Southeast-Asian J. of Sciences: Vol. 7, No 1 (2019) pp. 48-58

SIMULATION OF WATER FLOW IN A RICE FIELD

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Abstract

In this research, we investigated the effects of positions and sizes of entrance on the water flow in a rice field. We proposed mathematical models with three different designs of entrance on the rice field of 2301 square meters. The flow in the models is described by continuity and Navier-Stokes equations. The models are solved by finite element method in a 2D system with three positions of the entrance: left, right and central of the rice field for the entrance of 0.25 meters wide, 0.5 meters wide and 1 meter wide, respectively. The obtained numerical results are simulated and compared to the experimental data with the flow rate of 5.7635 m^3/s. The results from both methods show a good agreement that the velocity and the pressure of the flow decrease along the length of the rice field to zero at the end. We found that the flow of central entrance design makes the least damage of soil and rice plant.

1 Introduction

The rice cultivation is an important traditional farming in the world because the rice is nutritious recipes for everyone. Water is the most important component for sustainable rice production, especially in the traditional rice growing in Thailand. More than this, understanding the behavior of water flow is no less

Keywords: Finite Element method, Streamline of Water flow in a rice field, Navier-Stokes Equations.
2010 AMS Mathematics classification: 35Q30

important than the irrigation in the rice field. An effective and economical way to understand any flow is to construct a mathematical model for that problem. Since water is one of the incompressible Newtonian fluids, most of researchers tend to express the water flow by the Navier-Stokes equations. A popular method to obtain a solution of the Navier-Stokes equations is a numerical scheme. Moreover, nowadays there are lots of high-performance computing, so that the Navier-Stokes equations can be solved and obtained numerical simulation easily. Other than modelling, most researchers also study a problem by setting an experimentation. For the purpose of verification the obtained results from each method, many researches do study in both ways.

In 1972, Boger and Ramamurthy [1] used the rheo-goniometer to measure the rheological properties in an abrupt 2 to 1 contraction domain and they compared the collected result and numerical prediction of the power-law model. And then in 1982, Walters and Rawlinson [2] implemented the equipment to study the planar contraction flows in Boger fluid. After that Boger [3] set up an experimental result of a circular contraction flow for both Newtonian and Non-Newtonian fluids. To avoid calculation from analytical data, the mathematical model of fluid is simulated in form of partial differential equations via conservation law of mass and momentum. In this case, an inconvenient problem is eliminated by the numerical method. In 1999, Phillips and Williams [4, 5] used the semi-Lagrangian FVM to solve a 4:1 planar contraction of creeping flow via the Oldroyd-B model in cartesian and axisymmetric coordinates.

In 1995, Anderson [6] presented an exact solution of the Navier-Stokes equations for magnetohydrodynamic flow. In 2003, moreover, Tsangaris and Vlachakis [7] studied an analytical solution of the fully developed laminar flow.

There is one research work studied about the rice field in 2012. In this work, Pochai and Pongnoo studied ground water flow in rice field near marine shrimp aquaculture farm. They used a potential flow model and a dispersion model to simulate the salinity in the ground with varied flow velocity in a 2 dimensional system by finite different method but did not directly study or simulate the water flow.

However, there has been not much research work that study about the water flow in the rice field. In this work, we then investigate the effects of the various positions and sizes of the entrance. We propose mathematical models with different designs to compare with the experimental data on the actual rice field.

2 Construction of the Models

Since this work is based on field experiments and construction of the mathematical models in the rice field. Therefore, for the experimentation, we firstly collected data and surveyed the rice field of 2,301 of meter^2 at Takhram En, Tha Maka, Kanchanaburi, see Figure 1. After that, we designed how to get the appropriate data form the actual studied area.

Figure 1: Rice Field in Kanchanaburi Province

2.1 Data and parameters

From the collected data that we surveyed on the rice field, we obtained dimensions and parameters used for the studied area given in Table 1. Our studied domain is a rectangular area. Due to the complexity of actual area, we ignore

Parameter	Length (m)
The entrance of the rice field (L1)	0.25
The width of rice field (L2)	52
The length of rice field (L3)	44.25

Table 1: Dimensions of the rice field

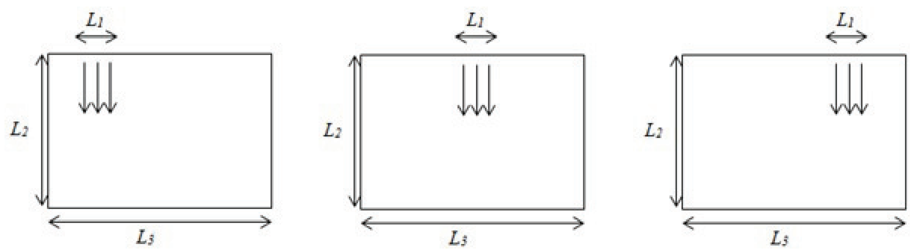
the roughness of the rice field ground floor. Moreover, the water flow in the rice field is very shallow, the deepness is then abandon. We therefore, present the models of two-dimensional geometries with different designs. The different designs are depended on positions and sizes of the entrance that water flows through to the rice field.

To investigate the effects of positions of the entrance on the flow, we then consider the three difference positions of entrance as depicted in Figure2.

1. Design1: The left entrance is set from the left 14 meters of the left-hand side of the ridge earthen dyke and from the right of 30.25 meters the right-hand side of the ridge earthen dyke.

2. Design2: The central entrance is set from the left 22 meters of the left-hand side of the ridge earthen dyke and from the right of 22 meters the right-hand side of the ridge earthen dyke.

3. Design3: The left entrance is set from the left 30.25 meters of the left-hand side of the ridge earthen dyke and from the right of 14 meters the right-hand side of the ridge earthen dyke.



(a) Left position (b) Central position (c) Right position

Figure 2: Positions of entrance in the rice field.

In order to investigate the effects of sizes of the entrance on the flow, we set up three difference sizes of entrance that are sizes of 0.25 meters, 0.5 meters and 1 meter, respectively. All other dimensions are the same as shown in Table 1

For the modelling, we set up the mathematical models as described in the next section.

2.2 Governing Equations and Boundary Conditions

In this work, we simulate the problem when the water is filled all over the area and the flow is in the shallow area. We also assume that the water is homogeneous and incompressible Newtonian fluid. In this research, we do not consider the effect of temperature, the evaporation and permeability of the water. Therefore, we propose the mathematical model for each design in two-dimensional system with no effect of time or steady-state problem. The governing equations described the water flow are the Navier-Stokes equations and the continuity equation in a cartesian coordinate system (x, y). These equations can be expressed in the following form.

$$\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} = 0, \tag{2.1}$$

$$\rho\Big(u_x \frac{\partial u_x}{\partial x} + u_y \frac{\partial u_x}{\partial y}\Big) = -\frac{\partial p}{\partial x} + \mu\Big(\frac{\partial^2 u_x}{\partial x^2} + \frac{\partial^2 u_x}{\partial y^2}\Big), \tag{2.2}$$

$$\rho\Big(u_x\frac{\partial u_y}{\partial x}+u_y\frac{\partial u_y}{\partial y}\Big)=-\frac{\partial p}{\partial x}+\mu\Big(\frac{\partial^2 u_y}{\partial x^2}+\frac{\partial^2 u_y}{\partial y^2}\Big), \tag{2.3}$$

where u_x, u_y are the velocity components in the directions x and y respectively, p is the pressure, ρ and μ are the density and dynamic viscosity of the water, respectively.

For the boundary conditions, we define as follows: The non-slip boundary condition, $\mathbf{u}=[u_x,u_y]=[0,0]$ is assigned to the inner walls. While the velocity in y direction u_y at inlet is 1.1527 m/s. The pressure at the end of rice field is zero Pa.

The governing equations (2.1)-(2.3) and all relevant boundary conditions are coupled to give the boundary value problem (B.V.P.) for each design of the domain.

2.3 Method of solution for the mathematical models

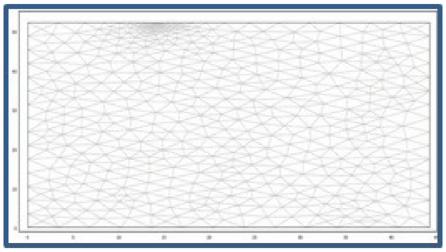
To solve the mathematical models of all different designs, we used the finite element method (FEM) in the commercial software COMSOL Multiphysics. In this study, we use $\rho = 1000kg/m^3$ and $\mu = 1mPa.s$ and all other parameters as given in Table 1. After we set up the governing equations and all boundary conditions, we set the mesh mode by dividing the domain into a collection of subdomain. For each design, we used number of mesh elements between 966 - 1015 elements. Figure 3 shows examples of mesh generation. The method of PARDISO is used for solving nonlinear system with the absolute tolerance and relative tolerance 10^{-7} and 10^{-8}, respectively.

3 Results and Discussion

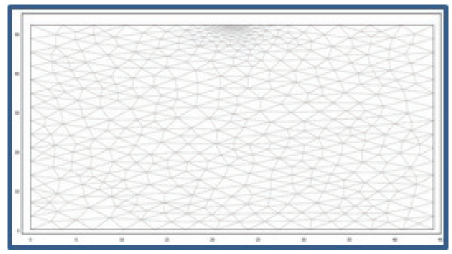
In this part, we discuss the results obtained from field experiments and the solutions obtained by the mathematical modelling together.

3.1 Effect of positions of the entrance

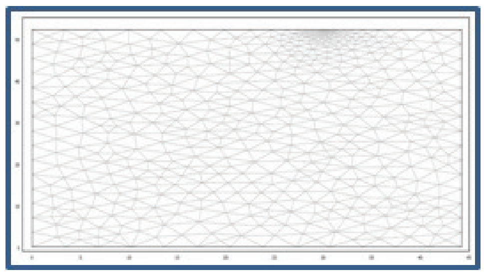
Based on the experimental results that we surveyed the rice field of 2,301 of $meter^2$ at Takhram En, Tha Maka, Kanchanaburi. The domain is started from the entrance of 0.25 meters to rice field with the width of 52 meters and the length of 44.25 meters as shown in Table 1. We found that the flow rate is 5.7635 m^3/s, the initial velocity of water flow is 1.1527 m/s and the maximum pressure is close to 4.1 Pa. The water is filled all over the area of height of 15 cm taking 3.67 hours. The high speed velocity and the maximum pressure at the entrance reduce slightly along the length of rice field to zero when it approaches the boundaries. The streamline of the water flow spreads to the left and the right step by step.



(a) Left entrance

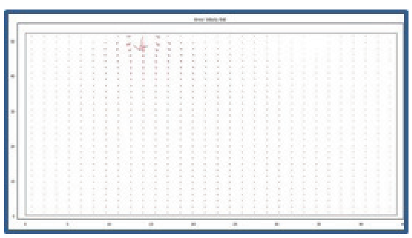


(b) Central entrance

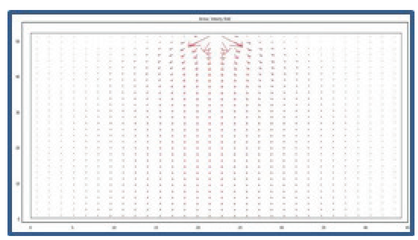


(c) Right entrance

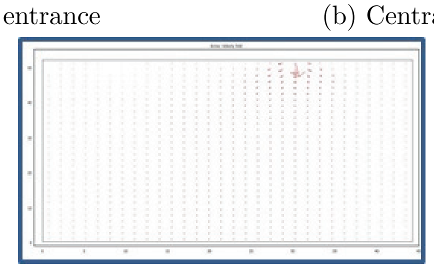
Figure 3: Mesh generation of 0.25 meters-entrance of the rice field



(a) Left entrance



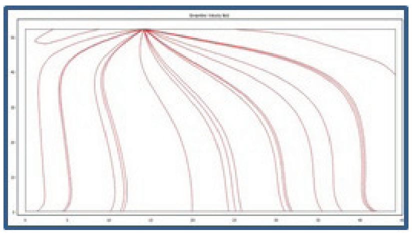
(b) Central entrance



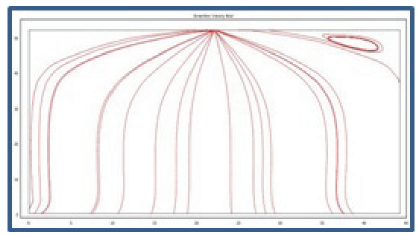
(c) Right entrance

Figure 4: Arrow plots of the water flow with three different positions of entrance in the rice field.

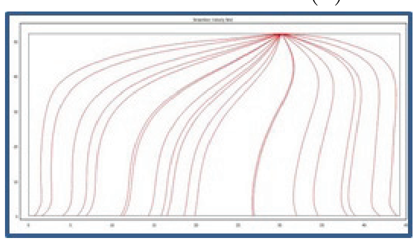
The arrow plots of the velocity field for each design of 0.25 meters are shown in Figures 4a-4c. Figure 4 shows that the water flows in different directions when it pass the different positions of entrance. Figure 4a illustrates that the flow spreads to the right-hand side more slightly than the left-hand side. While the flow spreads to the opposite way for Figure 4c. Figure 4b shows that the water spreads symmetric distribution to left-hand side and right-hand side. It is apparent when we consider the streamline in Figure 5 that the vortex appears at the right corner.



(a) Left entrance



(b) Central entrance



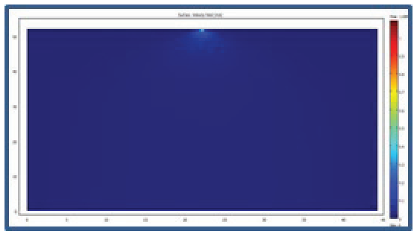
(c) Right entrance

Figure 5: Streamline plots of the water flow with three different positions of entrance in the rice field.

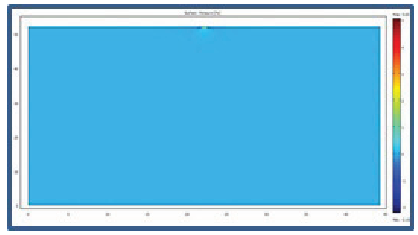
Figure 6 shows contour plots of the velocity field and pressure of the flow with 0.25 meters entrance, it is found that the velocity profiles reduces step by step along the length and approaches to zero at the end of the rice field. The maximum pressure takes place near the entrance of rice field and reduces to zero at the end of the rice field. When we compare for different designs, the maximum pressure of Design1, Design2 and Design3 are 4.55759 Pa, 4.132095 Pa and 3.771706 Pa, respectively. Design2 gives the results most close to the experimental data. In addition, the direction of velocity and pressure make the least damage of soil and rice plant. For Design1 and Design3, the flows go straight to left-hand side and right-hand side, respectively.

3.2 Effect of sizes of the entrance

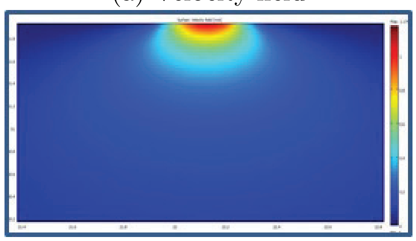
We set three different sizes, 0.25 meters, 0.5 meters and 1 meter of entrance for discussing the effects of sizes on the flow. By setting the same initial velocity



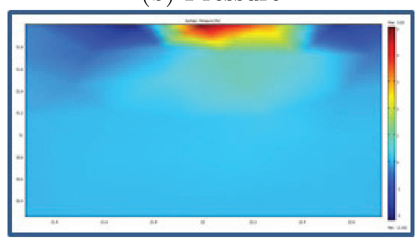
(a) Velocity field



(b) Pressure

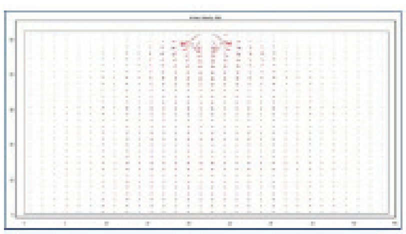


(c) Velocity field near entrance

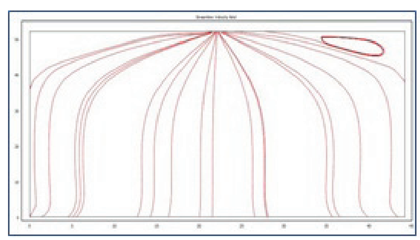


(d) Pressure near entrance

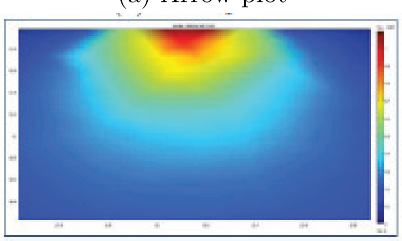
Figure 6: Contour plots of velocity and pressure of the central positions with size 0.25 meters entrance in the rice field.



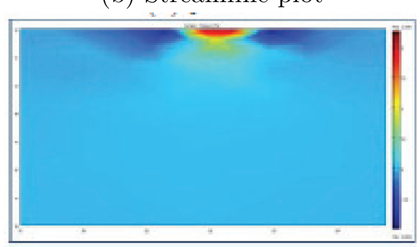
(a) Arrow plot



(b) Streamline plot



(c) Contour plot of the velocity



(d) Contour plot of the pressure

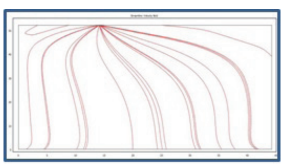
Figure 7: Velocity and pressure plots for the central positions with 0.5 meters entrance in the rice field.

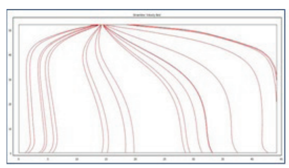
of 1.1527 m/s for different sizes of and different positions of entrance, we found that the water flow velocity takes place at entrance and gradually reduces to zero at the end of boundary. The pressure at the entrance drives the water flow into the rice field and then it slightly reduce to zero Pa at the end of boundaries. The direction of the flow of entrance 0.5 meters is same as of entrance 0.25 meters. The flow of central entrance spreads clearly symmetric to the left side and the right side, while the water of the left entrance flows straight to the left and deviate to the right, for the right entrance is opposite.

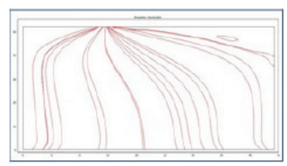
We can summarize that the sizes of entrance effect to the direction of the flow. The directions of the flow for bigger size (0.5 meters and 1 meter) of entrance clearly deviate more than the small size of the entrance (0.25 meters). Table 2 shows that different sizes of entrance effect to the pressure. The pressure of small size (0.25 meters) makes the largest pressure because it requires more force to push the water pass through the entrance to the rice field.

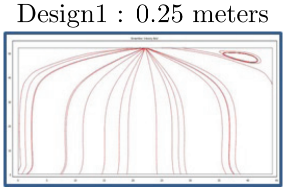
	Position		
Size	Left	Center	Right
0.25	4.5759000	4.132095	3.771706
0.5	1.6000880	2.197992	1.625210
1.0	0.6454950	0.922280	1.043249

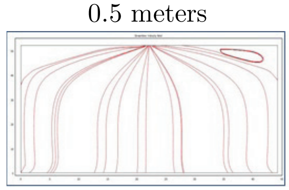
Table 2: Pressure (Pa) at the entrance

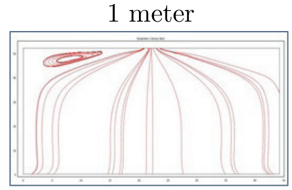

Design1 : 0.25 meters

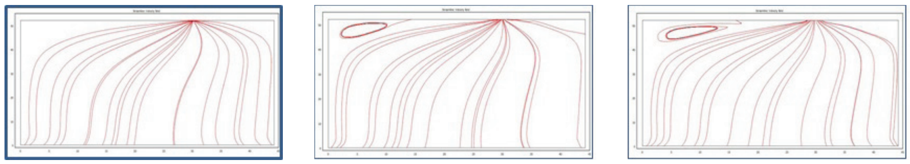

0.5 meters


1 meter


Design2 : 0.25 meters


0.5 meters


1 meter



Design3 : 0.25 meters　　0.5 meters　　1 meter

Figure 8: Streamline plots of velocity to different sizes of entrance Design1, Design2 and Design3 of the rice field.

4 Conclusion

The effective models of water flow in the rice field have been carried out. The results from the experimentation and the mathematical models show a good agreement. The simulations of the streamlines, arrow and pressure plots of the flow make us easily to investigate the effects of positions and sizes of the entrance of the rice field. We summarize that central entrance is better than others. The maximum velocity takes place near the entrance and reduces to zero value at the end of boundaries. The magnitude of pressure at the entrance varies with the sizes of the entrance. It reduces when the size of entrance increases.

Acknowledgment This research is supported by Thammasat University, Thailand. The authors thank to Department of Mechanical Engineering, Thammasat University for commercial software COMSOL Multiphysics support and are very grateful to Department of Mathematics and Statistics, Thammasat University for giving the all other facilities support. We thank you to Phitchaya Khongthanajaree, Tassawan Aramsoontornsuk, Thitinan Punsate and the owner of rice field for collecting the experimental data and numerical results.

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