the spraying process; to stimulate thought and hopefully to encourage a co-ordinated approach to future progress.

WHAT IS THE SPRAYING PROCESS?

The application of a pesticide by means of spraying is a superficially simple operation that in practise involves a great many highly interactive parameters. The complexity of the process has been presented in various ways in the literature, however I shall use a format that I have found useful for a number of years.

This breaks down the main stages of the process to the following:-

1) atomization
2) travel to the target surface
3) impaction with the target surface
4) deposit formation
5) movement or penetration to the site of action
6) biological action

Whilst obviously inseperable from the overall process the theme of this session is concentrated on the first two or three of these stages - namely the physics of the application process. I would now like to discuss a number of areas within this theme.

1. Atomization and Droplet Characterisation

We have heard in earlier sessions that there is no shortage of ideas for atomizing a pesticide. Many new techniques have been discussed; especially the rotary and electrostatic concepts. Meanwhile of course we must not forget that for the forseeable future many products, in many situations, will continue to be applied through conventional hydraulic nozzles - even if they are somewhat inefficient. The range and complexity of equipment that is available (in principle) is amazing; from simple hand tools to highly complex tractor systems. In the end the requirement is the same - to break up the liquid into appropriate sized droplets, and to put them where they are needed. Sometimes these requirements are complimentary, and sometimes they are in conflict. I believe some of the problems of the lack of penetration of cereal canopies and the move to the need for air-assistance for low volume systems is an example of the result ofsuch a conflict. In general, low volume, narrow droplet spectrum systems produce low velocity drops at the target compared to hydraulic nozzles. These differences will be discussed later on; and following speakers will be addresssing the problems of canopy penetration.

I suspect that two of the most controversial aspects of modern pesticide spraying are:-

1) What size droplets do we want for a particular purpose?
2) What size droplets are we actually getting?

The preoccupation with these questions is perhaps both surprising and understandable. In my mind they are certainly very important, but not necessarily paramount in the final analysis of "does a product work?" The final performance in influenced by all the stages of the process and it is of no value getting the ideal size droplets to the correct place if the subsequent behaviour is inappropriate.

There is a great danger in a research environment that we become shielded from reality, and that carefully proven laboratory concepts are shattered in the real world. As someone who works mainly in a spray laboratory situation - and as some of you know, laboratories with a high degree of flexibility and control - it never ceases to amaze me that things work in the field at all! The wind blows, the tractor bounces about, the nozzle/target distance goes haywire, all the leaves get in the way of each other and so on. It is a far cry from passing a single nozzle (of whatever concept) over a single row of potted plants at a constant speed.

So how can we cope? I believe we can make much progress in our understanding and control of the process; but we must always have a thought for reality and the practical limitations on our theoretical ideals. As I mentioned earlier, probably one of the most controversial areas at present is that of the measurement of droplet size. I shall carefully ignore the question "what size do we want for a particular purpose?" That may or may not be answerable by my more biological colleagues!

I do not intend to review the many traditional methods for measuring droplet size that have been - and still have to be used; however I think you will agree that the advent a few years ago of new laser measuring techniques was seen as the beginning of a new era. In concept these new techniques offered tremendous advantages in speed of use, quantity and type of data, and above all offered the prospect of measuring droplets in flight, without all the problems of droplet capture. Of course the techniques were not developed for our business originally, and we have tried to adapt them to our needs. Although by no means the only laser systems available, the most frequently used instruments in pesticide research are those manufactured by Malvern Instruments, Malvern, England, and by Particle Measuring Systems, Boulder, Co, USA, (subsequently referred to as the Malvern and PMS systems). It may be useful to ponder a moment on the origins of these systems, because it may help to explain some of the problems that have subsequently arisen. The former was developed for studying fuel atomisation processes, (Swithenbank et al,1976), which are generally high velocity dense sprays; the latter was developed for atmospheric physics and low density droplet clouds (Knollenberg,1976). For these reasons their fundamental modes of operation are entirely different. The essence of the Malvern system is to measure the composite diffraction pattern generated by a cloud of droplets, whilst the PMS system is designed to measure the shadow image of individual droplets in the cloud as they pass through the laser beam.

I do not intend to explain the detail of each system, that has been published on a number of occasions and literature is available from the manufacturers; however there are a number of aspects I do want to discuss. It is, I believe, most unfortunate that the acceptance of these new techniques has not been - and indeed is still not - harmonious, and that in some circles there is a great conflict as to which technique is "right" or "better". Perhaps this reflects one of the problems of our industry - in that there has not been a fully equipped, generally accepted central "body" whose function is to develop and evaluate new concepts - be it a measuring device or a spraying system. Such work has always tended to be done by individual groups - frequently with a commercial or financial interest in one system or another.

There are, and always will be, fundamental differences between these laser systems; and unfortunately little has been done to realistically assess their merits, or to relate them to practical needs rather than theoretical ideals. What I do think is important is that present - and future - users of either system realistically assess their requirements. Both systems have limitations and both need to be used within their design constraints. Both systems can now offer a number of options in terms of size range, and this should be carefully considered. It is irresponsible to use a technique "blind", without adequate thought to the implications or sense of the data. As with so many modern techniques, it is very easy to get masses of numbers from a print-out; it is much less easy to know what they mean. Equally to attempt to superficially judge one against the other can be very dangerous - far better to develop thoroughly evaluated assessment methods.

The concept of a test procedure where "identical nozzles" are tested by different individuals with different instruments is fine in principle - and I believe is under progress within BCPC at present. To my mind the first priority should be to start at a more fundamental level than that; using a more standard test sample than a hydraulic nozzle spraying water or dilute surfactant. In USA, members of the ASTM Sub-Committee E29.04 have attempted this on a number of occasions, with limited success to date.

As some of you know I have been attempting this by using clouds of glass beads instead of droplets. Such an approach offers the fundamental benefits that they can be collected and retested, taken from place to place, and will be independant of test conditions. The concept is intrinsically very simple - ie pouring a sample through the laser beam. To improve the methodology the "hour glass" concept can be used, thus controlling the flow rate and position of the falling cloud. This concept has been used by (Arai et al,1982) to study factors including the effect of "sample length" along the beam in the Malvern system, illustrating the potential problems of multi-diffraction and subsequent apparent size reduction that this can cause.

A number of bead samples have been tested that are readily available (Jencons Ltd., Leighton Buzzard, England). These are not monosized calibration systems but have a spectral width typical of at least some atomizing devices. Samples have been measured on a number of instruments, and typical data using a Malvern 2600 and PMS 2D system is shown in Figure 1. I believe this shows a most encouraging fact - that the two systems can give similar answers. Possibly of more importance is the fact that such a test emphasised the need to develop the most suitable method of using any technique. This was especially the case with the choice of lens for the Malvern system. Many of the early instruments had only one or two lens options, thus restricting the size range measurable. It concerns me that much of the early data that was published was obtained - in my view - with systems with unrealistic size ranges, especially for droplets greater than 200µm. Indeed, Bals (1983) suggests limitations for the various lenses now available. I would be interested to know how much support this approach has received. In my view this suggests that perhaps the 1000mm lens would be the most generally appropriate.

Equally I do not think the PMS system is without its own limitations. There are a number of models available, and with the 2-D imaging system that has found major use in pesticide research the optical range used by different individuals ranges from 10-640µm to 28-2062µm (each subdivided into 62 size channels). It is therefore just as important to relate the instrument's range to the system under investigation.

Measurement of coarse sprays with the 640µm range will lead to an underestimation of the coarse droplets, and measurement of, for example, an Ulva with the 2062µm range would so compress the data into the first few size channels that the data would be equally suspect. For some applications it is also most important to correctly position the laser beam to avoid "out of focus" rejection routines discarding data. These general instrumentation problems have recently been discussed in great detail, with contributions from a wide range of applications, at the 5th ASTM E35-22 Applications Symposium (November 1984, Kansas City, Missouri, USA.).

For now my point is simply this:- let us drop the competition between the systems, let us develop appropriate testing methodology, and apply either system as necessary to increasing our understanding of the droplet clouds themselves - after all these instruments are only tools with which to tackle the real problems!

2. Sampling the droplet cloud

I believe that the next major hurdle we have to tackle is "what do we want to know about a droplet cloud?" No practical atomizer produces a homogeneously distributed cloud of monosized droplets; so how are we going to sample and comment on what we have? I think we will all accept that the local size distribution from, for example, a fan nozzle can be very specific - frequently with coarser droplets at the edge, changing with distance from the nozzle, and of course changeable as a function of formulation composition. These effects have been illustrated on a number of occasions (Western 1982). Similar effects have been reported with spinning disc systems (Bode et al 1983). I believe we need to resolve generally acceptable sampling procedures. With a fan nozzle, for example, there are the options of sampling statically through the fan at any fixed point, traversing the width of the fan normal to the laser beam, or for the Malvern system, fitting the whole fan in "along" the laser beam. Markham (1982) elegantly describes a number of sub-sampling regimes for the Malvern system. For the normal PMS probe system the sample length is physically restricted so this latter option is not appropriate.

The method adopted may depend on individual needs, but finally the method should be appropriate to the end-use of the spraying system. Thus a leaf does not receive one segment of a spray cloud, but rather is subjected to the passage of a volume of spray. It does not receive droplets only from the nozzle directly above (perhaps fine ones), but also from the edges of adjacent nozzles (perhaps coarse droplets). Thus what is the value of static measurements directly under the centre of a nozzle? I believe we should try and reproduce with the laser beam what the leaf might experience. For a single nozzle test this might best be achieved by traversing the cloud across the laser beam at a typical target distance - but perhaps really we should start thinking about using a multi-nozzle system instead.

With spinning disc systems such as the Herbi or Micromax where do we measure the droplet distribution? Frost & Green (1978) have used photographic techniques close to the disc itself. Some published data tends, unfortunately, to be less specific in defining sampling position. I think this situation needs to be improved. Bode et al (1983) have used the PMS system close to the disc, and demonstrated a number of interesting effects - particularly the change in distribution brought about by using "real" formulations. I have recently been using our PMS system close to the disc, with the trajectories normal to the laser beam, and also slowly traversing the whole droplet cloud from the horizontal disc over the laser beam at a typical target distance. At low spin speeds these two methods have shown surprisingly good agreement. At higher speeds the close-up measurements have shown a higher proportion of fine droplets. Perhaps these are never adequately contained within the spray cloud as it falls, and so are not detected in the traversing mode.

Thus in concluding this section of the paper I do believe there are a great number of factors that we have to be continually aware of - and many that I have not touched on here. Tate (1982) gives a very useful summary of the whole situation, and concludes with the following comments that I support entirely.

> "It is evident that accurate instrumentation in itself is not sufficient. Equal attention must be given to sampling methods, data reduction procedures and terminology. With most atomizing devices, the liquid breakup mechanism is so complex that droplet size spectra cannot be predicted by hydrodynamic theory. Considerable reliance must therefore be put on empirical data. The ability to recognize and challenge questionable data is especially important. Thus, experience and judgement are valuable attributes for those who measure droplet size or utilize the information in the design or application of atomizing systems."

3. Travel to the target surface

I have discussed at length aspects of the atomization stage. It is of course only the beginning of the process; and I would now like to move to the next stage - that of transport to the target surface. This is the principal theme of much of this session, and I do not intend to impose on the following speakers' topics; but merely to make a few comments by way of introduction for what they may have to say.

As I mentioned earlier I do feel that the problem area of droplet transport and canopy penetration is one which has to some extent developed alongside new application techniques. With conventional hydraulic nozzles on a boom system the droplet velocities can be quite high. This can lead to droplet reflection and/or shatter on impact with upper canopy leaves; possibly fortuitously leading to improved penetration down into the canopy. I do believe that the importance of droplet velocity has been underestimated, and there is a general lack of relevant data. Hopefully I can now provide some data to stimulate thought in this area. It will be clear to all of us that with a horizontal disc system the droplets have no initial downward direction; and only subsequently begin their descent towards the target. Obviously this descent is a gravitational effect, and the droplets cannot achieve high velocities. I suspect that in many cases droplets of "real" formulations settling at or near to their terminal velocities are unlikely to bounce - and certainly unlikely to shatter. For this reason the initial capture may be good, but penetration of dense canopies by such droplet clouds is likely to be limited; as has been found to be the case.

In an attempt to improve this limitation we are now seeing a number of devices, such as Sprayrites' Turbo Rotary Atomizer, (Hardman, 1984) employing "air-assistance" in order to blow the cloud into the canopy.

An interesting alternative concept has been the development of a vertical disc - the Girojet, by Technoma - about which we have already heard in a previous session. One feature of this concept is that it imparts - at least on that portion of the spray reasonably under the disc - a significant downward velocity. Close to the disc these velocities are quite high, but inevitably by the time the droplets reach the target (40-50cm) the air drag has slowed them down significantly. These velocities are however still higher than they would be from gravity alone.

Examples of typical velocity profiles for these systems are shown in Figure 2. This data illustrates one of the major attributes of the most advanced PMS system, in its ability to simultaneously measure in-flight droplet size/velocity profiles, thus providing a rapid means of obtaining such data. As can be seen from the data, the droplet velocity is very dependant on droplet size in all cases. For the case of a typical fan nozzle at 296KPa operating pressure, a 250µm drop is typically travelling at 8 $m.sec^{-1}$ at 40 cm below the nozzle. This general profile will be raised for increasing pressure, increasing throughput and decreasing height. For the vertical disc, the velocities of equivalent sized droplets are somewhat less, and there is a marked dependance on spinning speed (as indicated). The speed has a major effect on velocity, but only a minor effect on size distribution, (at least for water), so it would be interesting to assess the relative penetrating power of the different speeds.

For the horizontal disc the vertical velocities at the target can be seen to be approximately terminal, as one might expect. Thus these techniques present an interesting range of conditions under which the droplets are propelled towards the target surface. It will be interesting in due course to measure the velocity profiles from the air-assisted devices using this technique.

Once again of course we must temper this seemingly valuable data with the reality that it is obtained from a stationary (or slowly moving) atomizer. In practise any atomizer may be travelling over the target at several metres per second. This is going to grossly complicate the trajectories. The final effect of this movement on the spray cloud has been illustrated by Goehlich (1979) and serves to remind us to think through all aspects of the process. Attempting to think through the whole process (or part of it) is of course a function of mathematical modelling, and we are fortunate to have speakers who have contributed much in this area. Modelling and computer simulations have been applied to many aspects of the spraying process - including sprayer performance droplet evaporation droplet transport, and droplet retention to give some examples. The number of factors to be considered can be enormous, and success has been somewhat variable. Modelling techniques have been successfully applied however; and predictive use is made of them for spray operations - particularly for forestry spraying in USA (Barry & Ekblad, 1983). New techniques and ideas continue to be investigated, and new models proposed (Schaefer & Allsop 1983), so it will be particularly interesting to hear the latest views of our speakers this morning.

4. Impaction with the target surface

The final area that I would like to comment on is that of droplet impaction with the target surface. This of course crosses boundaries with other sessions of this symposium, but again demonstrates the need for an overall view of the process. At the research level the use of individual droplets to study aspects of the impaction stage and resultant behaviour on the target surface has been very popular. The accurate production and placement of the minute volume contained in a single droplet continues to be a problem, and for purely practical reasons droplets of 0.2μl - 1.0μl are often applied by micro-syringe. These are of course enormous compared to typical spray droplets.

A new concept that offers exciting possibilities in the controlled production and placement of single droplets is that of Ink Jet technology. Some modern printers literally spit out individual droplets - as required - to build up characters on a dot matrix principle. This is a very active field of technology, and I believe could offer us many exciting opportunities (Keeling 1981).

Based on this technology I have constructed a single jet prototype, and this is currently being used in a number of projects. The device has been described in detail recently (Young 1984). The basic principle of operation is that a single voltage pulse is applied to a piezoelectric disc forming one wall of a liquid chamber. The resultant compression forces the liquid out through the tip; and under the correct conditions a single droplet is ejected. It must be stressed that this is a prototype, and colleagues will bear witness that it can be difficult to use! However it can produce individual droplets of repeatable constant size, and "fire" them over a constant trajectory with a high degree of accuracy. A wide choice of droplet size is possible by having interchangeable tips, and both aqueous and non-aqueous formulations have been used. The device enables accurately controlled dynamic impaction studies of "spray sized" individual droplets onto target surfaces for retention/spreading studies (identical droplets can be sequentially impacted onto different leaf surfaces), for calibration purposes (onto slides or cards), or for biological studies on specific areas of a plant or insect. The droplet size itself cannot be accurately preset at present but requires measuremennt. The PMS system has proven invaluable in this respect because the simultaneous size and velocity of a single droplet can be measured. Thus by positioning the laser beam just above the target surface, the conditions at the moment of impact can be accurately determined.

CONCLCUSION

In conclusion I hope that I have illustrated that pesticide spray application is both a nightmare of complexity and an area in which many exciting developments are taking place. New technologies are continually offering new opportunities - both in spray production and in studying the process. We must however continually be aware of any limitations new techniques may have, how best to apply them, and above all never to lose sight of the realities of the final operation.

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