The Transient Gas-Liquid Flow in Pipes by Two-Fluid Model

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Abstract

There are several flaws in the two-fluid model, which is mostly applicable to the hit flow pattern and is used to anticipate transitory flows. A unified model known as the "two fluid/two-flow-pattern model" is proposed in this work. It begins with the existence of two fundamental flow patterns: separated flow (stratified or annular) and dispersed flow (with bubbles or droplets). It is commonly recognized that slug flow is nothing more than a random pattern composed of time- and space-sequential sequences of separated flow (Taylor bubbles) and bubbly flow (liquid slugs). A continuous function of time and location, which represents the probability that the separated flow will occur, is intended to characterize the flow pattern. The mass and momentum conservation equations, which are defined for each phase and every fundamental flow pattern and averaged throughout the cross section, constitute the basis of the model. The fundamental equations are distributed by the probability of the related basic pattern to produce the generic two-phase flow equations for mass and momentum. Our focus has been limited to physical scenarios short of interfacial mass transfer. The order of magnitude of this term has been calculated for slug flow: the results show that it cannot be ignored, especially in transient flows.

Keywords: Two-fluid model, liquid slugs, Phase fractions, drift-flux models.

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Introduction

There are several flaws in the two-fluid model that is employed in computer programmers that forecast transient flows. Different approaches have been taken thus far. One approach is to ignore the different flow patterns and design the closure laws in a way that best fits the experimental data. In this scenario, the closure laws could not account for the physics of each flow pattern, particularly the scale effects and unless it is really complex. An alternative approach involves closing the set of equations for each flow pattern separately and adding the transition models that forecast the occurrence of that pattern. However, in this scenario, the model as a whole does not preserve the continuity of the solution; to put it another way, altering the set of closure laws from one flow pattern to another could lead to improper behavior of the numerical model. Furthermore, the slug flow pattern is not well addressed by any of these techniques; in fact, the commonly used equations have several assumptions that are unacceptable for transients. A single formulation is suggested in this study. It begins with the observation that there are two fundamental flow patterns: separated flow (stratified or annular) and dispersed flow (with bubbles or drips). The essential presumption will be to think of the other flow patterns as assemblages of the two fundamental patterns. For instance, slug flow is nothing more than an amorphous pattern composed of time- and space-sequential sequences of separated flow (Taylor bubbles) and bubbly flow (liquid slugs). The overall solution of the issue may be found by applying the particular balancing equations to each segment of the sequence. Nonetheless, each fundamental pattern's recurrence in space and time is unpredictable. Therefore, statistical averages are used to depict the physical balances. Formally, the procedure is the same as that which was employed to get the local two-phase flow equations.

We concentrate on transient fluxes in this work. The two-phase/two-flow-pattern model's fundamental ideas are explained and displayed. The relevant version of the two-fluid model for transient slug flows is then developed using the results.

THEORY OF THE BASIC FORMULATION

In order to construct the theory, the two-phase pipe flow classification has to be updated as follows. We'll explain how basic and irregular flow patterns vary from one another.

In addition to include flows in which the phase structure is not homogeneous in the cross section, such as droplet annular flow or bubbly annular flow, the basic flow patterns are defined by the homogeneity according to x and t of the interfacial structure: this is the case for bubbly flow and separated flow. Even under input stable circumstances, the various flow patterns are not uniform; instead, they are defined by space-time sequences of two fundamental patterns, one of which is slug flow. Remarkably, under certain flow circumstances, the fundamental pattern may exhibit unstable behavior giving rise to a diverse pattern. For instance, it is strongly assumed that the bifurcation of any bubbly flow results in the slug flow structure. For the two fundamental flow patterns, we'll assume that the closure problem has been resolved. For ease of writing, we will use the following formula to represent the balance of the physical amount f that is carried in the pattern q by the phase k:

$$\frac{\partial}{\partial t}(\rho_{kq} R_{kq} \mathbf{f}_{kq}) + \frac{\partial}{\partial x}(\rho_{kq} R_{kq} U_{kq} \mathbf{f}_{kq}) + \frac{\partial}{\partial x}\mathbf{j}_{kq} = \mathbf{F}_{kq} \quad \text{........1}$$

$$\chi_q(x,t) = \sum_{j=1}^{M} \{ H[x - x_{q,2j+1}(t)] - H[x - x_{q,2j}(t)] \} \quad \text{...........2}$$

$$\chi_q(x,t) = \sum_{j=1}^{M} \{ H[t - t_{q,2j}(x)] - H[t - t_{q,2j+1}(x)] \} \quad \text{.........3}$$

$$V_{q,i} = \frac{dx_{q,i}}{dt} \quad \text{...........4}$$

The phase fraction is denoted by R. It is always feasible to use the form above, which shows the flux j and the source F. Therefore, if we know when each fundamental pattern occurs and the coordinate x, we may solve the miscellaneous pattern in its entirety. To construct the general balancing equation, we must define the pattern q's characteristic function by q. For slug flow, $ is the separated flow's characteristic function in this case. Let us examine the most basic scenario, which does not entail intricate procedures such as the formation of Taylor bubbles, coalescence, and break-up. The function $ may be seen as the total of Heaviside functions related to the events that take place at time t, at locations x2j, x2j+1,...

$$\frac{\partial}{\partial t}\chi_q + V\frac{\partial}{\partial x}\chi_q = 0$$ **..........5**

It is convenient to introduce the sum of the Dirac delta function by putting:

$$\varpi_q = -\frac{\partial}{\partial x}\chi_q = \sum_{j=1}^{M}\{\delta[x - x_{q,2j}(t)] - \delta[x - x_{q,2j+1}(t)]\}$$ **........6**

$$\frac{\partial}{\partial t}[\chi_q \rho_{kq} R_{kq} \mathbf{f}_{kq}] + \frac{\partial}{\partial x}[\chi_q \rho_{kq} R_{kq} U_{kq} \mathbf{f}_{kq}] + \frac{\partial}{\partial x}[\chi_q \mathbf{j}_{kq}] = \chi_q \mathbf{F}_{kq} - \varpi_q [\rho_{kq} R_{kq} \mathbf{f}_{kq} (U_{kq} - V) + \mathbf{j}_{kq}]$$ **........7**

In order to generalize the cell velocity V, we will define that it is equivalent to Vq,i for χ = χqi(t) and can have any value in other places as long as it behaves properly. The basic property may be obtained by taking Eq. 2, which represents the generalized derivatives of the function $q with respect to χ and t. The local-instant 1D balance equation of the pattern q is deduced by multiplying Eq. 1 by χq: 5041
From the obvious relations

$$\sum_{q=1,2} H_{q,j} = 1 \qquad \sum_{q=1,2} \chi_q = 1 \qquad \sum_{q=1,2} \delta_{q,j} = 0 \qquad \sum_{q=1,2} \varpi_q = 0$$

the balance equation at the extremities can be written.

$$\sum_{q=1,2} \varpi_q [\rho_{kq} R_{kq} \mathbf{f}_{kq} (U_{kq} - V) + \mathbf{j}_{kq}] = 0$$ **.........8**

$$\sum_{q=1,2} \delta_{q,j} [\rho_{kq,j} R_{kq,j} \mathbf{f}_{kq,j} (U_{kq,j} - V_j) + \mathbf{j}_{kq,j}] = 0$$ **..........9**

$$\sum_{q=1,2}\left\{\frac{\partial}{\partial t}(\chi_q \rho_{kq} R_{kq} \mathbf{f}_{kq}) + \frac{\partial}{\partial x}(\chi_q \rho_{kq} R_{kq} U_{kq} \mathbf{f}_{kq}) + \frac{\partial}{\partial x}(\chi_q \mathbf{j}_{kq}) - \chi_q \mathbf{F}_{kq}\right\} = 0$$ **....10**

This equation in which the extremity terms do not appear will reduce after further algebraic calculation to the balance equation of the two-fluid model. In the further development we shall identify q=1 to the separated flow with H=H1, χ=χ1 and & δ= δ 1. Moreover, we shall distinguish the positive and the negative terms of Eq. 6 by putting

$$\varpi' = \sum_{j=1}^{M}\{\delta[x - x_{2j}(t)]\}$$ **............11**

The equations mentioned here have resemblance to the jump conditions or interfacial balance equations found in the local-instant 3D formulation. They might be understood as the physical quantities being conserved between the extremes. Now, for q=1,2, summing Eq. 7 yields the immediate balance and This equation in which the extremity terms do not appear will reduce after further algebraic calculation to the balance equation of the two-fluid model. In the further development we shall identify q=1 to the separated flow with H=H1, χ=χ1, and δ = δ1. Moreover, we shall distinguish the positive and the negative terms of Eq. 6 by putting.

$$\frac{\partial}{\partial t}[(1-\chi)\,\rho_{kD}\,R_{kD}\,\mathbf{f}_{kD}] + \frac{\partial}{\partial x}[(1-\chi)\,\rho_{kD}\,R_{kD}\,U_{kD}\,\mathbf{f}_{kD}] + \frac{\partial}{\partial x}[(1-\chi)\,\mathbf{j}_{kD}] = (1-\chi)\,\mathbf{F}_{kD} + \varpi'\,[\,\rho_k\,R_k\,\mathbf{f}_k\,(U_k - V) + \mathbf{j}_k] - \varpi''\,[\,\rho_k\,R_k\,\mathbf{f}_k\,(U_k - V) + \mathbf{j}_k] \quad \text{........12}$$

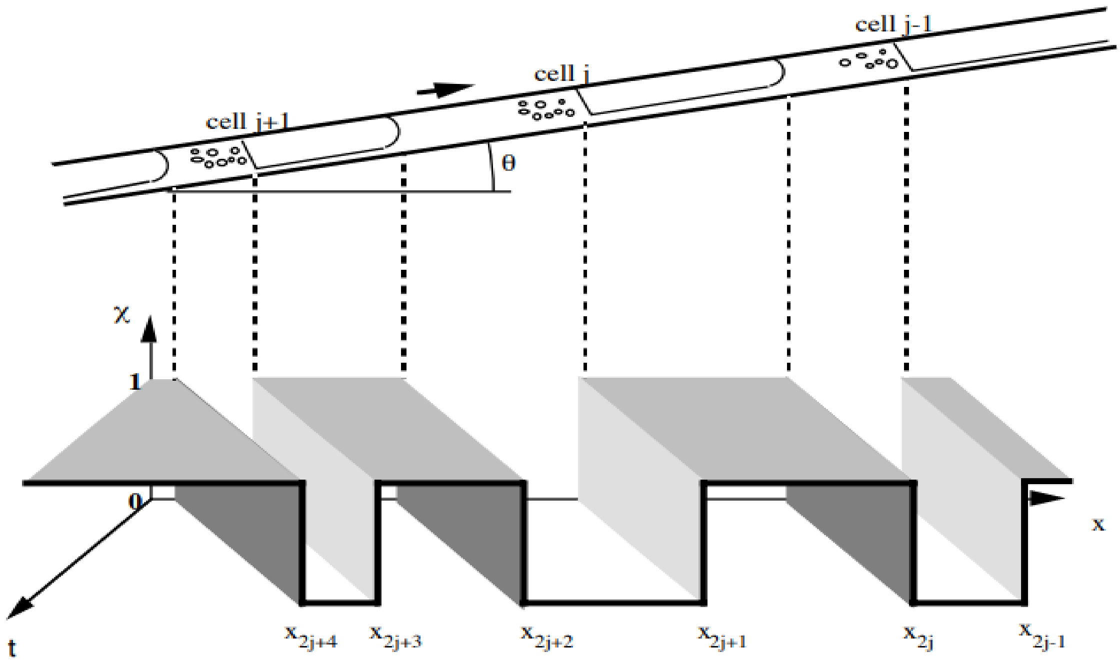

Figure 1. Example of miscellaneous flow-patter

Equation of average balance

If (χ,t) may originate from a deterministic occurrence, although its predictability has not been established. This renders the local-instant equations meaningless. Since we are primarily concerned with the behavior of the average pressure and void percentage, the problem is not particularly important. There are two possible Eulerian averaging procedures. -the statistical average taken over N samples of the same flow situation; however, the method fails when applied to Dirac delta functions (incidentally, it has been used frequently for the formulation of the local-instant 3D equations of two-phase flows). -the time averaging over the time lapse T: the method has the drawback of smoothing the fast transients the time scale of which is less than T: As far as we know, there is no evidence that

$$\overline{\varpi(x,t)} = \lim_{N\to\infty} \frac{1}{N} \sum_{i=1}^{N} \{\varpi_i(x,t)\} \quad \text{................13}$$

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$$\overline{F}(x,t) = \frac{1}{NT_h} \sum_{i=1}^{N} \left\{ \int_{t}^{t+T_h} F_i(x,t)\, dt \right\} \qquad \text{……………….14}$$

Therefore, the procedure consists of a statistical average over N independent samples, followed by a temporal average over the interval Th. We will refer to the time scale of transient events as Tp and the fluctuations to be filtered as Tc. N and T h have to meet the requirements listed below.

TWO-FLUID.

We can now describe the balance for mass, momentum, and energy after figuring out the set of equations for every physical variable. The exposition will be limited to the equations of mass and momentum, though. If we ignore the viscous stress based on χ as well as the transverse distribution of density and velocity, they are conservation equations by applying the previously described method. If surface tension is ignored, the pressure terms are calculated in full in the appendix, we derive the jump condition over the average momentum interfaces and Two-fluid models for separated and bubbly flows have been written. However, by using the same form of the conservation equations, it has been widely extended in computer programmers to slug flows. It is conceivable to show that some fundamental terms are absent; given that they occur as χ is derivatives in transients, they may be quite important. By adding the equations for the two-fluid/two-flow-pattern model for q=1,2, the governing equations of the two-fluid model are obtained.

$$\frac{\partial}{\partial t}(\rho_{kq} R_{kq}) + \frac{\partial}{\partial x}(\rho_{kq} R_{kq} U_{kq}) = 0 \qquad \text{………….15}$$

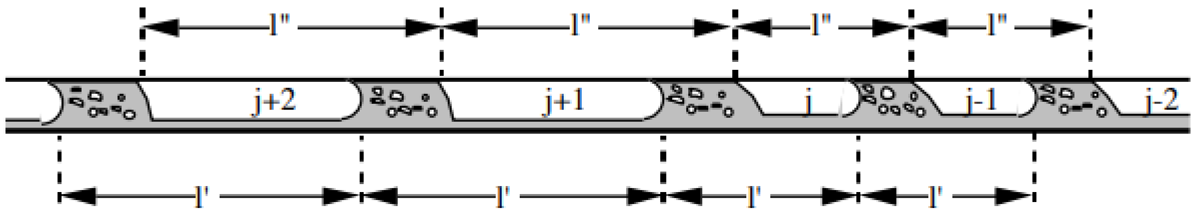
$$\frac{\partial}{\partial t}(\rho_{kq} R_{kq} U_{kq}) + \frac{\partial}{\partial x}(\rho_{kq} R_{kq} U_{kq}^2) + \frac{\partial}{\partial x}(R_{kq} P_{kq}) = T_{kq}^{w} + T_{kq}^{i} - \Pi_{kq}^{i} - \rho_{kq} R_{kq}\, g \sin\theta \qquad \text{……….16}$$

$$\sum_{k=1,2} R_{kq} = 1 \qquad \text{……………..17}$$

$$\sum_{k=1,2} (T_{kq}^{i} - \Pi_{kq}^{i}) = 1 \qquad \text{……………….18}$$

$$I_1 = \frac{\partial}{\partial x}\left[\frac{\beta\,(1-\beta)\,\rho_k^S \rho_k^D R_k^S R_k^D [U_k^S - U_k^D]^2}{\rho_k R_k}\right] \qquad \text{…………….19}$$

$$C_L = \beta\,(1-\beta)\,\frac{R_L^S\,R_L^D}{R_L^2}\left(\frac{U_L^S - U_L^D}{U_L}\right)^2 \quad \text{..............20}$$



Characteristic length for one flow sample: the slug flow structure is assumed periodic; the wavelength changes between the jth and the j+1th Taylor bubble

A better strategy for the choice of the closure equations is not so clear. Nevertheless, the overall balance of equation and unknown number can be worked out. As previously mentioned, there are 20 equations for using the aforementioned assumptions.

CONCLUSION

A thorough demonstration of the process for obtaining the two-phase pipe flow governing equations for various flow patterns has been made for transient flows. A generalization of the two fluid model, it results in the so-called "two-fluid/two-flow-pattern model". The example is presented for slug flow, in which they depict the mass and momentum transfers from liquid slugs to Taylor bubbles or vice versa. The model presents the fluxes of mass and momentum at the "interfaces" between the two distinct fundamental flow patterns. Due to the introduction of two length scales and two velocity scales as additional unknowns at the extremities, these fluxes significantly enhance the complexity of the model. It is demonstrated that these scales only equalize in steady flow, where they stand for the average velocity of the Taylor bubbles and their characteristic cell length. Although the overall closure problem is considered, no closure law solution has been put out. The capacity of the two-fluid/two-flow-pattern model to create the set of pertinent equations is an intriguing application. This set of equations is not confined to the two fundamental flow patterns, namely separated flow and bubbly flow. An additional inertia component for irregular flow patterns is produced by the momentum equation's non-linear term. This term takes into account the additional inertia resulting from the difference in average velocities between separated and scattered patterns. For slug flow, the order of magnitude of this term has been estimated; the findings indicate that it cannot be disregarded, particularly in transitory flows.

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