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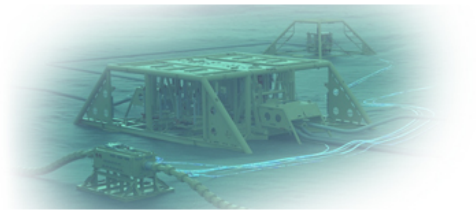

Documentation / User Manual for the MATLAB-simulator of the gravity separator model

SUBPRO Sub-Project 3.4

"Model library for accurate and efficient steady-state and dynamic simulation of subsea processes"

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1 Introduction

This document provides documentation for the gravity separator model developed by Christoph Josef Backi. The simulator consists of four files, a Simulink file containing the equations (*gravityseparator.slx*), a MATLAB code file providing parameters for the simulation and running the simulation (*init_gravityseparator.m*), another MATLAB code file plotting the results (*plotting.m*) as well as a data file (*init_distribution.mat*) containing initial distributions for oil in water and water in oil. In the following, the single parts of the simulator are presented and briefly explained.

2 Description of the simulator

The simulator is written in MATLAB/Simulink and consist of the following four files

- *gravityseparator.slx*, which is the main simulation file containing the dynamic and static equations, parameter calculations and automatic controllers,
- *init_gravityseparator.m*, which is the file containing parameters that are needed to run the simulation in *gravityseparator.slx*. In addition, *init_gravityseparator.m* directly runs the Simulink model *gravityseparator.slx* as well as the file *plotting.m* after simulation is over
- *plotting.m*, plots the results of the simulation and is called in the file *init_gravityseparator.m*.
- *init_distribution.mat* provides the pre-computed initial distributions for water in oil and oil in water

To simulate, simply run the file *init_gravityseparator.m* and the simulation will start and finish by itself providing the results in six generated plots. In addition to this documentation, the underlying MATLAB codes as well as the Simulink file are commented with necessary information in order to understand how the simulator works.

2.1 Simulink file *gravityseparator.slx*

The Simulink plan consists of several blocks, which will be explained in the following.

2.1.1 Dynamic model equations

The dynamic model equations are divided into three different MATLAB-functions, namely the one for the water level ODEs, one for the liquid level ODEs and one for the gas pressure ODE as shown in Figure 1. The MATLAB-functions can be opened and the underlying code can be accessed. The output of each block is integrated and distributed further as well as stored in the workspace as a 'Structure with Time'.

2.1.2 Liquid and gas inflow

The liquid and the gas inflow to the separator act as disturbance variables and can be changed with the blocks shown in Figure 6.

2.1.3 Static model equations

The static model equations representing the droplet distribution calculations are divided into three blocks parts, as can be seen in Figure 3: One subsystem for the calculation of oil particles in the water phase, one subsystem for the calculation of water droplets in the oil phase and a MATLAB-function for the efficiency calculation of oil and water removal. The two subsystems can be accessed by clicking on them and a new layer appears containing five MATLAB-functions. Each of these MATLAB-functions calculates for each volumetric segment the number of droplets (and hence the volume) going over to the succeeding volumetric segment or leaving into their bulk phase. There are five of these MATLAB-functions since the active separation zone is divided into five volumetric segments.

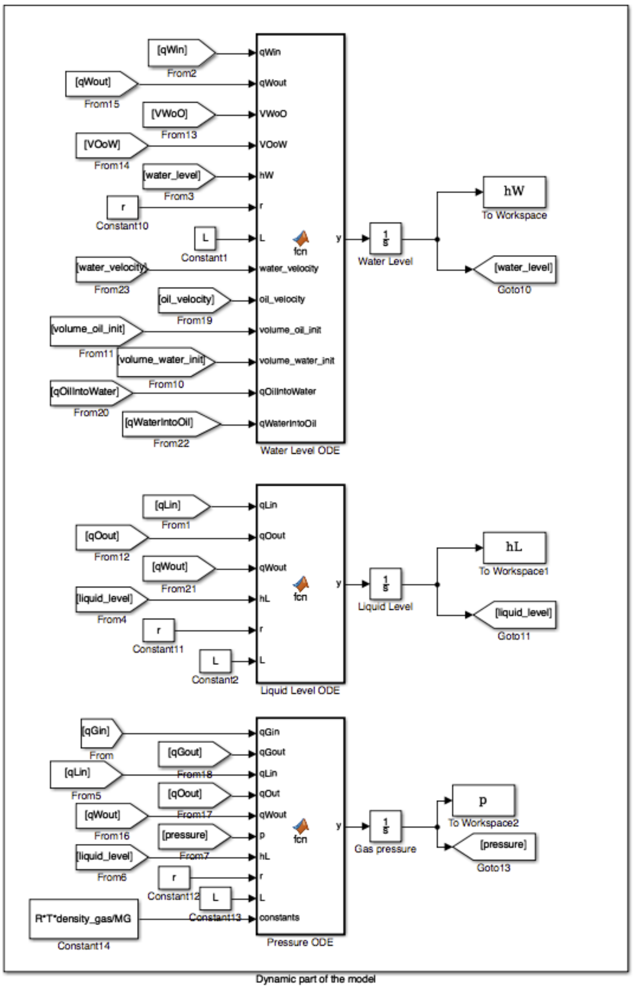

Figure 1: Dynamic part of the model

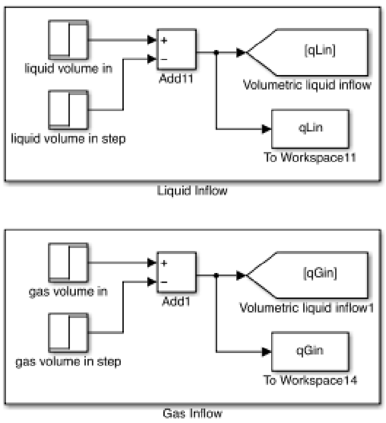

Figure 2: Liquid and gas inflow

2.1.4 Parameters

Several parameters, which are needed for simulation are calculated in the MATLAB-function block in Figure 4, such as oil and water velocities, oil and water factors as well as effective inflows to the water continuous phase ($q_{W,in}$) and to the oil continuous phase ($q_{O,in}$). Be advised that these flows are multiphase flows.

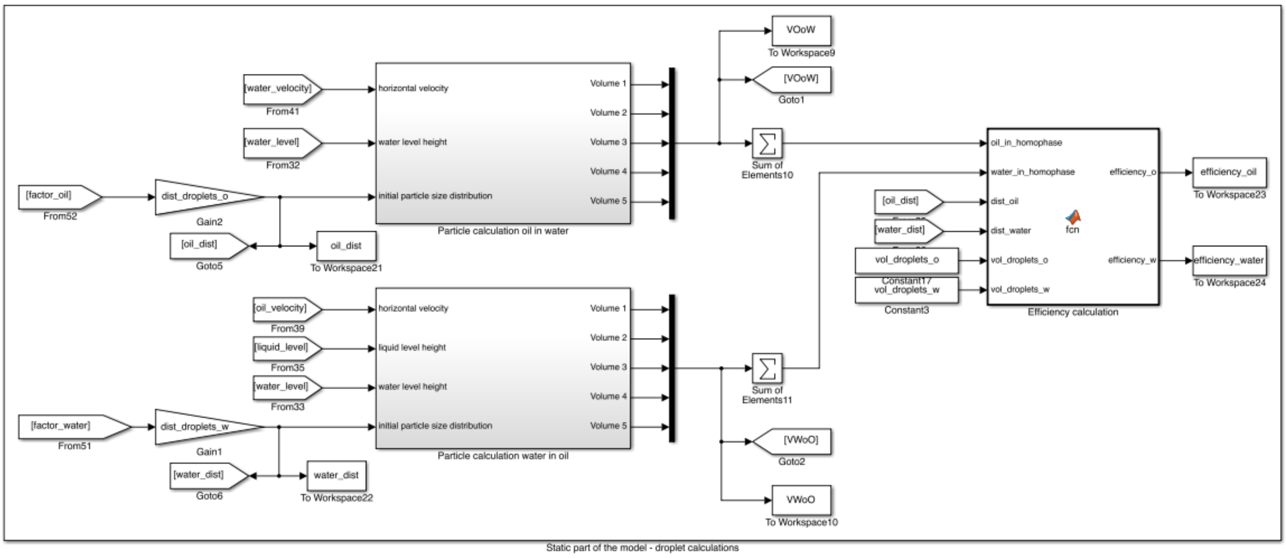

Figure 3: Static part of the model

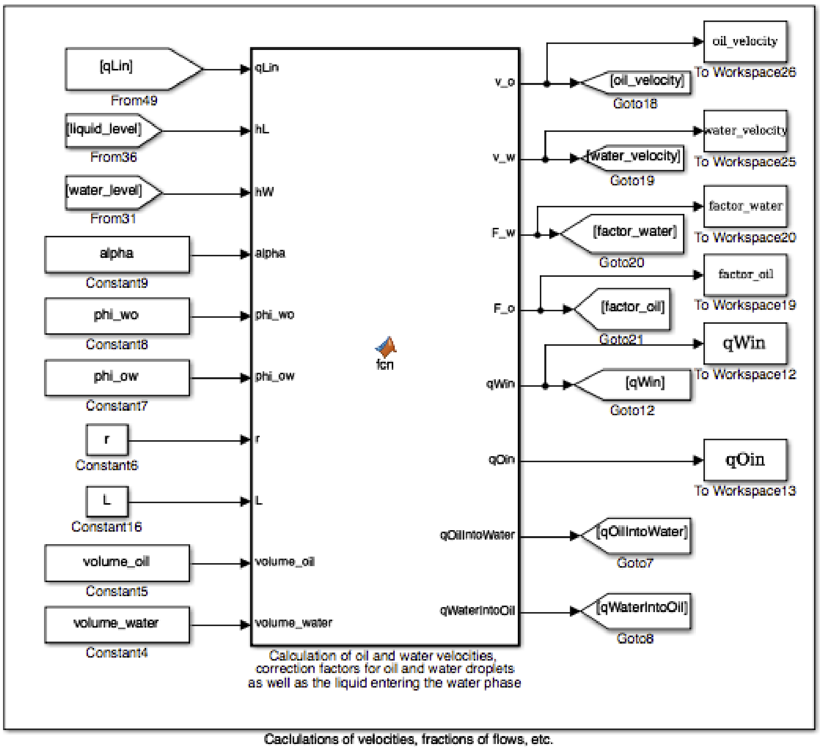

Figure 4: Parameter calculation

2.1.5 Controllers

The controllers for the water and liquid levels as well as the gas pressure are shown in Figure 5. They are of PI kind and can be accessed by clicking on the respective subsystems. Step-wise changes to the water level can be applied to its desired value.

2.1.6 Overall plan

In the overall plan the five interconnected blocks introduced above are shown together. This is what the user sees, when he opens the Simulink plan.

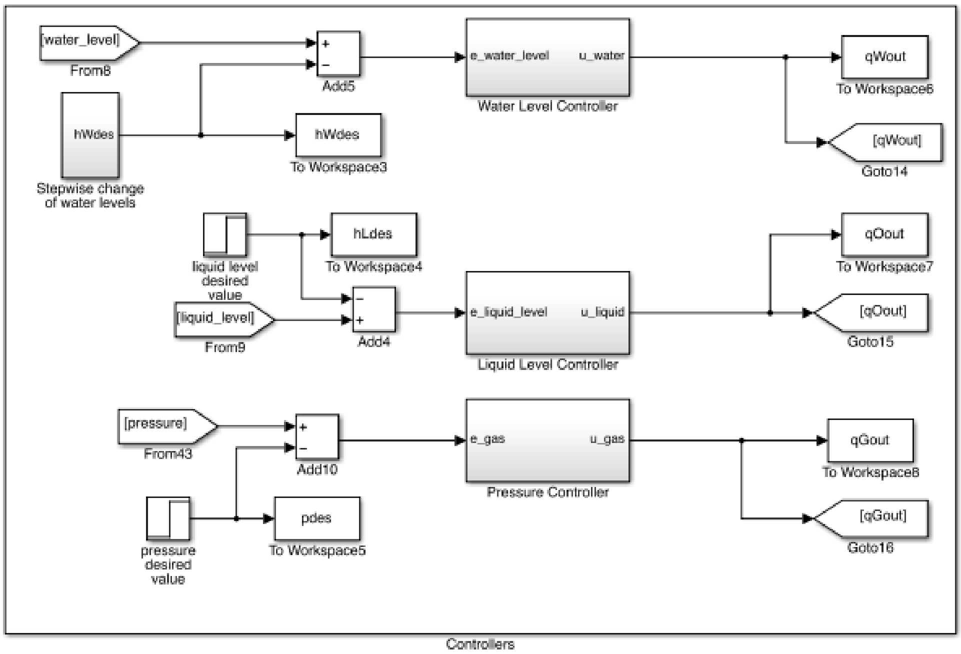

Figure 5: Controllers

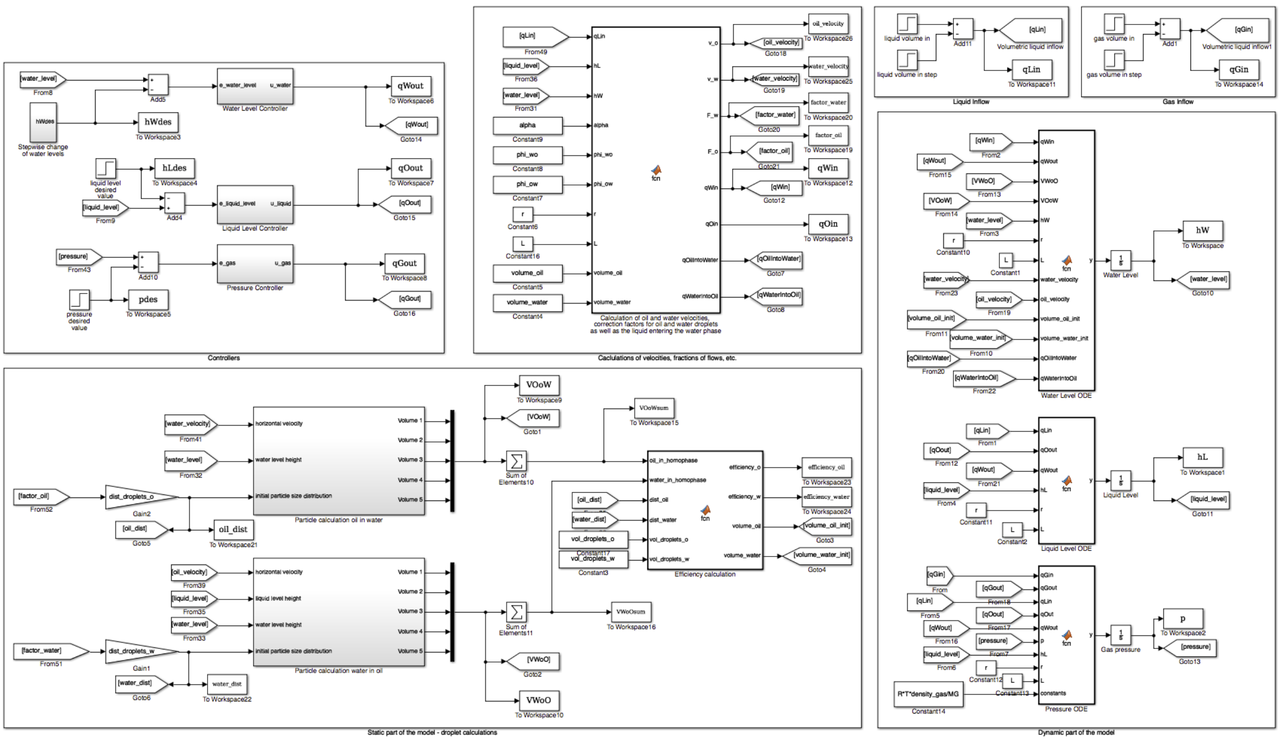

Figure 6: Liquid inflow

2.2 MATLAB code file *init_gravityseparator.m*

The MATLAB code file *init_gravityseparator.m* provides necessary parameters to run the Simulink file *gravityseparator.slx*. The first part is called initialization, providing parameters, such as dimensions and fluid properties, controller parameters and initial values. Thereafter, the droplet size distributions are imported from the data file *init_distribution.mat*. Furthermore, the volume for one droplet of each droplet class, as well as rising and settling velocities for one droplet of each droplet class are calculated. Also, the droplet distribution is plotted. Then, the simulation cases are defined, where the first represents the beginning of a reservoir lifetime with a low water cut and the second holds for a case towards the end of the lifetime with a higher water cut. This is followed by the start of the simulation, where the time when to perform step changes is defined as well as the step change in the water level and the simulation time. The Simulink file *gravityseparator.slx* is called. In the end, the results are plotted by calling the MATLAB code file *plotting.m*.

2.3 MATLAB code file *plotting.m*

The MATLAB code file *plotting.m* plots the results of the simulation, which is stored in the MATLAB-workspace. Four plots are created, the first one presenting the three dynamic states and their respective manipulated variables. The second one provides efficiencies and the factors F_O and F_W. The third one is a 3D-plot and shows the oil droplet distribution at the water outlet, whereas the fourth plot demonstrates the water droplet distribution at the oil outlet.

3 Variables and parameters

The following tables provide a list over most of the variables and parameters that are used in the Simulink file *gravityseparator.slx* together with short explanations about their meaning. Variables are thereby changing value during the simulation, whereas parameters are constant.

Variable	**Description**
qLin	Total volumetric inflow of liquid (oil and gas)
qWin	Volumetric inflow into the water phase (fractions of water and oil)
qOin	Volumetric inflow into the oil phase (fractions of water and oil)
qGin	Volumetric inflow of gas
qWout	Volumetric outflow of the continuous water phase
qOout	Volumetric outflow of the continuous oil phase
VOoW	Volume of oil leaving the continuous water phase
VWoO	Volume of water leaving the continuous oil phase
oil_velocity	Velocity of the continuous oil phase
water_velocity	Velocity of the continuous water phase
factor_water	Factor to keep ratio of dispersed water in oil volume constant
factor_oil	Factor to keep ratio of dispersed oil in water volume constant
water_dist	Distribution of water droplets in the oil volume
oil_dist	Distribution of oil droplets in the water volume
water_level, hW	Level of water
liquid_level, hL	Level of liquid (oil plus water)
water_level, hW	Level of water
liquid level, hL	Level of liquid (oil plus water)
pressure, p	Gas pressure
hWdes	Desired water level (setpoint)
hLdes	Desired liquid level (setpoint)
pdes	Desired gas pressure (setpoint)
efficiency_oil	Efficiency of oil removal from continuous water phase
efficiency_water	Efficiency of water removal from continuous oil phase

Parameter	**Description**
r	Radius of the separator
L	Length of the active separation zone
R	Universal gas constant
T	Temperature
density_gas	Density of gas
density_oil	Density of oil
density_water	Density of water
MG	Molar mass of the gas
dyn_visc_water	Dynamic viscosity of water
dyn_visc_oil	Dynamic viscosity of oil
volume_oil	Vector of volumes for single oil drops of different sizes
volume_water	Vector of volumes for single oil drops of different sizes
alpha	Water cut of the total volumetric inflow
beta	Oil cut of the total volumetric inflow
phi_ow	Factor of oil going into the continuous water phase in the inlet zone
phi_wo	Factor of water going into the continuous oil phase in the inlet zone
dist_droplets_o	Distribution of oil droplet sizes
dist_droplets_w	Distribution of water droplet sizes

4 Further information

The model, which is the basis for the simulator, is described in [1, 2]. In case of questions, please write an email to `christoph.backi@ntnu.no` or `christoph.backi@web.de` or call `+47 944 79 561`.

References

[1] C. J. Backi, B. A. Grimes, and S. Skogestad. A Control- and Estimation-Oriented Gravity Separator Model for Oil and Gas Applications Based upon First-Principles. *Industrial & Engineering Chemistry Research*, 57(21):7201–7217, 2018.

[2] C. J. Backi and S. Skogestad. A simple dynamic gravity separator model for separation efficiency evaluation incorporating level and pressure control. In *Proceedings of the 2017 American Control Conference*, Seattle, USA, May 24–26 2017.