A gravity separator model for liquid level control and purity evaluation of oil and water phases

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Abstract: In this work we present a model of a gravity separator for the separation of oil, water and gas. The model consists of a dynamic part constituted by the in- and outflow dynamics as well as a static part representing the evolution of droplets throughout the length of the separator. Thereby the separator is divided into volumetric elements along its length.

A gravity separator is a quite simple device for bulk separation of oil, water and gas utilizing differences in densities of the media and gravitational forces in order to separate phases (compare *Stokes' law*). Nevertheless, the dynamics of such a process are very complex, as many phenomena can occur, like e.g. sedimentation (settling of droplets), creaming (rise of droplets), coalescence (fusion of small droplets to a bigger droplet) and breakage (a big droplet breaking into smaller droplets). Accumulation of droplets can occur at the interface between phases as these have to overcome the surface tension and disjoining pressure in order to go over into their respective resolved bulk phases. This is known as a foaming layer between the oil and gas phases and as an emulsion layer between the oil and water phases.

The dynamic part of the model calculates the water level, the overall liquid level (oil plus water) as well as the pressure of the gas. This part is nonlinear mainly due to the cylindrical shape of the gravity separator. The volumetric flow into the separator depicts a disturbance variable, whereas the outflows for oil, water and gas act as controlled variables, respectively. The static part consists of a simple droplet balance calculation, which assumes distributed and constant particle size classes. This means that neither coalescence nor breakage are considered in the model for now. The only phenomena present in the model are thus sedimentation and creaming. The purpose of the model is to control the levels of liquid and water as well as the pressure of the gas and to calculate the amount of oil in water and water in oil of the outflows. In addition, no emulsion layer is considered, but the droplets are regarded to directly leave into their respective bulk phases at the interface. This assumption requires the rate of interfacial coalescence to be less than the flux of droplets to the interface between phases by sedimentation or creaming and is reasonable under conditions where an effective demulsifier is properly dosed to the separator inlet stream.

Besides the assumptions of not explicitly modeling an emulsion layer (a layer of accumulated droplets) and neglecting coalescence/breakage of droplets, several other assumptions have been employed in the model:

- gas is directly flashed out, such that there are no gas droplets in the liquid phases
- plug flow with average velocity in the horizontal direction of the separator
- static distribution of droplets throughout the volume (due to no coalescence or breakage)
- instant levelling of water and liquid with respect to changes of in- and outflows

The model itself is thus a differential algebraic equation (DAE) system, and is solved and simulated using MATLAB (Simulink). The water and liquid levels as well as the pressure are controlled by PI-controllers. The respective fractions of oil and water at the two liquid outlets can only be controlled by the residence time of the liquid in the separator, meaning that the inlet might have to be throttled. It holds that for a decrease in volumetric inflow the horizontal velocity will decrease as well (assumed that the liquid level is constant) and thus the residence time will increase, such that the outlets of water and oil will become purer (meaning lower oil/water concentrations in the water/oil continuous phases, respectively).

The capabilities of the model will be illustrated by simulation examples for different volumetric inflow rates together with variable water cuts whilst controlling the water and overall liquid level as well as the gas pressure.