Jiří Vondřička and Peter Schulze Lammers, Bonn

Mixing process as Part of a Direct Injection System

In order to reduce the response time of direct injection systems, the point of injection has to be moved close to the nozzle. This positioning dramatically hinders the mixing process of the medium (water) and the pesticide through natural turbulence. This paper discusses the mixing process in the nozzle and methods of homogenizing in flow.

Dipl.-Ing. Jiří Vondřička is member of the DFG-Graduiertenkolleg 722 and scientist at the department of Systemtechnics in Plantproduction (Head: Prof. Dr.-Ing. Peter Schulze Lammers; e-mail: *lammers@uni-bonn.de*) at the Institute of Agricultural Engineering of Bonn University, Nussallee 5, 53115 Bonn

Keywords

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Direct injection systems for pesticide application keep the pesticide and carrier (water) separately and meter and mix both on demand in the pipeline before entering the nozzle. Thus, the system is able to vary the pesticide concentration without leaving residues of pre-mixed solutions in the tank after operation. The ability to change the chemicals and their concentration makes the system suitable for site-specific pesticide application. As a consequence, there is a need to have a specific mixture at the nozzle at the correct time due to the spatial accuracy of the spray system.

There are two operation modes for site-specific pesticide application systems. The first is an offline system based on a weed map generated by a weed recognition system. In this case there is sufficient time to prepare the pesticide solution before entering the nozzle because the weed distribution is known in advance of the pesticide application. This operation mode allows premixing of the solution or preparing an appropriate mixture on demand to provide high spatial accuracy of the sprayer.

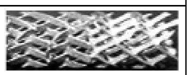
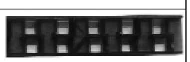
Typ	Beschreibung	Photo
KMS	Serie von links- und rechtsdrehenden Spiralelementen. Ein Element entspricht in der Länge dem Durchmesser. (Chemineer, Inc.)	
SMX	Gerüst sich kreuzender Stege, die schräg zur Strömungsrichtung liegen. Jedes Element entspricht in der Länge dem Durchmesser und benachbarte sind um 90° verdreht. (Koch-Glitsch, LP)	
QUADRO	Rechteckige Elemente, die den Flüssigkeitsstrom in jeder Ebene teilen und drehen. Ein Element entspricht in der Länge 0.75 des Durchmessers. (Sulzer Chemtech)	

Table 1: Static mixers tested for a direct injection system

The other operating mode, a real-time system, couples the recognition system (camera) with an application system (sprayer). The spatial accuracy of a real-time system depends on the distance between recognition and application system, operation speed and reaction time of the entire system. The maximum distance between camera and sprayer is expected to be less than 1 m, when mounted at the sprayer boom for mechanical stability. The regular operation speed is between 2 and 5 ms^{-1}. Therefore the maximum system response time should be less than 0.5 s. To reduce the response time of the direct injection system, the distance between the injection point and the nozzle has to be minimized [1]. The application system response time consists of two parts – injection time or response characteristic of the injection metering system, and transport time between the injection point and the nozzles by the carrier flow. In the second part a uniform pesticide mixture has to be provided before the mixture enters the nozzle.

Zhu et al. [5] stated that by injecting viscose materials in the spray boom, the mixture uniformity without a mixing device is not adequate. Rockwell and Ayers [4] reported about problems with mixing dye and carrier by injection in the nozzle as well. In this paper "Computational Fluid Dynamics" (CFD) software was used to optimize the mixing process and to design an appropriate mixing chamber by simulating the flow and mixing process in the direct injection system. The results were verified by experimental tests.

Material and Methods

The mixing process should reduce the concentration inhomogeneity in order to achieve a desired process result. To determine the mixture quality the standard deviation is normalized by dividing it by the mean concentration, giving a function called the coefficient of variation (CoV=standard deviation of concentration measurements/mean concentration). This function (most often reported as percent) is also called "intensity of mixing" or "degree of segregation" and is easy to comprehend. The Federal Biological Research Centre Germany (BBA) has determined the quality of the mixture in a conventional sprayer tank to have less than a 15 % deviation in homogeneity. In a typical industrial mixing process an additive might be considered well mixed at 5 % CoV [2]. In a direct injection system the 5 % CoV can be taken as the limit for a well mixed homogenous mixture as well. An effective water-pesticide concentration is needed before the mixture enters the nozzle which applies it to the target area. The mixing process inside the mixing chamber must be continuous, as fast as possible for real-time systems, and should result in a mixture with a high degree of homogeneity. In order to achieve the short re-

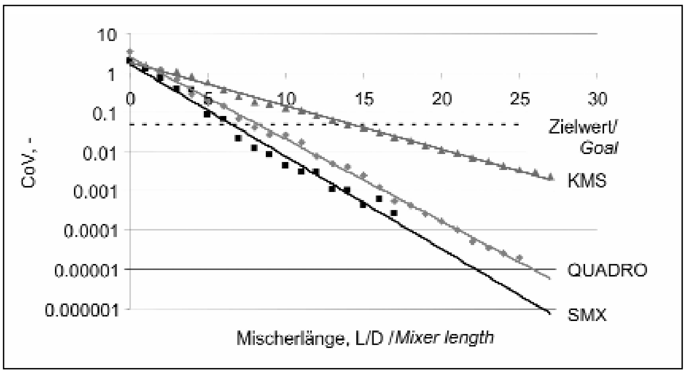


Fig. 1: Homogeneity expressed as coefficient of variation (CoV) versus mixer length for three static mixers operating in laminar flow

sponse time as required for the real-time application the mixing chamber should be as small as possible by constant carrier flow.

An early first step in the understanding of the continuous mixing process is the identification of the flow regime in which the process operates. The fluid flow rate and physical properties of the fluid are the determinants. The flow regime can vary with the flow rate and along with the length of the mixing chamber. However, the quality of the mixture cannot be dependent on the flow regime. It must never occur that a part of the mixture on the nozzle contains a toxic concentration, which can contaminate the environment.

Blending in a flow can be radial or axial. With turbulent flow there is mass interchange in both the radial and axial directions due the turbulent eddies. In laminar flow the velocity vectors are parallel and there is no radial mixing. When the flow is a highly turbulent single phase, there are many mixer design options like empty pipe, valves, nozzles, tee and jet mixers or static mixers. When the flow is laminar, either single or multiphase, there are static mixer the only design class option. Other mixing devices available for turbulent flow are not usable. The motionless mixers are based on the principle of moving the streams radially by a series of baffles.

These baffles may consist of twists of metal or plastic, corrugated sheets, parallel bars, small-diameter passages and of tabs sticking out from the wall. Because of the need to blend with different flow regimes and fluid properties, three different mixer designs presented in *Table 1* have been found and their optimization studied in direct injection system.

For theoretical investigation of the mixing process the Computer Fluid Dynamics (CFD) software from Comsol Multiphysics was used. This software allows modelling of flow relations as well as chemical reactions. The results were compared with known data from literature and verified by decolourisation method [3].

Results and discussion

The calculated efficiency of selected mixers is presented in *Figure 1*. It clearly shows the high efficiency of the SMX static mixer. This mixer has a highly complicated design, which is difficult for model calculation. It has to be made of stainless steel and the assembly is very costly. The other two static mixers (KMS and QUADRO) are low cost alternatives. The KMS mixer produces poor mixing result in comparison with the QUADRO mixer, which blends similar to SMX static mixer.

The mixing process of the static mixers was simulated under different conditions. The mixer length of each mixer was increased, when high mixing ratios were blended or the viscosity of mixed fluids differed significantly, to get the same output homogeneity.

The mixing process in the nozzle was measured using the decolourisation method. In *Figure 2a* data measured on the nozzle without mixing device are presented. The measurement homogeneity is presented as time function with mean homogeneity of 91.65 % (black line) and standard deviation of 3.34 % (white lines).

The homogenisation process was measured for 1 % additive concentration (viscosity 1 mPa s). According to this Gaussian distribution of data, 97.5 % of the mixture homogeneity is better than $\bar{x} - \sigma = 88.31$ % (*Figure 2a*, lower white line), which is not sufficient for DIS and an appropriate mixing device has to be used.

For comparison, the homogeneity of DIS equipped with 16 L/D static mixer is presented in *Figure 2b*. The mean homogeneity (black line) was 99.67 % and the standard deviation (white line) was 0.25 %. Consequently 97.5 % of the outflow volume was homogenised better than 99.42 % (see above).

Discussion and Conclusion

Based on the simulation results, the SMX static mixer offers the best mixing performance, however its complicated design make it difficult for modelling and it is very cost intensive for the DIS. Two low cost mixers (KMS and QUADRO) were further tested as an optimal alternative on different conditions in laminar flow.The KMS static mixer is a simple alternative for mixing but the QUADRO static mixer offers more mixing performance.

The mixing process depends directly on the initial parameters of the process. Thus, there is no universal solution for the DIS mixing chamber and the mixing device has to be designed individually. Because of the inaccuracy of each model, the mixing chamber was tested by experimental test.

A decolourisation method and specific light transmittance sensor were developed for on-line measurements of mixture homogeneity. Applying this method, the mixing process in the DIS nozzle with KMS static mixer was tested. The results indicated that an appropriate mixing chamber is necessary for homogenising of carrier and injected pesticide.

Literature

Books are marked by •

[1] • *Hlobeň, P.*: Study on the response time of direct injection systems for variable rate application of herbicides. Dissertation, Bonn, 2007

[2] • *Paul, E. L., V. A. Atiemo-Obeng and S. M. Kresta* : Handbook of industrial mixing: science and practice. John Wiley and Sons, Hoboken, New Jersey, 2003

[3] • *Bartels, P.V.* : An experimental study on turbulent mixing of visco-elastic fluids : proefschrift. Dissertation, Delft TU, 1988

[4] *Rockwell, A.D., and P.D. Ayers* : A variable rate, direct nozzle injection field sprayer. Applied Engineering in Agriculture 12 (1996), no. 5, pp. 531-538

[5] *Zhu, H., H.E. Ozkan, R.D. Fox, R.D. Brazee and R.C. Derksen* : Mixture uniformity in supply lines and spray patterns of a laboratory injection sprayer. Applied Engineering in Agriculture, 14 (1998), no. 3, pp. 223-230

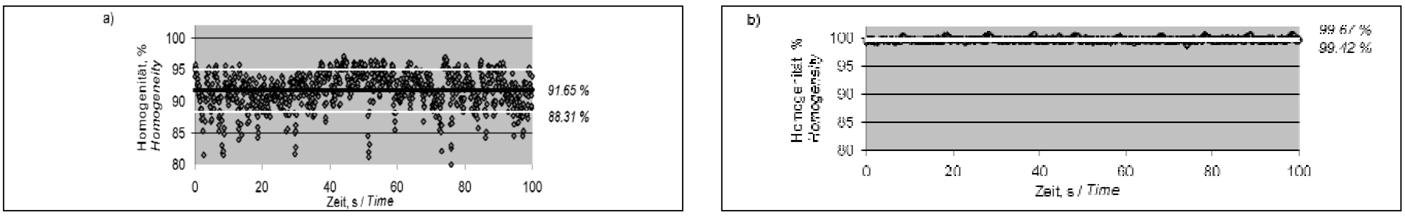


Fig. 2 a, b: Homogeneity as function of time in direct injection system without mixing device (a) and with 16L/D static mixer (b)