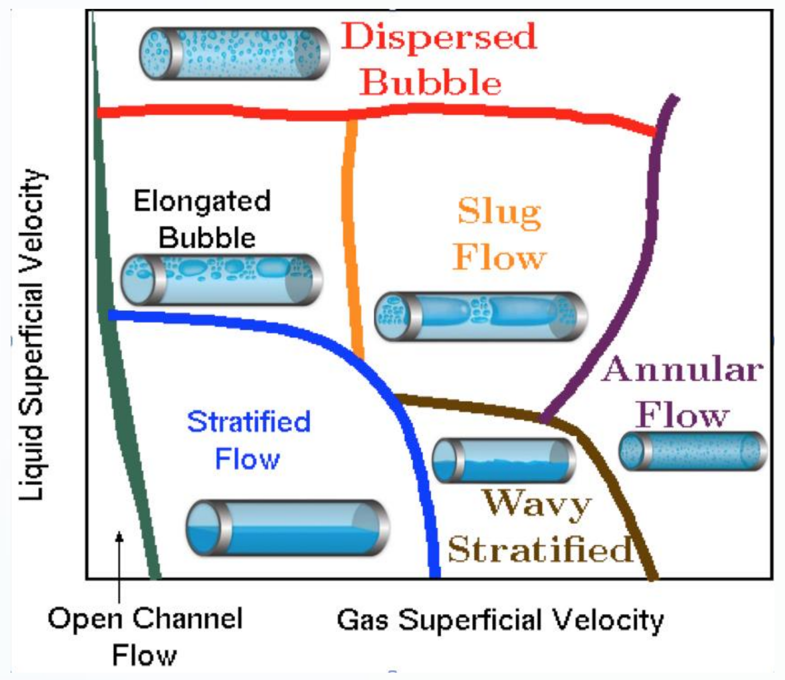
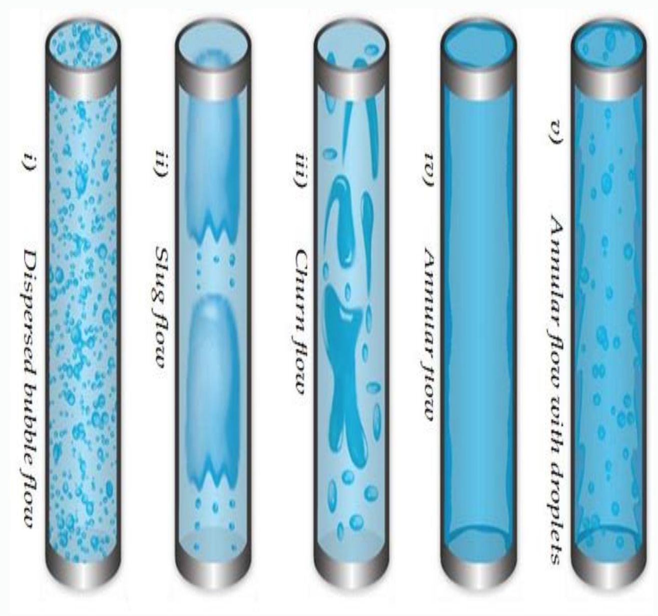
SLUGGING FLOW CONTROL WITH TIME DELAY IN OIL AND GAS PRODUCTION

Marsien Ngoufack (LSU Petroleum Engineering, Graduation date: May 2016). Supervisors: **Dr. Mayank Tyagi** (LSU Petroleum Engineering Department) and **Dr. Michael Malisoff** (LSU Mathematics Department)

Two Phase Flow in Pipe



Modified Mandhane Map for Flow Regime in Horizontal Pipe from Potto Project, Multi-Phase Flow (Genick Bar-Meir)



Gas-Liquid Flow Regimes in Vertical Pipes from The Flow Assurance Site (Ove Bratland)

Slugging in Oil and Gas Industry

Slugging Effects

- ➢ Decreases Production
- ➢ Increases Erosion
- ➢ Damages Compressor
- ➢ Damage Process Equipment

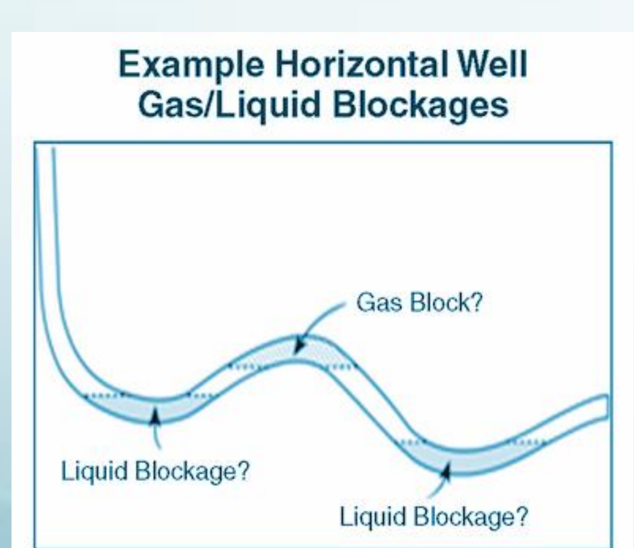
Types of Slugs

- ➢ Pigging Slugs
- ➢ Hydrodynamic Slugs
- ➢ Terrain induce Slugs
- ➢ Severe Slugging

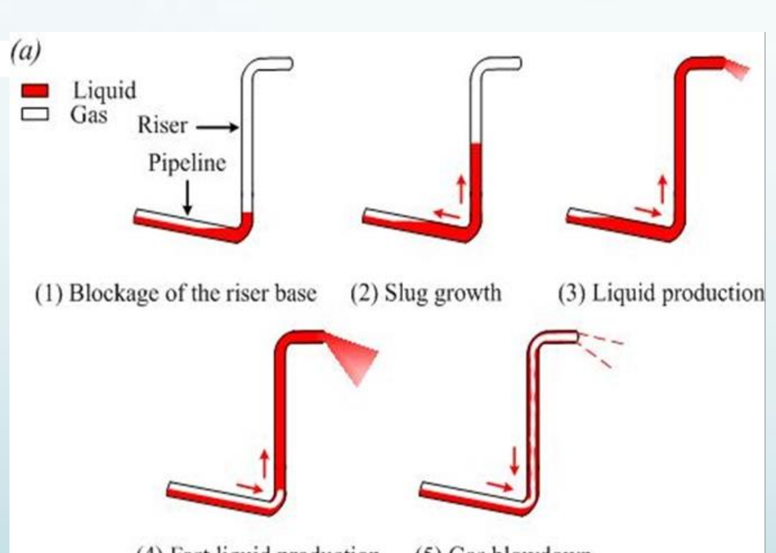
From Slugging in Pipelines: What You Need to Know (SPE, Mona Trick, Schlumberger)

Problem

Riser based slugging, also known as severe slugging, is associated with pipeline risers in offshore oil production facilities. In severe slugging, liquid accumulates at the bottom of the riser and the pipeline, blocking the passage of gas flow. This results in a pressure buildup in the gas phase that will push the liquid slug up the riser. A large liquid volume will be produced in the separator that might cause overflow and damage the surface equipment.



Two-Phase Flow in Undulated Pipe from the American Oil & Gas Reporter (Cleon Dunham and Cem Sarica)



Schematic of Severe Slugging from Reza Malekzadeh (Delta University of Technology, Netherlands)

- ➢ Design changes
- ➢ Operational changes and procedures
- ➢ Control methods that use process and/or pipeline information to adjust available degree of freedom (pipeline choke, pressure)

Slugging Model

➢ The slugging model consists of three ordinary differential equations and was developed in 2009 by Florent Di Meglio et al. The following state equations were built using numerous assumptions:

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$
$$\mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{D}\mathbf{u}$$

State Equations from Analysis and Design of Feedback Control Systems (Rowell, 2002)

- Mass balances

$$\dot{m}_{g,eb}(t) = (1-\epsilon)w_{g,in} - w_g(t)$$
$$\dot{m}_{g,r}(t) = \epsilon w_{g,in} + w_g(t) - w_{g,out}(t)$$
$$\dot{m}_{l,r}(t) = w_{l,in} - w_{l,out}(t)$$

- With w_{out} and w_g

$$w_{out} = uC_c\sqrt{p_{r,t} - p_s}$$
$$w_g = C_g \max(0, p_{eb} - p_{r,b})$$

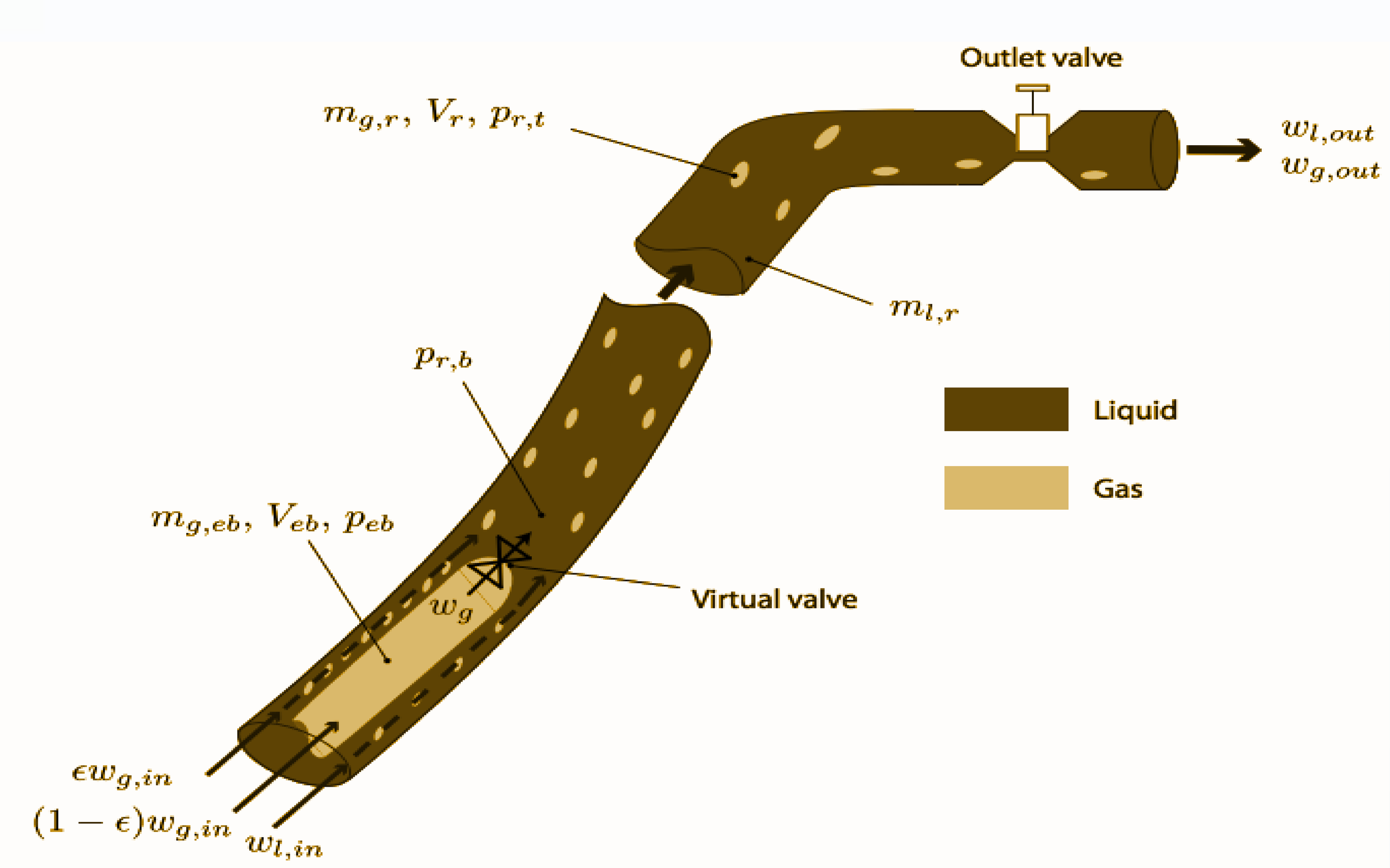
- Mass flow rate

$$w_{l,out} = \frac{m_{l,r}}{m_{l,r} + m_{g,r}} \approx w_{out}$$
$$w_{g,out} = \frac{m_{g,r}}{m_{l,r} + m_{g,r}} \approx \frac{m_{g,r}}{m_{l,r}} w_{out}$$

- Pressure

$$p_{eb} = \frac{m_{g,eb}RT}{MV_{eb}}$$
$$p_{r,t} = \frac{m_{g,r}RT}{M(V_r - \frac{m_{l,r}+m_{l,still}}{\rho_l})}$$
$$p_{r,b} = p_{r,t} + (m_{l,r} + m_{l,still})\frac{g\sin\theta}{A}$$

Model-Based Control of Slugging Flow: An Experimental Case Study (Florent Di Meglio et al, 2010 American Control Conference)



Schematic Diagram of System: From Model-Based Control of Slugging Flow: An Experimental Case Study (Florent Di Meglio et al, 2010 American Control Conference)

➢ Predictive control is an advanced method of process control used in the process industries in chemical plants and oil refineries.

- Linear system with input delay

$$\dot{X}(t) = AX(t) + BU(t-D)$$

(1) Linear System with Time Delay

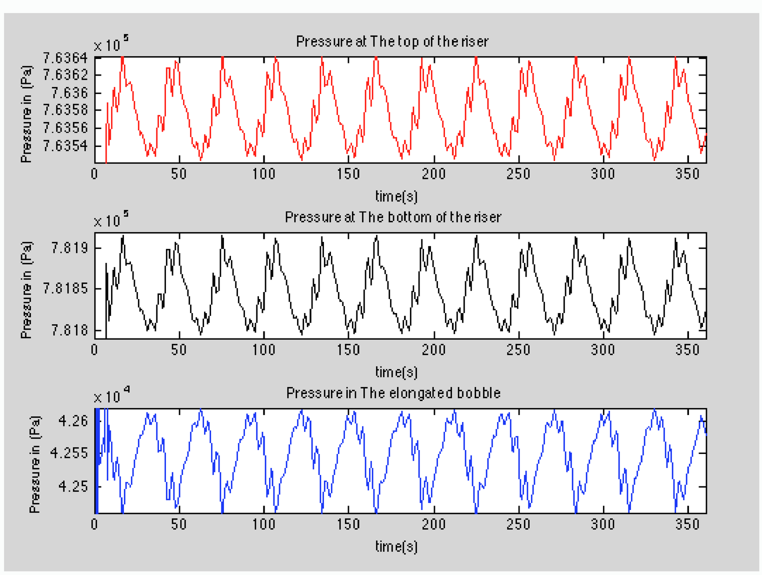
- Predictor feedback law

$$U(t) = K\left[e^{AD}X(t) + \int_{t-D}^{t} e^{A(t-\theta)}BU(\theta)d\theta\right]$$

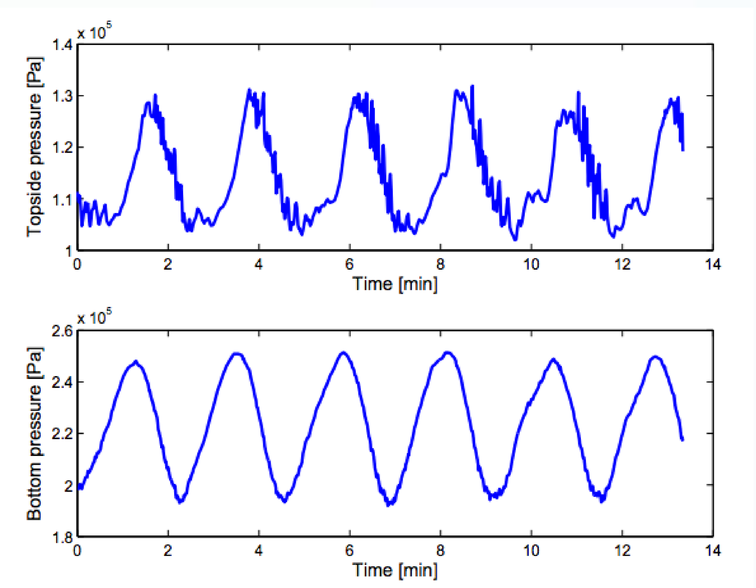
(2) Input Signal with Time Delay D

(1), (2) , and (3) from Nonlinear Control Under Nonconstant Delays (Nikolaos Bekiaris-Liberis and Miroslav Krstic)

Simulations and Results



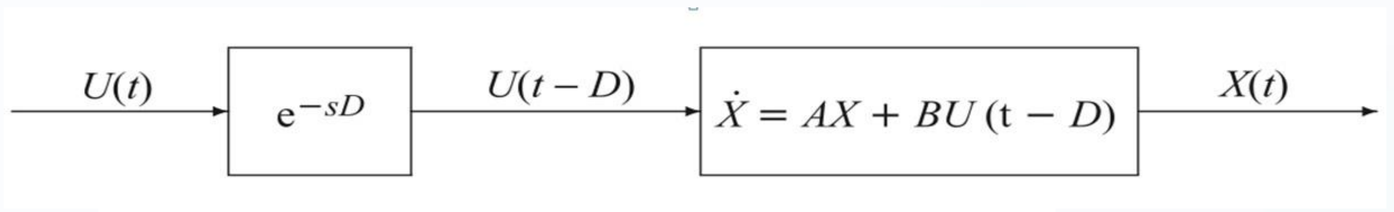
ODE Solution Using MATLAB



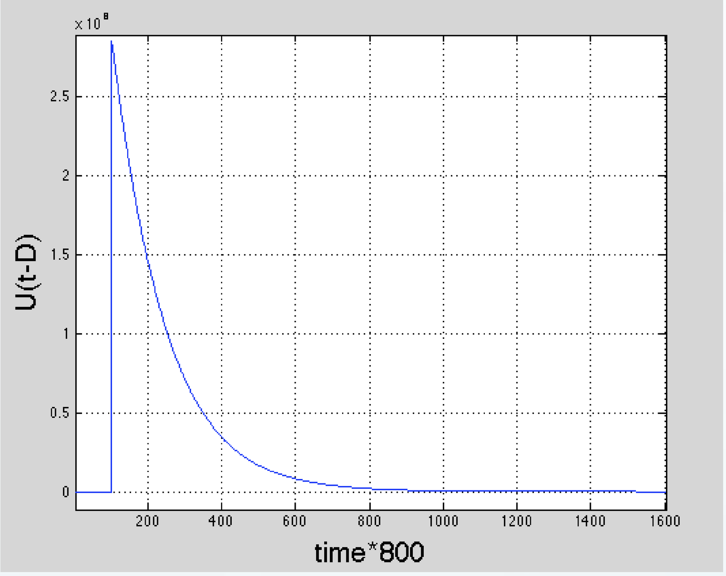
Pressure Oscillation with No Control by Florent Di Meglio (University of Mines of Paris France)

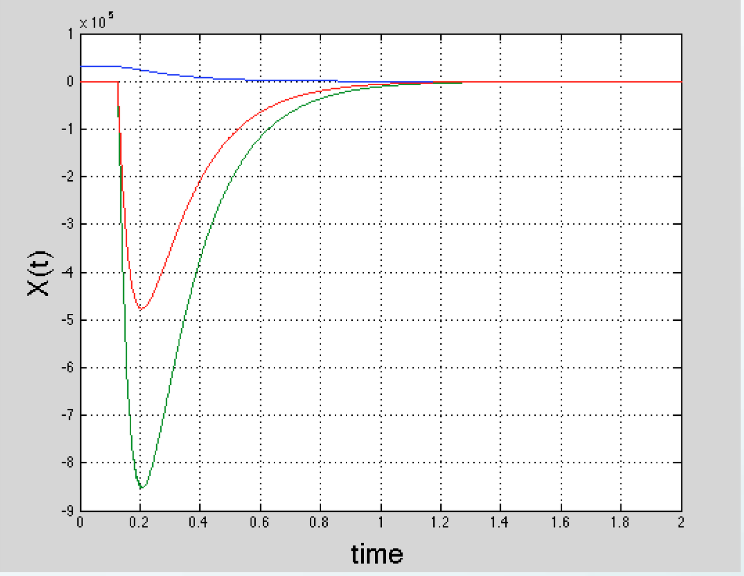
Data collection and control

- Sensor to measure pressure at bottom of riser
- Actuator to adjust wellhead valve
- Controller to maintain constant flow by maintaining constant pressure at bottom of the riser
- Delay between where the slug forms and how long it takes to go through the valve



(3) Linear System with Actuator Delay D





Conclusions

One major challenge associated with severe slugging is that it is characterized by large pressure and flow rate fluctuations, which can damage downstream processing equipment, increase pipeline stress, reduce productivity, and shorten the reservoir operational life.

- We implemented a time delay controller on a key basic slugging model.
- Future work will consist of implementing the time delay controller in a more complex nonlinear slugging control model.

Acknowledgements

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