Simulation and Design of Mixing Mechanism in Fertilizer Automated Proportioning Equipment Based on Pro/E and CFD

Liming Chen, Liming Xu

Simulation and Design of Mixing Mechanism in Fertilizer Atuomated Proportioning Equipment Based on Pro/E and CFD*

Liming Chen[1] Liming Xu[1*]

1: Address: College of Engineering, China Agricultural University, 17 Tsinghua East Road, Beijing, 100083, P. R.China.

Email: clm871111@126.com.

1*: Corresponding author, Address: College of Engineering, China Agricultural University, 17 Tsinghua East Road, Beijing, 100083, P. R.China.

Email: xlmoffice@126.com.

Abstract. Precision agriculture is the developing trend of modern agriculture, and the rational utilization of fertilizer is one of the key technologies in the precision agriculture, which needs to fertilize variably according to the crop needs and soil fertility conditions. Thus a fertilizer automated proportioning equipment is developed to Proportion the three fertilizers: Nitrogen fertilizer, Phosphorus fertilizer and Kalium fertilizer. The fertilizer will take greater effect after mixing sufficiently, so this paper mainly researched the mixing mechanism. The simulation and analysis of the velocity field and flow field of the fertilizer for the two paddles worked, the spiral-type paddle and multiple-fan-type paddle, are conducted respectively using Pro/E（Pro/Engineer） and CFD(Computational Fluid Dynamics) fluid dynamics analysis software. During simulation, the paddle models are meshed using the Gambit software. Then the multiple- fan-type paddle is determined to be the more suitable one through the FLUENT software.

Keywords: Precision agriculture, Fertilizer Proportioning, Mixing mechanism, Multiple- fan-type paddle, CFD fluid dynamics analysis

1 Introduction

Agriculure is the foundation of our country's economy, but the rough-type form of agriculture is no longer able to meet the development requirements of modern agriculture. Therefore, the development of precision agriculture has become an inevitable trend. Fertilizer, as one of the Production materials in agriculture can increase the crop yield. But for a long time, the extrude Problem of fertilization is illogical fertilizer Proportion and low utilization ratio, high fertilizer input, especially the phosphorus fertilizer input, which results the nutrient input imbalance and the increasing fertilizer input cost . From 1978 to1995, the national fertilizer consumption has increased by 97%, but grain output has increased by only 36% while the crop yield increased by 1%, and the fertilizer amount applied increased by almost 3%. The average fertilizer utilization ratio is less than the developed countries by more than 10%. The utilization ratio of Nitrogen is 30%, Phosphorus is from 10% to 25%, Kalium is from 40% to 50%. The increasing fertilizer consumption with low utilization ratio results the decreasing fertilizer returns, serious soil pollutions and groundwater, food contamination. If the fertilizer utilization ratio is enhanced by 10%, 100Mt fertilizers will be saved, which comes up to saving about 10 billion RMB Therefore, the reasonable fertilizer amount according to the crop need can enhance the fertilizer utilization ratio and reduce the environmental pollution.

The precision variable-fertilizing technology determines the usage amounts for different kinds of fertilizers according to the soil fertility condition and the crop need. The Proportioned fertilizers should be mixed sufficiently so as to achieve the best effect. Thus it is necessary to design and simulate a mixing mechanism for different kinds of fertilizers.

The key component of the Proportioning mechanism is the stirring paddle, which is closely related to the mixing time and the mixing effect for different kinds of fertilizers. For mechanical mixing， the paddle is the only source of momentum and has close relationship with the fluid flow in the mixing tank. Thus it is very important to design the paddle. This paper mainly designs and simulates two types of paddles in order to choose a more suitable one.

Many researchers have achieved a lot on the variable fertilization technology. The “SOILECTION” fertilization system has been developed by America Ag-chen Equipment Company. It could be applied to solid and liquid fertilizers. This system applied air-seeder and no-tillage seeder can change the used amounts of seeds and fertilizers, even it can change the Proportion of three kinds of fertilizers or seeds. The "SOILECTION" has the advantages of simple, easy to control, high precision and reliability, but it is expensive (Zhao Wuyun et al., 2007). The ST820 variable ratio fertilizer machine with the plant function has been developed by Case Company, it could use the IHAFS software to get the prescription map with computer and then generate prescription file which will be stored in the PCMCIA card. The PCMCIA card could be inserted into the variable ratio controller to Provide preparations for the fertilizer machines to fertilize automatically (Zhao Jun, 2004).

The fertilizer machines and equipments for plant Protection in France have the highest automation level among all the agricultural machineries. The French AMASAT variable ratio fertilizer control system has been applied to various types of the centrifugal fertilization machines (Zhang Xiaohui et al., 2002).

At present, there are two variable ratio fertilizer machines at home, 2F-VRT1 variable ratio fertilizer machine and 1G-VRT1 rotary variable fertilizer machine. The two machines control the fertilizing amount mainly according to the preferences set by users or the prescription map calculated by the upper computer. The machines can receive the GPS location information and the operating speed signals while they are working in real time, then the rotation speeds of the fertilizer-driven systems are adjusted automatically to achieve the purpose of variable ratio fertilization. The machines also support the manual and automatic control modes, and they can broadcast fertilizers evenly on the soil surface. The two machines are applicable to the fertilization work before sowing seeds, the variable fertilization work for the striking root fertilizer of the winter wheat and the variable fertilization work for forages (Wang Xiu et al., 2008).

In addition, Israel and China Agricultural Research Institution have developed the liquid fertilizer automated Proportioning machine, which can finish the irrigation work. The one developed by China Agricultural Research Institution mainly control the fertilizer Proportion by detecting the PH value and electrolytic conductivity of the Proportioned fertilizer liquid. In the Proportioning Process, it needs to adjust the flow of each kind of fertilizer manually. The machine is mainly used for the greenhouses.

There are many researches on the variable ratio fertilization, but the researches are mainly focused on the liquid fertilizer or just for one kind solid fertilizer. Thus, there are few researches focused on the mixing mechanism for the fertilizer automated Proportioning equipment. In China, the solid fertilizers are used mostly currently, therefore, it is very important to develop a mixing mechanism used in the variable ratio fertilizer machine for several kinds of fertilizers.

2 The Variable Ratio Fertilizer Mechanism for Precision Agriculture

An automated matching mechanism for three kinds of fertilizer (N, P, K) is developed in this paper, Fig. 1 shows the working diagram .The mechanism consists of three tanks for three fertilizers. The fertilizers are fertilized by external fluted roller feeds according to the crop needs and soil fertility conditions. The fertilizer feed are driven by step motors to discharge certain amount of fertilizers. The three kinds of fertilizers exhausted get into the mixing tank, in which the fertilizers are stirred and mixed before being fertilized into the soil by another team of fertilizer feeds.

The three kinds of fertilizers discharged into the mixing tank must be sufficiently mixed before being fertilized into the soil. Therefore it is needed to develop a paddle to mix the fertilizers sufficiently. The design of paddles should be done according to the form of installation, and the work block diagram of stirring a mechanism is given in the Fig. 1.

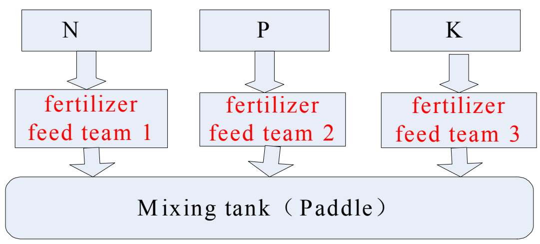

Fig. 1. The work block diagram

Fig.1 shows that the three kinds of fertilizers are distributed in three areas in the horizontal direction respectively. To meet the installation reliability of the whole mechanism, the paddle can be installed in the form of vertical installation or horizontal installation. But the vertical installation needs the blade diameters to be long, while the blade number of the paddles is to be decreased, so the mixing effect is reduced. Thus the paddle is installed in the form of horizontal installation. Due to the low power, large flow and short mixing time of axial paddles, the multi-axial paddle is applied. In this paper, the velocity fields and flow fields of the spiral paddle and the multiple-fan-type paddle are compared and analyzed to determine the suitable one.

In this paper, PRO/E（Pro/Engineer） software is used to design the paddles and finish the motion simulation. CFD (Computational Fluid Dynamics) is used to compare and analyze the velocity fields and flow fields to determine the more suitable paddle. Fig. 2 shows the design flow block.

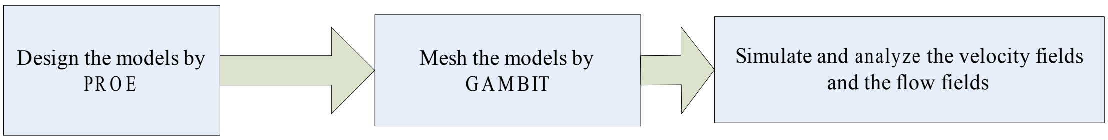

Fig. 2. Design flow chart of the stirring paddle

3 Paddle Design

3.1 Design the Spiral Paddle

In order to gather the fertilizers on both sides to the center, the spiral paddle (Fig. 3) moves in two-opposition-way, and the fertilizers is decentralized when the rotation direction of the spiral paddle changes

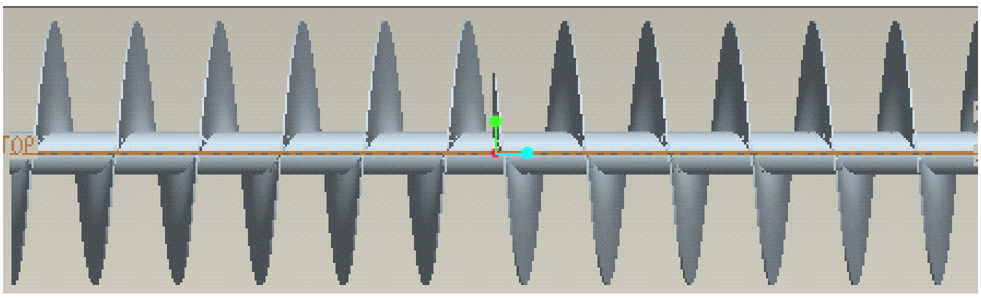

Fig. 3. The structure chart of the spiral paddle

The motion form, motion trace and velocity distribution of the spiral paddle were analyzed through motion simulation in this paper.

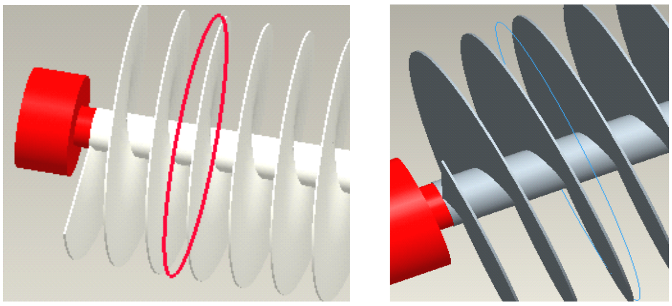

Fig. 4. The path lines of the spiral paddle

The lines with deep color in Fig. 4 are path lines of certain point on the paddle. Fig.4 shows that when the spiral paddle rotates reversely, the path line is outward, so it indicates that the spiral paddle can achieve the effect of decentralizing fertilizers. When the spiral paddle rotates forward, the path line is inwards, so it indicates that the spiral paddle can achieve the effect of gathering fertilizers.

3.2 Design of the Multiple- fan-type Paddle

The design idea of the multiple-fan-type paddle is similar to the spiral paddle, and the biggest difference between them is the blade shape. The blades of the multiple-fan-type paddle are fan-shaped.(Fig.5)

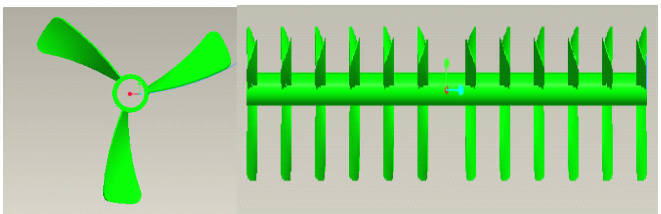

Fig. 5. The geometric structure of the multiple- fan-type paddle

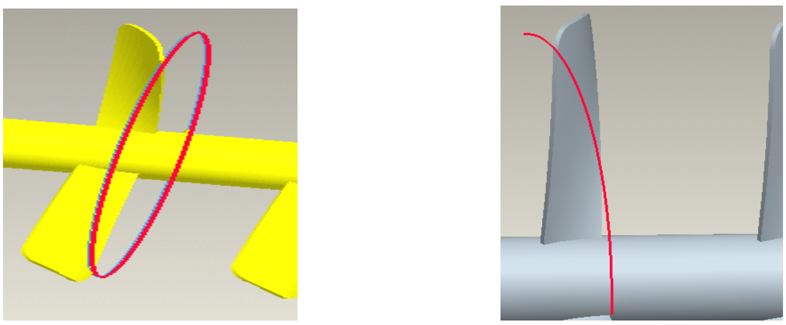

Fig. 6. The path lines of the multiple- fan-type paddle.

It can be seen from the path lines of certain point on the blade that the multiple-fan-type paddle can make the three kinds of fertilizers decentralized or gathered.

4 Simulation of the Stirring Paddles

The fertilizers stirred by the two paddles moved axially according to the PRO/E-based simulation. But the design and simulation in PRO/E can only supply the paddles' own movements, and the mixing Process was simulated by the CFD fluid dynamic software. First of all, the designed geometries were imported into the GAMBIT software to finish the work of meshing and setting the boundary conditions. The GAMBIT was chosen for its compatibility with PRO/E. The GAMBIT software can automatically repair the tolerances in the course of importing files established by PRO/E, which guarantees the stability and fidelity of the interface between PRO/E and GAMBIT. The strong meshing ability makes GAMBIT can finish high-quality meshes with special requirements. The special mesh algorithm for GAMBIT can ensure the high quality of tetrahedral, hexahedral and hybrid grids meshed directly in the area with complex geometry. The most important reason is the meshed file established by GAMBIT can be exported into the mesh file, which can be imported into the FLUENT software to Provide good preparation for analysis. But if the whole paddle is to be meshed and simulated, the amount of meshes will increase greatly, which will make the calculation time too long. Because this paper mainly compares the advantages and disadvantages of the two paddles, some part of each paddle was intercepted to simulate in order to meet the design requirements. The simulation models are shown in Fig. 7 and Fig. 8.

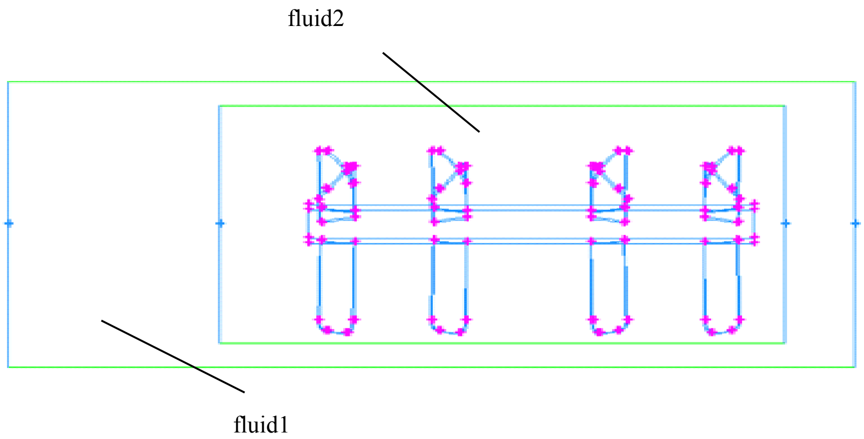

Fig. 7. The simulation model for the spiral paddle

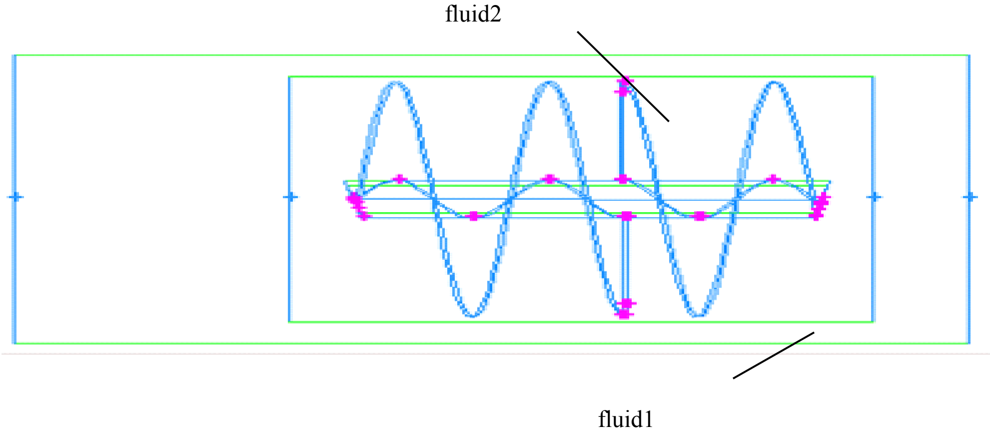

Fig. 8. The **s**imulation model for the multiple- fan-type paddle

In the meshing Process, the mixing tank was firstly subtracted with the fluid area retaining the fluid area, and then the fluid area was subtracted with stirring paddle forming the two basins: fluid1 and fluid2. The mesh size of the field containing the stirring paddle, fluid2, is smaller, while the mesh size of the filed containing the mixing tank, fluid1, is larger .This meshing method could make the analysis of the effect generated by the movement of the stirring paddle to the fluid better. Due to the complex blades of the two stirring paddles, the unstructured tetrahedral mesh was chosen for its strong adaptive ability (Fig. 9, Fig. 10).

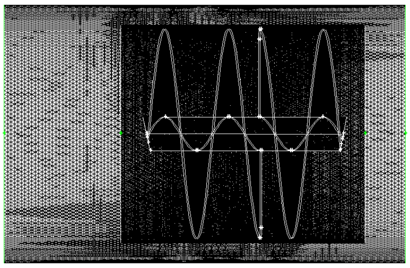

Fig. 9. The grid chart of the spiral paddl.

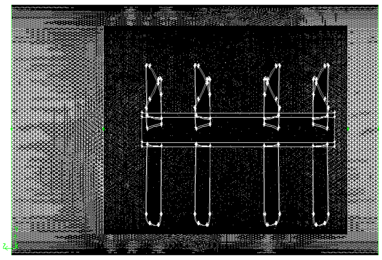

Fig. 10. The grid chart of the multiple- fan-type paddle

After the models were meshed and the mesh quality was checked, the models should be exported in the form of mesh file, and be read into FLUENT to finish the numerical simulations. FLUENT software is designed for fluid analysis, which can simulate fluid floe with complex from incompressible to highly compressible. As a result of a variety of solving methods and multi-grid convergence acceleration technique, the FLUENT software can achieve the best convergence speed and accuracy.

The standard k-ε turbulence model is used to simulate the single-phase flow fields, and the relationship between the paddles movement and the static wall of the mixing tank is apProached using MRF. The area of fluid1 is set to be motive while the area of fluid2 as static. The paddle is set to be moving wall with the movement of rotation, in other words, the paddle rotation is synchronized with fluid2.The momentum exchange and energy exchange between fluid1 and fluid2 are achieved through the interface. Fig. 11 and Fig. 12 are the convergence curves of the two types of paddles. From the two figures, it can be seen that the residuals of the parameters are convergence, which indicates that the used algorithm is feasible.

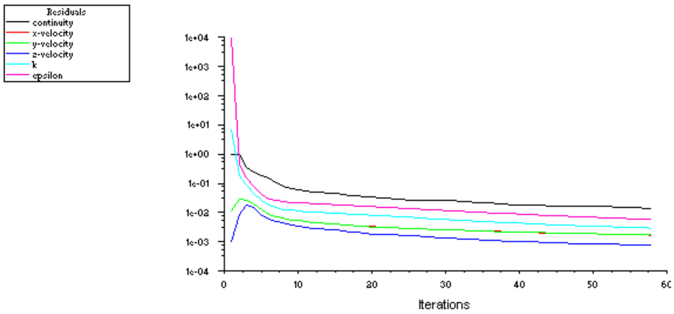

Fig. 11. The convergence curve of the spiral paddle

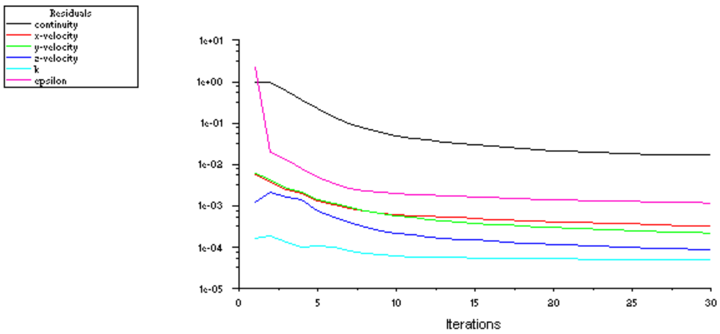

Fig. 12. The convergence curve of the multiple- fan-type paddle

Fig. 13 and Fig. 14 are the speed cloud maps of the two paddles.From the figures, it can be seen that the fluid velocity increases with increasing of the distance from the stirring shaft, and at the blade end position the velocity reached maximum. Then the velocity declines quickly with the distance increasing.

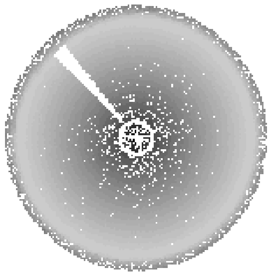

Fig. 13. The speed cloud map of the spiral paddle

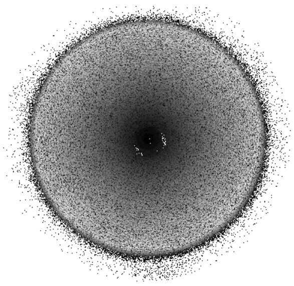

Fig. 14. The speed cloud map of the multiple- fan-type paddle

For a paddle, the flow field formed at work is also an important basis to determine whether the fertilizers can be mixed sufficiently. Because the fertilizer-flow shape is the key factor of sufficient mixing.

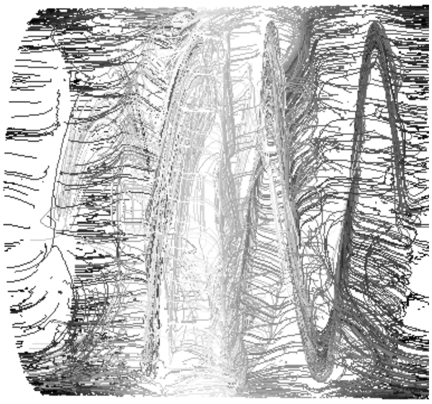

Fig. 15. The flow chart of the spiral paddle

Fig. 15 is the flow field formed while the spiral paddle is operating. It shows that while the paddle is rotating forward, the fertilizers are pushed to move along the spiral by the paddles. Due to the mutual friction of materials, the materials are made to roll up and down, while some part of the materials move along the spiral, which forms the axial spiral movement. The spiral paddle finishes the radial mixing work mainly through making the fertilizers rolling up and down. Because the purpose of the spiral paddle's movement is to gather or decentralize the fertilizers, there is a swirl with high rotation speed in the center of the paddle while the paddle is rotating.

Fig. 16 is the flow field diagram of the multiple- fan-type paddle, from which it can be seen that the fertilizers mainly rotate under the action of the blades. But because the blades are inclined to install and the blade shape is a curved surface, the blade rotation can Promote the fertilizers contacted to move along the axial direction in the spiral form. It also can be seen from the Fig.16 that the multiple- fan-type paddle finishes the radial mixing work mainly through making the fertilizers rolling up and down.

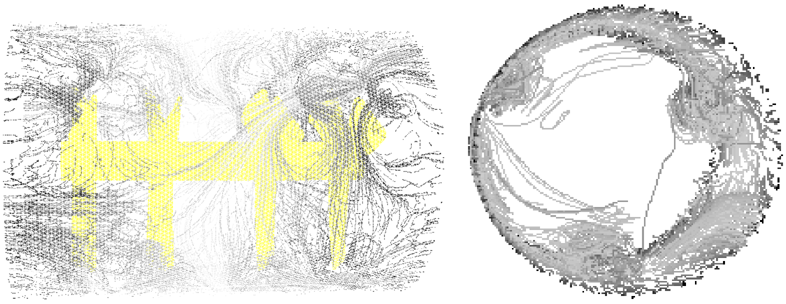

Fig. 16. The flow chart of the multiple- fan-type paddle

From the above simulation and analysis, it can be seen that the two types of paddles both can gather up fertilizers into the center, on the contrary, they also can decentralize fertilizers. Thus, as long as there is one paddle installed in the mixing tank with certain rules to rotate, the fertilizers can be mixed sufficiently.

The two types of paddles both can mix fertilizers sufficiently according to the analysis of the speed cloud maps and the flow field maps. Considering the high manufacturing cost of the spiral stirring paddle, and it causes the high-cost mix mechanism, the multiple-fan-type paddle is chosen to be the stirring paddle for the automated Proportioning equipment.

5 Conclusion

Precision variable ratio fertilization can increase the fertilizer utilization ratio and decrease the environment pollution. Fertilizer automated Proportioning equipment can Proportion the three kinds of fertilizers: Nitrogen fertilizer, Phosphorus fertilizer and Kalium fertilizer, according to the crop needs and soil fertility conditions. The Proportioned fertilizers are spread into the soil after being mixed sufficiently. In the equipment, the stirring paddle is one of the key components. Thus， this paper mainly researched the models designed by PRO/E through motion simulation , comparing and analyzing the velocity fields and flow field by the CFD software. The research results supply enough evidences to determine the more suitable paddle. According to the paper, the following conclusions can be launched:

(1). Design the geometric structure and finish the motion simulation of the two paddles: the spiral paddle, the multiple-fan-type paddle by using PRO/E. The result shows that the two paddles can gather up or decentralize the fertilizers.

(2). Mesh the two models by using the GAMBIT software. In the meshing Process, the mesh size and grid type should be chosen correctly, which is closely related to the simulation results in the FLUENT software.

(3). Analyze the velocity fields and flow fields of the two paddles by using the FLUENT software. According to the analysis, the multiple-fan-type paddle is determined to be more suitable, which can make fertilizers mixed sufficiently.

The multiple-fan-type paddle is chosen through simulation and comparison. In further researches, this paddle could be manufactured and installed in the automated matching mechanism.

Acknowledgements. Funding for this research was Provided by National Science & Technology Pillar Program during the Eleventh Five-Year Plan （2007BAD89B00）.The first author would like to acknowledge her tutor in College of Engineering in China Agricultural University for her help.

References

1. Blackmore, B .S.: An information System for Precision farming.Presented at the Brighton Conference Pests and Disease, British Crop Protection Counci1.pp.18--21(1996)
2. Yang, C.: A variable ratio applicator for controlling ratios of two liquid fertilizers. Applied engineering in agriculture,vol.17(3), pp.409--417(2001)
3. Duan, W.G.: Simulation of Mixing Machine Internal Flow Based on FLUENT.Modern Manufacturing Technology and Equipment, pp.33--34(2009) (in Chinese)
4. Han Z.Z: FLUENT—Examples of Fluid Engineering Simulation and Analysis .Beijing Polytechnic University Press, beijing(2009) (in Chinese)
5. Wang, X., Meng, Z.J, Bai,Y.L.: Application of Mechanical variable rate fertilizer in China.China Digital Agriculture and Rural Information Research Conference (2005) (in Chinese)
6. Wang, R.J., Zhang, K.: The Base and Application Examples of the Fluent Technology.Tsinghua University Press, beijing (2007) (in Chinese)

7. Zhang, G.J., Min, J.: The numerical simulation of the mixing Process of the turbo-Propeller in the stirring tank. Beijing Chemical University Journal,vol.31（6）,pp.24--27(2004) (in Chinese)
8. Zhang, S.H., Ma, C.L.: Development and application of a variable ratio fertilizer Applicator for Precision agriculture. Transactions of the Chinese Society of Agricultural Engineering，vol. 19(1),pp.129--131（2003）(in Chinese)
9. Zhang, X.H, Li, R.X.: The Research and Application of Precision Agriculture in France.Agricultural Research,vol.1,pp.12--15（2002.2）(in Chinese)
10. Zhao, J.: Variation Technology and Its Applications in Agricultural Mechanization.Journal of Modern Agriculture, vol.12,pp.25（2004）(in Chinese)
11. Zhao, W.Y., Yang, S.M., Yang, Q., Yang, S.C.: Development and Reflection of Precision Agriculture. Journal of Agricultural Mechanization Research, vol.4（2007） (in Chinese)