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The Nature of Streamline Flow: A Short Study

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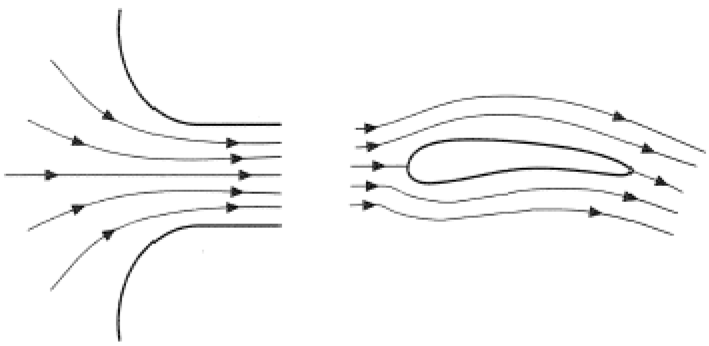
ABSTRACT: A streamline flow or laminar flow is defined as one in which there are no turbulent velocity fluctuations. In consequence, the only agitation of the fluid particles occurs at a molecular level. In this case the fluid flow can be represented by a streamline pattern defined within an*Eulerian description* of the flow field. These *streamlines* are drawn such that, at any instant in time, the tangent to the streamline at any one point in space is aligned with the instantaneous velocity vector at that point. In a steady flow, this streamline pattern is identical to the flow-lines or path-lines which describe the trajectory of the fluid particles within a *Lagrangian description* of the flow field, whereas in an unsteady flow this equivalence does not arise.

KEYWORDS: Streamline, flow, path, line, trajectory.

I. INTRODUCTION TO STREAMLINE FLOW

Streamline flow in case of fluids is referred to as the type of flow where the fluids flow in separate layers without mixing or disruption occurring in between the layers at a particular point. The velocity of each fluid particle flowing will remain constant with time in streamline flow.

In case of low fluid velocities, the fluid will flow without any sort of lateral mixing because of lack of turbulent velocity fluctuations. The fluid particles tend to follow a particular order where the movement or motion of fluid particles will be on the basis of particles flowing in a straight line parallel to the pipe wall. The movement happens in a way that the adjacent layers of the fluid will smoothly slide past each other.Streamflow is the characteristics that determine how the water of the stream will move in a stream channel. Streamflow can either be streamline/laminar flow or turbulent flow. In this paper, a study is carried out on the concept of streamline flow.



(a) Pipe Intake (b) Aerofoil

Streamline flow in fluids is defined as the flow in which the fluids flow in parallel layers such that there is no disruption or intermixing of the layers and at a given point, the velocity of each fluid particle passing by remains constant with time.

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II. REVIEW OF RELATED LITERATURE

Streamlines have been in the petroleum literature as early as Muskat and Wyckoff's 1934 paper. In 1937, Muskat presented the governing analytical solutions for the stream function and the potential function for 2D domains using the assumption of incompressible flow. Since then, streamlines and stream tubes have received repeated attention as a way to numerically predict the movement of fluids, even after the advent of finite-difference methods in the early 1960s. Important early contributions were made by Fay and Pratts,Higgins and Leighton, Bommer and Schechter, Martin and Wegner. In the early 1990s, streamlines were revived because advances in geological modeling techniques were producing models that were too large for finite differences to simulate in an acceptable time frame. For streamlines to be applicable to real field cases, important advances were made that extended streamlines to 3D using a time-of-flight variable allowed for streamlines to be periodically updated and included gravity.

Streamlining Fluid Dynamics

In Fluid Mechanics, the path of imaginary particles suspended in the fluid and carried along with it. In steady flow, the fluid is in motion but the streamlines are fixed. Where streamlines crowd together, the fluid speed is relatively high; where they open out, the fluid is relatively still.

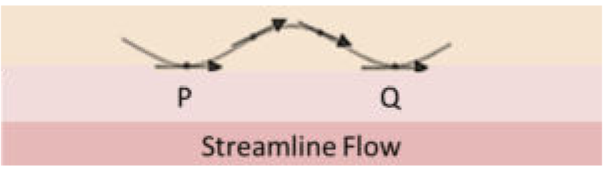
Steady Flow

The flow is steady when the velocity of every particle within the fluid is constant in time. However, this statement does not mean that the velocity of fluid particles will not vary at a different point in space. The velocity of a fluid particle can change as the fluid moves from one particular point to the other.

This means that at a different point the particle can have a different velocity. Steady flow signifies that each particle passing through the second point will behave the same as the previous fluid particle that has initially crossed that point. Therefore, under steady flow condition, the fluid particles will follow a smooth path that will not cross each other.

Hence, streamline is the path taken by fluid particles under the steady flow condition. In case of a streamline flow, the tangent drawn at any point of the curve (path) will be in direction of the velocity of the fluid at that point.

Below diagram represents a curve with tangents at different points. It describes how the particles present within a fluid moves with respect to time.



The diagram act as a permanent map to describe how the fluid flows during streamlines condition. Thus, no two streamlines can intermix or cross each other. Under steady flow, the map of the movement of fluid is stationary with respect to time. Hence, the continuum of lines will form if we try to describe the streamline flow of every particle.

Examples of Stream line Flow

Some streamlining flow examples from real life include smoke, taps, fountains, aircraft, water balloons, blood flow, rivers/canals, and many more.

Streamline and laminar flow

laminar flow, also called streamline flow, type of fluid (gas or liquid) flow in which the fluid travels smoothly or in regular paths, in contrast to turbulent flow, in which the fluid undergoes irregular fluctuations and mixing

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Equation of streamline flow

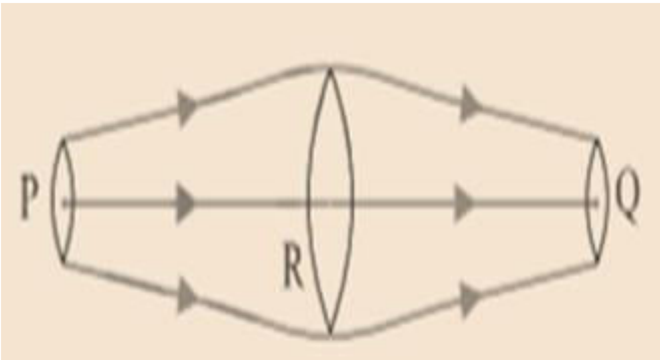
The differential equations of the streamline may be written $d\vec{r} \times \vec{v} = \vec{0}$, where $d\vec{r}$is an element of the streamline and $\vec{v}$the velocity vector; or in Cartesian coordinates, dx/u = dy/v = dz/ w, where u, v, and w are the fluid velocities along the orthogonal x, y, and z axes, respectively.

Implications of streamline

Streamlines are ideally suited for modeling large, geologically heterogeneous, multi-well systems where production is principally a result of fluid injection (water, polymer, CO2, etc.).

Derivation of Streamline Flow

Consider three parts (P, R, and Q) in planes that are present in the perpendicular direction to the fluid. Refer to the diagram below



We will be able to determine the boundaries the selected points in the plane by the same set of the streamlines. Hence, the particles of fluid passing through the surfaces at the three-point P, R and Q will be the same. Now consider the area at the three points as A_P, A_R, and A_Q. Consider the speed of the fluid particles as v_P, v_R, and v_q.

Now, we will calculate the mass of fluids. The mass of the fluid m_P crossing at the area A_P at a small time interval t will be "ρ_P $A_P v_P$ t". Similarly, the mass of fluid m_R and m_Q will be "$\rho_R A_R v_R$ t" and "ρ_Q $A_Q v_Q$ t" passing at A_P and AQ respectively at a small interval of time Ät.

In all the three cases, the mass of liquid flowing in and flowing will be equal. Therefore, we can write the equation as

ρ_P $A_P v_P$ t = $\rho_R A_R v_R$ t= ρ_Q $A_Q v_Q$ t

If we consider the fluids as incompressible in nature then $\rho_P = \rho_R = \rho_Q$ will be equal. So the above equation can be rewritten as

$A_P v_P = A_R v_R = A_Q v_Q$ (after elimination of ρ)

The above equation is the *equation of continuity*. The equation also represents conservation of mass in case of the flow of the incompressible liquids.

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General Equation of Continuity

$$Av = \text{Constant}$$

where Av is the flow rate of the liquid or volume flux of the liquid. The flow rate in case of streamline flow remains constant throughout the flow of liquid through the pipe. Hence, the streamlines in narrower regions are present closely thereby resulting in the increase of velocity and vice versa.

From the above diagram, the area of R will be greater than Q.Thus velocity in the R will be less than Q. Thus, the fluid will increase in velocity while crossing from R to Q. Therefore, it is easy to acquire steady flow at low fluid flow speed. However, after reaching a particular speed, the flow will lose its steadiness and gradually tend to become turbulent.This speed is called critical speed. The classic example of streamline flow to turbulent flow is the formation of white-water rapids when a fast-moving stream comes in contact with rocks.

Applications of streamlines

Streamlines are a powerful complementary tool to more traditional simulation techniques, and they are expected to play an important part in optimizing field production and management in the future. Specifically, streamlines can be used to:

1. Validate upscaling techniques by allowing to generate reference solutions of fine-scale models.
2. Efficiently perform parametric studies
3. Visualize flow
4. Balance patterns
5. Determine efficiency of injectors and producers using data provided by streamlines
6. Aid in history matching
7. Enable ranking of production scenarios/geological models
8. Optimize and manage field injection/production
9. Conduct reservoir surveillance
10. Validate upscaling techniques by allowing to generate reference solutions of fine-scale models.
11. Efficiently perform parametric studies.
12. Visualize flow.
13. Balance patterns.
14. Determine efficiency of injectors and producers using data provided by streamlines.
15. Aid in history matching.

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