Brine String Stability Studies - Phase II at McGill University

SMRI Project Sponsor Summary

Joe L. Ratigan
Ratigan Engineering & Consulting LLC

Background

The Solution Mining Research Institute (SMRI) has recognized issues with flow-induced vibration failures of brine injection strings and the significant financial and operational aspects of such failures. The SMRI has previously funded a research program at McGill University directed at developing an understanding of the physics of the problem and attempting to develop technologies for determining the maximum allowable flow velocities and completion methods that could increase the maximum flow velocities.

In 2009, the SMRI funded a Phase I research project at McGill University under the direction of Professor Michael Paidoussis. The research project involved the development of a "bench-scale" laboratory testing system that simulated a solution-mined cavern with a brine string. Following development of this testing device, numerous flow schemes (see Figure 1) were evaluated for studying flow-induced deformation. The major conclusions from this research effort (Paidoussis [2010]) included:

1. *Pipes with internal flow are subject to static divergence (buckling) or flutter, depending on boundary conditions.*
2. *Pipes with external flow are generally subject to both types of instability.*
3. *Pipes with both internal and external flow are subject to a cascade of instabilities (multiple bifurcations).*
4. *It has been shown that it is possible through appropriate simple experiments to decide on injection/retrieval strategies which would increase the trouble-free operation, and prolong the lifespan, of brine strings*

Phase II Research Project Summary

In 2013, the SMRI funded a second phase of the McGill research. The second phase involved a more focused set of flow configurations (see Figure 2) and included considerations for different tubular lengths and cross-sectional areas and development of a mathematical model for flow configurations *i* and *iii.* The Phase II research benefited from numerous improvements over the earlier Phase I work – including the development and application of a more sophisticated displacement measurement technology. The Phase II research program resulted in the following significant conclusions:

- All flow configurations exhibit vibration or instability after reaching a certain flow velocity
- Configuration *ii* was most stable and exhibited the smallest displacement magnitude

- Configurations *i* and *iii* showed exponential growth in displacement magnitude after reaching a critical flow velocity
- Configuration *iv* was by far the least stable
- The mathematical model developed for Configuration *iii* indicated the annular flow had minimal impact on instability, but only for the parameters of the experimental system. For long, highly confined systems, this statement is not generally true.

The presence of an external flow in configuration *iv* led to a profound decrease in stability, with critical internal flow velocities less than half those of the all other configurations (*i, ii,* and *iii*). This is despite the fact that the external flow velocity was only about 5% of the internal flow velocity. The flow configuration *iv* is encountered in (1) liquid hydrocarbon storage caverns in the product injection mode, (2) compressed natural gas storage caverns in the dewatering mode, and (3) brine production caverns in the "reverse circulation" mining mode.

The Phase II McGill research project is the first research program that has possibly identified the most critical flow configuration for flow induced tubular damage in solution-mined caverns. This flow configuration is encountered in liquid and gas storage caverns and cavern development and brine mining caverns and is therefore of interest to the whole of the cavern industry.

Future Research Possibilities

The Phase II research program at McGill University did not include (1) development of a mathematical model of flow configuration *iv* or (2) bench-scale testing with the external velocity approaching the magnitude of the internal velocity. Research into these two specific areas could result in direct benefit to the brine mining and hydrocarbon storage cavern industry and could lead to the development of specific well completions that could mitigate flow-induced brine string damage and increased allowable velocities.

A mathematical model developed for flow configuration *iv* could be validated not only with bench scale tests in the laboratory, but could also possibly be validated in field tests.

References

Paidoussis, Michael P., 2010. *Study of Casing Pipe Vibration in Solution-mined Caverns*, Solution Mining Research Institute Research Report 2011-03, December.

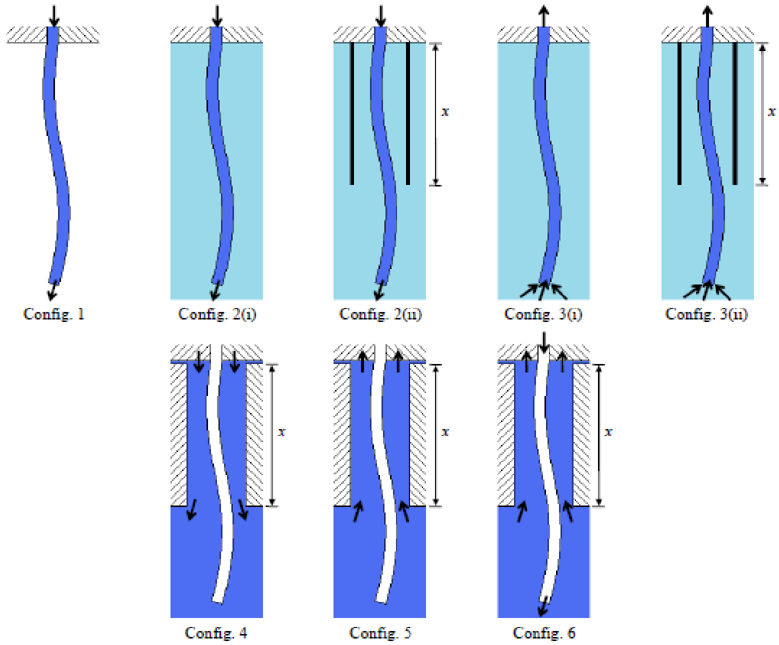


Figure 1. Flow Configurations Evaluated in the McGill University Phase I Research Program.

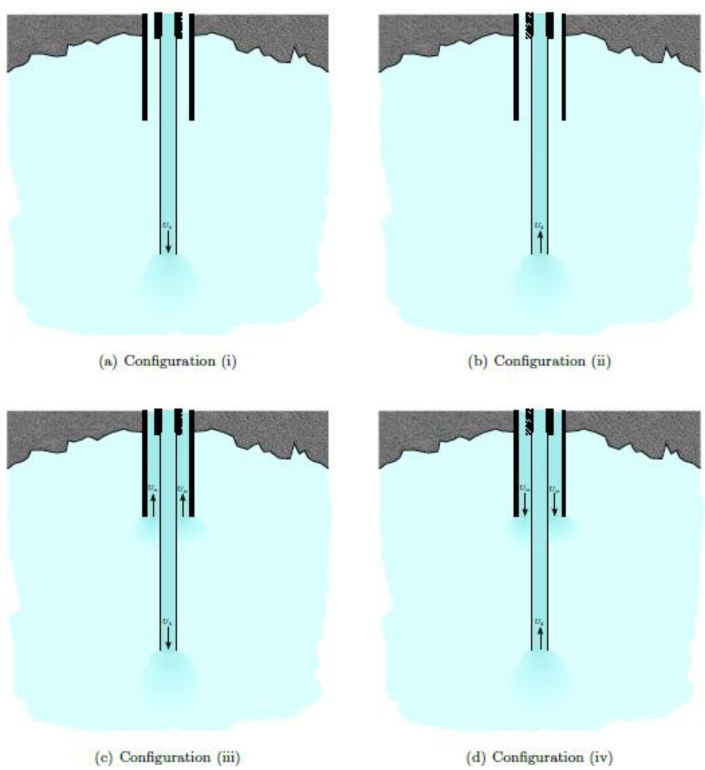
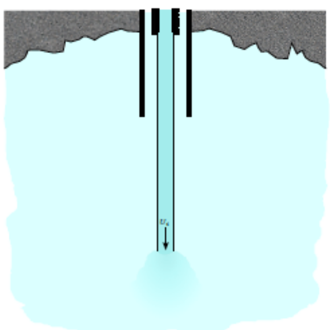
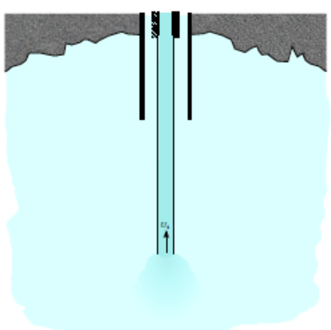
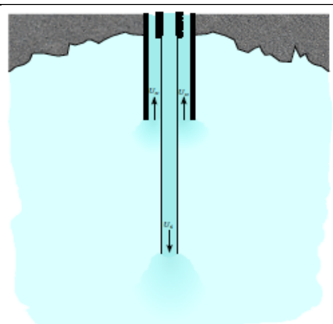
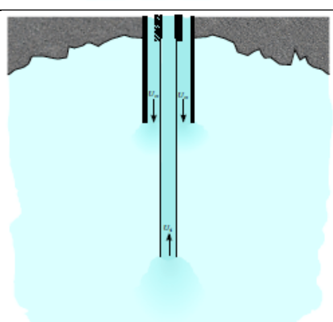


Figure 2. Flow Configurations Evaluated in the McGill University Phase II Research Program.

Table 1. Solution-Mined Cavern Operations Addressed in the Phase II Research

Schematic Illustration of Flow Configuration	**Description**	**Solution-Mined Cavern Operations Addressed**
	• Discharging Tubing • Quiescent Annulus	• Solution Mining Pressurizing for MIT Freshwater flush for salting • Liquid Storage Pressurizing for MIT Freshwater flush for salting • Natural Gas Storage Freshwater flush for salting
	• Aspirating Tubing • Quiescent Annulus	• Solution Mining Cavern depressurizing • Liquid Storage Cavern depressurizing • Natural Gas Storage "Incremental" de-watering
	• Discharging Tubing • Aspirating Annulus	• Solution Mining Direct mining • Liquid Storage Product withdrawal • Natural Gas Storage Cavern re-watering
	• Aspirating Tubing • Discharging Annulus	• Solution Mining Reverse Mining • Liquid Storage Product injection • Natural Gas Storage Cavern de-watering