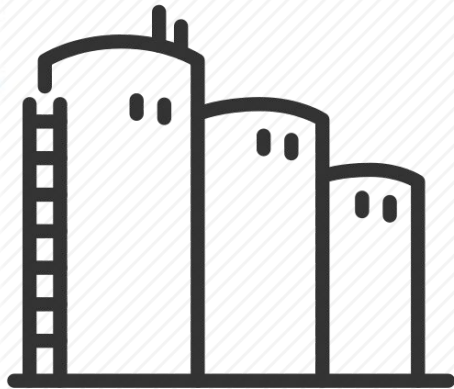


TP N° 5: Granular Flow

Grupo N° 5

Daniel Lobo | Agustín Golmar



A decorative network diagram in the top-left corner, featuring a complex web of interconnected nodes and lines. Some nodes are highlighted with blue circles, and others with blue dots. The diagram is rendered in a light gray color.

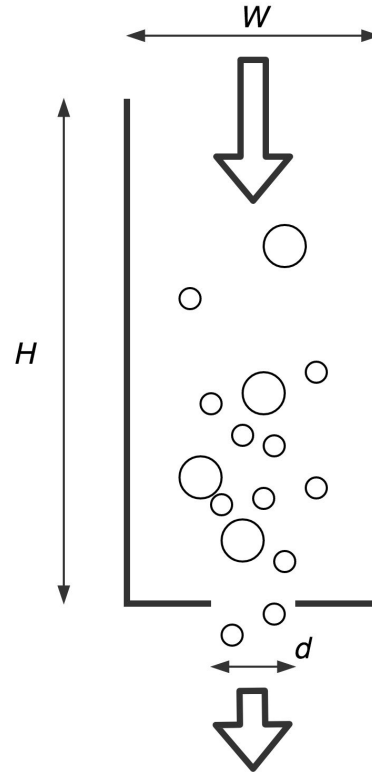
Fundamentos

A decorative network diagram in the bottom-right corner, featuring a complex web of interconnected nodes and lines. Some nodes are highlighted with blue circles, and others with blue dots. The diagram is rendered in a light gray color.

Sistema Físico

*“Comportamiento de un **flujo granular** dentro de un silo rectangular vertical, con y sin drenaje.”*

*“El silo posee alto **H**, ancho **W** y drenaje **d**.”*



Modelo Matemático

$$\bar{F}_{flow} = \bar{F}_{gravity} + \sum \bar{F}_{contact} + \sum \bar{F}_{friction}$$

- Fuerza de **Gravedad**

$$\bar{F}_{gravity} = -mg \hat{y}$$

- Fuerza de **Contacto** (*choque*)

$$\bar{F}_{contact} = (-k_n \xi_0 - \gamma \xi_1) \hat{n}$$

- Fuerza de **Fricción**

$$\bar{F}_{friction} = -k_t \xi_0 \langle r_1^\Delta, \hat{t} \rangle \hat{t}$$

Modelo Matemático

$$\bar{F}_{contact} = (-k_n \xi_0 - \gamma \xi_1) \hat{n}$$

- Dirección **normal**

$$\hat{n} = \frac{r_0^j - r_0^i}{\|r_0^j - r_0^i\|}$$

- Superposición

$$\xi_0 = R_i + R_j - \|r_0^j - r_0^i\|$$

- Velocidad de superposición

$$\xi_1 = \frac{\langle r_0^j - r_0^i, r_1^\Delta \rangle}{\|r_0^j - r_0^i\|}$$

Modelo Matemático

$$\bar{F}_{friction} = -k_t \xi_0 \langle r_1^\Delta, \hat{t} \rangle \hat{t}$$

- Dirección **tangencial**

$$\hat{t} = (-\hat{n}_y, \hat{n}_x)$$

- Velocidad relativa

$$r_1^\Delta = r_1^i - r_1^j$$

- Fricción **cinética**

A decorative network diagram in the top-left corner, featuring a complex web of interconnected nodes and lines. Some nodes are highlighted with blue circles, and a few are solid blue dots.

Implementación

Modelo Computacional

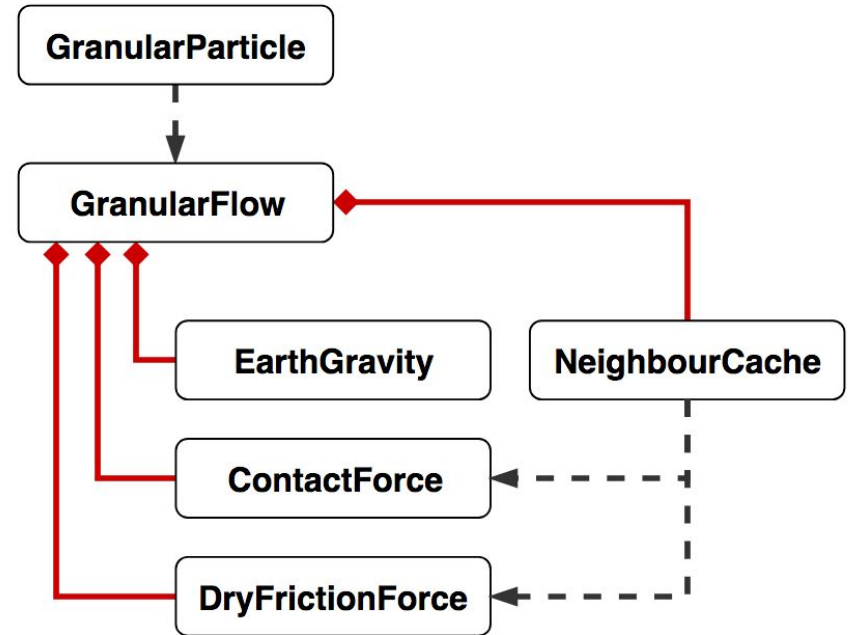
- Java 8 SE Release
- JSON
(<https://www.json.org/>)
- Jackson 2.9.5
(<https://github.com/FasterXML/jackson>)
- Ovito
(<https://ovito.org/>)

- Reutilización de:
 - TimeDrivenSimulation
 - ForceField
 - BeemanIntegrator
 - CellIndexMethod

Campos de Fuerza

(ForceField<T> Interface)

- GranularFlow
 - EarthGravity
 - ContactForce
 - DryFrictionForce



Configuración

(JSON Input)

- Paso temporal (3×10^{-5})

$$\Delta t < \sqrt{\frac{m}{100 k_n}}$$

- Rigidez reducida: $\Theta(10^4)$
- Amortiguación **diferencial**

$$\gamma_{critic} = 2\sqrt{mk_n}$$

```
{  
  "output"      : "res/data/output.data",  
  "delta"       : "0.00003",  
  "time"        : "15.0",  
  "fps"         : "50",  
  "playbackSpeed" : "0.5",  
  "samplesPerSecond" : "500",  
  
  "integrator"   : "BeemanIntegrator",  
  "reportEnergy" : "false",  
  "reportTime"   : "true",  
  "radius"       : ["0.01", "0.015"],  
  "mass"         : "0.01",  
  
  "elasticNormal" : "1.0E+4",  
  "elasticTangent" : "2.0E+4",  
  "viscousDamping" : "20.0",  
  "siloDamping"   : "15.0",  
  
  "generator"    : "64684095347601931",  
  "n"            : "370",  
  "height"       : "1.0",  
  "width"        : "0.3",  
  "drain"        : "0.15",  
  "flowRate"     : "0.1",  
  "injection"    : ["0.75", "1.0"]  
}
```

Formato de Archivos

(Output)

- Formato **.data* y **.small*

<x> <y> <r> <speed> <pressure>

...

- Formato **.xyz* (para Ovito)

<n>

<t>

<x> <y> <r> <speed> <pressure>

...

- Formato **.drain* (para eventos)

<t> <id>

...

- Formato **.flow* (caudal, a paso *flowRate*)

<t> <flow>

...

Para calcular la
energía cinética!

Para la ley de
Beverloo!

A decorative network diagram in the top-left corner of the slide. It features a complex web of interconnected nodes and edges. The nodes are represented by small circles, some of which are solid blue, some are solid grey, and some are outlined in blue. The edges are thin grey lines connecting the nodes. The overall structure is a dense, interconnected mesh.

Simulación

Condiciones

- Colorear partículas según la **presión**:

$$P = \frac{1}{2\pi R_i} \left\| \sum \bar{F}_{contact} \right\|$$

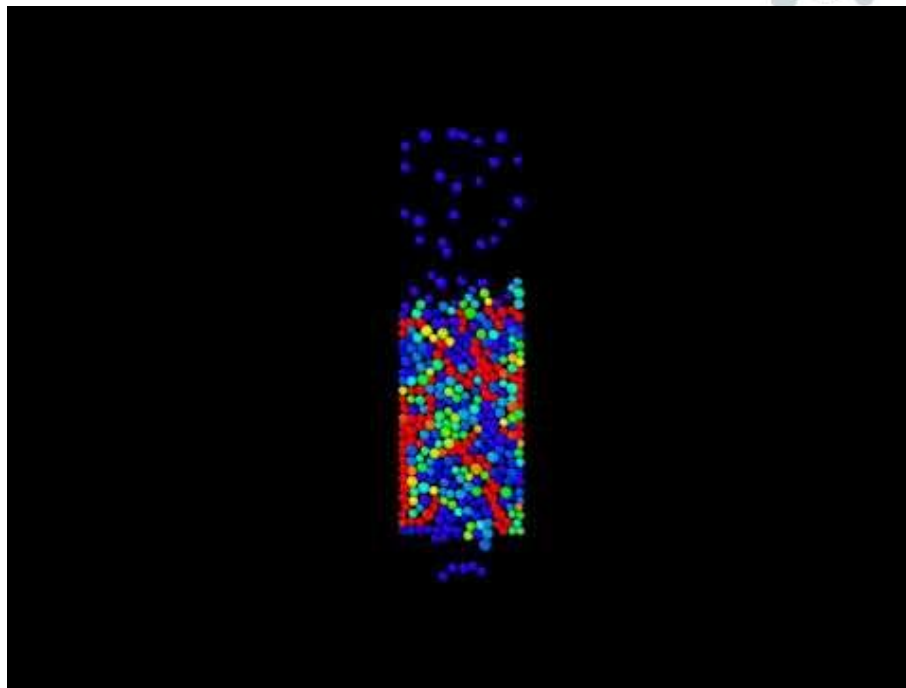
- Los parámetros geométricos del silo deben verificar:

$$0.15 \, m \leq d < W < H$$

Simulación - 1

(50 FPS | Speed x0.5 | 720p)

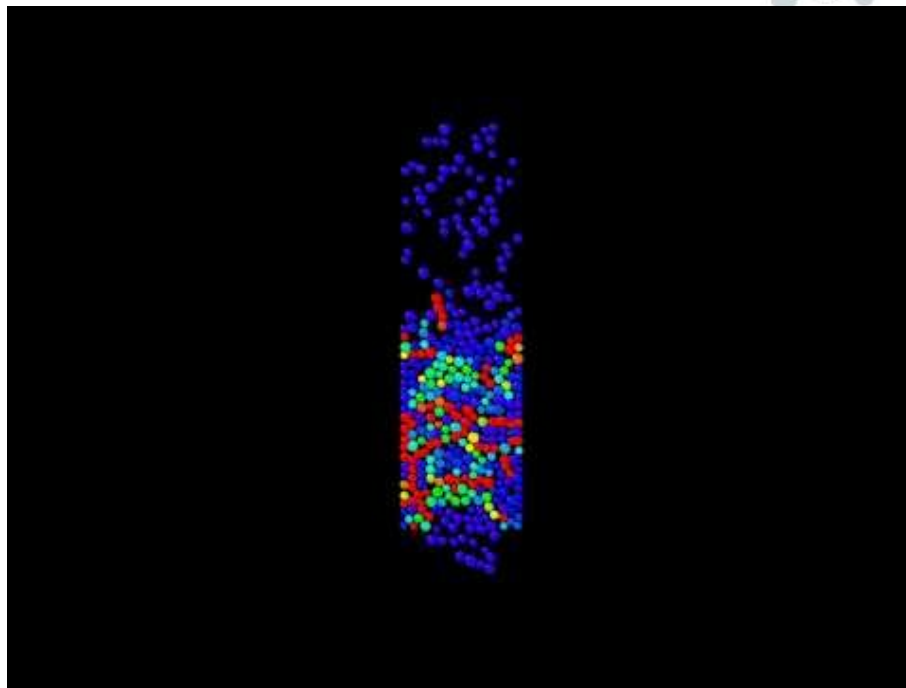
```
{  
  ...  
  "n"      : "370",  
  "height" : "1.00",  
  "width"  : "0.30",  
  "drain"  : "0.15",  
  ...  
}
```



Simulación - 2

(50 FPS | Speed x0.5 | 720p)

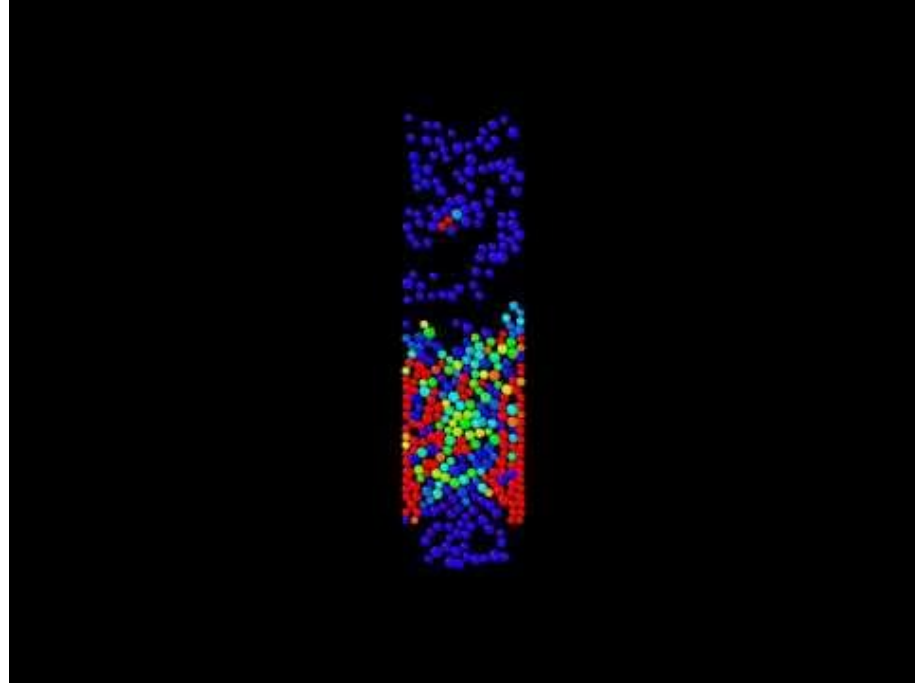
```
{  
  ...  
  "n"      : "370",  
  "height" : "1.00",  
  "width"  : "0.30",  
  "drain"   : "0.19",  
  ...  
}
```



Simulación - 3

(50 FPS | Speed x0.5 | 720p)

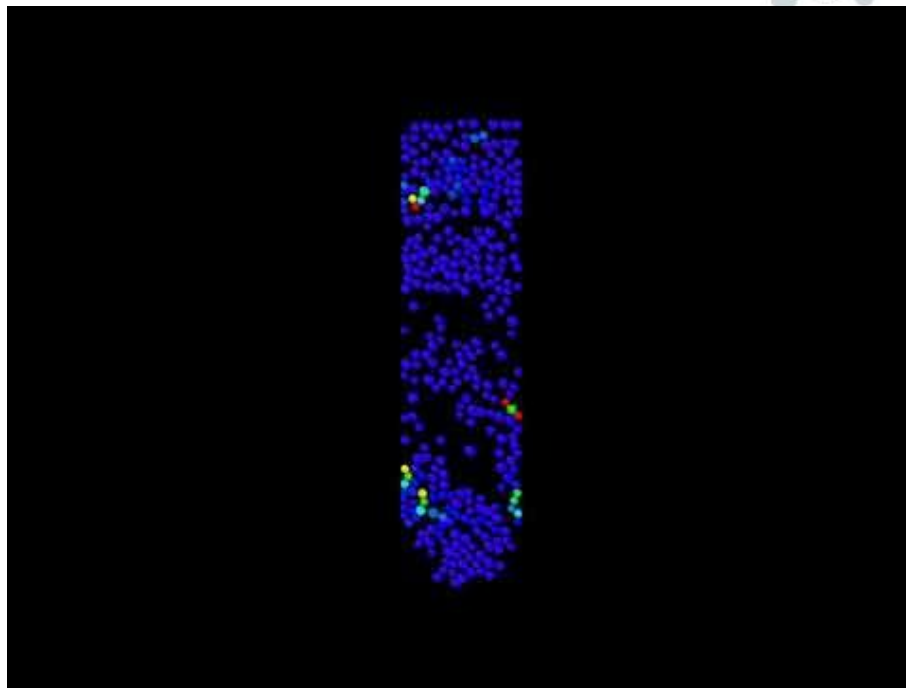
```
{  
  ...  
  "n"      : "370",  
  "height" : "1.00",  
  "width"  : "0.30",  
  "drain"  : "0.23",  
  ...  
}
```



Simulación - 4

(50 FPS | Speed x0.5 | 720p)

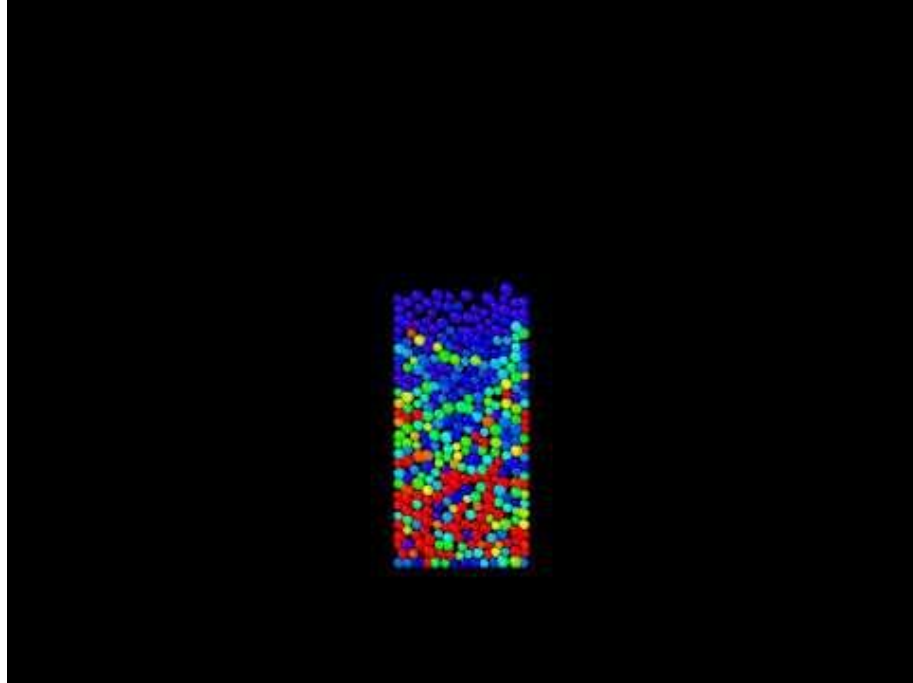
```
{  
  ...  
  "n"      : "370",  
  "height" : "1.00",  
  "width"  : "0.30",  
  "drain"  : "0.27",  
  ...  
}
```



Simulación - 5 (*critic damping*)

(50 FPS | Speed x0.5 | 720p)

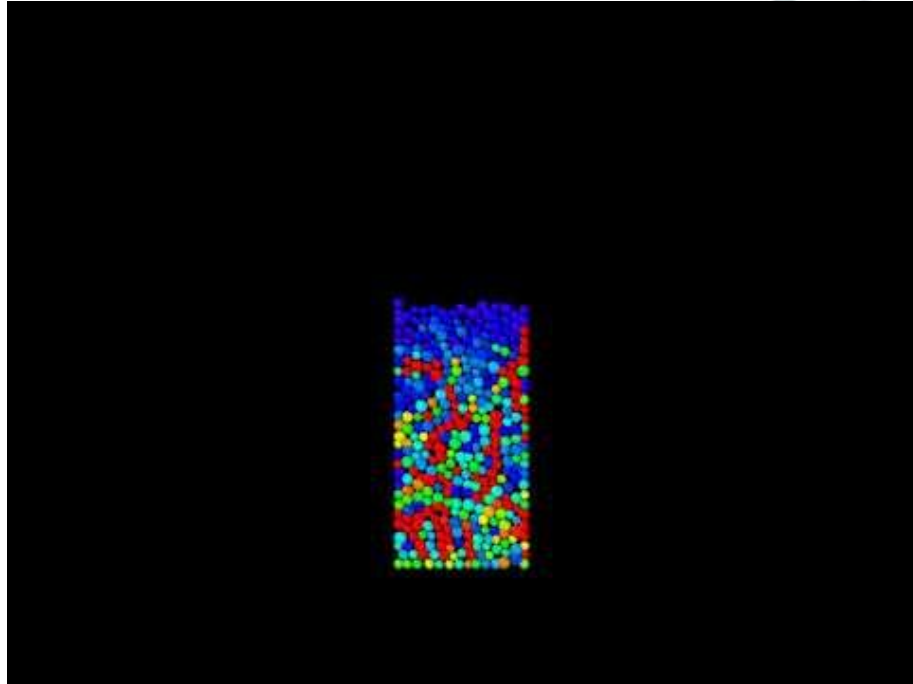
```
{  
  ...  
  "n"      : "370",  
  "height" : "1.00",  
  "width"  : "0.30",  
  "drain"   : "0.0",  
  ...  
}
```



Simulación - 6 (*over-critic damping*)

(50 FPS | Speed x0.5 | 720p)

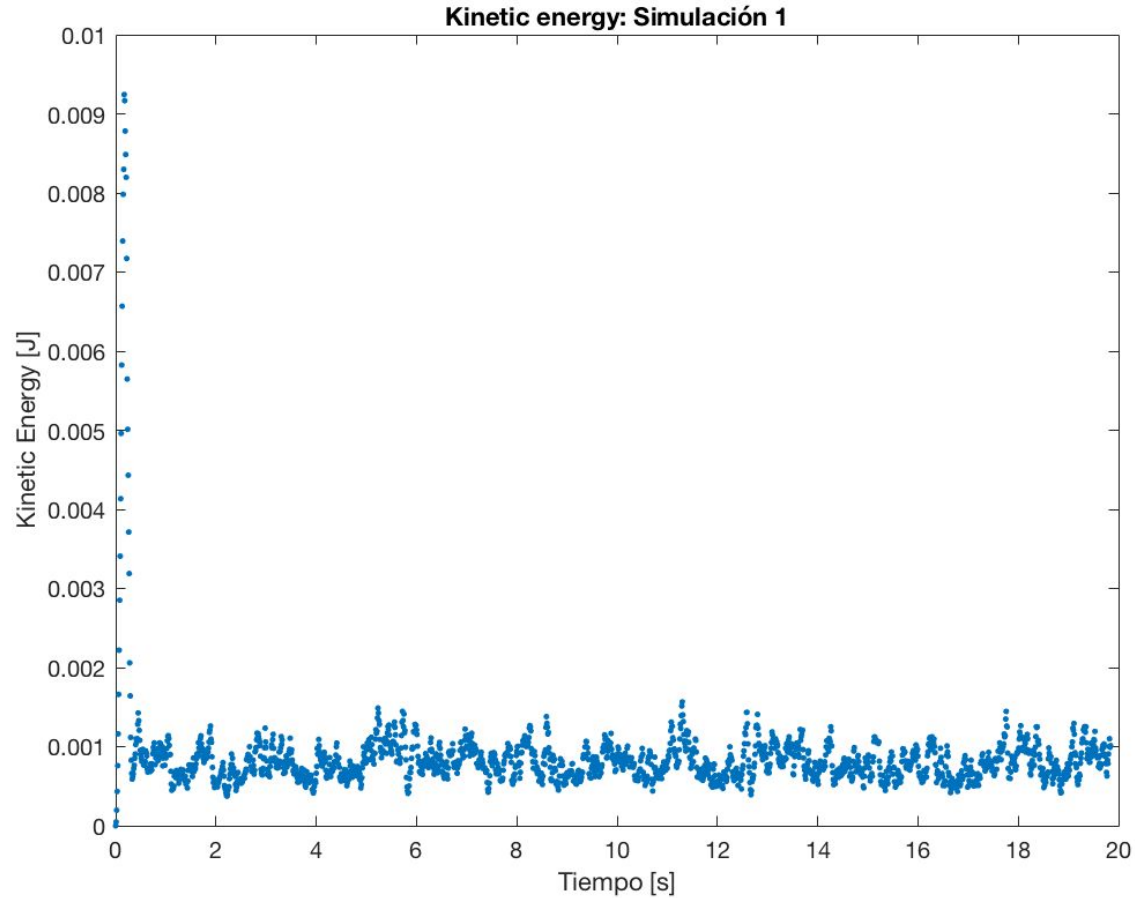
```
{  
  ...  
  "viscousDamping" : "60.0",  
  "siloDamping"    : "45.0",  
  ...  
  "n"              : "370",  
  "height"         : "1.00",  
  "width"          : "0.30",  
  "drain"          : "0.0",  
  ...  
}
```



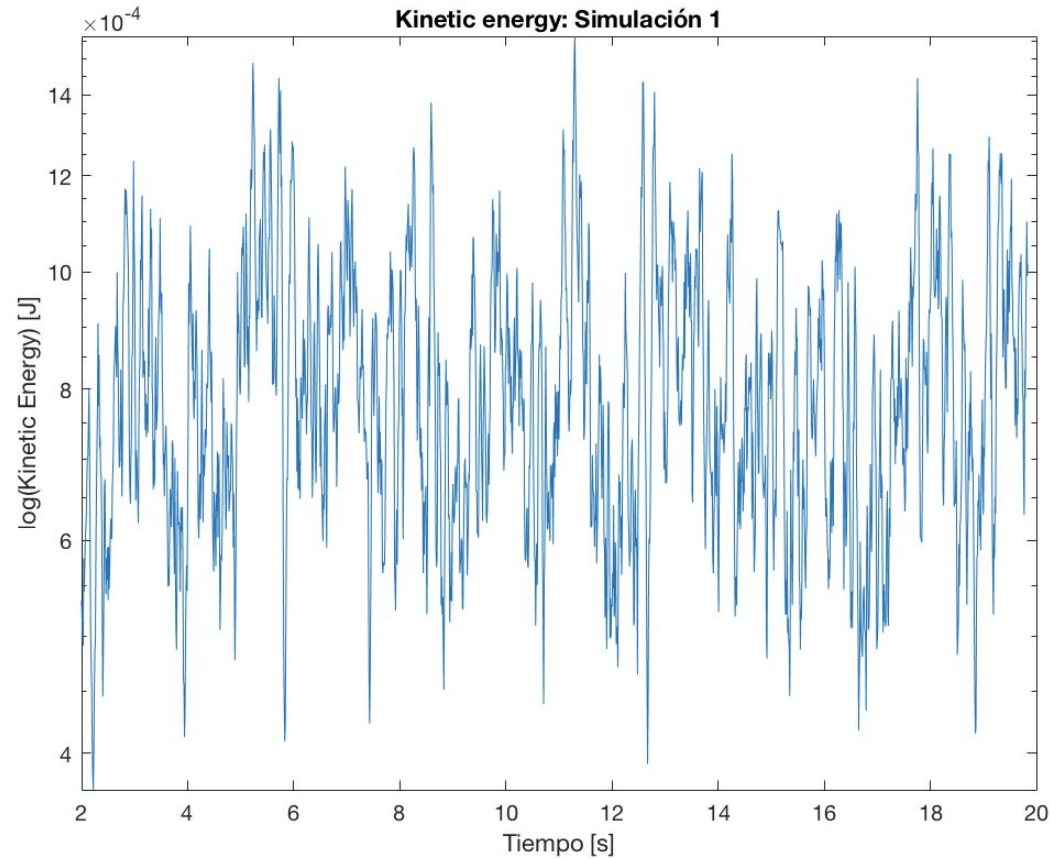
A decorative network diagram in the top-left corner, featuring a complex web of interconnected nodes and lines. Some nodes are highlighted with blue circles, and others with blue dots.

Resultados

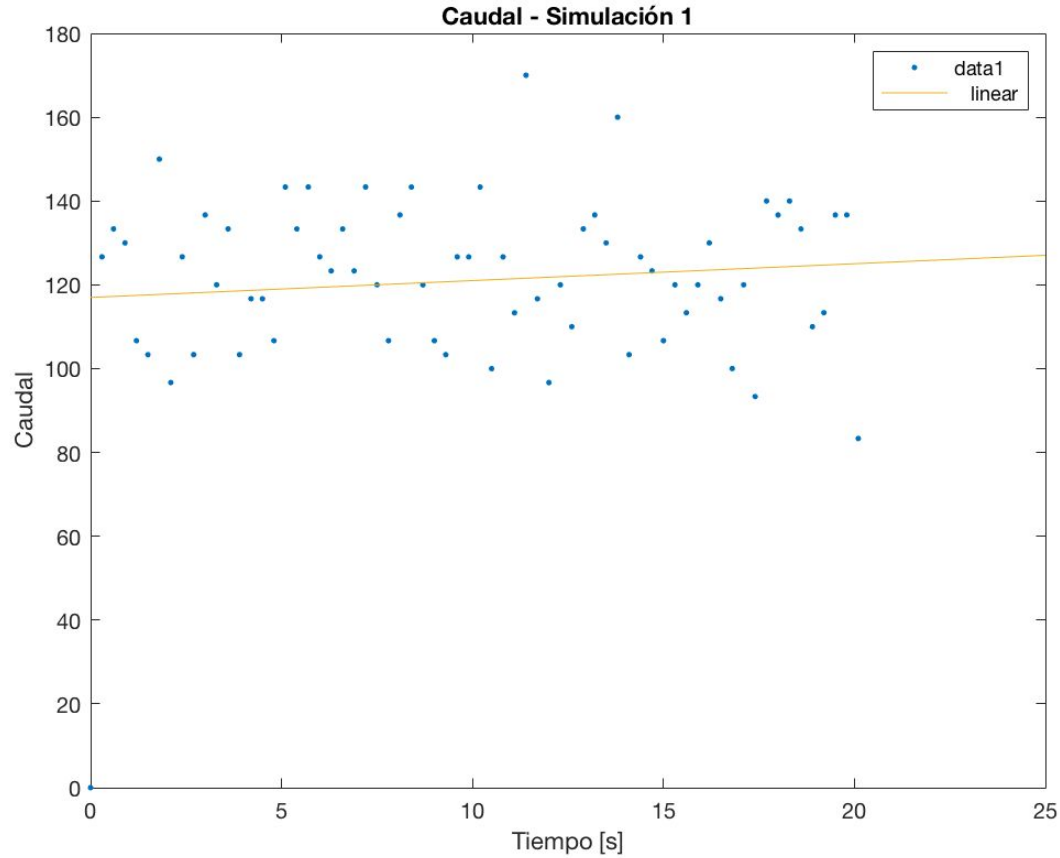
Energía Cinética del Sistema: Simulación 1



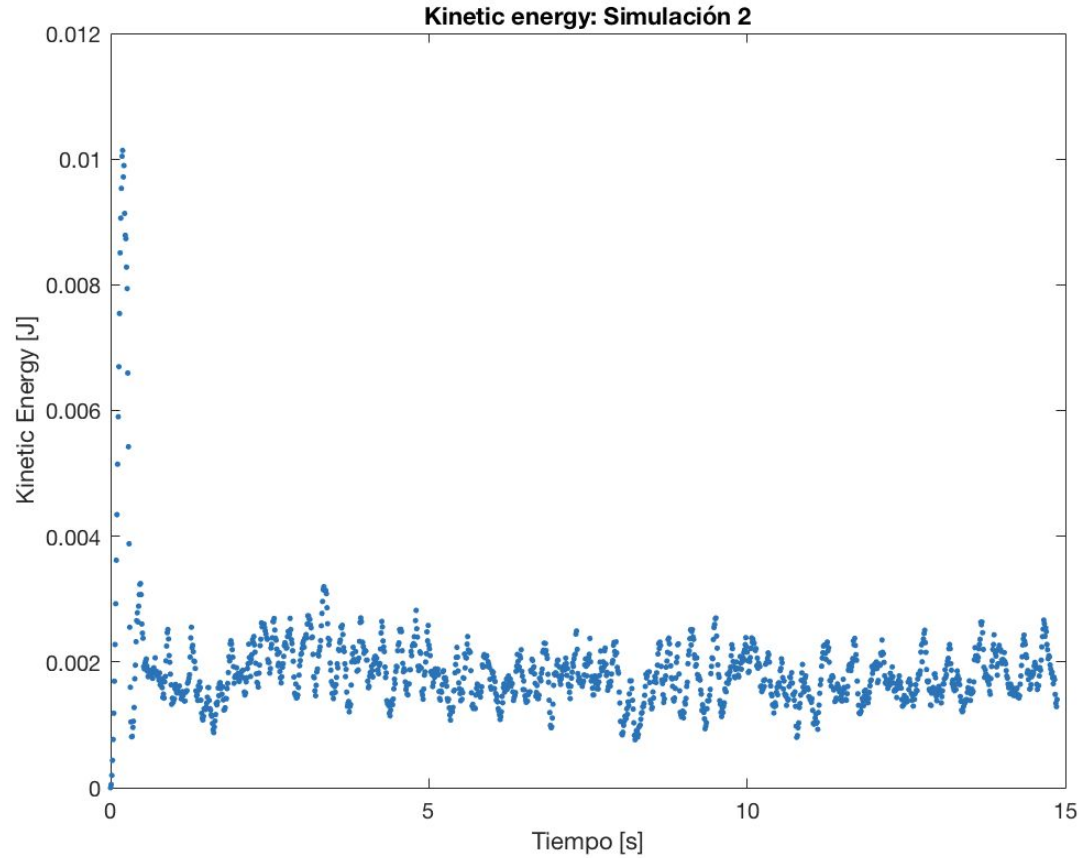
Energía Cinética del Sistema: Simulación 1 (zoom)



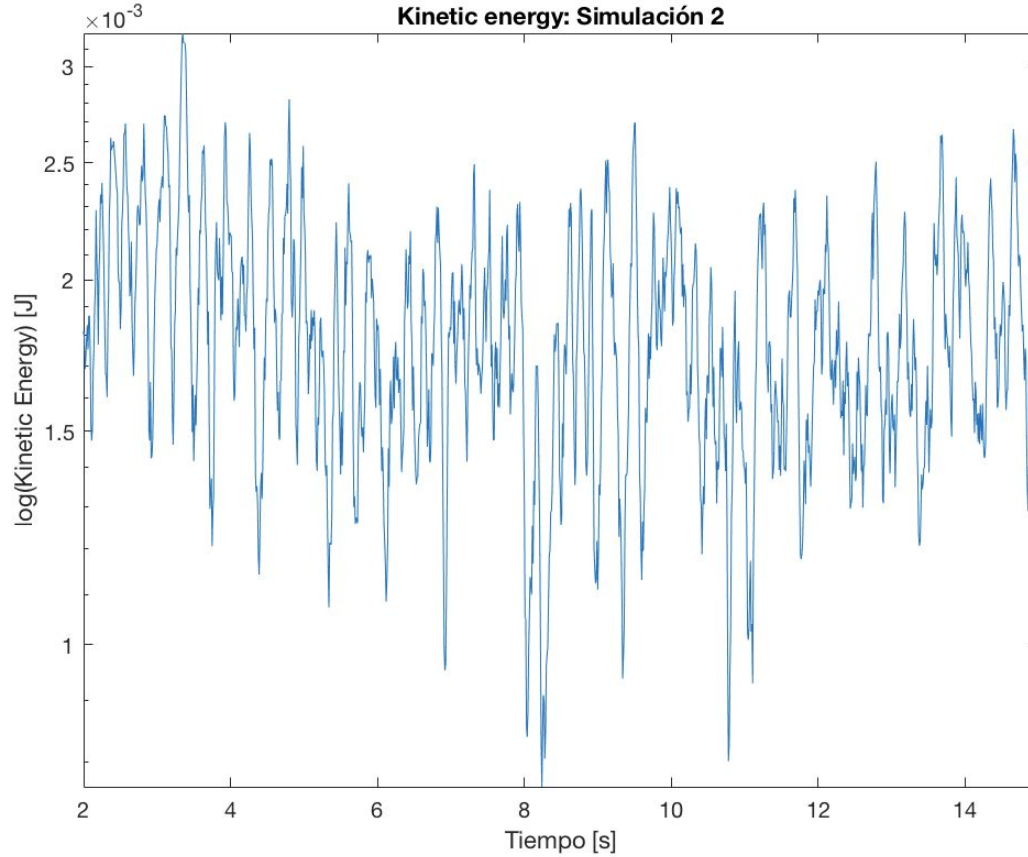
Caudal: Simulación 1



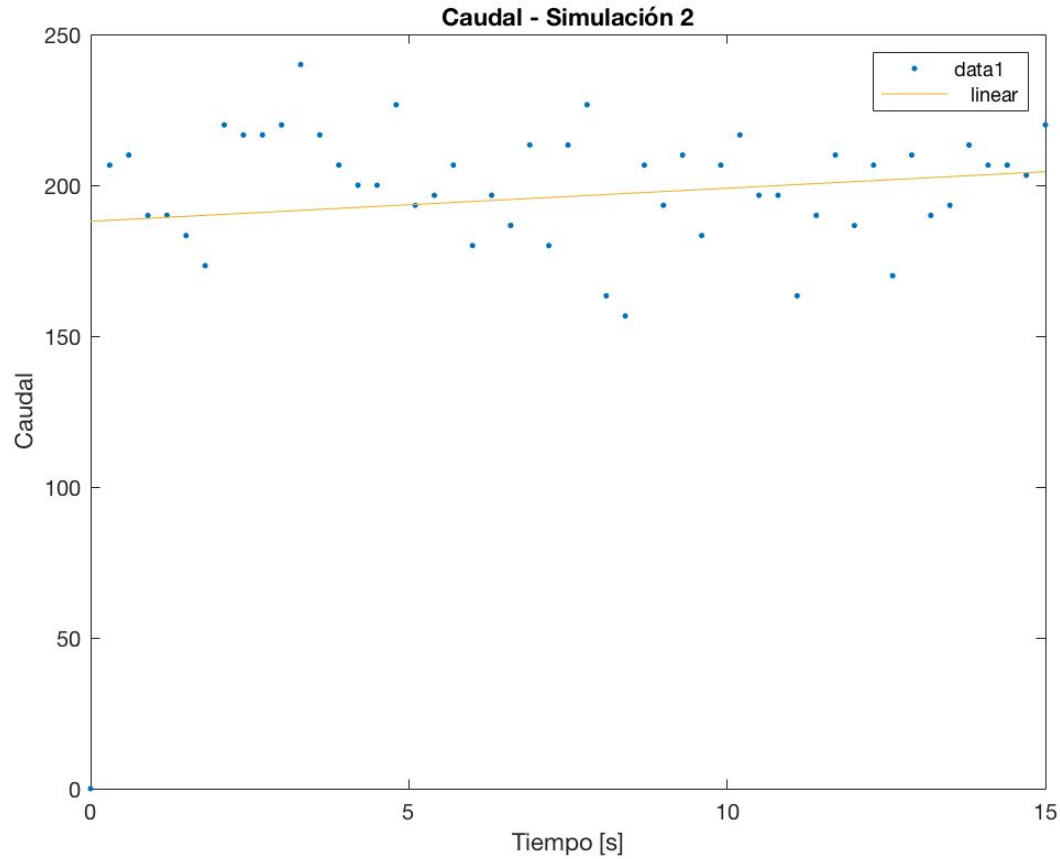
Energía Cinética del Sistema: Simulación 2



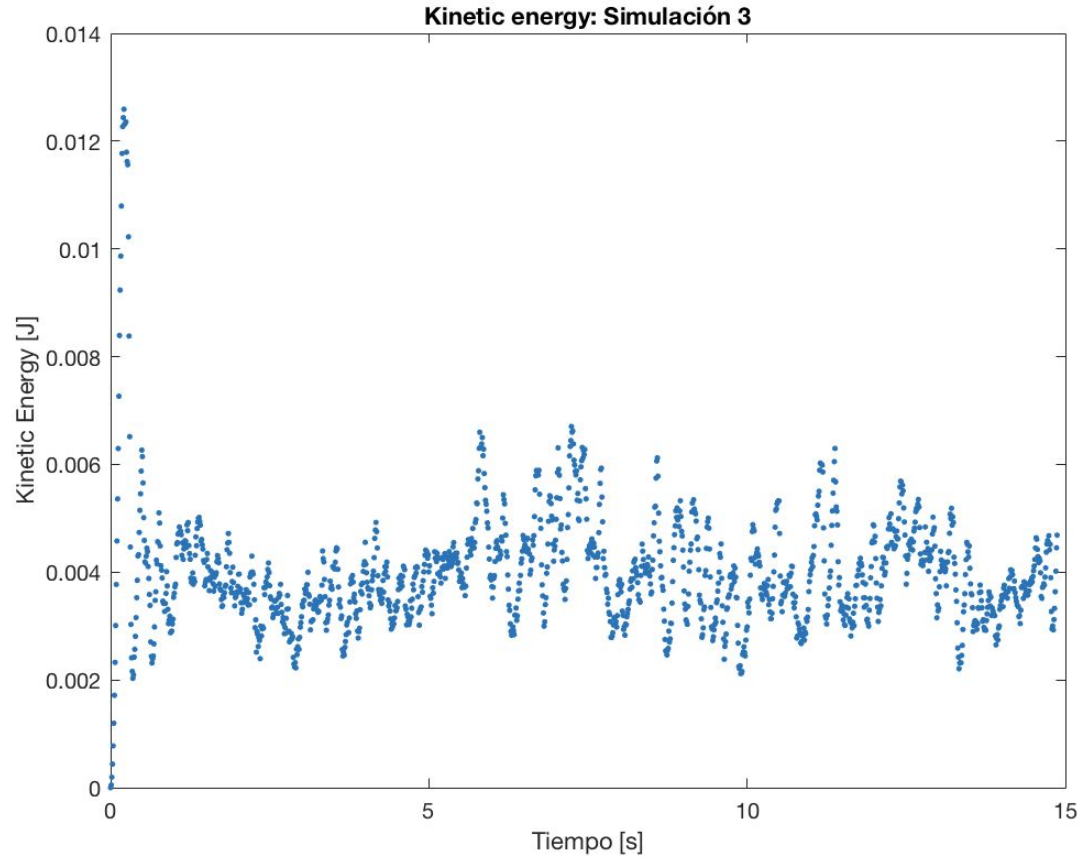
Energía Cinética del Sistema: Simulación 2 (zoom)



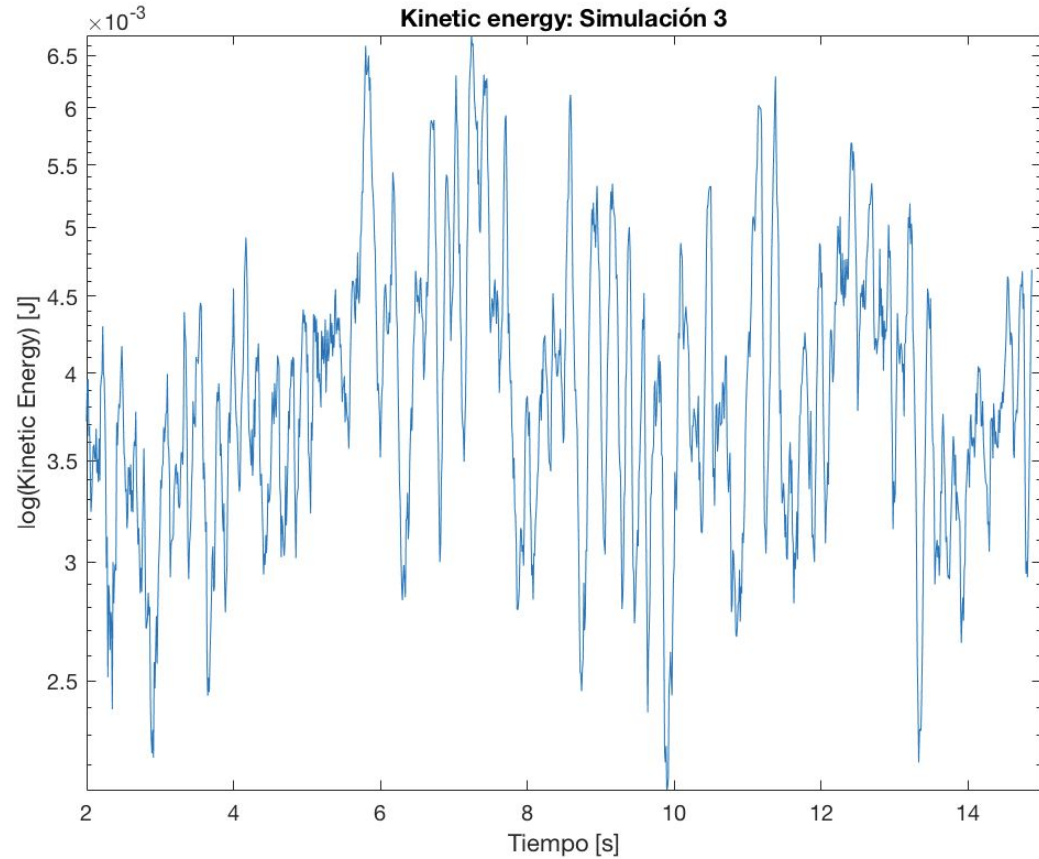
Caudal: Simulación 2



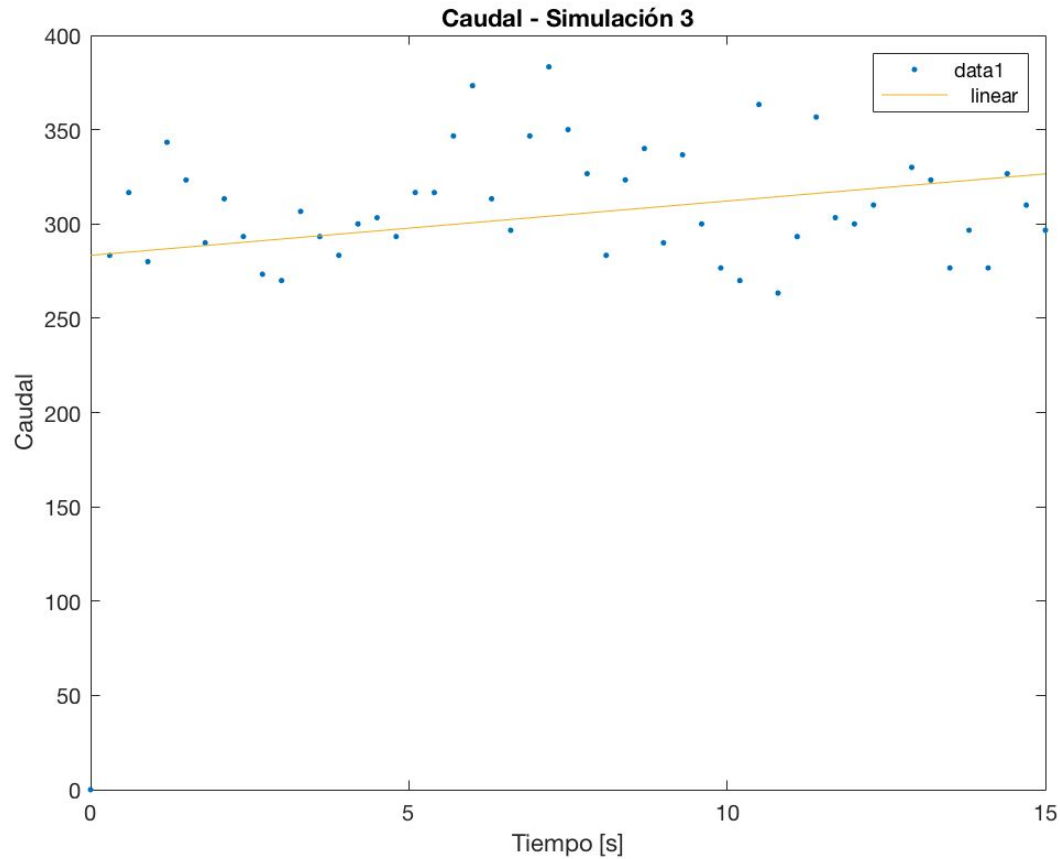
Energía Cinética del Sistema: Simulación 3



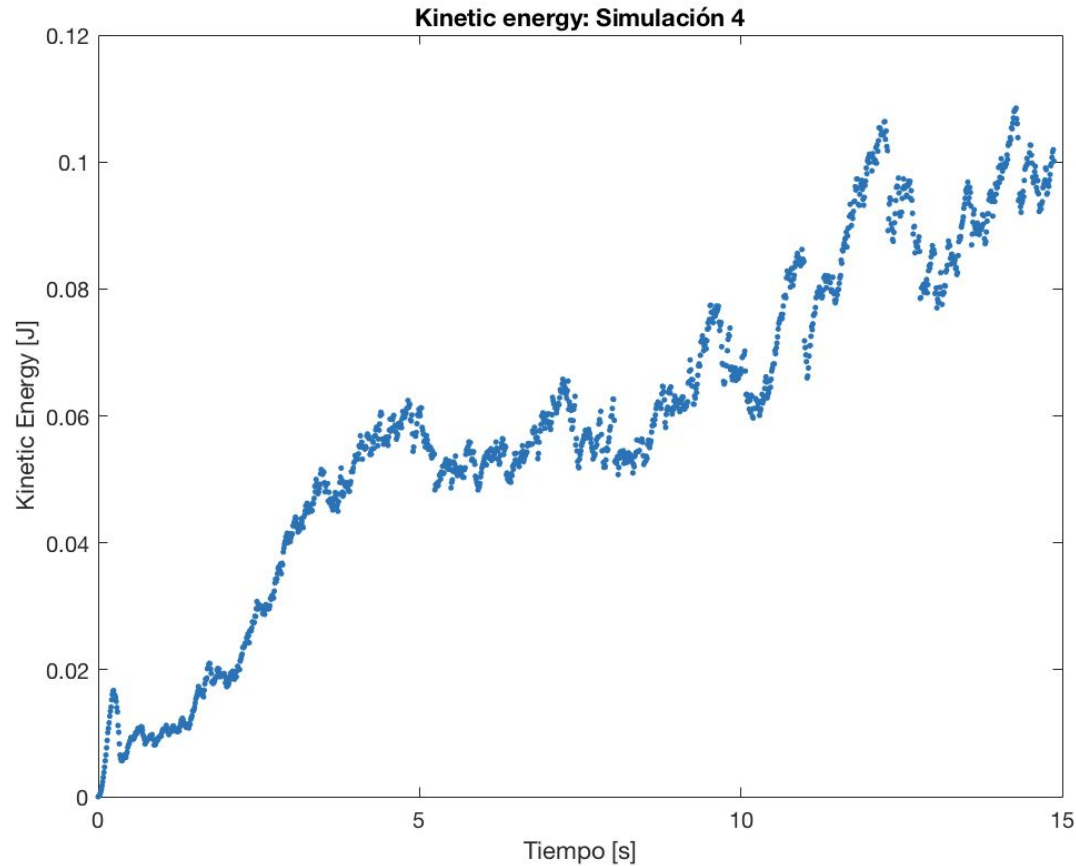
Energía Cinética del Sistema: Simulación 3 (zoom)



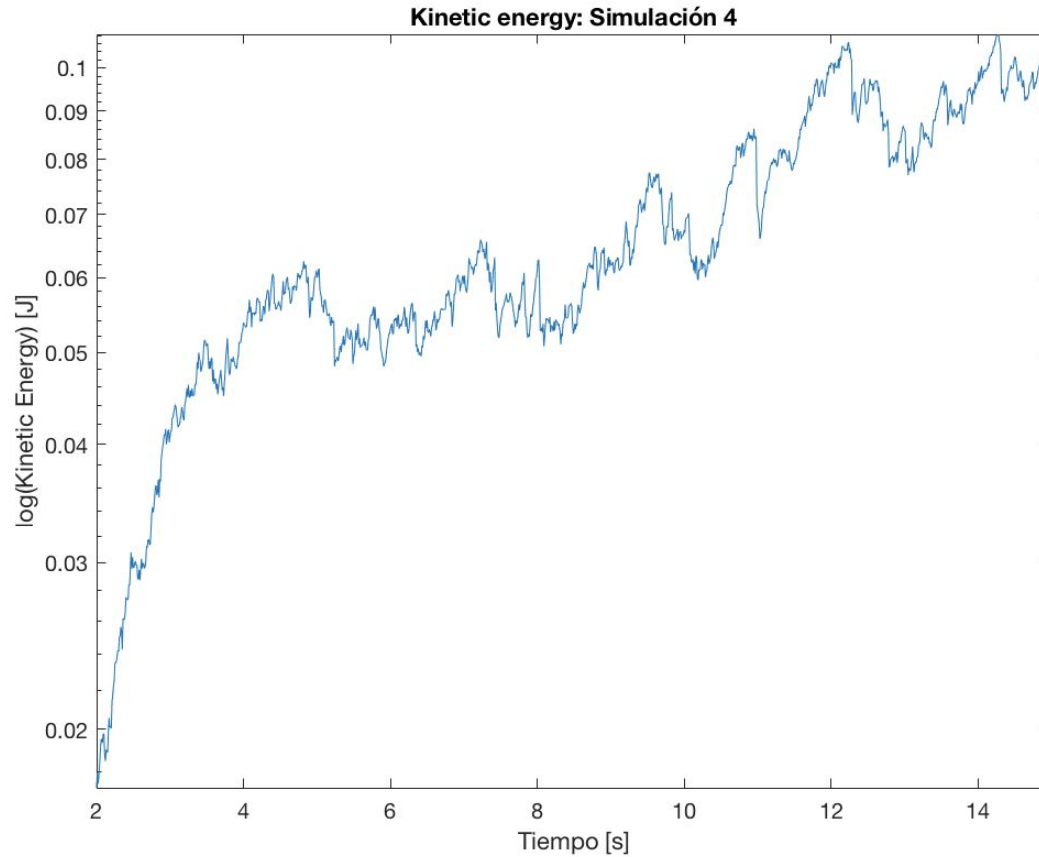
Caudal: Simulación 3 (zoom)



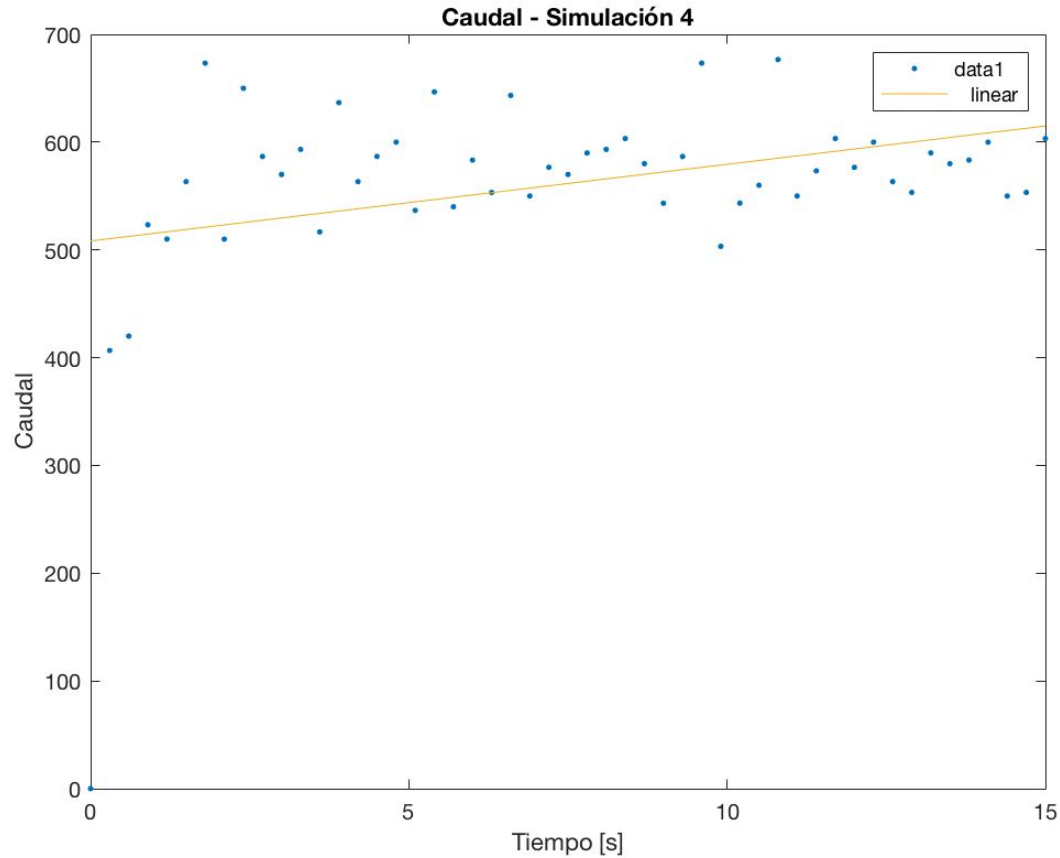
Energía Cinética del Sistema: Simulación 4



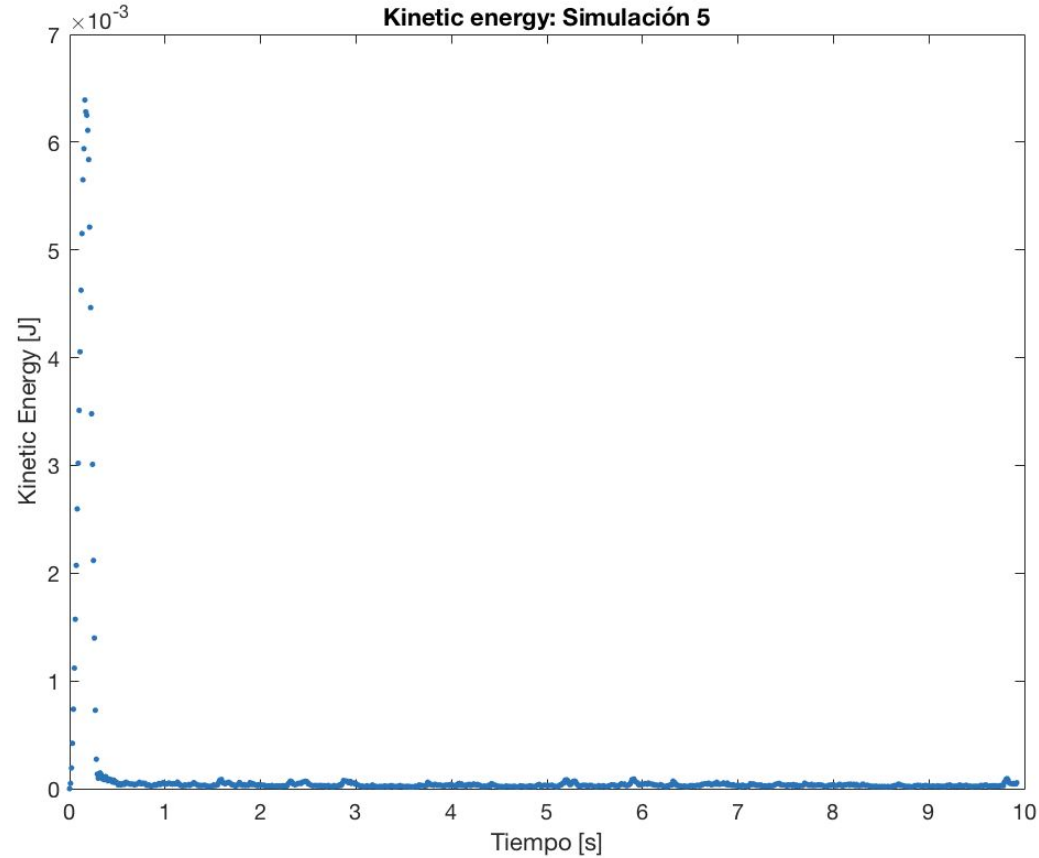
Energía Cinética del Sistema: Simulación 4 (zoom)



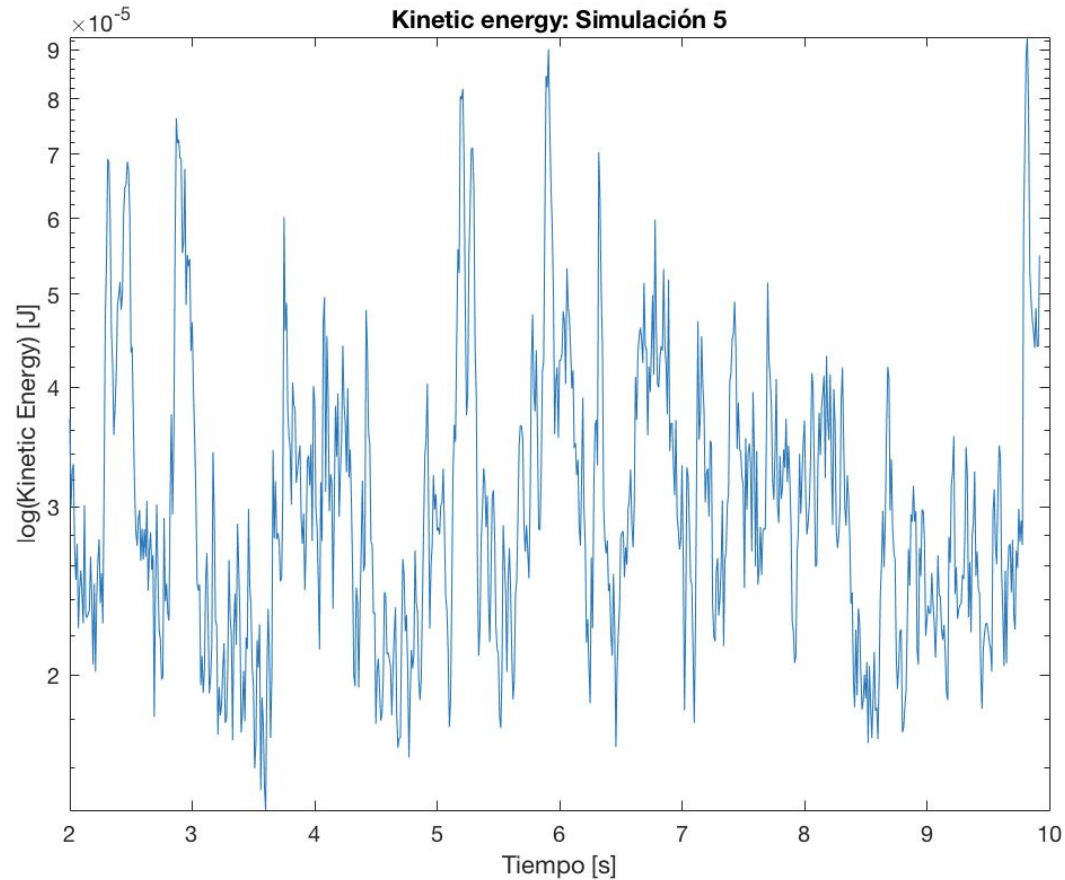
Caudal: Simulación 4 (zoom)



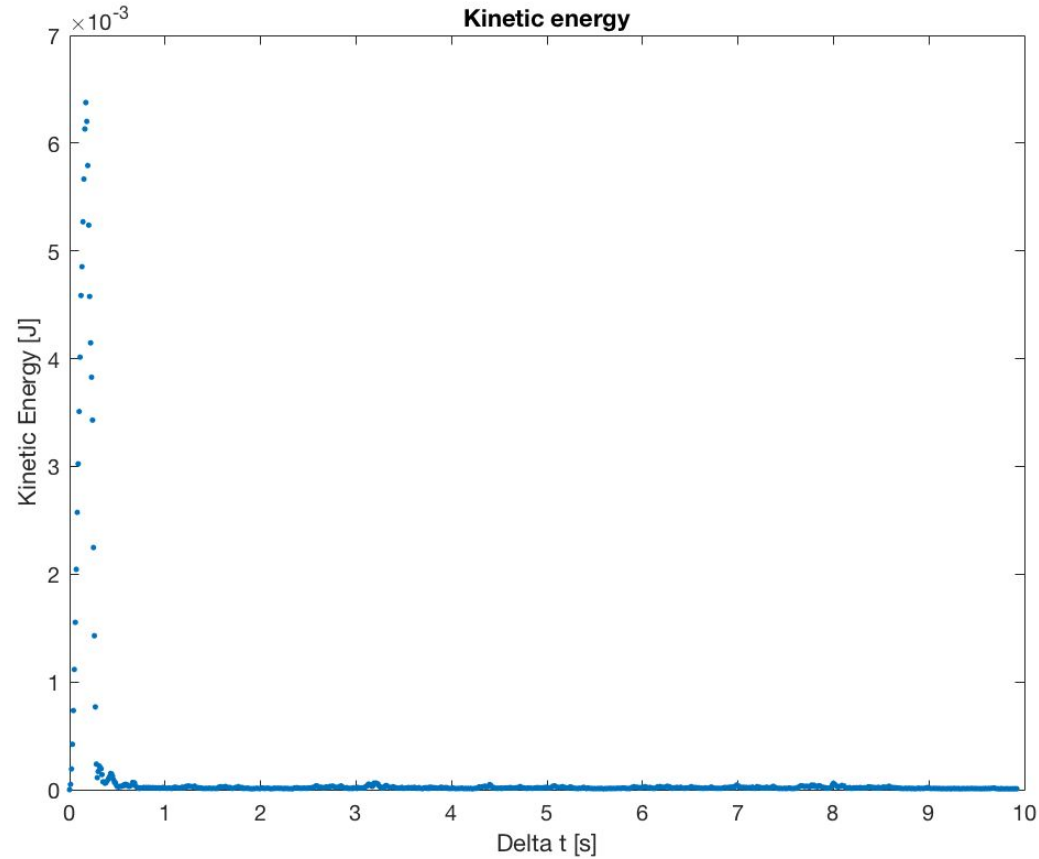
Energía Cinética del Sistema: Simulación 5



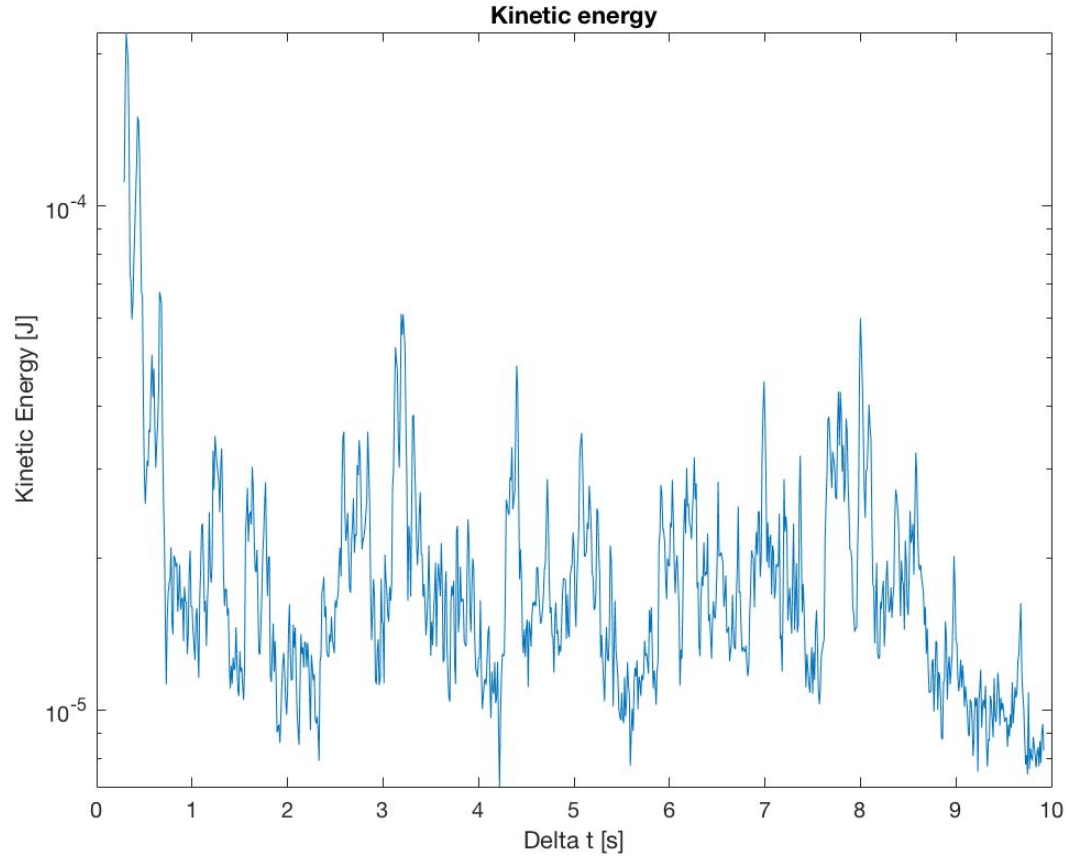
Energía Cinética del Sistema: Simulación 5 (zoom)



Energía Cinética del Sistema: Simulación 6



Energía Cinética del Sistema: Simulación 6 (zoom)



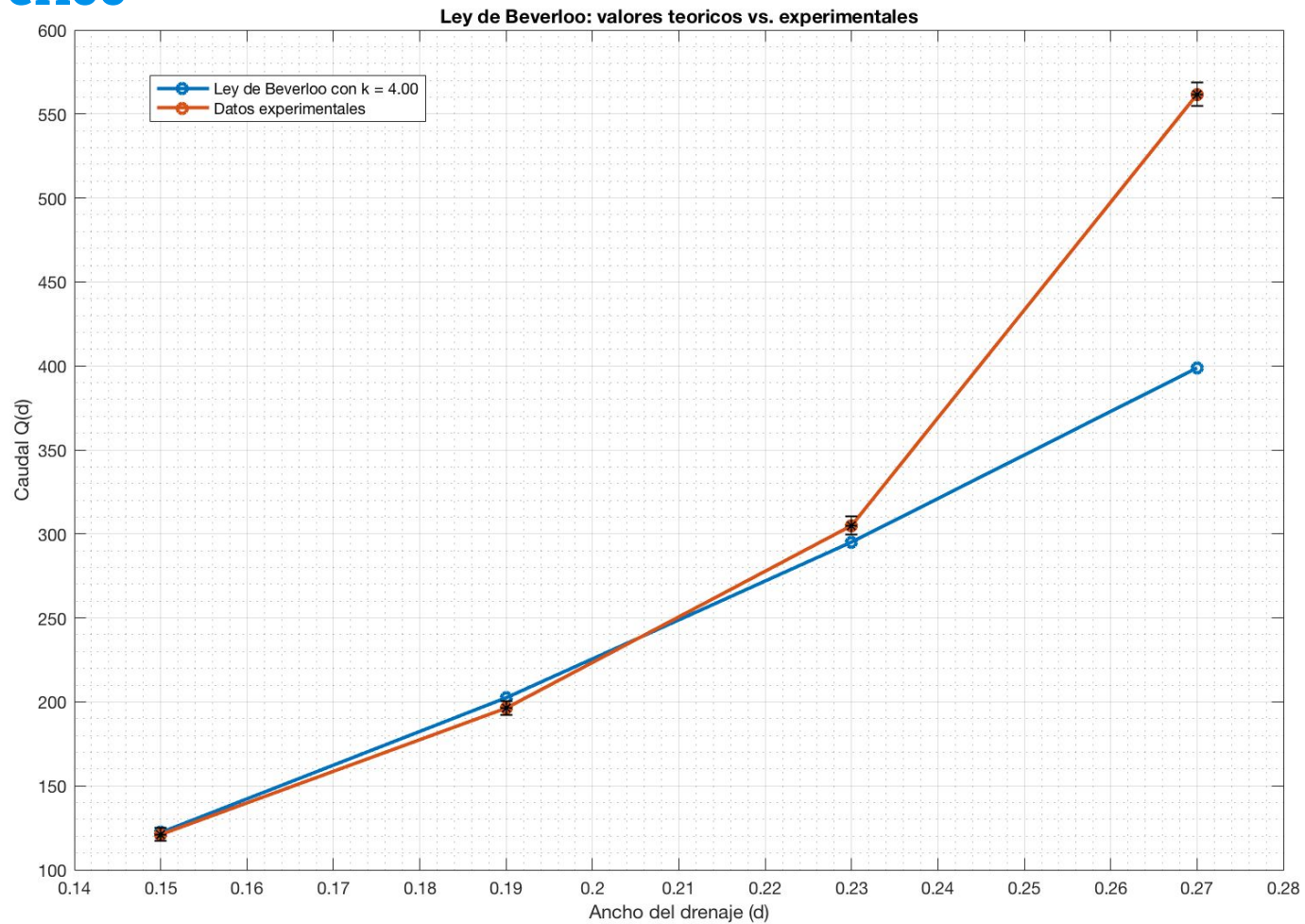
Ley de Beverloo

(Estimación del Caudal)

$$g = 9.8196 \frac{m}{s^2} \quad R_{min} = 0.010 \, m \quad m = 0.01 \, kg$$
$$R_{max} = 0.015 \, m$$

$$Q(d) = \frac{N}{WH} \sqrt{g \left(d - k \frac{R_{min} + R_{max}}{2} \right)^3}$$

Ley de Beverloo



A decorative network diagram in the top-left corner of the slide. It features a complex web of interconnected nodes and edges. The nodes are represented by small circles, some of which are solid blue, some are solid grey, and some are hollow with a blue outline. The edges are thin grey lines connecting the nodes. The overall structure is dense and organic, resembling a molecular or biological network.

Conclusiones

Conclusiones

- El tiempo de relajación se determina a través de la **energía cinética**.
- El sistema disipa más energía a mayor **damping** y a mayor constante **elástica tangencial** (mayor fricción).
- En general, la energía cinética del sistema se mantiene alrededor de un valor fijo (luego de la caída inicial).
- La ley de Beverloo estima correctamente el caudal, siendo k dependiente de la forma* de los granos.

**(según Mankoc et. al., “The flow rate of granular materials through an orifice”)*

The background of the slide is a light gray network pattern. It consists of numerous small circles, some of which are solid gray and others are hollow with a gray outline. These circles are interconnected by thin, light gray lines, creating a complex, web-like structure that fills the entire background.

Gracias!

Grupo 5: Golmar & Lobo