Numerical simulation of valveless pumping phenomenon using an energy preserving lumped model

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ABSTRACT

By the phenomenon of valveless pumping, we mean directional net power take places when a periodic external excitation is applied at an asymmetric position on an elastic tube. It causes a directional net flow in a closed loop system or triggers a directional energy storing effect, in an open tank system with gravity effect. Experiments have shown such phenomena well but its corresponding simulations based on numerical models have produced many issues. The reliability of models will be the most important one among them. Therefore, we focus on the reliability or feasibility of the energy preserving lumped model which is newly proposed by the authors.

OPEN TANK SYSTEM

An open tank system to consider is illustrated in Fig. 1. An elastic tube is connected to two rigid tanks and the gravity is applied in the downward direction. Incompressible fluid, for instance water, fills both tanks by some height and the elastic tube as well. If we stimulate an asymmetric part by a simple periodic force, the fluid starts moving and finally it approaches a periodic state. At the periodic state, the average heights of fluid in tanks can differ. This phenomenon will be called the energy saving obtained from the directional net power.

A simple and theoretical tank model is studied by G. Propst [1] in an open tank system. On the closed loop systems, Abrahami [2], Jung [3], and Lee [4] analyzed the valveless pumping mechanism using the software package, a lumped model, and the immersed boundary method.

To analyze the energy saving phenomenon, we propose an energy preserving lumped model or shortly an EPL model. The EPL model is basically derived by using the energy principle on each compartment of the elastic tube. The key point in this model is laid on how to treat the part near the junction of tanks and how to make a relationship between the fluid pressure and the elasticity of the tube.

RESULTS AND DISCUSSION

Let us consider the swing flow in which no external pumping is involved. In computation of the EPL model, 5 compartments are employed. At the initial time, the fluid heights of the left and right tank is set to be $H_L(0) = 30$ and $H_R(0) = 10$, the radii of all compartments in the elastic tube to be $r_i(0) = 0.5$, the Young’s modulus to be $E = 1.0 \times 10^7$, and the thickness of
the tube to be \( h_i(0) = 0.02 \). We consider two cases: (1) equal size tanks \( r_L = r_R = 10 \) (2) unequal size tanks \( r_L = 10, r_R = 15 \) where \( r_L \) and \( r_R \) represent the radii of left and right tank, respectively.

In case of (1), starting from this initial condition, the fluid at the left tank starts moving downwards for a while and then the right tank gets filled with the incoming fluids. The fluid flows back to the left tank at around 8 [s], which is depicted in Fig. 2. On the other hand, in case of (2), there happens slightly different flow patterns compared to the case (1) as shown in Fig. 3.
Figure 4. (Left) External pumping frequency-difference of heights (Right) External pumping frequency-difference of energy changes of both tanks: 5 compartments $r_L = 10, r_R = 15$

Finally, the relationship between the pumping frequency and the difference of fluid heights in two tanks are plotted in Fig. 4 (Left). The energy variation between two tanks are computed and Fig. 4 (Right) shows the difference of average energies in two tanks. In this case, the number of compartments, fluid density, fluid viscosity, gravity, and Young’s modulus are set to be 40, 1, 0.01, 980, and $1.0 \times 10^7$, respectively. The length of each compartment is 1, so that the length of entire elastic tube becomes 40. The external pumping location on the elastic tube is laid on the second part from the left tank out of 8 even subdivisions on each subdivision there are 5 equal compartments. As shown in Fig. 4, we can conclude that the difference of fluid heights implies an amount of storing energy in the open tank system.

REFERENCES


