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EXPERIMENTS IN FLOW OF FLUIDS IN UNSTEADY STATE

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ABSTRACT

The authors are professors of Chemical Engineering in the Faculty of Chemistry at the Universidad Nacional Autónoma de México (UNAM) and work in the so called Laboratory of Unit Operations. In this laboratory the students of the Chemical Engineering take practical courses in which they apply what they have learn in the theoretical courses. The experimental teaching is very important in the significant learning of the students of engineering. It foments the interactivity and the participation of the students, propitiating that they acquire knowledge, dexterities, habits and attitudes. In this work an experiment of flow of fluids is presented by means of which the students could acquire the significant learning when facing a classic experiment. Among the practical exercises with apparatus and equipments, the authors are interested in the field of unsteady state in fluid flow. This kind of flow is present, for example in the discharge of tanks. In this article we present some experiments that the students perform and which can be controlled automatically and related to the theoretical models.

KEYWORDS: Experimentation, Unsteady State, Flow of Fluids, Control

INTRODUCTION

Flow of Fluid in Transient State

The flow of fluid at the transient state can be found in the phenomenon of the unloading of tanks. We can take for example, a tank like the one that appears next, which has an orifice in its part inferior by which the water escapes.

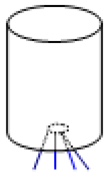

Figure 1

Another experiment more complicated is the unloading of a tank that has a pipe in its base.

Unloading of a Tank that has a Pipe in its Base

The system that is analyzed is the following one:

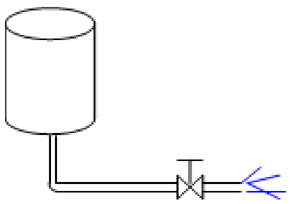

Figure 2

The tank unloads the liquid to the atmosphere.

For this case the matter balance would give:

$$u_T = -\frac{A_T}{A_o}\frac{dH}{d\theta} \tag{1}$$

Being u_T the speed of the water coming out of the pipe, A_T the cross-sectional area of the tank and A_o the cross-sectional area of the unloading pipe. The energy balance would be for this case the following one, considering that there is potential energy, kinetic, of present pressure and friction:

$$\Delta Hg + \frac{\Delta u^2}{2} + \frac{\Delta P}{\rho} = -\frac{\sum F}{M}$$

Making the simplifications pertinent we have left that:

$$-H\,g + \frac{u_T^2}{2} = -f_D\frac{u_T^2 Le}{2D} \tag{2}$$

Where u_T is the average speed in the unloading pipe, Le is the equivalent length of the unloading, D is the diameter of the unloading pipe and f_D is Darcy factor.

Making adjustments we will have:

$$\frac{u_T^2}{2}\left(1 + f_D\frac{Le}{D}\right) = Hg \tag{3}$$

Of where: $u_T = \sqrt{\frac{2H\,g}{1+K}}$ (4)

Being $K = f_D\frac{Le}{D}$ (5)

Uniting (1) with (4)

$$u_T = -\frac{A_T}{A_o}\frac{dH}{d\theta} = \sqrt{\frac{2H\,g}{1+K}} \tag{6}$$

Of where: $d\theta = -\frac{A_T}{Ao}\frac{dH}{\sqrt{\frac{2Hg}{1+K}}}$ (7)

$$d\theta = -\frac{A_T}{Ao\sqrt{\frac{2g}{1+K}}}H^{-\frac{1}{2}}dH \tag{8}$$

That upon integration gives us:

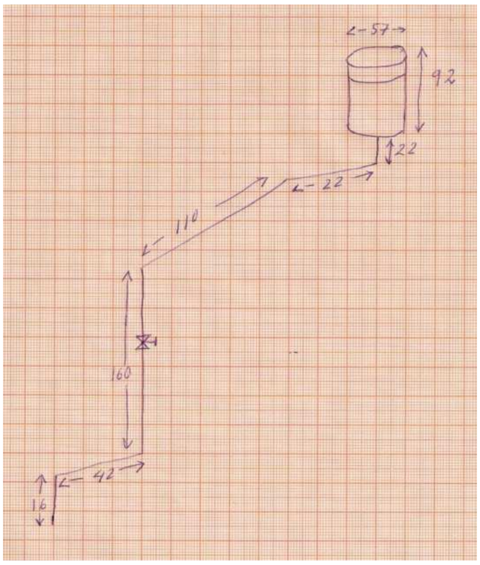

Figure 3

$$\int_0^{\theta} d\theta = -\frac{A_T}{A_o\sqrt{\frac{2g}{1+K}}}\int_{Hi}^{Hf} H^{-\frac{1}{2}} dH \quad (9)$$

$$\theta = \frac{2A_T}{A_o\sqrt{\frac{2g}{1+K}}}\left(\sqrt{H_i} - \sqrt{H_f}\right) \quad (10)$$

In a system similar to the following one, experiments of unloading of tanks took place. In a laboratory experiment it was let the water escape of a tank connected to a pipe obtaining the following data:

Table 1

Height Total Z in cm.	Time θ in Seconds	Total Height Z in cm.	Time θ in Seconds
273	0	235	146.7
271	7	233	154.2
269	14.57	231	162.3
267	22	229	170.8
265	29.7	227	180
263	36.9	225	188.8
261	44.7	223	197.4
259	52	221	208
257	60	219	217.2
255	67.7	217	227.6
253	75.3	215	237.7
251	83		
249	90.8		
247	99.3		
245	106.6		

Table 1: Contd.,

243	114		
241	122.3		
239	130.5		
237	138.6		

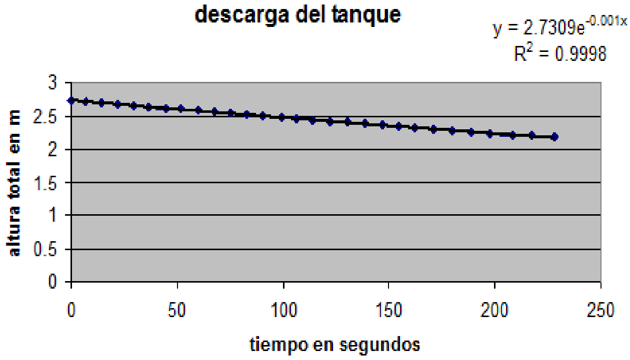

Figure 4

In the shown case, the length of straight tube is of 3,72 m, the equivalent length of the accessories is of 4,6 m. The diameter of the pipe is of 2,093 cm., reason why K = K = $f_D \frac{L}{D}$ =12.72. The area of the tank is of 0,255 m^2 and the cross-sectional area of the pipe is of 3,439 xs 10-4 m^2. Therefore the equation is for our equal case a:

$$\theta = 1240(\sqrt{Z_{A1}} - \sqrt{Z_{A2}}) \tag{11}$$

Applying the previous equation to the height data it is obtained that:

Table 2

Real Time in sec.	ZA m	Increment of Time	Total Calculated Time in sec.
0	2.73	0	0
7	2.71	7.51861708	7.51861708
14.57	2.69	7.54641262	15.0650297
22	2.67	7.57451873	22.6395484
29.7	2.65	7.60294124	30.2424897
36.7	2.63	7.63168613	37.8741758
44.7	2.61	7.66075953	45.5349353
52	2.59	7.69016776	53.2251031
60	2.57	7.7199173	60.9450204
67.7	2.55	7.75001478	68.6950352
75.3	2.53	7.78046706	76.4755022
83	2.51	7.81128115	84.2867834
90.8	2.49	7.84246428	92.1292477
99.3	2.47	7.87402388	100.003272
106.6	2.45	7.90596757	107.909239
114	2.43	7.93830322	115.847542
122.3	2.41	7.97103891	123.818581
130.5	2.39	8.00418295	131.822764
138.6	2.37	8.03774391	139.860508

Table 2: Contd.,

146.7	2.35	8.0717306	147.932239
154.2	2.33	8.10615209	156.038391
162.3	2.31	8.14101774	164.179409
170.8	2.29	8.17633719	172.355746
180	2.27	8.21212036	180.567866
188.8	2.25	8.24837749	188.816244
197.4	2.23	8.28511914	197.101363
208	2.21	8.32235619	205.423719
217.2	2.19	8.36009989	213.783819
227.6	2.17	8.39836181	222.182181

Which agrees rather well with the experimental data. The discrepancy in the last data must be due to the eddy appearance that alters the flow of fluid.

But what would happen if we use a cylindrical tank, in an horizontal position as the one presented in the following figure?

Experiment 2

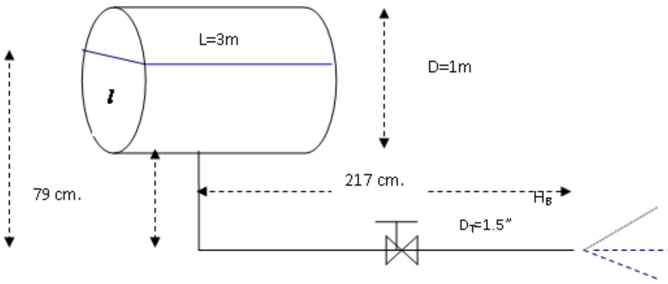

Figure 5

Performing an experiment in the above tank we found the following data:

Table 3

Liters	Time in Seconds	Height in cm.
100	0	164
200	38	158.5
300	75	153.5
400	116	149.2
500	158	145
600	195	141.3
700	234	137.7
800	271	134.5
900	309	131.2
1000	347	127.9
1100	389	124.5
1200	427	121.1
1300	468	117.4
1400	516	113.6
1500	556	110

Table 3: Contd.,

1600	596	106.3
1700	640	102.7
1800	685	98.8
1900	727	94.6
2000	771	90.1
2100	816	84.3

From the above table we constructed the following graphics:

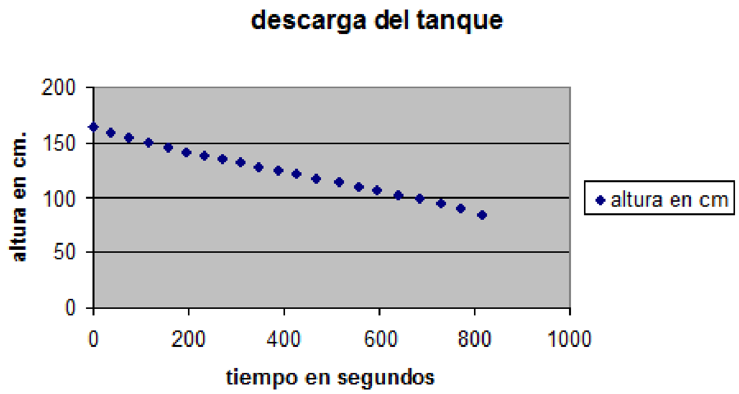

Figure 6

How to interpret these data?

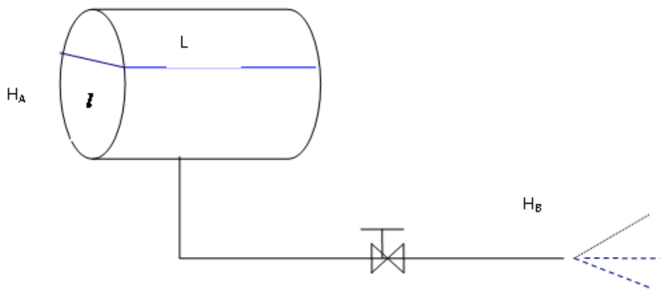

Figure 7

In this case the energy balance would give an equation like number 4

$$u_B = \sqrt{\frac{H_A 2g}{\left(1 + \frac{f_D Le}{D}\right)}}$$

And the material balance would give:

$$C_A = A_A\left(\frac{-dH}{d\theta}\right) = A_B u_B \qquad (12)$$

If we make 1 equal to 4 we would obtain:

$$A_A\left(\frac{-dH_A}{d\theta}\right)=A_B\sqrt{\frac{H_A 2g}{\left(1+\frac{f_D Le}{D}\right)}} \tag{13}$$

But in this case the A_A area varies with the height H. Since: $A_A = l \times L$

l is the cord and L is the length of the cylinder.

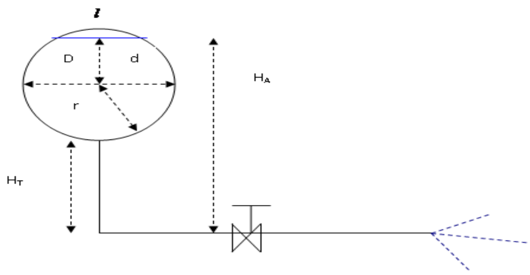

Figure 8

$$l = 2\sqrt{r^2 - d^2} \tag{14}$$

d = height of liquid above the tank diameter $H_A - H_T - r$ (15)

Thus uniting with 5 6 and 7 then:

$$L\times 2\sqrt{r^2-[H_A-(H_T+r)]^2}\left(\frac{-dH_A}{d\theta}\right)=A_B\sqrt{\frac{2gH_A}{1+\frac{f_D Le}{D}}}$$

And:

$$d\theta = -\frac{L\times 2\sqrt{r^2-[H_A-(H_T+r)]^2}}{A_B}\sqrt{\frac{1+\frac{f_D Le}{D}}{2g}}H_A^{-\frac{1}{2}}dH_A \tag{16}$$

Which is not easy to integrate. However, equation (16) can be set as:

$$\Delta\theta = -K\sqrt{r^2-[H_A-(H_T+r)]^2}H_A^{-\frac{1}{2}}\Delta H_A \tag{17}$$

$$K= \frac{L\times 2}{A_B}\sqrt{\frac{1+\frac{f_D Le}{D}}{2g}} \tag{18}$$

Note that to find the download time we must integrate from r +2 HT which is the original Ha until the Ha final which is just HT. Therefore to obtain partial discharge times we have to integrate (numerically) from the fractions of the original height (HT +2r).

In the case at hand:

System equivalent length Le = 9.26 m

Diameter of discharge pipe 1.5 inches, Cd 40 = 0.04089 m.

The pipe roughness $\frac{\varepsilon}{D} = 0.0015$

Friction factor at full turbulence $f_D = 0.023$

Tank length L = 3m

Discharge pipe area AB = 0.0013125 m2.

Therefore K = 2572

And the equation (10) for our system is:

$$\Delta\theta = -2572\sqrt{r^2 - [H_A - (H_T + r)]^2}\, H_A^{-\frac{1}{2}} \Delta H_A \quad (19)$$

With the above equation can be calculated the increments of time, depending on the height.

Table 4

Height in cm.	T Real Time	Increment of H	Increment of Time	Calculated Time
164	0			
158.5	38	-0.055	42.564832	42.56
153.5	75	-0.05	43.3299263	85.8947583
149.2	116	-0.043	40.2082381	126.102996
145	158	-0.042	41.5128754	167.615872
141.3	195	-0.037	38.1434457	205.759317
137.7	234	-0.036	38.3232733	244.082591
134.5	271	-0.032	34.9171332	278.999724
131.2	309	-0.033	36.7098687	315.709593
127.9	347	-0.033	37.2829204	352.992513
124.5	389	-0.034	38.8604803	391.852993
121.1	427	-0.034	39.1521766	431.00517
117.4	468	-0.037	42.7361497	473.74132
113.6	516	-0.038	43.7821277	517.523447
110	556	-0.036	41.1125223	558.63597
106.3	596	-0.037	41.5861421	600.222112
102.7	640	-0.036	39.4787639	639.700876
98.8	685	-0.039	41.2272956	680.928171
94.6	727	-0.042	41.9269788	722.85515
90.1	771	-0.045	40.9628292	763.817979
84.3	816	-0.058	43.8297489	807.647728

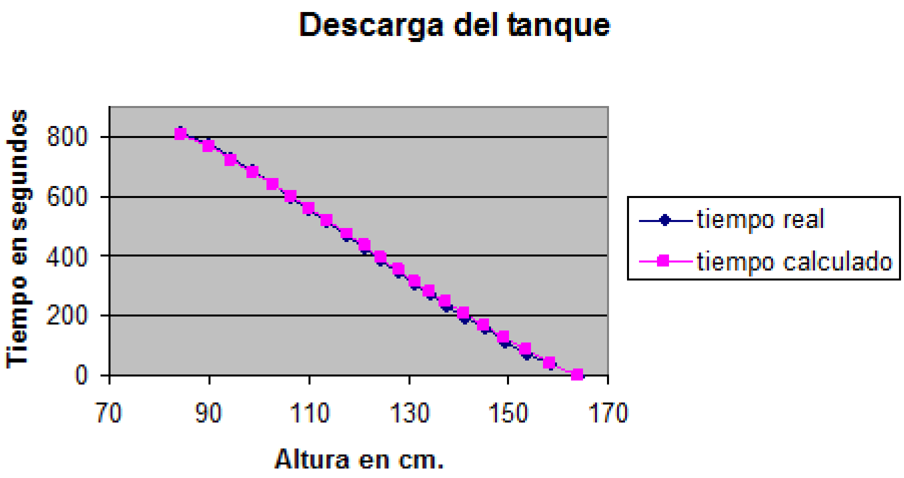

Figure 9

Those experiments could be controlled and monitored by means of new control devises provided by the company Emerson.

CONCLUSIONS OR RESULTS

The experiments were performed with simple equipment that could be monitored by means of control devises as level and flow control, provided by a company. The data were plotted in a computer. After these, the students had to predict the behavior observed in the experiments by means of their knowledge in flow of fluids. They developed the appropriated equations for each case, and later compared the predicted with the experimental data. They found a very good agreement, between the theory and the experiments.

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