Problem 5
Whirlpool in a Bottle

International Physics Tournament 2020 · University of California, Berkeley
Abrego, Ceja, Hathaway, Kadam, Mal, Mehrotra

Prompt

- When an open bottle of water is turned upside down and slightly rotated, a whirlpool is formed.

1. What are its characteristics?
    a. Impact Factors
    b. Result Factors
2. How fast can the bottle be emptied that way?
3. What will change if the bottle is filled with sand instead?

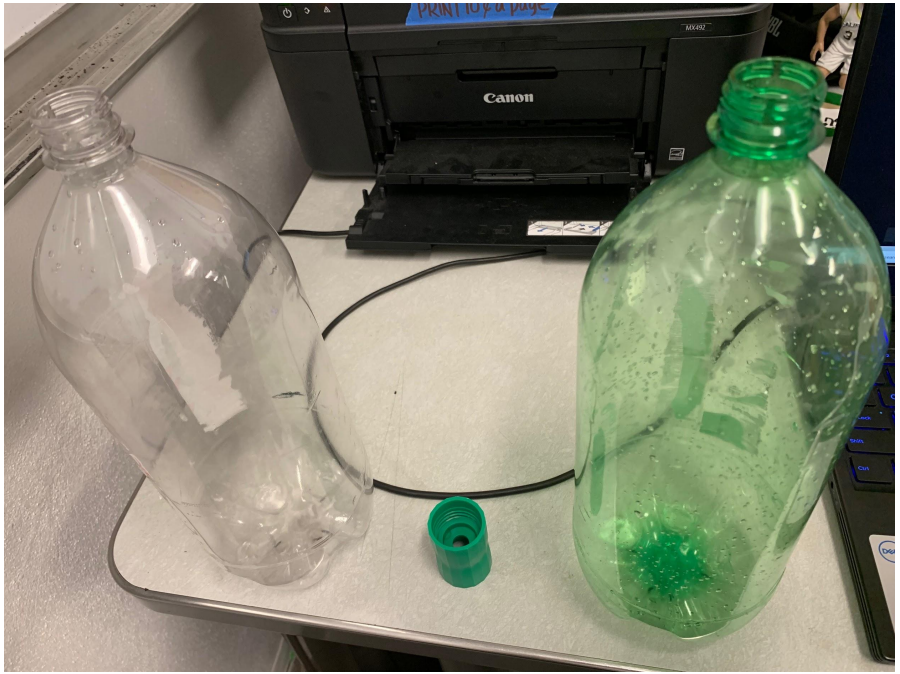
Theory

- TIme constraints, complexity ⇒ experimental approach first
- General: air pressure beneath water vs pressure of water to fall
  - Same passage for both water & air
- Whirlpool ⇒ continuous use of passage by both water & air

- Calculus: rate of change for cylindrical, elliptoid (approx sphere)

Experimental Setup

- same for all three tasks



Procedure (Potential Characteristics)

- Initial Influences
  - Rotational Initiation
    - Definition: cycles per second
    - # of seconds
  - Angle of Rotation
  - Volume of Water
  - Hole Size
- Resulting Properties
  - Drainage Time*
    - Definition: flow rate
  - Bird's Eye Radius
  - Vortex thickness

- Observations
  - Flow sticks to walls ⇒ definition: start/stop timing for creation of whirlpool
    - Small leakage during whirling (insignificant) accounted for in deciding optimal rotational initiation

Potential Characteristics: Results

Insignificant

- Rotational Initiation
- Angle of Rotation

Significant

- Volume of Water
- Hole Size

Insignificant Properties (Analysis)

Trial	10 (cycles/5sec)	15 (cycles/5sec)
1	31.2±0.3	34.9±0.3
2	31.1±0.3	35.0±0.3
3	30.0±0.3	32.4±0.3
4	33.2±0.3	29.2±0.3
5	30.7±0.3	33.0±0.3
Cumulative	31.2±0.6	32.9±1.1

Trial	5 (Degrees)	45 (Degrees)
1	31.2±0.3	29.4±0.3
2	31.1±0.3	29.4±0.3
3	30.0±0.3	29.6±0.3
4	33.2±0.3	30.8±0.3
5	30.7±0.3	30.3±0.3
Cumulative	31.22±0.6	29.9±0.4

Significant Properties (Analysis)

- Hole Size
  - Small: 0.50 cm^2
  - Large: 2.34 cm^2

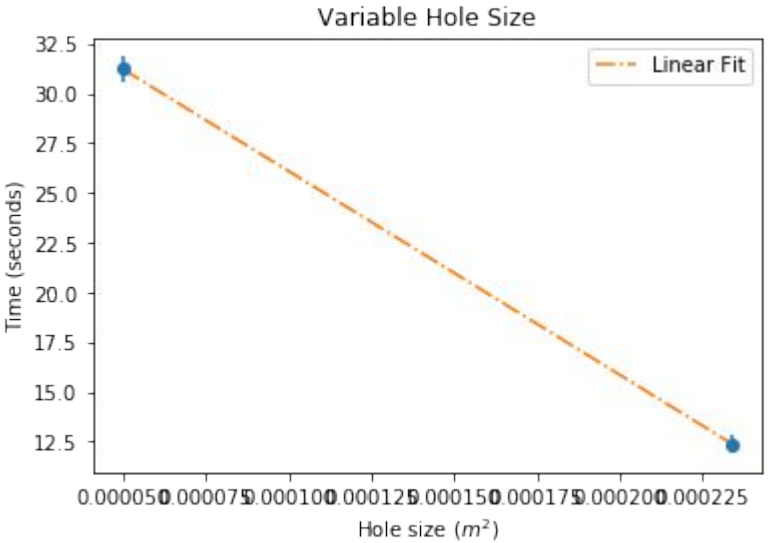
- No Rotation (Small): N/A
- Optimal Setup (Small): 29.9 ± 0.4 s
- No Rotation (Large): 26.8 ± 1.0 s

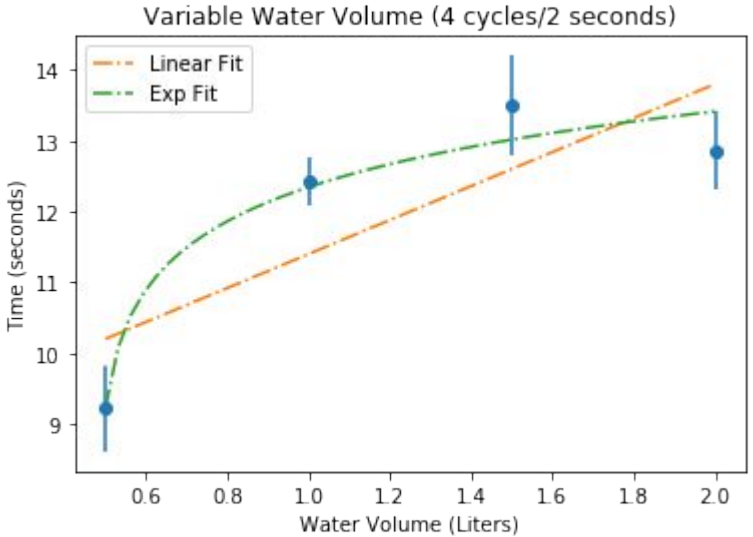
- Maximum Flow (Small): 31.2±0.6 s
- Maximum Flow (Large): 12.38±0.4 s

Duration of Rotational Initiation (2 cycles/second)

Trial	1 second	2 second	3 second
1	N/A	13.86±0.3	11.63±0.3
2	N/A	12.43±0.3	11.87±0.3
3	N/A	13.64±0.3	12.00±0.3
4	N/A	13.03±0.3	13.13±0.3
5	N/A	11.33±0.3	13.26±0.3
Cumulative	N/A	12.4±0.5	12.9±0.5

Significant Properties (Analysis)





- Qualitatively expected
- Lacking

- Whirlpool formation vs. rotations completed
- Definition of “timing”

Task 2: Emptying the Bottle

- Minimum Time:11.3 ± 0.3 seconds
  - 2 Liters
  - 4 cycles/2 sec
  - large hole size
- Minimum Mean Time: 12.4 ± 0.5 seconds
  - Whirlpool formed before rotational initiation complete

Task 3: Sand

- Qualitative: Whirlpool not formable.

- Quantitative: Drain time increased
- No whirlpool drain time (2L): 43.20±0.30 seconds
- Constant rotation: 40.10±0.30 seconds

Future Goals/Improvements

- Characterize ⇒ More Complete Theory
  - Bird's Eye Radius
  - Vortex Thickness
- Explore Further
  - Volume vs. Time trend
  - Hole size vs. Time trend
- Increase Accuracy
  - More sig figs

Acknowledgements

- Research papers, citations,

Additional: Task 1 Data Tables

	Small Hole	Large Hole
Time (seconds)	31.22	11.63
	31.05	11.87
	29.99	12.00
	33.16	13.13
	30.67	13.26
Cumulative	31.22	12.38

Additional: Task 2 Data Tables

Additional: Task 3 Data Tables