Appendix B: CSMPlug Example Problems

B.1 Introduction

This tutorial will guide the user through some sample problems to familiarize them with the features of CSMPlug. The following sample problems will be illustrated:

- One-sided dissociation (1SD)
- Two-sided dissociation (2SD)
- Safety simulator
- Electrical heating

Please see the "Read me" statement on the CD for installing the program. Also note a complete user's guide on the CD.

The authors acknowledge the DeepStar members for the funding and data required for the development of CSMPlug. DeepStar Members: Anadarko, BP, Chevron Corporation, ENI/Agip, Kerr-McGee, Marathon, Petrobras, Statoil, Total.

B.2 Example Problem for One-Sided Dissociation

Figure B.1 shows the layout of the one-sided form in CSMPlug by selecting the 1SD tab. Inputs to the model are upstream and downstream temperature and pressure, equilibrium pressure, hydrate structure, plug porosity, permeability, diameter of the pipeline, and plug length. Input details are given by placing the mouse at each input box.

A 30 ft hydrate blockage occurs in a 12 in. diameter un-insulated pipeline. The upstream and downstream pressures are 780 and 180 psia, respectively. The Structure II equilibrium pressure is 200 psia (from CSMGem at the ambient temperature).

The temperature of the seabed is known to be 42°F, but the downstream end of the pipeline will be colder than this (38°F) due to Joule–Thompson cooling when it is vented. A porosity of 0.5 and a permeability of 0.01 mD are default values. An annulus spacing of 0.1 is required for pressure flow communication.

Using this information, what is the dissociation time until flow and pressure communication can be re-established?

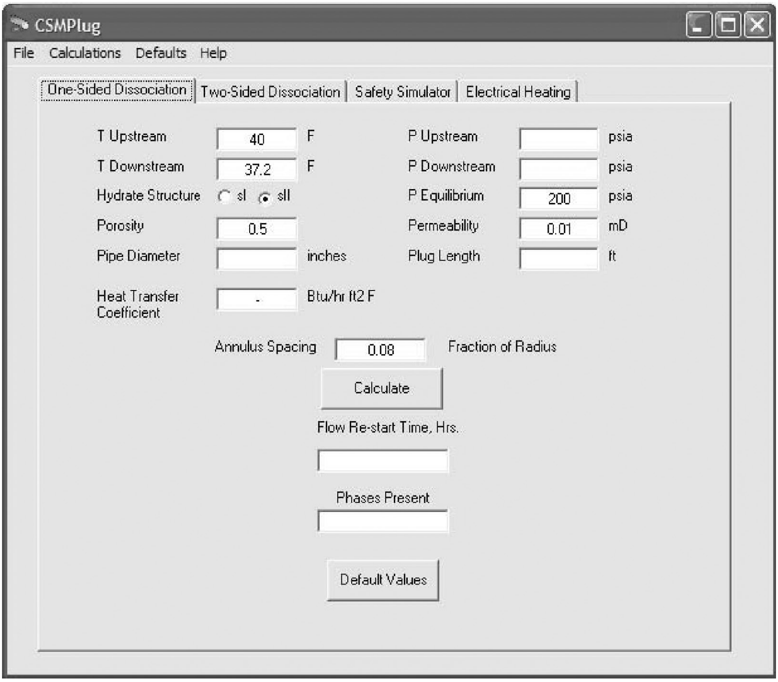

FIGURE B.1 Layout of the 1SD tab in CSMPlug with default values.

Inputting these values and then clicking the "Calculate" button gives these results in the output boxes: flow restart time and phases present during dissociation. Simulation runtime increases substantially for large values of:

1. Pipe diameter
2. Upstream pressure
3. Plug length
4. Annulus spacing

Runtime also increases for small values of:

1. Plug porosity and
2. Heat transfer coefficient

Note: To calculate without a heat transfer coefficient, outside the pipe enter a "—" in the input box.

B.3 1SD Solutions

The input parameters required for running this calculation are:

1. Upstream temperature: 42°F
2. Downstream temperature: 38°F

3. Hydrate structure: sII
4. Porosity: 0.5 (default)
5. Diameter of the pipe: 12 in.
6. Heat transfer coefficient: −Btu/h ft^2 °F
7. Upstream pressure: 780 psia
8. Downstream pressure: 180 psia
9. Equilibrium pressure: 200 psia
10. Permeability: 0.01 mD (default)
11. Plug length: 30 ft
12. Annulus spacing: 0.1

Restart time: 38.03 h.

B.4 Example Problem for Two-Sided Dissociation

Figure B.2 shows the layout of CSMPlug for a 2SD calculation. Inputs to the model are ambient and dissociation temperature, hydrate structure, plug porosity, and the pipeline diameter. Selecting the default values option on the 2SD tab or from the defaults pull down menu will enter the default values. The default values for the parameters can be seen in Figure B.2.

An sII hydrate blockage occurs in an 18-in. diameter insulated pipeline. The seabed temperature is known to be 41°F. The heat transfer coefficient is known to be 4 Btu/h ft^2°F. The default values for the hydrate dissociation temperature and plug porosity will be used.

What is the time required to fully dissociate (hydrate and ice phases dissociated) the plug?

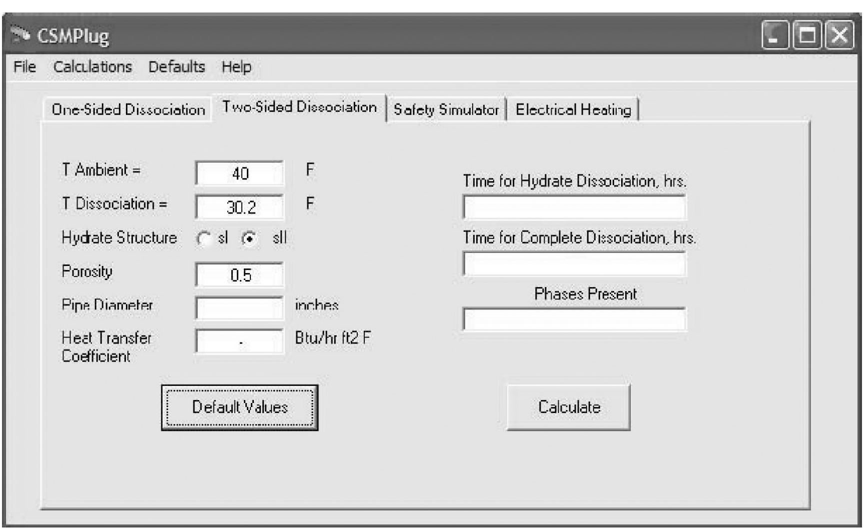

Figure B.2 Layout of the 2SD tab in CSMPlug with default values.

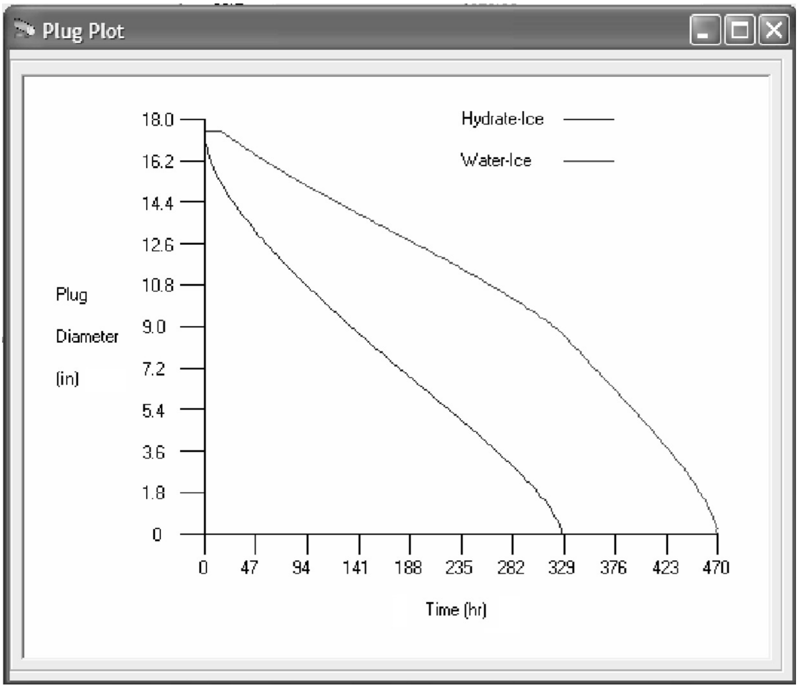

FIGURE B.3 Diameter of the hydrate core and hydrate ice plug as a function of time.

Inputting the values into the respective text boxes, and clicking the "Calculate" button, gives the result for 2SD. The calculation can be stopped if it is taking too long. The results are shown in the output boxes labeled: Time for Hydrate Dissociation and Time for Complete Dissociation (hydrate and ice). The phases present are W–H–I as well as the vapor phase, but only W–H–I phase should be listed?

The presence of insulation slows the dissociation as it reduces heat transfer from the sea to the plug. To calculate without a heat transfer coefficient, enter a "–" into the input box.

A figure similar to Figure B.3 is displayed once the run is complete. The figure shows the water–ice and ice–hydrate interface positions as a function of time. This plot can be used to determine the time when the pipeline can be restarted or when methanol can be flowed based upon the annulus spacing available.

The time for the annulus spacing to achieve 2 in. can be determined by opening the file "two.dat" (see below) in Excel and looking at the time for the diameter of the ice phase to reach 14 in.

CSMPlug automatically plots relevant data, but the data can be viewed in Excel by (1) loading Excel, (2) clicking File, Open, (3) changing the dropdown box titled "File Type" at the bottom of the window to "All Files," then (4) going to C:\Program Files\CSMPlug Version 2.1\two.dat or to the file where you installed the CSMPlug program. Use Excel to plot a graph of the diameter versus time for the hydrate core and the ice-hydrate plug.

B.5 2SD Solution

For this calculation the inputs required were:

1. Ambient temperature: 41°F
2. Dissociation temperature: 30.20°F
3. Hydrate structure: sII
4. Porosity: 0.5
5. Pipe diameter: 18 in.
6. Heat transfer coefficient: 4 Btu/h ft^2 °F
7. Time to dissociate hydrate phase: 327 h
8. Time to dissociate ice phase: 470 h
9. Time before methanol can be flowed (a 2-in. wide annulus is required): 136 h

B.6 Example Problem for Safety Simulator

A hydrate plug has been formed in a 4-in. diameter gas condensate pipeline. The plug length is 30 ft, and the plug is located at 5660 ft from the pipeline inlet. The downstream length is 9750 ft. The upstream pressure is 550 psia, and the downstream pressure is 50 psia. The pipeline burst pressure is 5000 psia. Assume a porosity of 0. Find the maximum plug velocity and final position of the plug. Run the simulation for 100 s. Figure B.4 shows the layout of CSMPlug for the safety simulator tab.

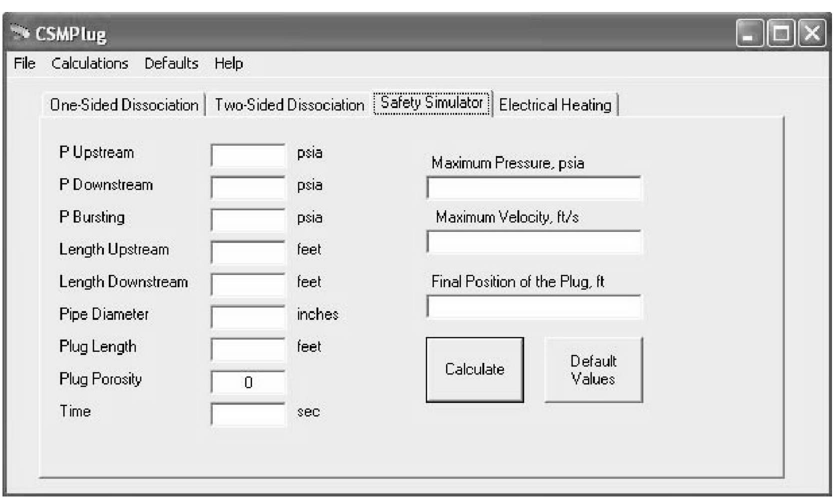

Figure B.4 Layout of the safety simulator tab in CSMPlug.

What is the maximum pressure in the system, the maximum plug velocity, and the final position of the plug?

B.7 Safety Simulator Solutions

The values that should have been entered for the calculation were:

1. *P* upstream: 550 psia
2. *P* downstream: 50 psia
3. *P* bursting: 5000 psia
4. Distance upstream: 5660 ft
5. Distance downstream: 9750 ft
6. Pipe diameter: 4 in.
7. Plug length: 30 ft
8. Plug porosity: 0
9. Time: 100 s

Inputting the above values and clicking the "Calculate" button give the result in the text boxes—maximum pressure, maximum velocity, and final position of the front end of the plug (Figure B.5). A file is created called "safe.dat" with details on the plug position (ft), the velocity (ft/s), and the upstream and downstream pressures (psia). If bursting pressure is exceeded, the program asks you to input values for safe operating conditions. This can be accomplished by increasing downstream pressure, bursting pressure, downstream distance, plug porosity, or by decreasing upstream pressure or distance.

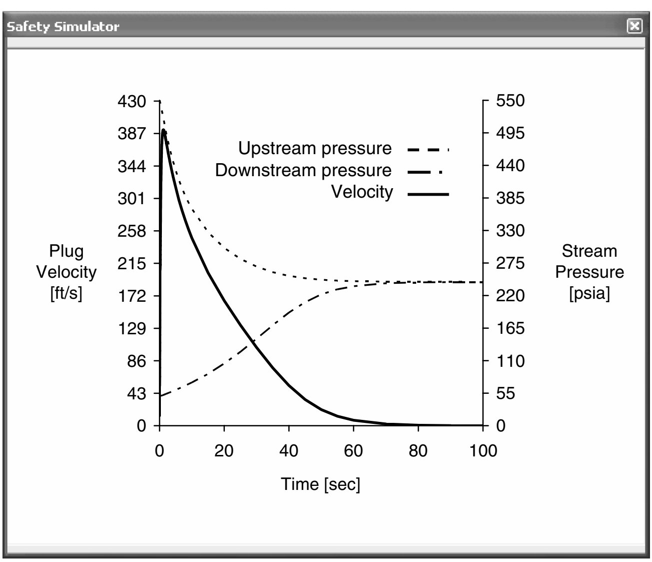

Figure B.5 Results from the safety simulator in CSMPlug.

Maximum pressure: 550 psia
Maximum velocity: 391.85 ft/s
Final position of the plug: 13,468.94 ft

Note: The final position of the plug is 13,500 ft from the wellhead.

B.8 Example Problem for Electrical Heating

Figure B.6 shows the layout of CSMPlug for an electrical heating calculation. Inputs to the model are ambient temperature, dissociation temperature, hydrate structure, plug porosity, heat input per unit length, and the pipeline internal diameter. Selecting the default values option on the heating tab or from the defaults pull-down menu will automatically replace the dissociation temperature, ambient temperature, and porosity with the default values. These default values can be seen in Figure B.6.

A hydrate blockage occurs in a 12-in. electrically heated pipeline. The hydrate dissociation temperature is known to be 58°F. The seabed temperature is 40°F. The heat input per unit length is 30 W/m. Assume the plug porosity is 0.5 and that the hydrate plug is structure II.

What is the complete dissociation time?

B.9 Electrical Heating Solutions

The values that should have been entered for the calculation were:

1. Dissociation temperature: 58°F
2. Ambient temperature: 40°F
3. Hydrate structure: sII

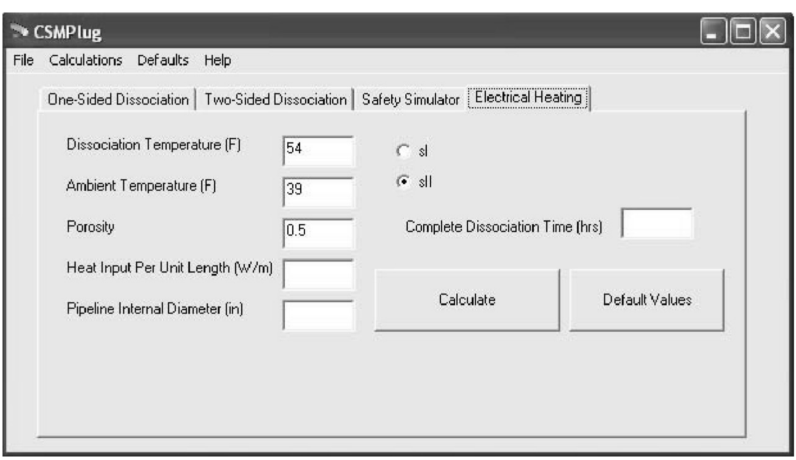

Figure B.6 Layout of the heating tab in CSMPlug with default values.

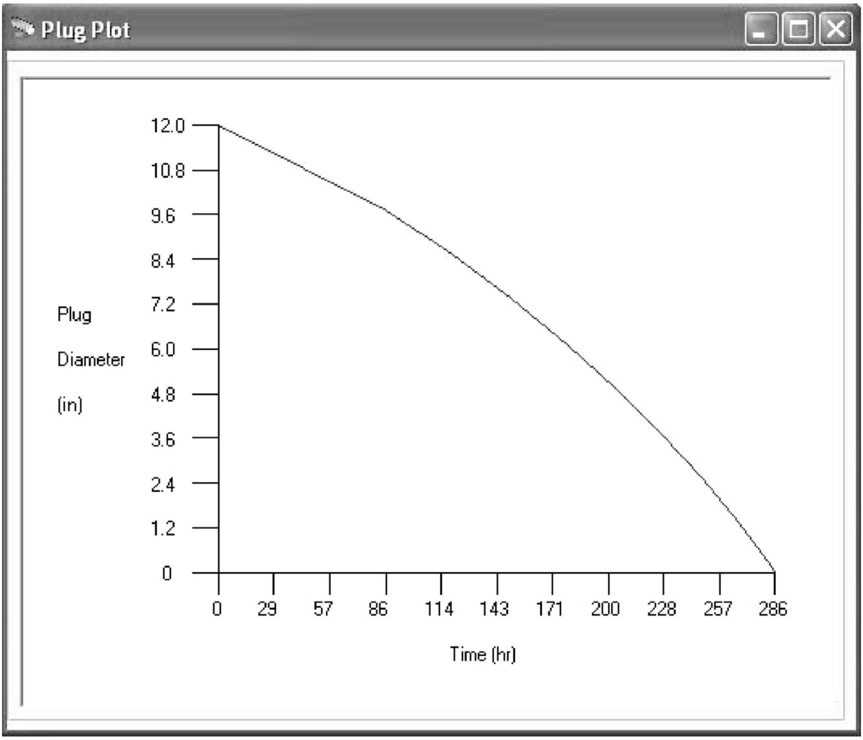

FIGURE B.7 A typical plot of plug diameter vs. time.

4. Porosity: 0.5
5. Heat input per unit length: 30 W/m
6. Pipe diameter: 12 in.

Inputting these values into the respective text boxes, and clicking the "Calculate" button gives the result for final dissociation time. The result is shown in the output box labeled: Complete Dissociation Time (h). A graph is also automatically plotted of plug diameter versus time (Figure B.7). The values of the plug diameter in inches and the corresponding dissociation time in hours are also automatically written to "heat.dat" located in the CSMPlug directory. These values can be copied into a spreadsheet program and used in flow simulation calculations or to predict when the given annulus spacing exists.

Dissociation time: 286 h.

CSMPlug is capable of predicting hydrate dissociation for three scenarios: two-sided depressurisation, one-sided depressurisation and electrical heating. Predictions are most sensitive to the plug porosity and in the case of the one-sided depressurisation model, plug permeability. The model should be used to perform a sensitivity analysis on these parameters in order to determine the best and worst case dissociation times, prior to dissociating a plug. The default values in the program were chosen to represent a worst case scenario.

CSMPlug can predict the total dissociation time by two-sided depressurisation, and by evenly applied radial heat input to an accuracy of 10%, provided accurate plug properties are known. Predictions from the one-sided depressurisation module are less accurate than those of the other modules, but are within an order of magnitude of those observed; dissociation times for laboratory scale hydrates are typically over predicted but industrial hydrates are under predicted.

The key assumptions are:

1. The hydrate plug dissociates radially
2. The hydrate dissociation is in the heat transfer limited regime
3. The plug is immersed in water
4. Heat transfer resistance in the hydrate phase is neglected

The models were validated on laboratory scale hydrates made from powdered ice, with diameters between 1 and 1.9 inches and lengths between 8 and 36 inches. The one-sided depressurisation module has had limited experimental validation due to problems creating a laboratory scale plug with a low permeability. CSM Plug has been used to model published field data for Tommelieten[1] (970 psi, 40°F, 6″ ID) and the Genesis[2] pipeline (1600 psi, 42°F, 10″ ID). Predictions were within an order of magnitude of those observed. The discrepancies are due to the high gas fraction of these pipelines.

1. Berge L., Gjertsen L. and Lysne D. *The Importance of Porosity and Permeability for Dissociation of Hydrate Plugs in Pipes*. Proc. 2nd International Conference on Gas Hydrates, pp 533–540, Toulouse, 1996.
2. Kashou S. et al *GOM Export Gas Pipeline, Hydrate Plug Detection and Removal*. Offshore Technology Conference, OTC 16691, Houston, 2004