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STUDY ON THE MIXING PROCESS IN DIRECT INJECTION SYSTEMS FOR SITE-SPECIFIC HERBICIDE APPLICATION

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Abstract: The direct injection systems for herbicide application keep the herbicide and carriers (water) separetand meter and mix both on demand in the pipeline before entering the nozzle. That makes possible varying of herbicide concentration without leaving residues of pre-mixed solutions in the tank after operation. The ability to change the chemicals and their concentration make the system suitable for site specific herbicide application. As a consequence, there is a need to have a specific solution at the nozzle at the correct time due to the spatial accuracy of the spray system.

Key words: *herbicide, site specific application, mixing process, homogeneity, CFD.*

INTRODUCTION

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

There are two operation modes for site specific herbicide 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 herbicide solution before entering the nozzle because the weed distribution is known in advance of the herbicide application. This operation mode allows premixing of the solution or preparing an appropriate mixture on demand to provide high spatial accuracy of the sprayer.

The other operating mode, an online system, couples the recognition system (camera) with an application system (sprayer). The spatial accuracy of an online 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 lies between 2 and 3 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. The sprayer response time consists of two parts – firstly injection time or response characteristic of the injection metering system, and secondly transport time between the injection point and the nozzles by the carrier flow. In the second part a uniform herbicide mixture has to be provided before the mixture enters the nozzle.

Zhu et al (1999) stated that by injecting viscose materials in the spray boom, the mixture uniformity without a mixing device is not adequate. Rockwell and Ayers (1996) reported about problems with mixing dye and carrier by injection in the nozzle as well.

In this paper Computational Fluid Dynamics (CFD) software is 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 will be 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 average, giving a function called the coefficient of variation (CoV=standard deviation of concentration measurements/mean concentration). This function (most often reported as a percent) is else often called intensity of mixing or degree of segregation and is easy to comprehend. The BBA (Federal Biological Research Centre Germany) 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 (Handbook of Industrial Mixing). 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-herbicide 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 online systems, and should result in a mixture with a high degree of homogeneity. In order to achieve the short response time as required or the online 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 determinates are the fluid flow rate and physical properties. Flow regime can vary with flow rate and along the length of the mixing device. 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 has 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 highly turbulent single phase, there are many mixer design options like empty pipe, valves, nozzles, tee and jet mixers, static or motionless mixers. When the flow is laminar, either single or multiphase, there is only one design class option: static or motionless mixers. Other inline mixing devices 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 (vide infra), three different mixer designs (KMS, SMX and Quadro) have been found and their optimization studied in direct injection systems.

I. KMS: twisted ribbon or bowtie type, with alternating left- and right-hand twists. One element is 1.5 or 1.0 diameter in length. (Chemineer, Inc.)

II. SMX: several stacked sheets of corrugated metal running at 30° or 45° to the pipe axis. Each element is 0.5 to 1.0 diameter in length and adjacent elements are rotated 90° relative to each other. Mixer hydraulic diameter is determined by the height of the corrugation or the number of stacked corrugated sheets. (Koch-Glitsch,LP)

III. QUADRO: square shaped mixer doubles the number of formed layers on each mixing element. One element is about 1 side size in length. (Sulzer Chemtech)

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. Because of the numerical diffusion effect by CFD software, the results will be compared with known data from literature and verified by experimental methods after that.

For different mixing chamber designs the effect of mixing ratio, fluid properties (viscosity and density) and the effect of different inlet position in the mixing process will be studied.

The results for blending in pipeline mixing chamber can be correlated by plotting the coefficient of variation reduction (CoVr = final CoV value/initial CoV value) versus length/diameter ratio (L/D). In laminar flow there is no effect of viscosity, flow rate or initial CoV on these correlations by motionless mixers. CoVr is usually found to correlate with the L/D in an exponential form,

$$\mathrm{CoVr} = \mathrm{Ki}^{L/D} \tag{1}$$

where blending coefficient Ki depends on the mixing device design and flow regime. The CoVr represent the effect of mixing ratio in this case. The effect of viscosity in turbulent flow for motionless mixers has been described by empirical relation (Streif et al 1988)

$$\left(\frac{L}{D}\right)_{\mathrm{uneyual}} = \left(\frac{L}{D}\right)_{\mathrm{equal}} + K \log \frac{\mu_c}{\mu_d} \tag{2}$$

where μ_c/μ_d is the viscosity ratio and K is a coefficient depending on mixer type. There is no relation for the density effect, because the impact depends mostly on position of the mixing unit. The initial injection position affects the quality of mixing, especially in motionless mixers where the division on the edge of an element is important for the mixing process. The determination of the optimal inlet position is also necessary for the mixing chamber design.

The mixing process is studied for the sprayer with a forward speed up to 3 m s/1, water application rate 100 – 500 l/ha, herbicide application rate 0,2 – 5 l/ha and different herbicide viscosity 1 – 500 mPa s and density 900 – 1200 kg/m^3.

RESULTS AND DISCUSSION

The main problem with studying the mixing process in direct injection systems is the identification of the fluid dynamic mode in sprayer pipelines. Usually it varies with the machine operation speed and water application rate. The flow regime changes from laminar, to transient to fully turbulent. There is no mixing in the pipeline in the laminar flow regime. It is possible to achieve transient and fully turbulent flow in pipeline during operation by reducing the diameter.

The simplest possibility to mix the fluids is using axial interchanges in an empty pipe in turbulent flow. The value for Ki is 0.95 (Streiff et al. 1999) in this case. As initial conditions for the mixing process investigation, normal operation values for conventional field sprayers (200 l ha-1 water application rate, 2 l ha-1 herbicide application rate and 2 m s-1 operation speed) and herbicide with physical properties similar to water have been used. It is necessary to move the injection point up to 105 L/D before the nozzle to achieve the final CoV of 5 %. The mixing length will be several times longer for viscose materials or turbulence flow (slower application speed etc.). For example, the mixing process for injecting in an empty pipeline used by Hloben (2006) has been studied and calculated. Two types of direct injection systems were considered in that study. For the configuration with a central injection in the pipeline boom section consisting of 6 nozzles the calculated CoV value on the nozzle was as high as 192 % and for the configuration with direct nozzle injection it was as high as 800 %. The mixing in a pipeline without a mixing device is also not suitable for direct injection systems.

A simple approach to pipeline mixing in turbulent flow involves the use of side injection tees. Fornay and Lee (1982) found that the momentum of the side stream must be high enough to mix fully with the bulk stream to achieve shortest mixing length. When the momentum is low, the side stream will be deflected and becomes a sidewall injection and the mixing length will be about 50 to 100 diameters. A tee mixer can rapidly reduce the mixing length by ca. 7 diameters under optimal condition but the mixing length will increase with low momentum of the side stream, low turbulences, higher viscosity etc. Therefore, using a tee or jet mixer (similar mixing principle) cannot ensure optimal homogeneity in all condition by direct injection systems.

Motionless mixers are a very efficient design option in all flow regimes and also mix fluids with high viscosity ratios. The efficiency of their mixing process was evaluated by the Ki coefficient. The CFD software calculates the blending coefficient for different flow regimes. The calculated efficiency in laminar flow is compared with known values (Streiff et al. 1999) in Table1.

Table 1: Blending coefficient Ki for different motionless mixers – comparing calculated and known values and laminar and turbulent flow regime

Device	Ki –Laminar (calc.)	Ki-Laminar (Streiff)	Ki-Turbulent (Streiff)
Empty pipe	0	0	0.95
KMS	0.78	0.87	0.50
SMX	0.58	0.63	0.42
Quadro	0.61	-	-

Lower values of the blending coefficient (i.e. better mixing properties) in the column with calculated numbers is probably caused by numerical diffusion (see above). The effect of inlet position has been studied by CFD simulation as well. Especially with the KMS and Quadro mixer it is preferable if the herbicide concentrate flow is divided by the edge of the first element alternatively 2 – 6 mixing L/D has to be added to ensure the mixture quality.

The effect of viscosity on the mixing process can be documented with a simple mixing device (Fig.1), where two fluids are mixed under same initial flow condition. The CoV for low viscose fluid is 0.27 and for high viscose fluid it is 0.56! The impact of viscosity on the mixing process becomes clear. The coefficient K for selected mixers will be looked for.

Figure 1: Simple mixing device for testing viscosity impact on mixture homogeneity

By using known parameters the SMX mixer is an optimal solution because it has highest performance compared to other devices when mixing fluids with high viscosity ratios. A length 11 L/D is necessary to mix a herbicide to water ratio up to 1:1000 (corresponding 0.2 litre herbicide and water application rate 200 l/ha), and a viscosity ratio up to 500:1 (viscose herbicide 500 mPas and water) in turbulent flow regime while 14 L/D is required in laminar flow regime. With the KMS mixer the mixing length will be ca. 16 L/D in turbulent or 46 L/D in laminar flow regime. Turbulent flow is also needed to achieve the possible shortest response time in online driven direct injection systems because of more mixing efficiency in comparison with blending in laminar flow regime (Table 1). By direct nozzle injection the smallest mixing chamber volume can be just about 233 mm^3. The time delay for standard flow conditions should be 12 ms for the SMX mixer under average flow conditions.

CONCLUSION

If all possible herbicides should be mixed, an effective mixing device is necessary to achieve appropriate homogeneity of water – herbicide mixture by all after-carrier pump injecting systems according to the first CFD investigation. Nowadays, current injection systems using only mixing in turbulent flow need a long L/D ratio to achieve the required homogeneity and are not usable with viscose chemicals. If a short mixing length or reaction time is required, the motionless mixers show good accuracy for application in direct injection systems.

Turbulent flow is recommended to optimize the mixing process and to minimize the time delay in the mixing chamber, which can be very small under optimal conditions.

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PROUČAVANJE INJEKTORSKIH SISTEMA U PARCIJALNOJ APLIKACIJI HERBICIDA

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Sadržaj: Sistemi za direktno injektiranje herbicida drže herbicid i nosač (voda) odvojeno i mešaju ih neposredno pred razvodni sistem tj pred ulazak u raspršivač. Na taj način se omogućava variranje koncentracije herbicida bez ostavljanja ostataka u toku pred-mešanja. Mogućnost promene hemikata i njihovih koncentracija svrstava ovaj sistem u jedan od tehničkih sistema lokalno-specifične aplikacije herbicida. Ovo ima za posledicu distribuciju specifičnog rastvora, ka raspršivaču u određenom trenutku kako bi se ostvarila adekvatna preciznost sistema aplikacije.

Ključne reči: *herbicidi, lokalno-specifična aplikacija, proces mešanja, homogenost, CFD.*