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Experimental and theoretical study for best distribution of perforations for horizontal wellbore with porous medium

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بسم الله الرحمن الرحيم

وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ

صدق الله العظيم

سورة المجادلة الاية (١١)

DEDICATION

We wish to dedicate this work to our parents, brother, sister and martyrs of Iraq who sacrifice to continue the life.

Acknowledgment

We would like to express our deep thanks to our supervisor; Assist. Prof. Dr. Ahmed K. al-Shara for his guidance and support during of the project.
Thanks to staff of Laboratory Fluids.

Would not forget to appreciate the support and help rendered by Ali Abdul Hussein.

ABSTRACT

The use of horizontal wells has become an established practice in the petroleum industry. Productivity of horizontal wells is limited by the pressure drop within the wellbore. During the flow process from the toe-end of the horizontal well to the heel-end; the drop in pressure is imminent within the wellbore. If the pressure drop within the wellbore is significant as compared to the reservoir drawdown, the reservoir drawdown along the well length will change gradually, and consequently the production along the well length will also change subsequently. The total pressure drop in the horizontal wellbore consists of acceleration, wall friction, perforation roughness and fluid mixing etc. Horizontal oil drilling can be used in many situations where conventional drilling is either impossible or cost prohibitive.

In the present work numerical models have been developed to determine the effect of perforated pipes on the flow behavior through the horizontal well. These models represent steady state incompressible, three dimensional of turbulent flow The continuity and momentum equations were discretized by means of a finite volume technique and the SIMPLE algorithm scheme is applied to link the pressure and velocity fields inside the domain. Numerical simulations by commercial code CFX is also conducted with multiple values of Reynolds numbers for axial flow and with multiple values of influx flow rate to observe the flow through the perforated pipe.

The aim of the present study is to analyze the flow patterns, pressure drops, wall shear stress, and friction factors inside the horizontal wellbore. For this purpose, first, the results for Tee-junction models had

been discussed. Secondly the wellbore with two perforations, later the wellbore with multiple perforations,

MOHAMMED ABDULWAHID (AUTHOR) study the flow behavior in horizontal wellbore with 60 and 150 perforations of perforation densities equivalent to 6 and 12 SPF respectively has been studied. The pressure drops in a perforated pipe that includes the influence of inflow through the pipe walls compares for two pipes that difference in perforation density. 3D numerical simulations for the pipe with two numbers of perforations were investigated by using ANSYS CFX modeling tool with Reynolds number ranging from 28,773 to 90,153 and influx flow rate ranging from 0 to 899 lit/hr to observe the flow through perforated pipe, measure pressure drops. The effect of density perforations on the flow through perforated pipe was conducted. CFD simulations yielded results that are reasonably close to experiments data.

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Chapter one
Introduction

1.1 Introduction

The use of horizontal wells has become well established practice for the recovery of oil and gas from both onshore as well as offshore drilling activity. It has become increasingly attractive for the production of thin-layered reservoirs. The major advantage of the horizontal well is to enhance the reservoir contact and there by enhanced the well productivity .As an injection well, a long horizontal well provides a large contact area, and therefore enhances the well injection, which is highly desirable for enhanced oil recovery application. Unlike a directional well where the drilling position is directly into the reservoir entry point, a horizontal well is commonly defined as a well in which the lower part of the wellbore is parallel to the oil zone. Horizontal wells have become a preferred method of recovering oil and gas from reservoirs in which these fluids occupy strata that are horizontal, or nearly so, because they offer greater contact area with the productive layer than vertical wells. While the cost factor for a horizontal well may be as much as two or three times than that of a vertical well، the angle of inclination used to drill the well bore need not have to maintain the angle of 90° for the well to be considered as a horizontal well. Applications for horizontal wells include the exploitation of thin oil-rim reservoirs, avoidance of drawdown-related problems such as water or gas coning, and extension of wells by means of multiple drain holes. In a horizontal well, depending upon the completion method, fluid may enter the wellbore at various locations and at various rates along the well length. The complex interaction between the wellbore hydraulics and reservoir flow performance depends strongly on the distribution of influx along the well surface and it determines the overall productivity of the well. Therefore, the optimization of well completion to improve the performance of horizontal wells is a complex but very practical and important problem .The most commonly used assumptions in studying horizontal well production behavior are: infinite_conductivity, and uniform influx. Infinite conductivity assumes no pressure drop along a horizontal well, and uniform influx assumes that the influx from the reservoir is constant along a horizontal well.

Productivity of horizontal wells is primarily limited to the various pressure drops within the wellbore. Deep analysis is required to study the reasons for the pressure drop from the toe-end of the horizontal well to the heel-end is essential to maintain fluid flow within the wellbore If the pressure drop within the wellbore is significant as compared to the reservoir drawdown, the reservoir drawdown along the well length will change. Consequently, production along the well length will also change. Normally, the pressure drop within horizontal wellbores becomes important when the production rate is so high that the wellbore flow reaches turbulent such rates are possible in high- impermeability reservoirs where the pressure drawdown from the reservoir to the wellbore is very small the reason can be attributed to the pressure drop within the well. In reservoirs with gas and water coning problems, an excessive pressure drop through the wellbore may enhance the tendency of gas and water to cone at the heel-end of the well, which is the point of minimum pressure in the horizontal wellbore.

The production section of the horizontal well must be parallel to horizontal reservoir, Because of its large flow area, a horizontal well may be several times is more productive than a vertical one with draining the same volume. Recent interest in horizontal wells has been accelerating because of improved drilling and completion technology. This has led to increase the efficiency and economics in oil recovery. Increase in oil production rate and improvement in ultimate recovery has given horizontal wells an edge over the vertical wells in many marginal reservoirs.

However, it is more expensive to drill the horizontal well than a vertical one. In petroleum engineering, well productivity means well flow rate and the output of a well during a unit time period under a steady pressure drop. Well productivity formula is the formula to compute the productivity with the known well parameters and formation parameters such as well length, wellbore radius, formation thickness, reservoir fluid, viscosity and formation permeability

Many horizontal wells in the industry are partly perforated. The perforated section of the wellbore is followed by blank section for such wells. The pressure drop in the blank section of a pipe is mainly caused by the pipe wall friction and therefore, can be calculated by the Darcy-Weisbach equation once the flow velocity and friction factor are known. However, how the flow in the perforated section affects the friction factor behavior in the blank section downstream remains unclear.

Perforation is a commonly practiced method for horizontal well completion. Perforating completion belongs to the category of case completion. It consists of pierced casing wall and the cemented behind, to provide openings through which formation fluids will enter the wellbore. The perforation geometry parameters include the perforating density (Spf, shots per foot), Phasing (angular separation between neighboring perforations), perforation diameter, and perforation length. The perforation of horizontal wells with a shot density of forty shots per meter involves the cost of $500/m of a horizontal wellbore (Abdulwahhab and et al (2014), [1]) . The horizontal well is drilled parallel to the reservoir bedding plane. Strictly speaking, the vertical well is a well which intersects the reservoir bedding plane at 90°. In other words, the vertical well is drilled perpendicular to the bedding plane. Typical horizontal well project is different from a vertical well project because the productivity of a well depends upon the well length. However, the well length depends upon the drilling technique that is used to drill the well. Therefore, it is essential that the reservoir and the drilling engineers work together to choose the appropriate drilling technique which will give the desired horizontal well length. The prediction of the pressure drop factor is complicated for various reasons. The researchers conducted the tests in such a way that the recorded measurements agreed with the other researchers and went a step further describing by separate pressure drop terms, which is a sum of the measured four different pressure drops. They have suggested the separate pressure drop terms as frictional, perforation roughness, fluid mixing and acceleration pressure drop components. The pressure drop caused by perforation roughness and fluid mixing were lumped together and classified as additional losses. The additional losses pressure drop term was obtained from the measured pressure drop after subtracting the pressure contribution due to wall friction and fluid acceleration. The modified results indicated a reduction in additional pressure drop with an increase in injection. They presented these results as a pressure loss coefficient for injection ratios spanning from 0% to 35%. They proved that most of the pressure drop in the perforated pipe is due to frictional and acceleration effects. However, the mixing term is significant and its contribution to the pressure drop is often negative. It is, therefore suggested that radial inflow lubricates the pipe flow. The pressure drop due to kinematic energy change which is-nothing but acceleration effects, frictional pressure drop due to wall friction in a perforation .The additional losses pressure drop term was obtained from the pressure drop after subtracting the pressure drop contribution due to wall friction and fluid acceleration, The pressure drop due *to* mixing effects arises from the interaction between perforation flow and wellbore flow which is causing disturbances in the boundary layer and therefore it affects the pressure drop. The fluid enters radially into the wellbore through a perforation it mixes with the axial flow and increases the mass in the well, there by the flow velocity increases. Therefore, the acceleration of the flow will also increase this give pressure drop across the perforation. Subtracting the acceleration and frictional pressure drops from the total pressure drop with flow through the perforations, the remaining pressure drop should be a practical representation the additional pressure drop (perforation roughness and mixing effect).

Chapter Two

LITERATURE REVIEW

2.1 Introduction

Wang and et al. (2005),[1] , studied an oil well subject to different completion schemes (perforated casing and open-hole completion) is presented using a coupled reservoir geomechanical model. They developed based on an extension of a theoretical and numerical model the volumetric sand production and associated wellbore stability. This was done within the framework of mixture theory in which mechanics and transport equations are written for each of the concerned phases, i.e. solid, fluid (oil, water), gas, and fluidized solid. The numerical model is implemented into three integrated computational modules, i.e. erosion module, reservoir module, and geomechanics module. The key idea in the modular system is the reformulation of the stress- flow-erosion coupling so that any existing advanced stress and reservoir code can be incorporated with minimum development efforts. Numerical results showed that the wellbore stability depends on the delicate interaction between geomechanics and hydromechanics processes. Formation tensile and plastic shear failures, incurred during hydrocarbon drawdown and in situ stress changes increase the sand production potential. In return, the production of sand also weakens the formation matrix through degradation of its mechanical strength (cohesion and friction angle). Abdulwahid.(2002),[2] ,carried out numerical simulations have been on the flow in a partly perforated pipe with inflow through perforations The geometry of the pipe used was similar to the pipe used in the experimental tests The total pressure drop in a horizontal wellbore is the sum of the pressure drops due to momentum change (acceleration), perforation roughness, and fluid mixing. The acceleration pressure drop cannot be ignored compared with the frictional pressure drop. The total pressure drop for perforated section was larger than the total pressure drop in the plain section without perforations. The additional pressure drop caused by the perforation roughness was eliminated by the smoothing effect once the flow rate ratio reached a certain limit. It was observed that the local friction factor ratio for a perforated pipe with fluid injection decreased with increase of the radial flow . Proett,et al.(2004) , [3] ,introduced a new perforation performance prediction model for optimizing the design of cased and perforated well completions. Based on results from preliminary application of the new model, the following conclusions were drawn:

* The artificial neural network model introduced in this work provides efficient means of optimizing a completion design by quickly analyzing a large number of FEA(finite element analysis) simulated completion scenarios.

* Several primary and secondary factors, including perforation length, casing entrance hole diameter, crushed zone properties, formation anisotropy, dip angle of the bedding planes, etc., affect the productivity of a perforated well.

Subbiah and Samsurr.(1997), [4] ,found that all the perforated wellbore models may fail and sand fragments were produced based on to the shot density and perforation pattern. As the shot density increases and perforation pattern changes from spiral, in plane, inline, the wellbore stability decreases and the amount of sand fragments produced increases. In other word, the more sand fragments produced by the unstable perforated wellbore. They done Understanding the effect of the perforation parameters i.e. shot density and perforation pattern to the wellbore stability and sand production, thus, optimization of production and minimizing the sand production problem can be done. Consideration the wellbore stability effects in designing phase of petroleum field development can accomplish mention optimizations. Abdulwahid.(2014),[5],studied the pressure drops, velocity profiles, wall shear stresses, pressure loss coefficients and friction factors etc in perforated and partly perforated horizontal wellbore and T-junctions. Furthermore different number of perforations in horizontal wellbores in three dimensional flows was investigated. For this purpose, the numerical models similar to experimental models were conducted with Gambit and ICEM-CFD for drawing and meshing respectively. Different input parameters were considered for both axial flow and radial flow. Flow interaction between axial flow and radial flow through perforations was also studied. Three dimensional numerical techniques were considered where ever it is essential.

Chapter Three
Theoretical Analysis

3.1 Model Description and Assumptions

The physical model which is studied showed in Fig 1 (A, B and C) which represents the flow in the perforated pipe which consists from pipe (horizontal well bore) closed from one end and open from the other. The fluid is water with constant properties. There are three distributions for perforation of wellbore as following: uniform (Fig. 1. A), convergence (Fig. 1. B) and divergence (Fig.1.C).

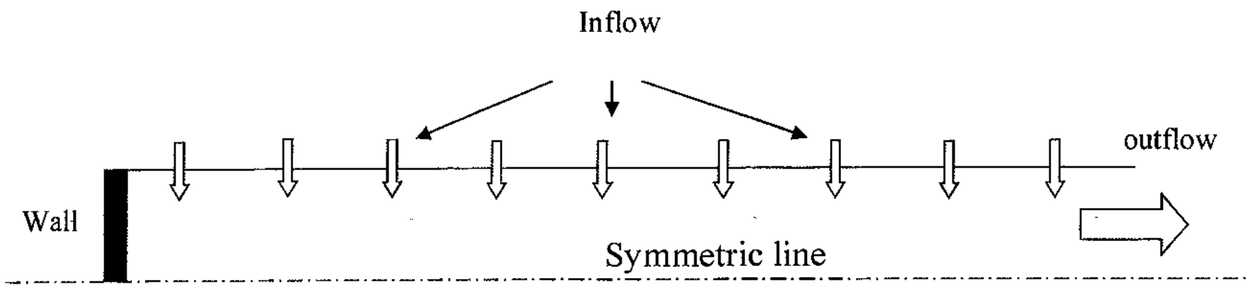


Fig. 1-A Uniform perforated wellbore

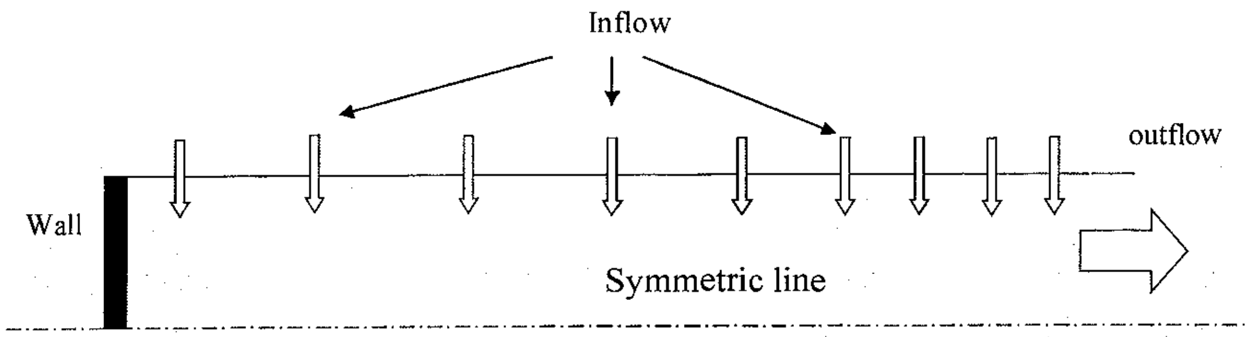


Fig. 1-B Convergence perforated wellbore

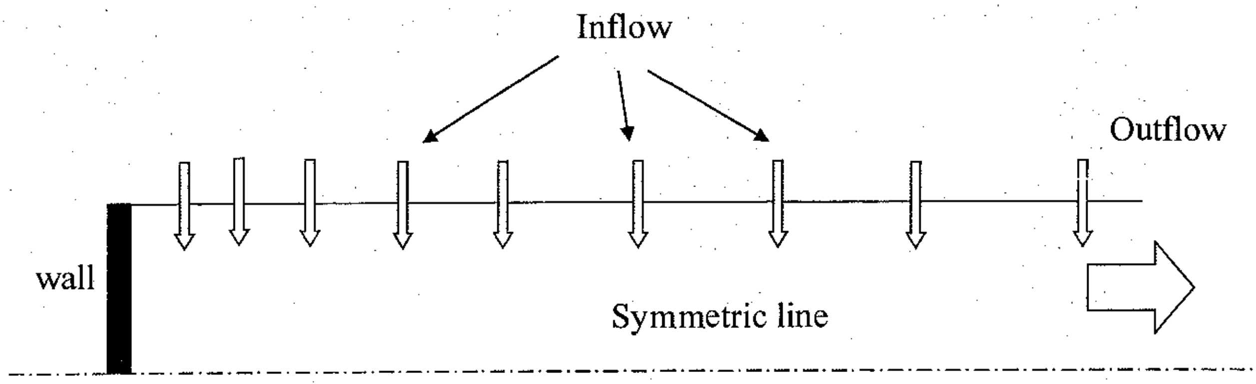


Fig. 1-C Divergence perforated wellbore

To analyze the flow characteristics of this model, the following assumptions are made:

(1) The flow is 2D, incompressible, laminar and steady state.

(2) Fluid properties are constant.

(3)The gravity effect is negligible.

(4) The wellbore pipe is horizontal.

3 Governing Equations

Based on the previous assumptions, the governing equations in Cartesian coordinates can be written as:

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

X-momentum equation

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \qquad (2)$$

Y-momentum equation

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \quad (3)$$

Boundary Conditions:

The boundary conditions are:

$u=0,\ \ v=0\ \ \&\ \ \frac{\partial p}{\partial x}=0$ at left end of pipe

$\frac{\partial u}{\partial x}=0,\ \ v=0\ \ \&\ \ \frac{\partial p}{\partial x}=0$ at symmetry line (center line of pipe)

$u=0,\ \ v=0\ \ \&\ \ \frac{\partial p}{\partial x}=0$ at the regions of the wall of pipe (without opening)

$u=0,\ \ v=-1\ \ \&\ \ \frac{\partial p}{\partial x}=0$ at opening of perforation (with opening at the wall of pipe)

$\frac{\partial u}{\partial x}=0\ \ \&\ \ v=0\ \ \ p=0$ at right end of pipe (outflow)

In order to solve Eqs. 1, 2 and 3, we use the penalty finite element method where the pressure p is eliminated by a penalty parameter γ and the incompressibility criteria given by Eq. (1) results in:

$$\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}=\gamma\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right) \quad (4)$$

The solution of governing equation using software package (Flexpde) for all cases.

Nomenclature

p pressure (N/m^2)

u,v velocity components (m/s)

x,y Cartesian coordinates (m)

Greek symbols

γ penalty parameter

ρ density of fluid (kg/m^3)

μ viscosity (kg/m.s)

Chapter four

4.1 Experimental apparatus

The apparatus is consisting from rectangular a glass vessel (10mm thickness of glass that used). The dimensions of rectangular a glass vessel is (90, 30, 20) cm in length, width and height respectively. The apparatus contains three opening from the front of the device and connected with three pipes (100 cm in length for each pipe) inside a vessel (3/4 inches in diameter). The three pipes are closed from end and open in another end .The open end are jointed with three valves to control flow rate and contact to out hose with gage pressure to the beaker for record the reading of volumetric flow rate . Also the three pipes are perforated with 9 holes the diameter of hole is 1mm (perforation diameter 1mm). Three pattern of perforation distribution (uniform, Convergent, divergent) are used and each of pattern contain (11) perforation, the pump is used to fill the glasses vessel with water. The hose used to balance water level in vessel. The vessel is filled with porous medium such as sand and there is a flow inside the vessel and assuming the pressure or change pressure are constant ($\nabla p = c\, , where\ the\ liquid\ lost\ is\ compensation$) also the horizontal velocity=0. The examination of each one of these pipes by opening one of the valves and close the other and record the time of flow rate by stop watch and knowledge the amount of flow rate to the purpose of Comparison between three pipes of different distribution (uniform , Convergent , divergent) and we choose the best perforation.

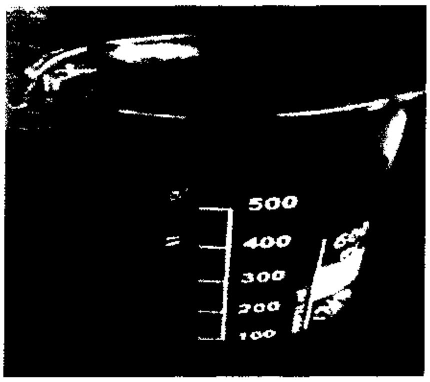
Type of perforation pipe:

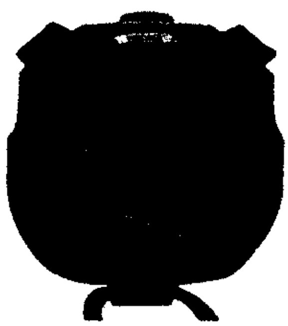
1-Uniform.

2-Converage.

3-Diaverage.

Apparatus


500
400
300
200
100



Chapter five

5.1- Procedures of the Experiment

For the purpose of figure out the best way to distribute the perforations in horizontal wells and the possibility of getting the best rate of flow and the lowest value for the pressure drop. We had made the following experience:

The apparatus of experiment is consist from a glass rectangular vessel .It was contains three pipelines with different distribution of the perforations method (regular, convergent, divergent) respectively. By using incompressible fluid (water), pump, beaker and stopwatch, where has experience on the first two stages without pours medium and the second presence of porous medium (sand). Where carried out every process in two stages for the purpose of confirmation of the accuracy of the results obtained.

* Without porous medium

After running the pump fill the vessel with water where. we installed the water level so that the differential pressure is between inside and outside is fixed by control between the rate of internal flow and rate of the outer flow. where one level and where we open the outer portion of the pipes through a valve for each tube which respectively .

Where we start with a regular perforation and the volume of water accumulated in the glass beaker 500 mm during a time of (1:16:48) . The second tube is converging distribution where the accumulated volume of water 500 mm over a period of (1:02:17). Either the tube with divergent distribution or the volume of accumulative in the beaker 500 mm with a time of (0:59:32).

And after the experience once again observed does not appear significant change in the results. Where the volume of water from the pipe of uniform distribution inside the beaker during the time of (01:17:62). The tube is converged distribution of water was outside of it the size of 500 mm during the time of (1:00:00), while the tube with divergent distribution was the volume of accumulative water in the beaker during than 500 mm during the period of time (0:59: 06).

It is a comparative of results during both phases of the experiment note that the tube has a divergent distribution is preferable that the accumulated volume of water was over a period of time less than from the other pipe in the rest of the pipeline.

2- With porous medium

After addition the porous (sand) with grains of diameter (1.5mm-2.5mm) with the same procedure in the last experiment by using the same tools (pumps ,beaker ,stop watch)we start the work by filling the vessel with the liquid (water) by using the pump with constant water level inside the vessel for accuracy to measurements ,the obtained results from this experiment were respectively :

For the pipe of uniform distributions the volume of the produced water which be cumulated in the beaker 500mm with time of (01:42:17) .While the pipe of converge distribution the volume of the produced water which accumulative in the beaker 500mm with time of (01:15:67).while the pipe of diverge distribution the volume of the produced water is equal to 500 mm with time of (01:26:50).

When we reset the experiment we get the following results for the three pipes respectively (uniform, converge, diverge) for the same volume of the accumulated water (500mm) with different production time respectively (01:43:26, 01:17:13, 01:14:19).

5.2 Results of experimental part

*with no porous medium

Table (5-1) shows the results in the First experiment:

Uniform	01:16:48
Converge	01:02:17
Diverge	00:59:32

Table (5-2) shows the results in the second experiment:

Uniform	01:17:62
Converge	01:00:00
Diverge	00:59:06

*with porous medium

Table (5-3) shows the results in the First experiment:

Uniform	01:43:45
Converge	01:10:49
Diverge	01:15:16

Table (5-4) shows the results in the second experiment:

Uniform	01:29:23
Converge	01:08:40
Diverge	01:13:28

5.3 Comparing

We conclude that the period of time in the same volume of water which produced is different from the first experiment (without porous medium) with the second experiment (with porous medium) with constant pressure, because the porous medium contribute to an increased pressure drop and partially hold the flow of fluid through the perforations and reduce the perforations diameter and this occurs actually in the horizontal well when we have long time period of production at constant rate of flow which lead to decreases in porosity of the pay zone and lock perforations especially if the layer is soft(sand layer) that should be the reason .The cause of that the flow rate of the first pipe (uniform distribution of perforations) is less than the other pipes (converge and diverge distribution) is the high friction factor due to high density of perforation which lead to low flow rate and increase in pressure drop more than the others .While in the converge distribution pipe the pressure drop is less and the flow rate is greater than the uniform distribution pipe because of that the friction factor is lower due to the density of perforations which is less than the first pipe and due to the flow direction too. In the third pipe (diverge distribution of perforations) the flow rate is greater than the first pipe with low drop pressure but less than the second pipe (converge pipe),so in the second pipe (converge pipe) we have the best distribution in this experiment with porous medium but actually in the horizontal well we must make perforations with high density at the layer which we expect high flow rate from this layer.

The pressure drop in perforated wellbore for horizontal wells, depends upon the fluid entry profile. The fluid influx will increase the apparent friction factor along the horizontal wellbore, but in some cases the influx will decrease the apparent friction factor which means that the injected fluid has a lubrication effect. This effect may be happened in the case of convergence perforated.

The specific flow rate i.e. the inflow rate per wellbore length is not equal for all profiles except for uniform case. This is because in a real horizontal wellbore, pressure near the well toe is higher than that at the well heel due to the wellbore pressure drop. The pressure drawdown near the well toe is less than that near the well heel . Hence the specific inflow rate near the well toe is smaller than that near the well heel. On the one hand, wellbore pressure or pressure drop is needed to determine the specific inflow rate distribution along the wellbore.

Chapter six
Results and Discussionof theoretical part

6.1 Results and Discussion

Figure (1): presents the velocity contour for x-axis (U) of pipe with uniform perforation distribution which has the maximum value at the end of pipe in the middle because the accumulative flow and shear stress effect. The minimum value of (U) at the walls of that pipe which equal to zero (no slip condition).

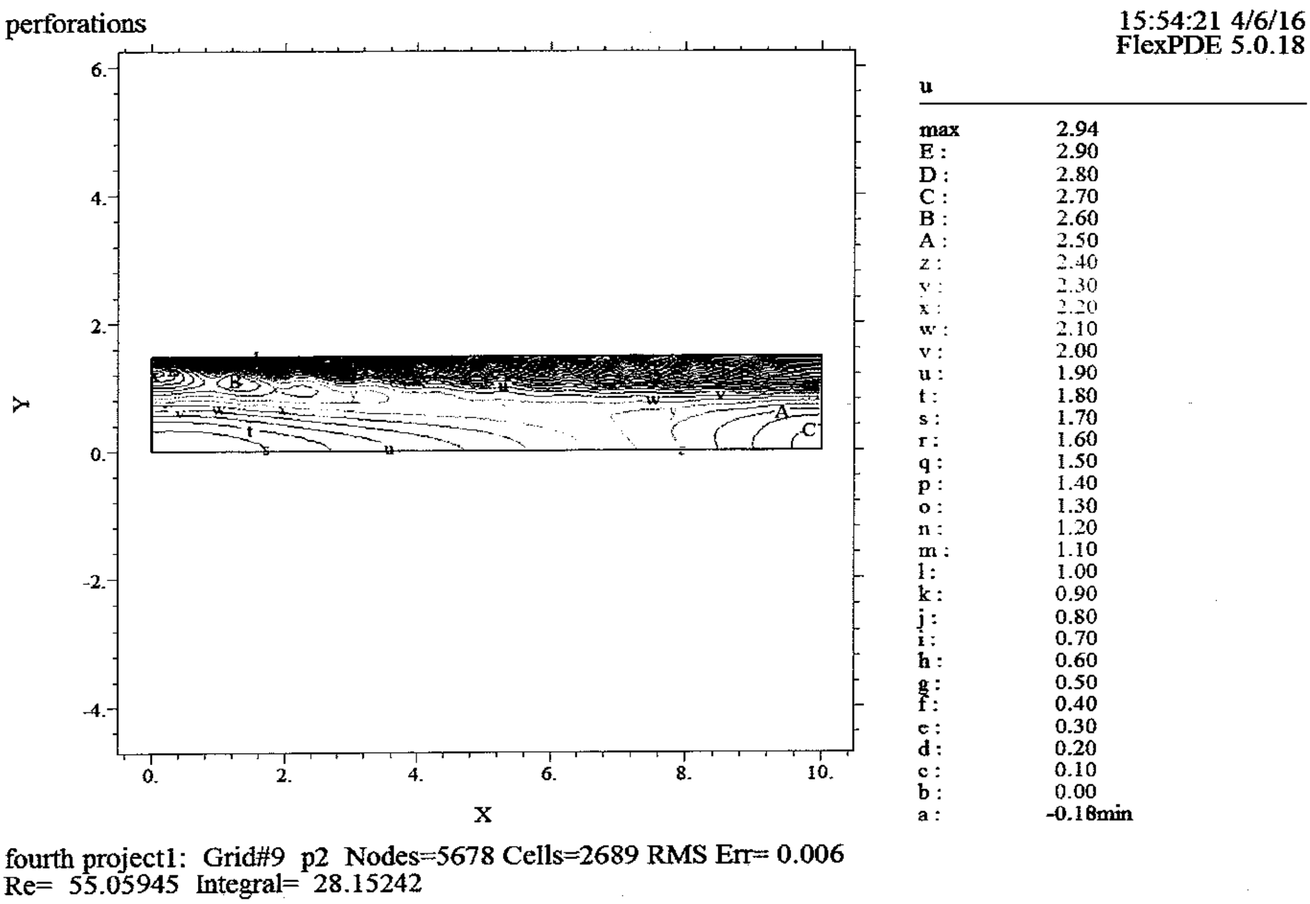


Fig.1 U-velocity contour for uniform perforations

Figure (2): represents the velocity contour for the y-axis (V) of the uniform pipe which shows that maximum value at the inlet part during the perforations (boundary condition) .The minimum value of this velocity at the wall (no slip condition) and center line (symmetric line).

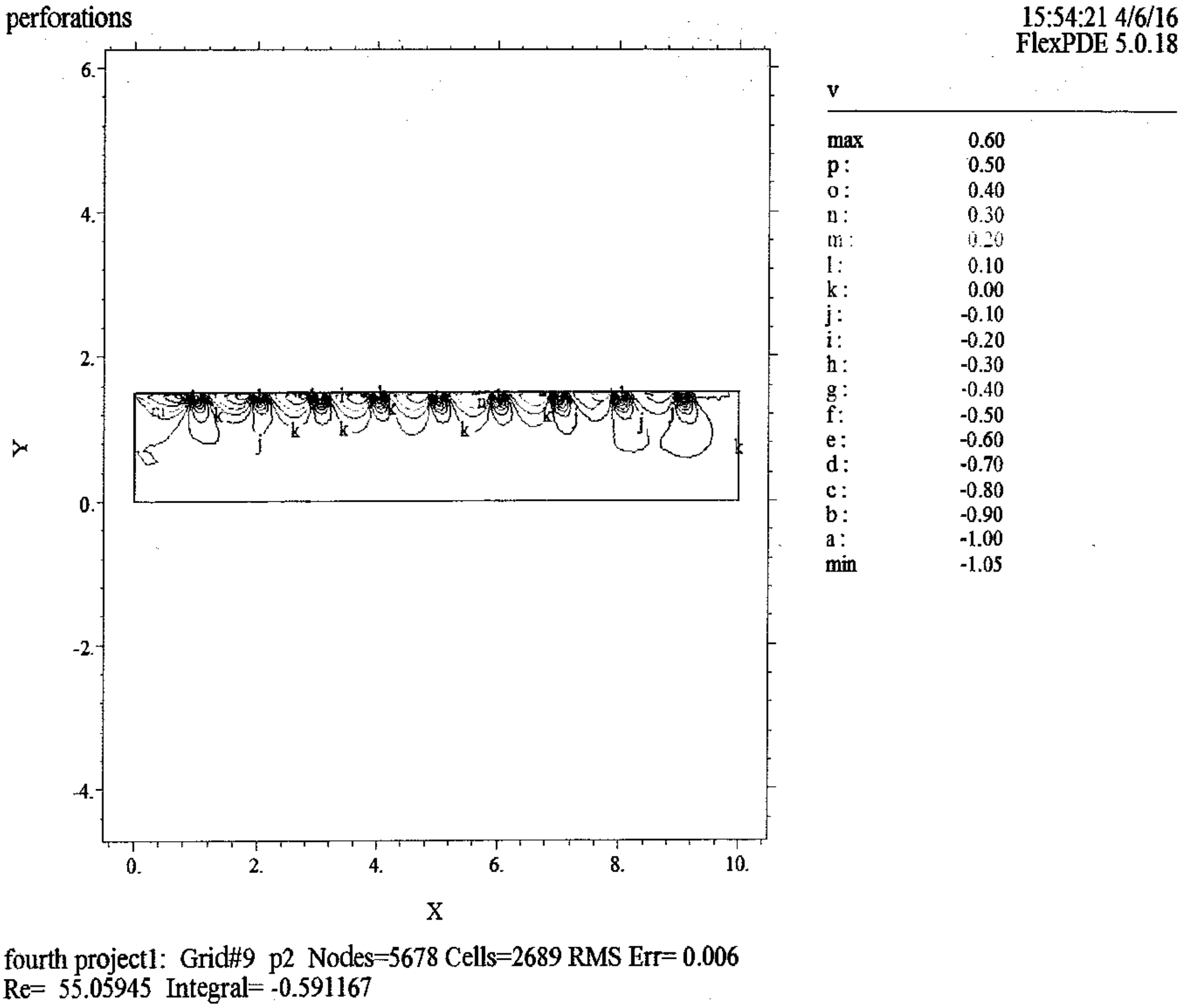


Fig. 2 V-velocity contour for uniform perforation

Figure(3): shows the speed distribution in the uniform pipe which illustrates that the maximum value at the middle region of the pipe due to mixing effect of flow through the total perforations of the pipe. Also the minimum value of speed would be always at the walls of the pipe.

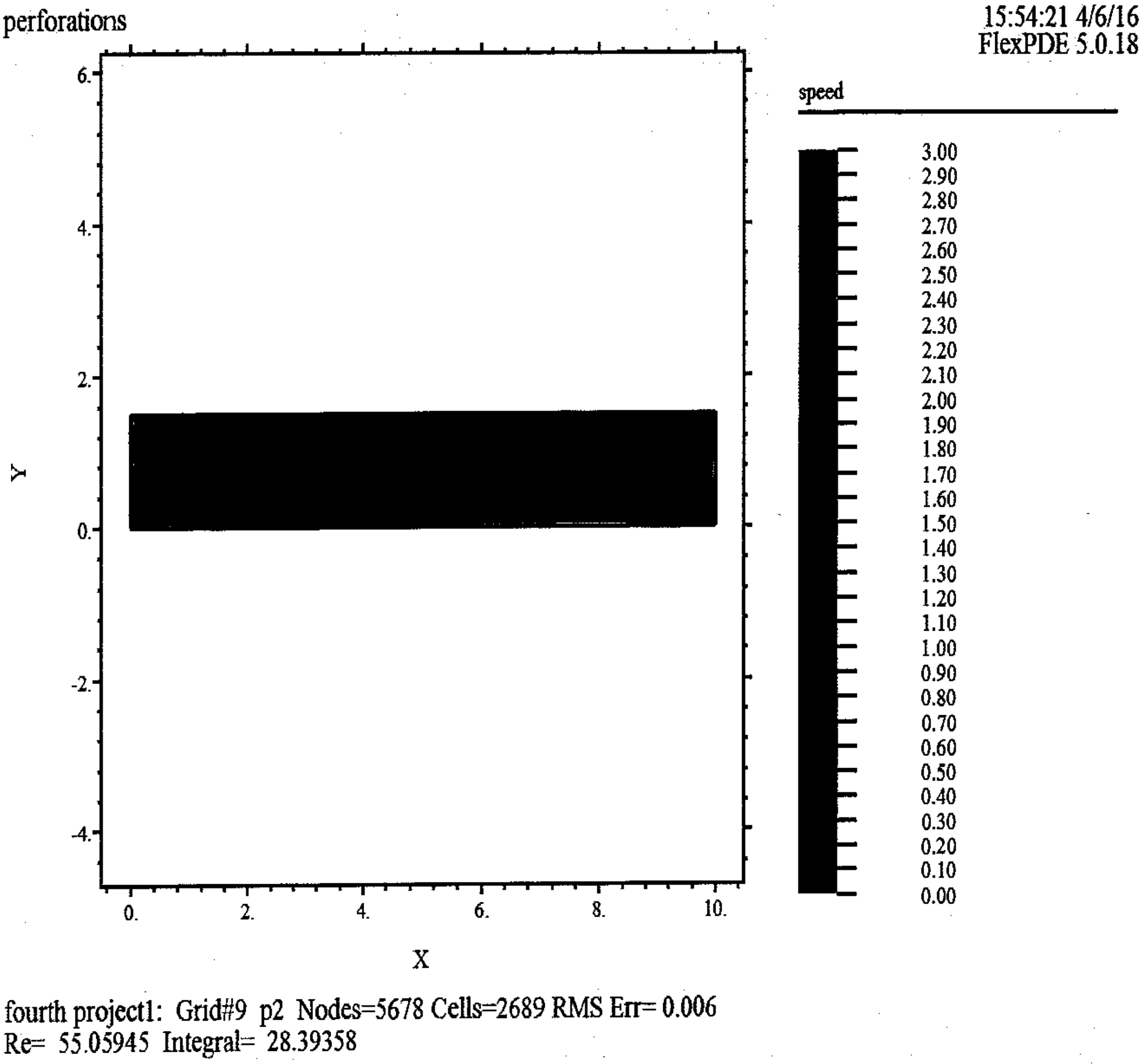


Fig. 3 speed contours for uniform perforation

Figure (4): represents the pressure contour through the uniform pipe which increases with perforations due to friction factor and because of the mixing of the flow inside the pipe and acceleration effect.

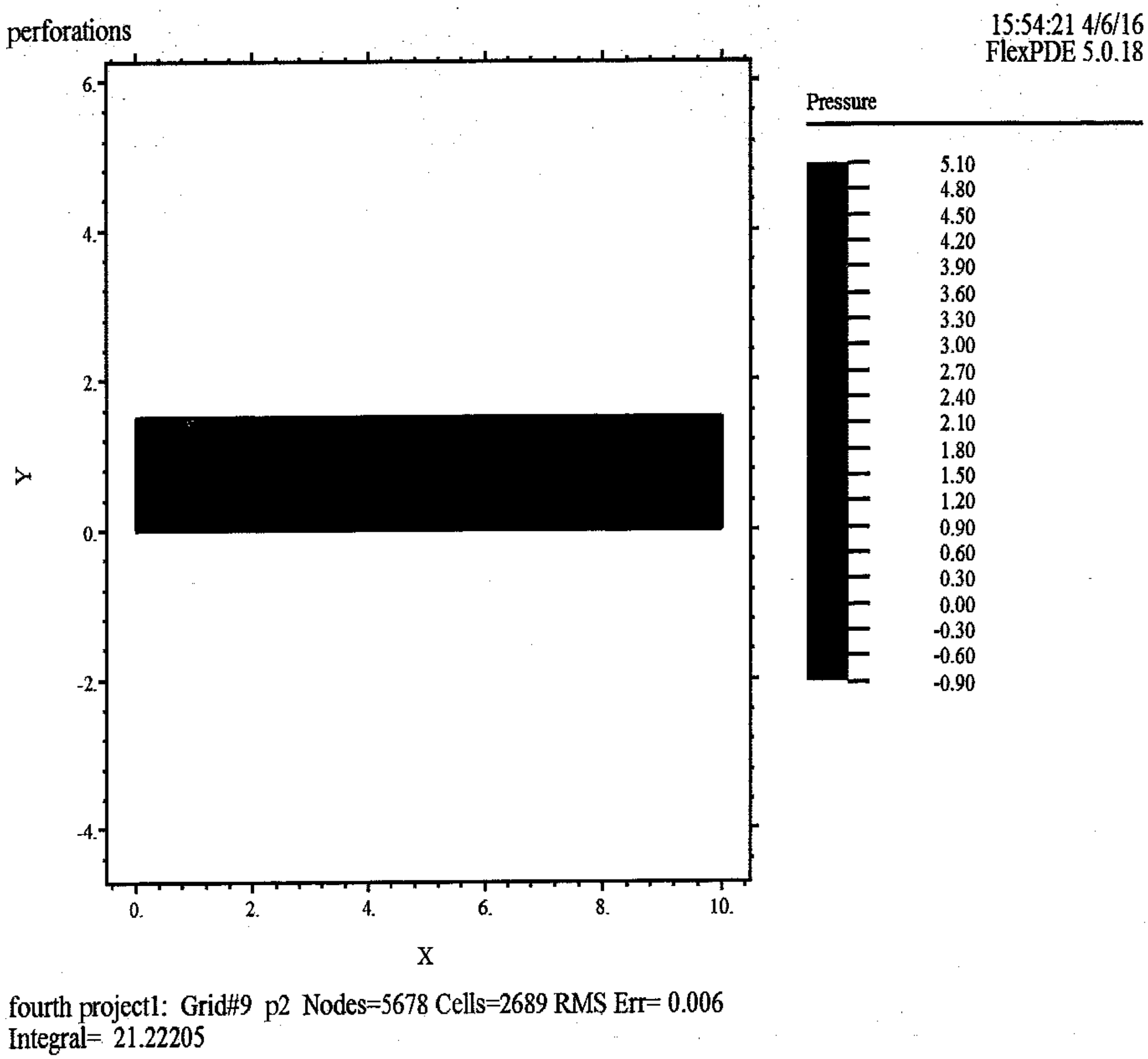


Fig. 4 Pressure contour for uniform perforations.

The summary of the uniform pipe:

U_m=1.989578

P_{in} -P_o =-2.00000

U_m/ P_{in} –P_o= 0.994789

P_{in} –P_o: pressure difference between neck end heel of pipe.

U_m: the mean velocity.

P_{in}: pressure at heel of pipe

P_o: outlet pressure (at the neck of pipe)

Figure (5): presents the velocity contour for x-axis (U) of pipe with converge perforation distribution which has the maximum value at the end of pipe in the middle because the accumulative flow and shear stress effect. The minimum value of (U) at the walls of that pipe which equal to zero (no slip condition).

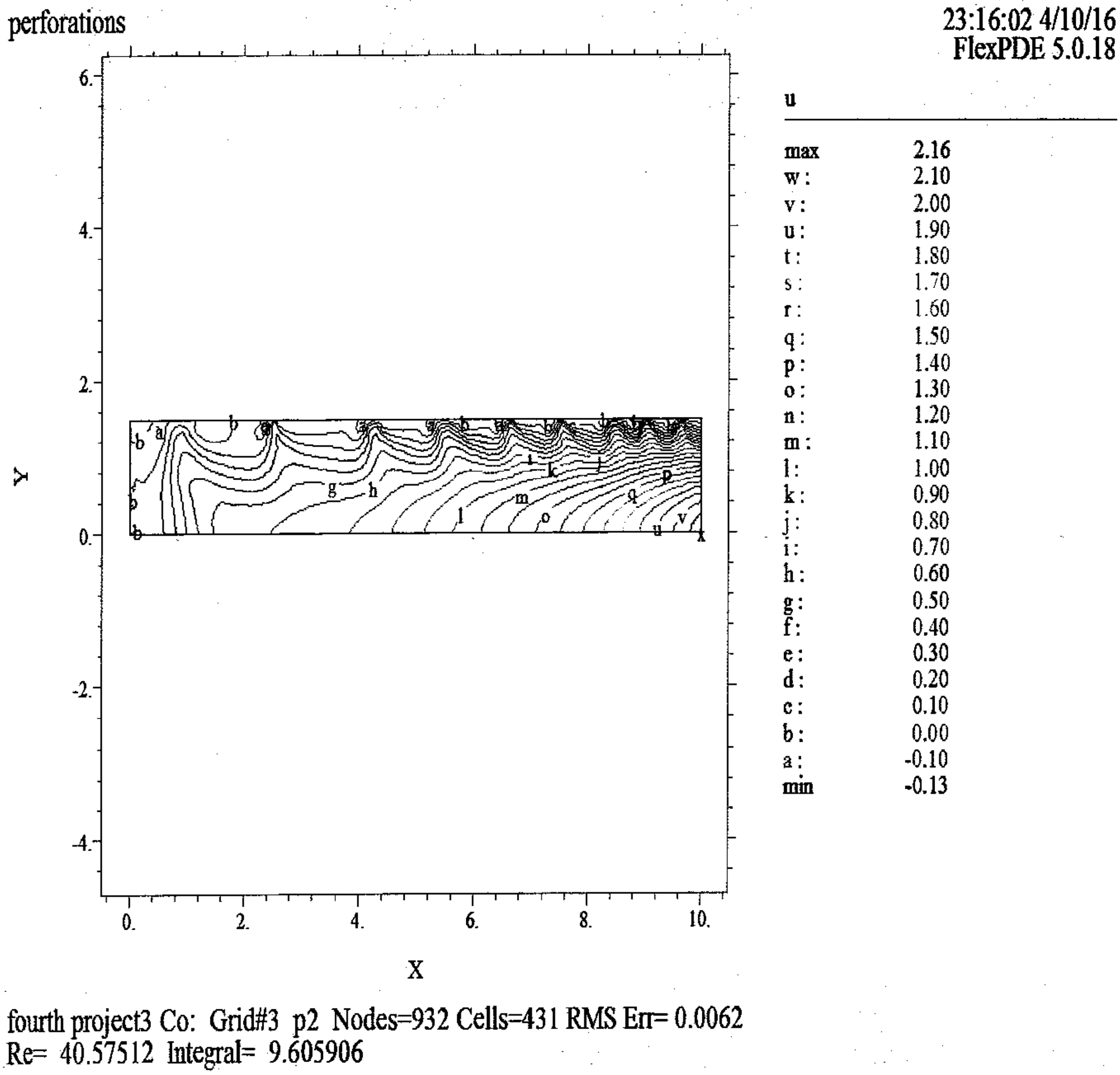


Fig. 5 U- velocity contours for converge perforations.

Figure (6): represents the velocity contour for the y-axis (V) of the converge pipe which illustrate that the maximum value at the inlet part during the perforations (boundary condition) .The minimum value of this velocity at the wall (no slip condition).

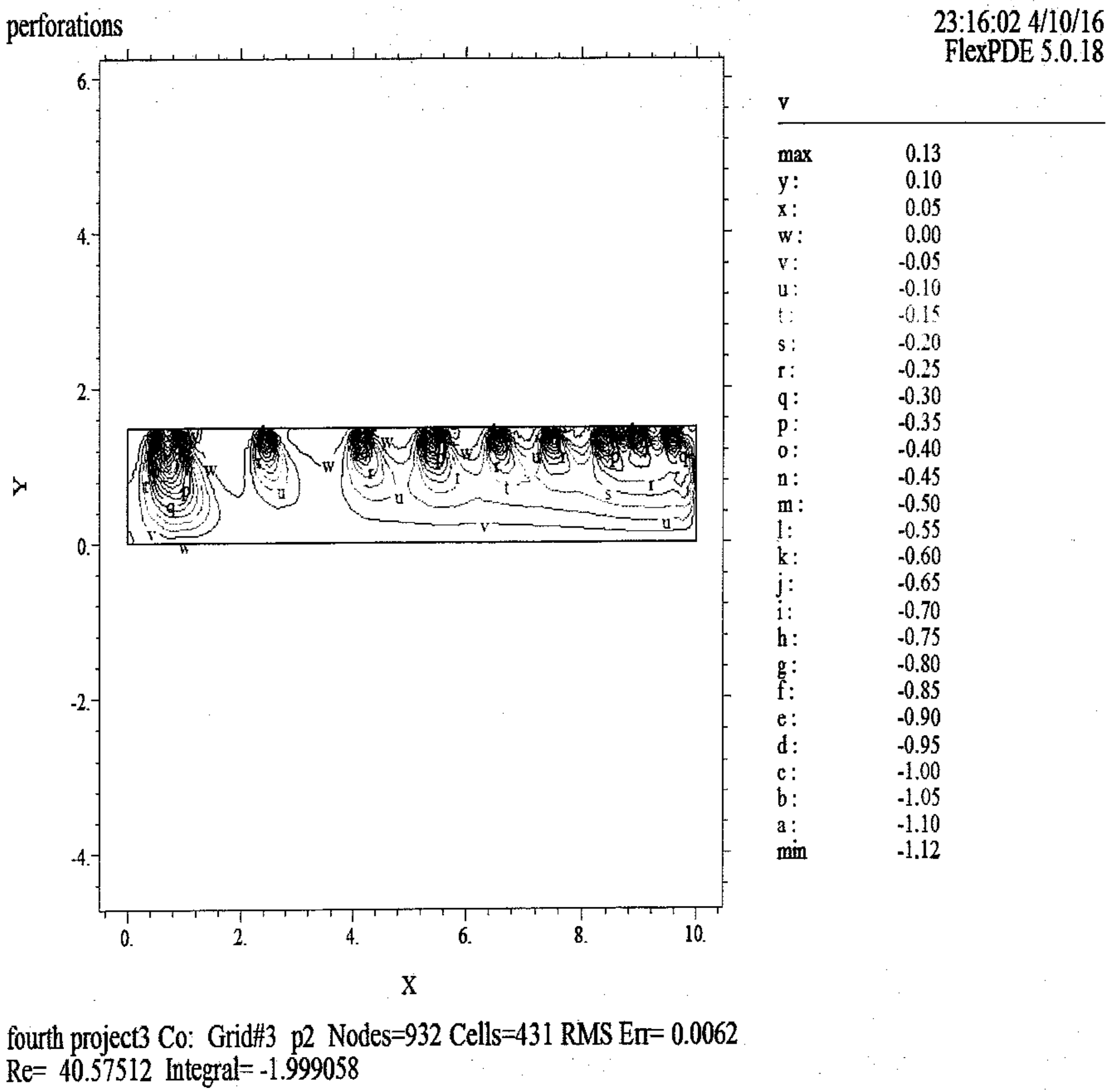


Fig. 6 V- velocity contours for converge perforations.

Figure(7): Indicates the speed distribution in the converge pipe which shows that the maximum value at the middle region of the pipe due to mixing effect of flow through the total perforations of the pipe and the minimum value of speed would be always at the walls of the pipe.

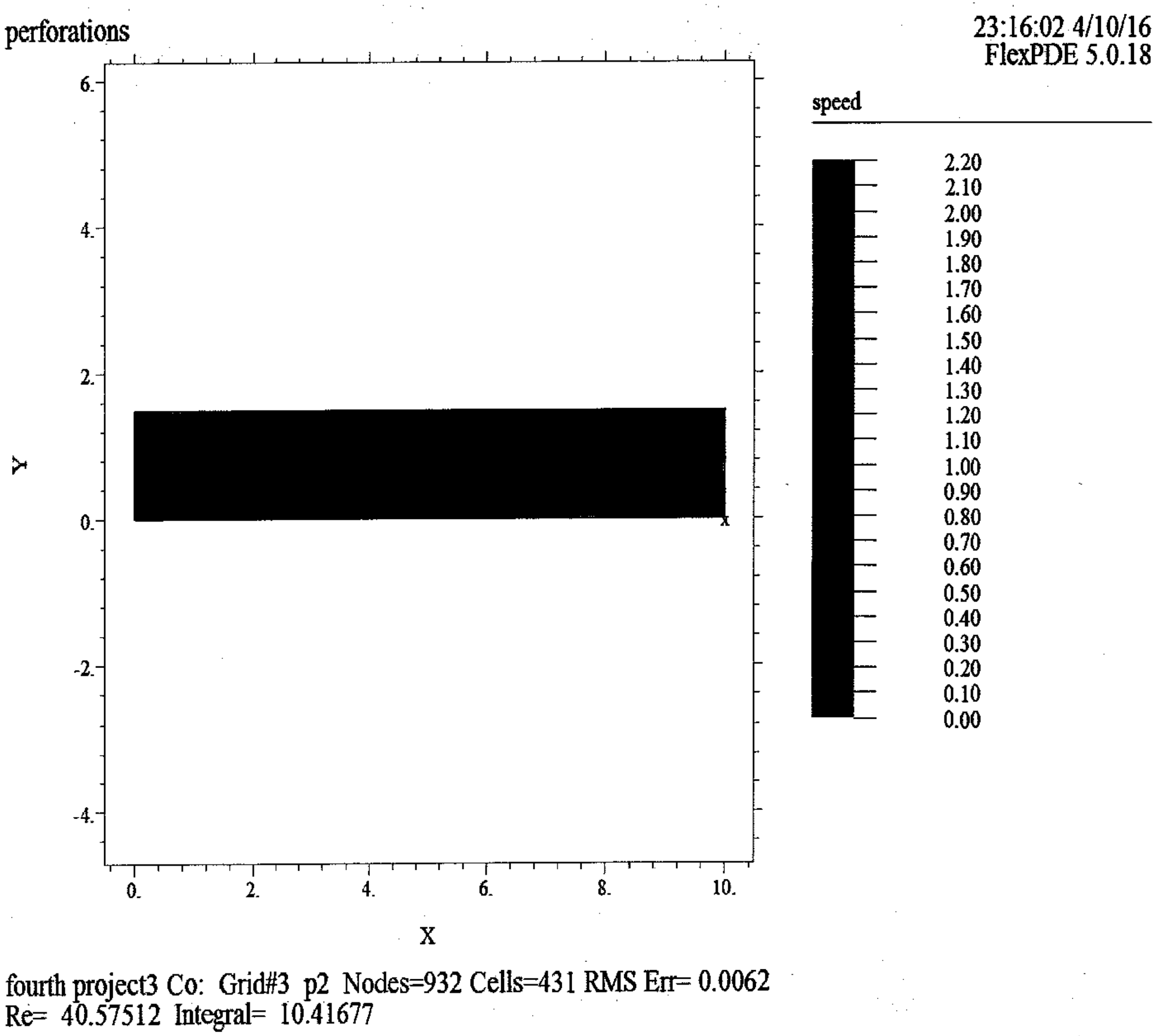


Fig. 7 Speed contours for converge perforations.

Figure (8): represents the pressure contour through the converge pipe which increase with increase the perforations due to friction factor and because of the mixing of the flow inside the pipe and acceleration effect.

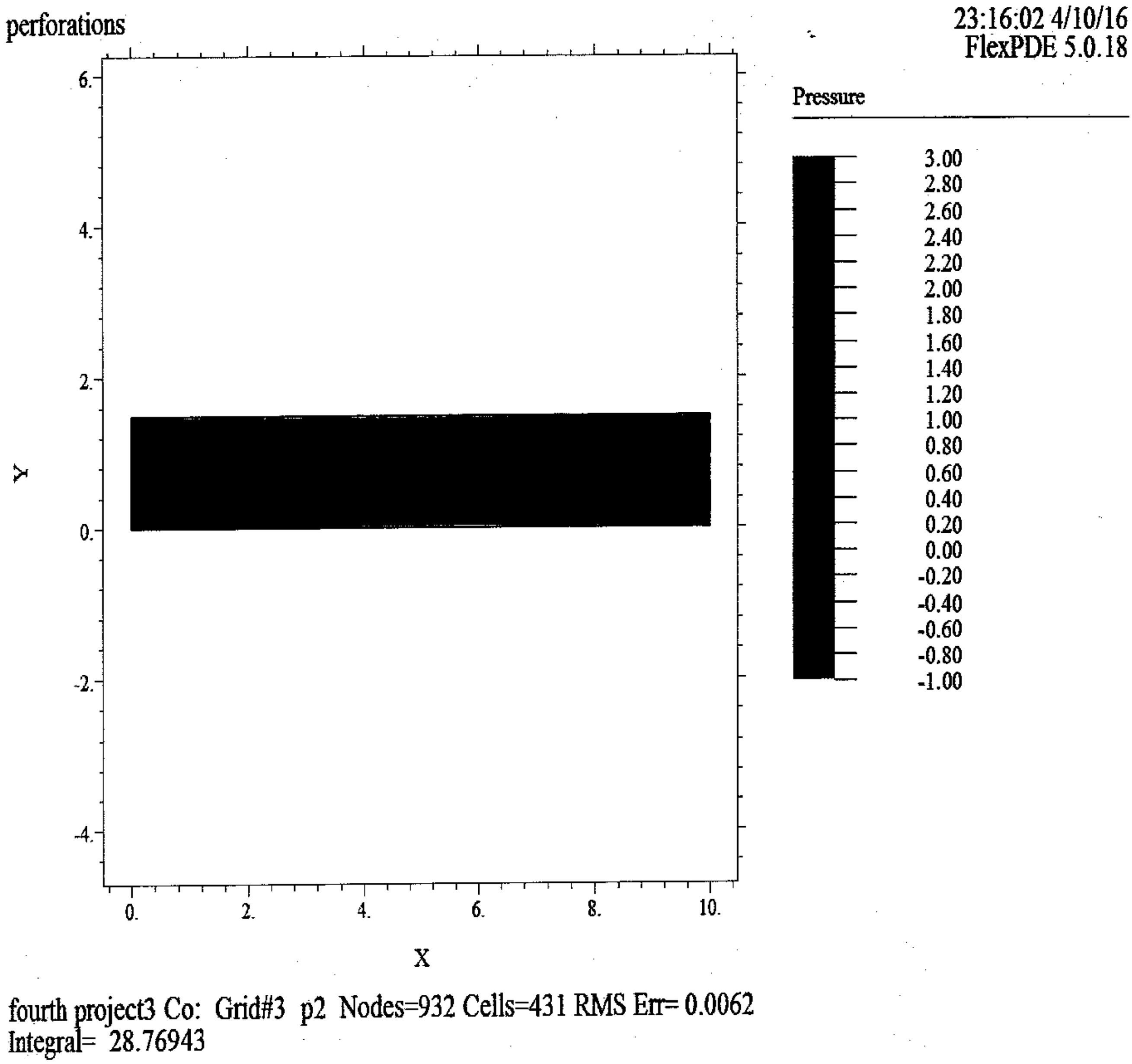


Fig. 8 Pressure contour for converge perforations.

The summary of the converge pipe:

U_m=1.396995

P_{in} -P_o =2.655133

U_m/ P_{in} –P_o= 0.526149

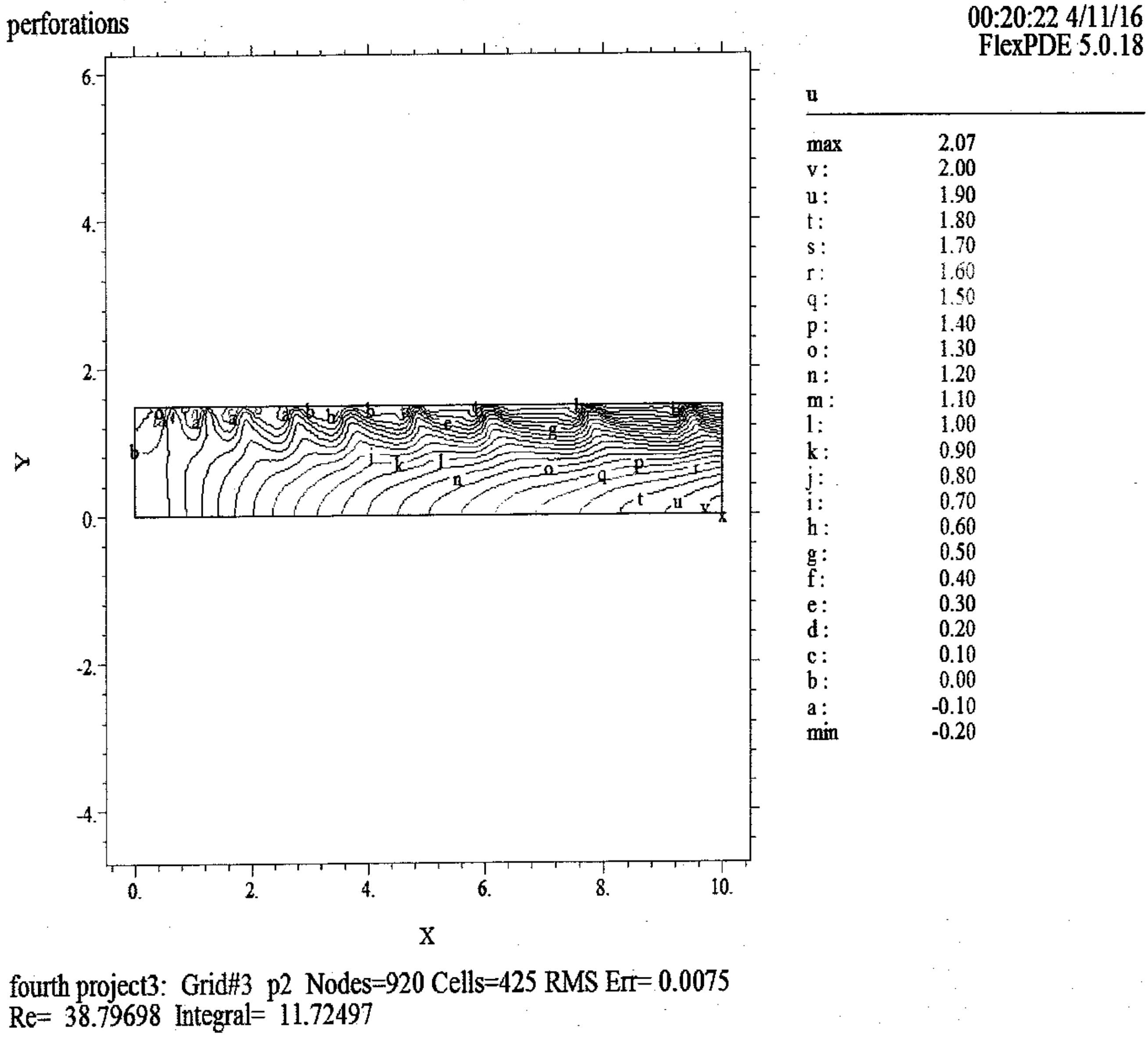
P_{in} –P_o: pressure difference between neck end heel of pipe

U_m: the mean velocity.

P_{in}: pressure at heel of pipe

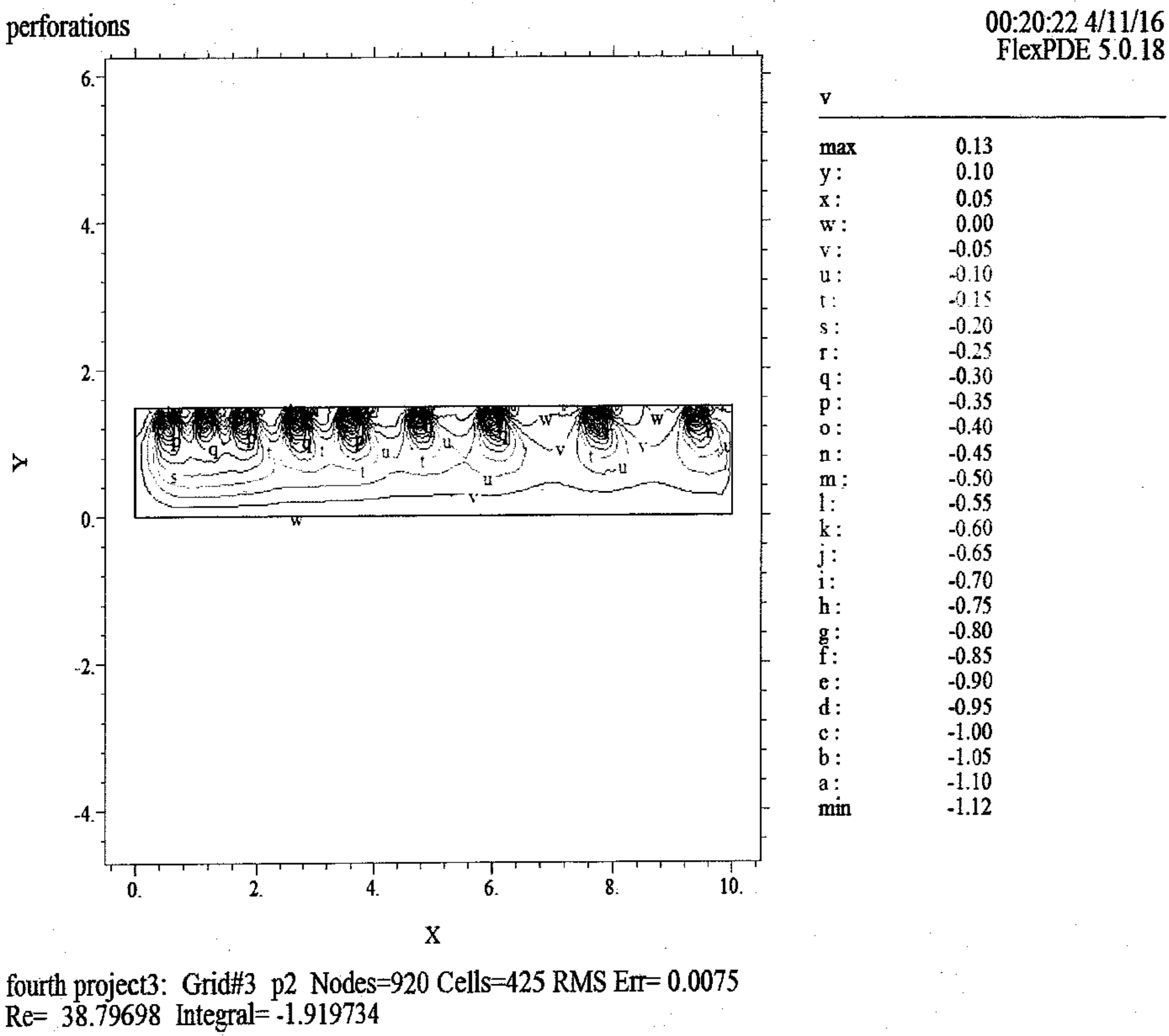
P_o: outlet pressure (at the neck of pipe)

Figure (9): presents the velocity contour for x-axis (U) of pipe with diverge perforation distribution which has the maximum value at the end of pipe in the center because the accumulative flow and shear stress effect. The minimum value of (U) at the walls of that pipe which equal to zero (no slip condition).



Fiq.9 U-velocity contour for diverge perforations.

Figure (10): represents the velocity contour for the y-axis (V) of the diverge pipe which shows that the maximum value at the inlet part during the perforations (boundary condition) .The minimum value of this velocity at the wall (no slip condition).



Fiq.10 V-velocity contour for diverge perforations.

Figure(11): shows the speed distribution in the diverge pipe along the pipe which gives with maximum value at the middle region of the pipe due to mixing effect of flow through the total perforations of the pipe. Also the minimum value of speed would be always at the walls of the pipe.

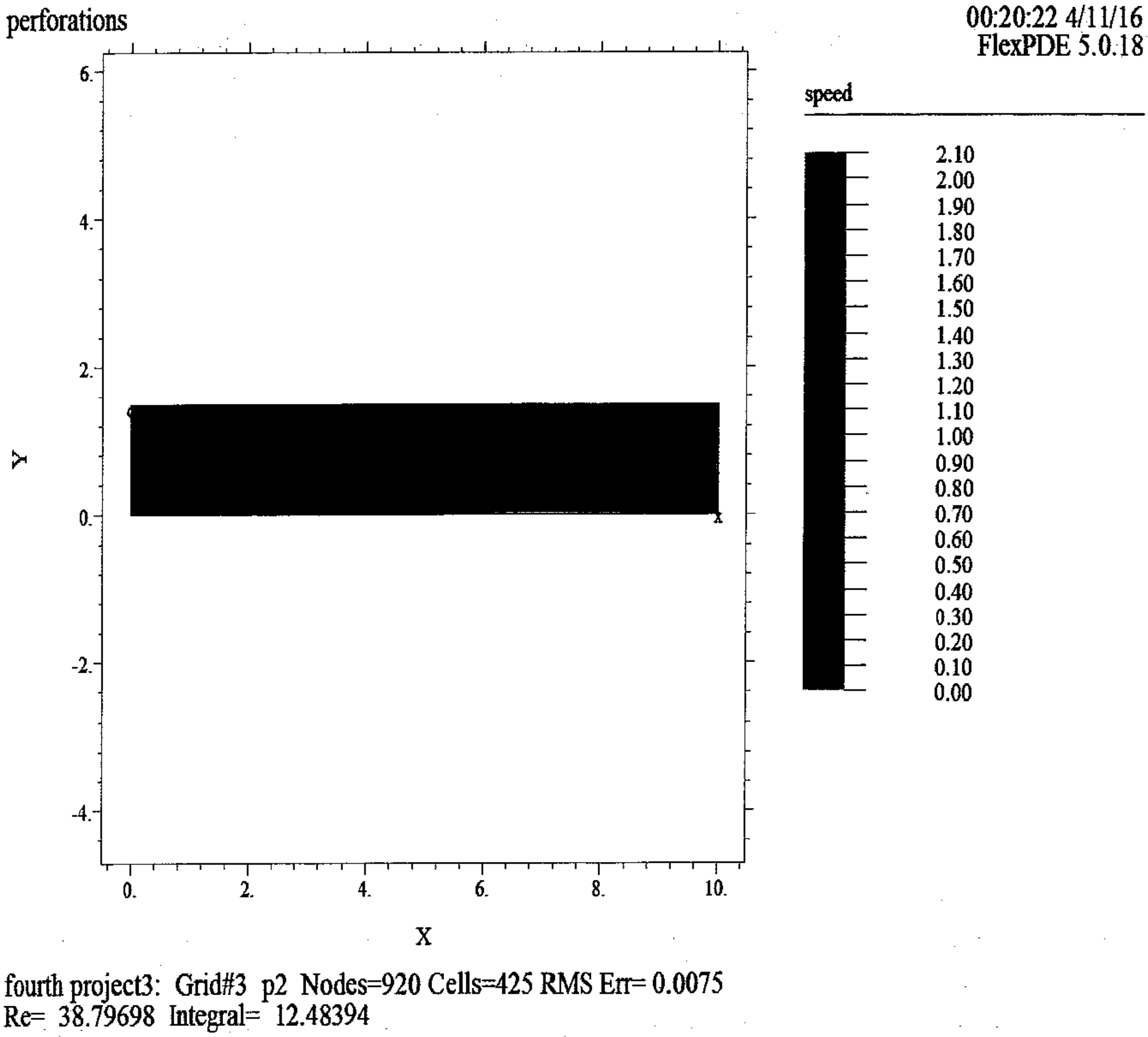


Fig. 11 speed contours for diverge perforations.

Figure (12): represents the pressure contour through the diverge pipe which increases inside perforations due to friction factor and because of the mixing of the flow inside the pipe and acceleration effect.

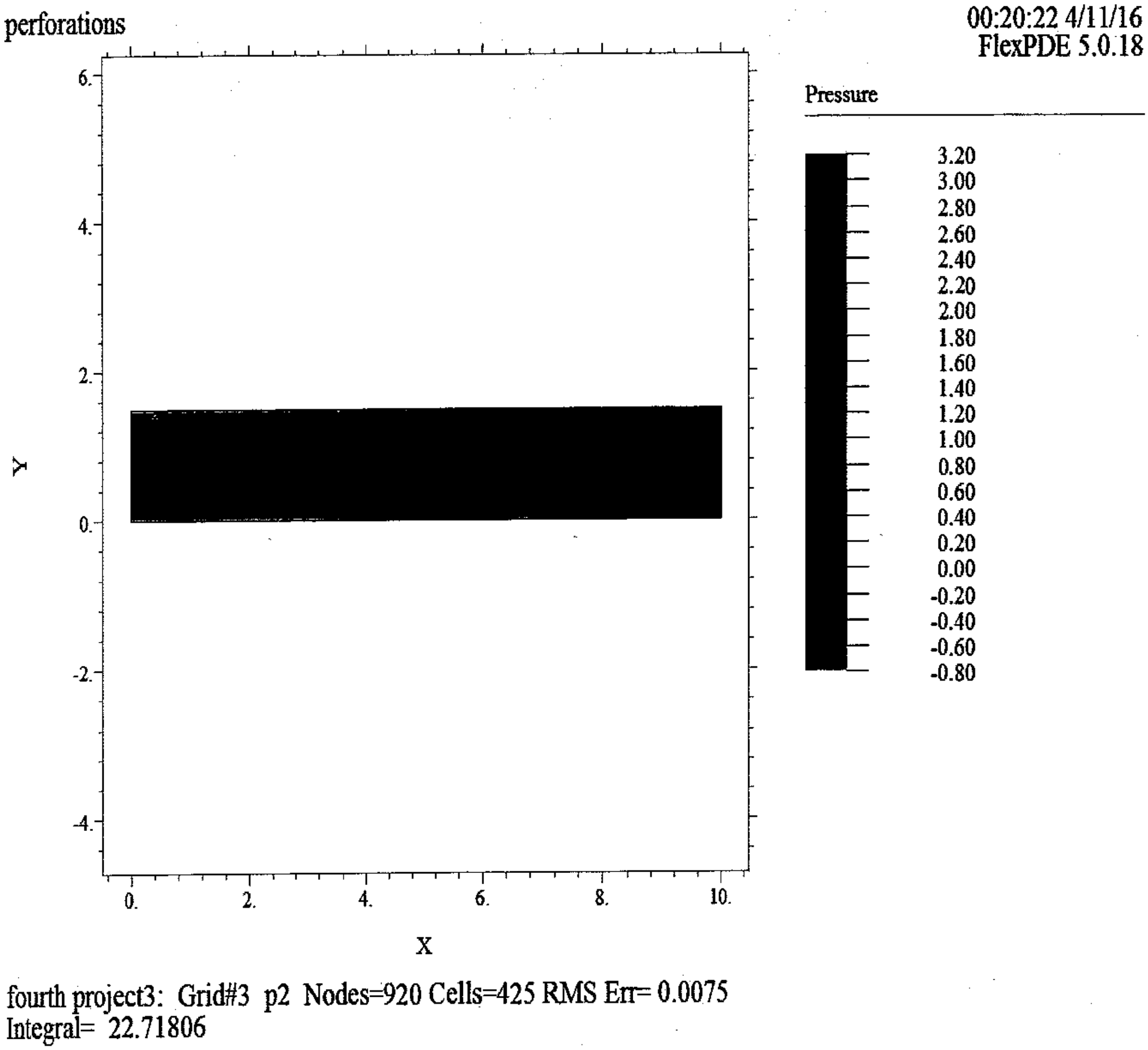


Fig. 12 Pressure contour for diverge perforations.

The summary of the uniform pipe:

U_m=1.353757

P_{in} -P_o =2.549991

U_m/ P_{in} –P_o= 0.530887

P_{in} –P_o: pressure difference between neck end heel of pipe

U_m: the mean velocity.

P_{in}: pressure at heel of pipe

P_o: outlet pressure (at the neck of pipe)

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