EX150

Archimedes Screw

A CFD simulation of an Archimedes screw is presented in this example. The VOF and sliding mesh models in FLUENT work together to capture the transient lifting of water from a lower to an upper reservoir by the rotating screw.

A 3D CFD model is used to simulate the operation of an Archimedes screw, a simple mechanical device invented by the Greek mathematician Archimedes (287-212 BC) for raising water (or other material). Used for irrigation in ancient times, it consists of a helical element, or screw, that rotates inside a close-fitting cylinder. The axis of the device is inclined at some angle above the horizontal. One end is placed in a lower reservoir of water and as the screw turns, a small quantity of water is scooped up and trapped in a cavity between the screw and outer cylinder. As the rotation continues, this scoop is lifted and additional scoops are trapped and lifted as well. At the top of the device, the scoops of water are released into an upper reservoir. In modern pump classification, the Archimedes screw is a positive displacement (PD) pump.

The geometry of an Archimedes screw is governed by certain external parameters (its outer radius, length, and slope) and certain internal parameters (its inner radius, number of blades, and the pitch of the blades). The external parameters are usually determined by the location of the screw and how much material is to be lifted. The internal parameters, however, are free to be chosen to optimize the performance of the screw. The optimal parameters for maximizing the volume of water lifted in one turn of the screw are given in a paper by Rorres (2000).

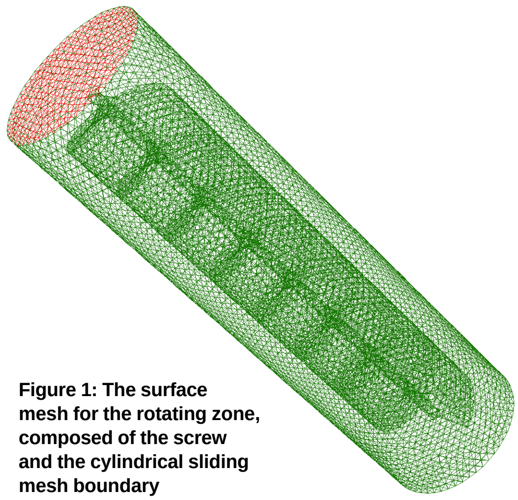

Figure 1: The surface mesh for the rotating zone, composed of the screw and the cylindrical sliding mesh boundary

As more material is lifted by the screw, more effort is required to turn it; this puts a practical limit on how long (or wide) such a tube can be. Nagel (1968) observed that the rotational velocity of a screw, in revolutions per minute, should not be more than $50/D^{2/3}$, where D is the diameter of the outer cylinder in meters. If the screw is rotated much faster, turbulence and sloshing prevent the cavities from being filled. The screw churns the water in the lower reservoir and does not efficiently lift it.

A simple, single-blade screw is modeled in this simulation. The screw is inclined from the horizontal at 45 degrees and is rotated at a constant speed of 4 rad/s (76 rpm). To simulate the motion of the screw, a rotating mesh zone of 105,000 tetrahedral cells (derived from the surface mesh shown in Figure 1) is used. A fine grid is used in this region so that sloshing of water may be captured in the CFD model. Outside the rotating zone is a stationary zone containing 70,000 hexahedral cells. This zone encompasses the upper and lower

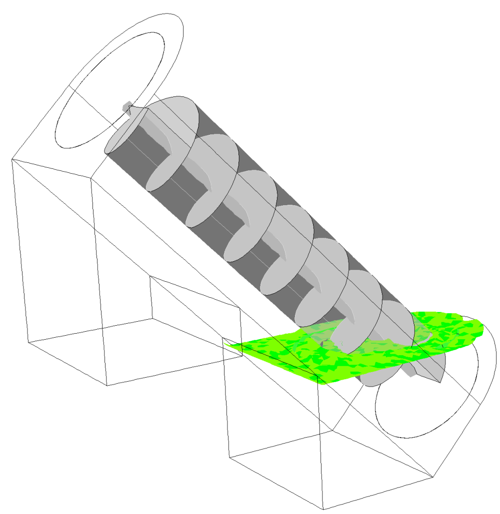

Figure 2: At time zero, the fluid is at rest in the lower reservoir

reservoirs. A non-conformal grid interface links the rotating and static zones.

Initially (Figure 2), the lower reservoir contains a finite volume of water, and the upper reservoir is empty. At this time, the water is at rest. Figure 3 shows the screw in action raising water from the lower reservoir to the upper reservoir. During this process, the water level in the lower reservoir decreases. After about 8 seconds (Figure 3a), the first scoop of water (a tiny amount, owing to the initial orientation of the screw) begins to emerge from the upper end of the screw. About two seconds later (Figure 3b), the second scoop of water begins to emerge. After another revolution of the screw (Figure 3c), the third scoop of water empties into the upper reservoir. (The details of the flow in the upper reservoir are not accurately captured by this model because a coarse grid is used in this region.)

The equilibrium water volume is defined as the maximum volume of water that can be held in each chamber between the threads when the screw is stationary. During the early stage of operation, when the water level in the lower reservoir is high, the screw scoops up more than the equilibrium water volume in each revolution. As the water is raised with each turn of the screw, the excess water cascades down to the next chamber. This cascading effect can be seen near the bottom of the screw in Figure 3. When the water level in the lower reservoir reaches a certain critical level, the efficiency of the screw begins to drop, because the screw scoops up less than the equilibrium volume with each revolution.

The Archimedes screw is still in use today. The underlying principle of the device is applied in machines used for drainage, irrigation, oil well extraction, food processing, and in high-speed tools. It can also be applied for handling light, loose materials such as grain, sand, and ashes in machines known as screw conveyors, direct descendants of the Archimedes screw. While the Archimedes screw lifts fluids because of its inclined position, the screw conveyor propels granular materials through the pushing action of its rotating blades. Most screw conveyers in use today have a single blade, while modern Archimedes screws typically have two or three blades. For screw conveyors or for the Archimedes screw itself, FLUENT is an excellent tool for simulating the mechanics of the process at work. The VOF and sliding mesh models working together can capture the essential physics of devices of this type. This is a powerful combination that can be applied to other free surface tracking applications that involve rotating parts.

References:

1. Rorres, C. (2000), The turn of the screw: optimal design of an Archimedes Screw, ASCE Journal of Hydraulic Engineering, Vol. 126, no. 1, pp. 72-80, January, 2000.

2. Nagel, G. (1968), Archimedean screw pump handbook, Prepared for Ritz-Atro Pumpwerksb au GMBH Roding, Nurnberg, Germany.

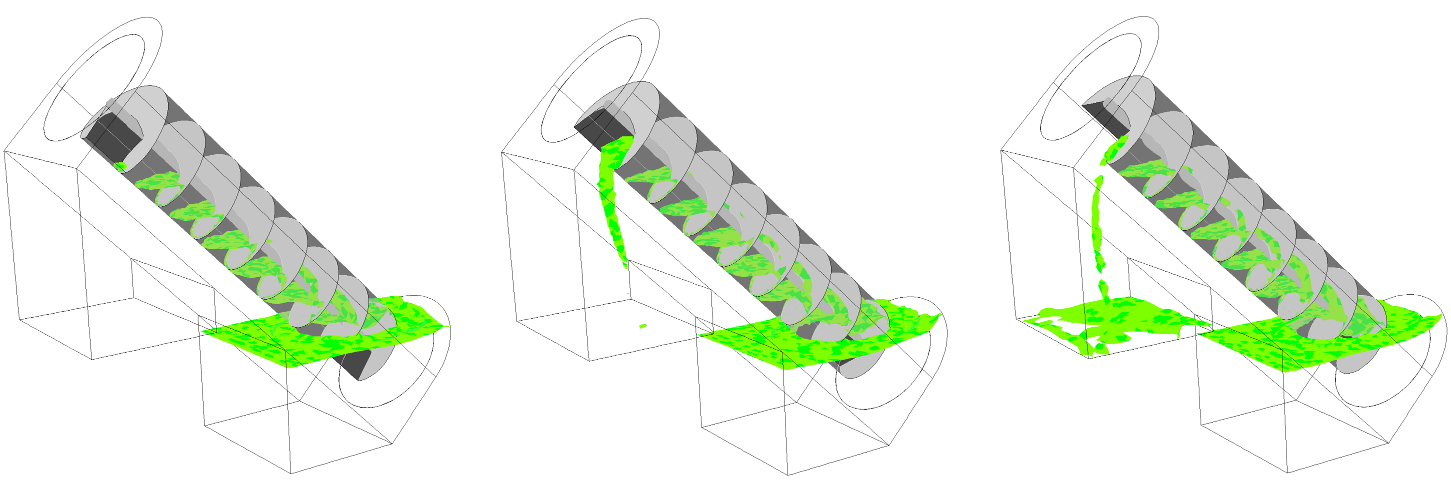

Figure 3 : The lifting of water by the rotating screw is illustrated after 8 seconds (a), 10 seconds (b), and 13 seconds (c)