ENE 310 ENGINEERING LABORATORY – I

HYDROSTATIC BENCH

The ***Hydrostatic Bench*** enables the study of the main properties and the behavior of such liquids under hydrostatic conditions, with the aid of some accessories to make the different experiments.

Equipment Description

The equipment consists of a metallic structure assembled on wheels with a panel at the top. In the lower part of the bench there is a tank where water is stored. Water is then sent to a methacrylate tank placed at the upper part of the bench and to other plastic deposit. Two hand-operated pumps are used for such distribution. The methacrylate tank is connected to two communicating tubes on the front panel, enabling to perform some practices; the other deposit placed on the horizontal surface of the bench is necessary for performing the rest of the practices. All water in excess is sent back to the storage tank by the drain. The rest of the equipment consists of the following different elements and independent accessories:

- Barometer (10)
- Thermometer (3)
- Ubbelohde capillary viscosimeter, 0.6-3 cp (0c)
- Ubbelohde capillary viscosimeter, 2-10 cp (I)
- Ubbelohde capillary viscosimeter, 10-50 cp (Ia)
- Ubbelohde capillary viscosimeter, 60-300 cp (IIc)
- 3 graduated cylinders
- Accessory for demonstration of free surface in static conditions (7)
- Bourdon manometers calibration (13)
- Mercury manometers (9)
- Accessory to determine the metacentric height (FME11)
- Accessory for studying Archimedes´ principle
- Accessory for studying the hydrostatic pressure (FME08) (14)
- Fluid level gauge calibrator (16)
- Set of weights (5, 10, 20, 50, 100, 400, 1000, 2000, 5000 gr.)
- Air pump
- 2 water pumps (11 and 12)

- Universal hydrometer (1)
- Chronometer
- Set of measurement cylinders (2 of 600 ml) (4)
- Spare parts for the viscosimeter elements

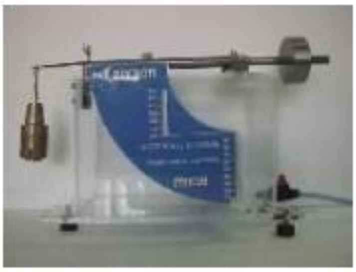


Figure 2.0.1. Main parts of the Hydraulic Bench

Experiment – 1

Density and Specific Gravity Measurements

Theory

The density of a substance is defined as the mass of such substance in relation with the volume that it occupies, and it is called "ρ".

$$\rho = \frac{mass\ of\ liquid}{volume\ occupied} = \frac{M}{L^3}$$

We must have into account that the density of a liquid is practically constant, since the volume occupied by a given mass of a liquid is almost invariable. But in the case of gases, the density varies in accordance with the volume occupied (for a mass of such a gas). As a result of that, a liquid can be considered virtually incompressible (except when it is working in critical conditions), while gasses are compressible.

The specific gravity or relative density of a fluid is defined as the ratio between its mass and the mass of the same volume of water at 4ºC, and “S” represents it.

$$S = \frac{given\ mass\ of\ the\ liquid}{mass\ of\ water\ (same\ volume)}$$

If V is the volume of a liquid and V_w the volume of water, ρ_l is the density of the liquid and ρ_a□□is the density of water, then:

$$S = \frac{\rho_1 . V}{\rho_w . V} = \frac{\rho_1}{\rho_w}$$

- **Hydrometer**

The two previous properties can be studied using the hydrometer placed in the left hand end of the front panel.

The operation of the hydrometer is based on Archimedes´ principle, which consists in that, when a body is submerged into a liquid, it becomes subject to a vertical force equal to the weight of the liquid that the body displaces.

Thus, a simple hydrometer can consist of a glass tube, closed by an end having a scale within. A small amount of lead, sand or mercury is placed at the bottom for preventing flotation.

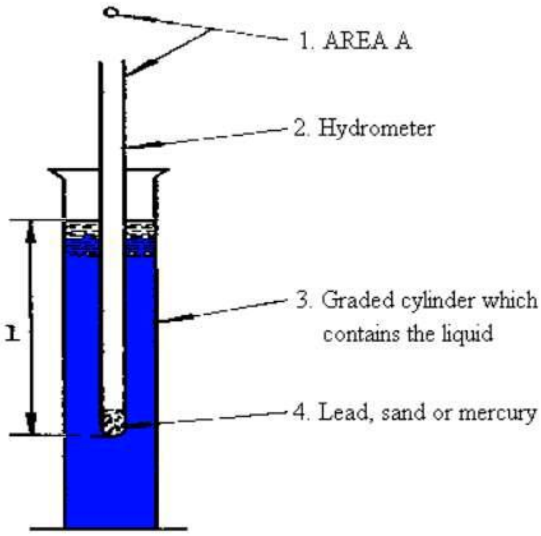


Figure 1. Scheme of a simple hydrometer

First, the tube must be submerged in water, and the scale marked in the submerged part. Then, the operation is repeated by submerging the tube in another liquid, and the submerged length is marked again

If L_w = submerged length in water of density ρ_w

If L_l = submerged length in a liquid of density ρ_l □

then, the weigh of water displaced is equal to ρ_w □□□ $\boldsymbol{g . A . L_w}$ and the weigh of the liquid displaced is equal to ρ_l $\boldsymbol{. g . A . L_1}$

By applying Archimedes´ principle, we shall get:

$$\rho_w g A L_w = \rho_1 g A L_1$$

And so,

$$S = \frac{\rho_1}{\rho_w} = \frac{L_w}{L_1} = \frac{length\ submerged\ in\ water}{length\ submrged\ in\ the\ liquid}$$

The immersion depth in water was marked in the paper scale as 1.00 and the liquid passed L_w/L_1.

<u>Aim of this Experiment</u>

To determine density and specific gravity.

<u>Necessary devices</u>

Universal hydrometer.

Open precipitate tubes or cylinder

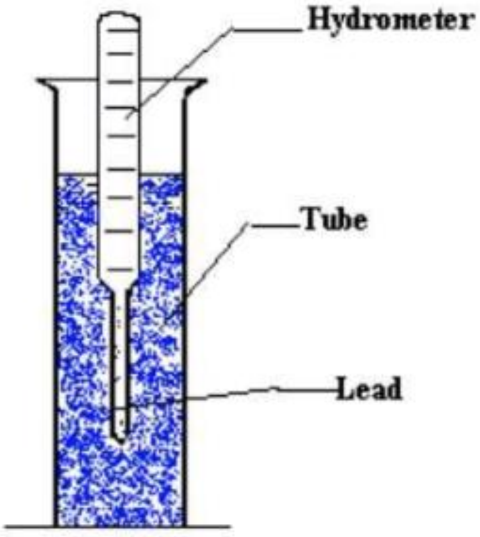


Figure 2. Schematic representation of density and dpecific gravity measurement set-up

Procedure

1. Fill the precipitate tube or cylinder with water in such a way that the hydrometer floats. Check that the submerged length corresponds to 1.00 in the graduated scale.

2. Fill the other three cylinders with the liquids to work with, and note down the scale mark for each one. This value in the scale indicates the specific gravity.

3. Note down the results obtained in the following graph, taking into account the values of the atmospheric pressure and temperature in the moment of performing the practice.

Pressure .... mm Hg

Temperature .... º C

Sample Test Results

Liquid	Specific gravity	Density
Water		
Glycerine		
Motor oil		
Oil		

Experiment -2.1

Viscosity measurement with Ubbelohde viscometer

Theory

The viscosity of a liquid is defined as the grade or measure in which a fluid opposes the changes of shape when an external force is applied on it. Viscosity depends on molecular cohesion and the activity of the fluid. The gas viscosity, where cohesion of the atoms is low, increases when temperature rises. In liquids, due to the fact that molecular cohesion is higher than their activity (mainly at low temperature), viscosity decreases when temperature rises.

In order to obtain a measure of viscosity, it is necessary to consider the viscous flow of a liquid; for this purpose, two considerations have to be taken into account:

1. Maybe there is not a sliding or relative movement.

2. Maybe the applied effort is directly proportional to the movement.

In the first case, we have that, in a fluid that is at rest, by definition, there are not shearing stresses between the fluid and the solid in contact with it, neither between the adjacent layers of the fluid itself. Nevertheless, when the fluid is in movement, different speeds appear between the outer faces and the inner faces of the fluid, causing forces that exert a friction. If one of the body faces moves with a speed *u* and the other does it with a speed *u+du*, then the ratio of the force applied to the movement or the speed gradient equals to *du/dy*.

In the second case, the effort applied is proportional to *du/dy*, that is, τ=□η□.du/dy, where η is a proportionality coefficient called viscosity coefficient.

- **Viscosity measurement**

The measurement of flux velocity through a capillary tube of known radius allow us obtain the viscosity □ for a liquid or solid, using the equations:

$$\frac{V}{t} = \frac{\pi r^4}{8\eta}\frac{P_1 - P_2}{y_1 - y_2} \qquad \textit{liquid laminar flow} \qquad (1)$$

$$\frac{dn}{dt} = \frac{\pi r^4}{16\eta RT}\frac{P_1^2 - P_2^2}{y_1 - y_2} \qquad \textit{ideal gas laminar flow} \quad (2)$$

where V is liquid volume that cross a transversal section of the tube in t time and □ P_2 □ P_1)/ (y_2 □ y_1) is the pressure gradient along the tube (P_1 pressure at point y_1 and P_2 pressure at point y_2, therefore y_2-y_1 is tube longitude), η viscosity, R ideal gas constant, r tube radius, T temperature in K, dn/dt flux velocity in moles per time unit.

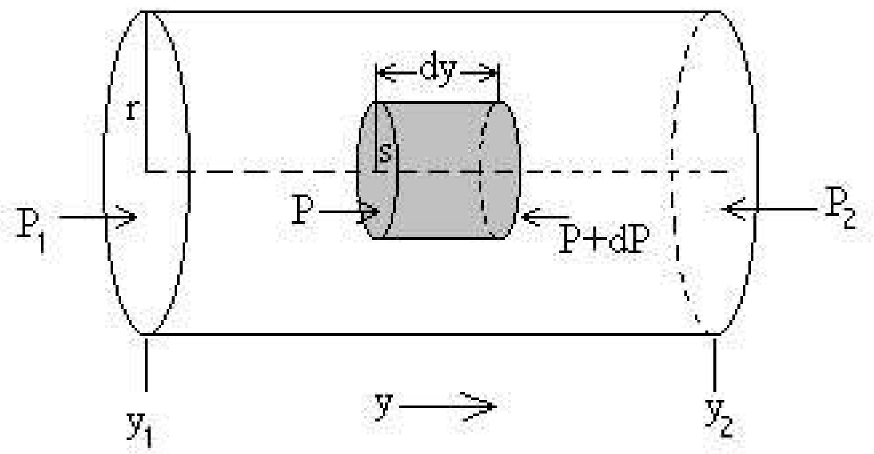


Figure 3. Fluid moving in a cylindrical tube. The shadowed section is used to probe the Poiseuile´s law.

A convenient method for viscosity determination of a liquid is using **Ostwald viscosimeter**, a capillary tube joined to a lower bulb L and an upper bulb A, as you can see in next figure forms it.

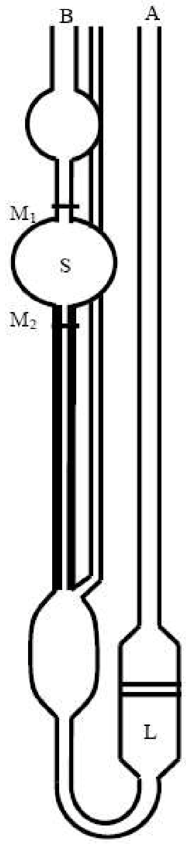


Figure 4. Ostwald viscometer. Is measured the time that use the liquid going from level M2 to M1.

First, lower bulb L is filled with sample solution, getting it into the viscometer through A. Liquid is sucked through branch B until liquid level goes up upper bulb, taking care of avoiding the formation of air bubbles.

It is measured the time t that a liquid delay on passing from mark M1 to mark M2 in liquid level, while the liquid flows through the capillary tube.

Then the viscometer is filled with a liquid of knowing viscosity, using the same volume, and again is measured t. Pressure exercised by liquid through the tube is ρgh (where ρ is liquid density, g gravity acceleration and h the difference between the arms of the viscometer). ρgh substitute P_1-P_2 Poiseuille´s law (Equation 1). Because h change in time, flux velocity change and it should be written like:

$$\frac{dV}{dt} = \frac{\pi r^4}{8\eta}\rho g h(y_2 - y_1)$$

Consider h_0 as the level difference when t=0 and the liquid level in left arm is in mark A. Since in all experiment is used the same liquid volume, h_0 is constant. h variation from its initial valour h_0 is function of the volume V that has fluxed through the viscosimeter: h-h0=f(V), where f function depends on the viscosimeter geometry. We have:

$$[h_o + f(V)]^{-1}dV = \left[\frac{\pi r^4 \rho g}{8\eta(y_2 - y_1)}\right]dt$$

$$\int_0^V \frac{1}{h_o + f(V)}dV = \frac{\pi r^4 g}{8(y_2 - y_1)}\frac{\rho}{\eta}t$$

where V’ is the volume that flux in t time when the liquid level goes from A to B. Since V’ and f(V) are the same in all the experiments made on the same viscosimeter, the previous volume integral is constant, therefore ρt/η is constant in all experiments. If we consider two different liquids a and b, we have,

$$\frac{\rho_a}{\eta_a}t_a = \frac{\rho_b}{\eta_b}t_b$$

regrouping

$$\boldsymbol{\frac{\eta_b}{\eta_a} = \frac{\rho_b}{\rho_a}\frac{t_b}{t_a}}$$

If we know η_a, ρ_a and ρ_b, we can find η_b.

Aim of this Experiment

Determine the viscosity of different liquids at atmospheric pressure and environmental temperature.

Necessary devices

- Ubbelohde capillary viscosimeter, 0.6-3 cp
- Ubbelohde capillary viscosimeter, 2-10 cp
- Ubbelohde capillary viscosimeter, 10-50 cp
- Ubbelohde capillary viscosimeter, 60-300 cp
- Chronometer
- Hydrometer
- Thermometer

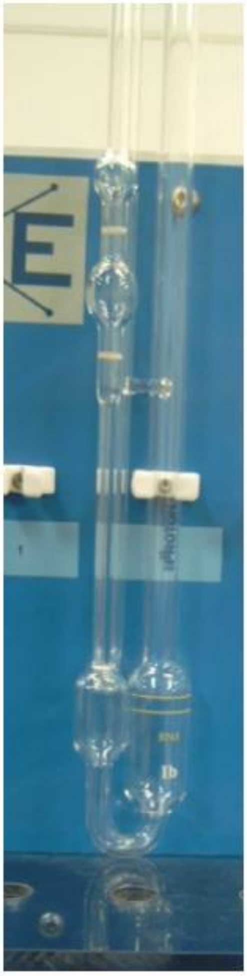


Figure 2. Viscosimeter provided with the equipment

Procedure

The liquids to be studied are:

- Car Motor oil

- Glycerol
- Castor oil

1. Find in tables four liquids of known viscosity, each one inside the measurement range of each viscosimeter.
2. Fill each Ubbelhode capillary viscosimeter, with the same volume of liquid of known viscosity and density, and write down the time used by the liquid of going down the viscosimeter.
3. Make four problem samples aliquots, with the same volume as used with known viscosity solutions. Measure their falling time in each viscosimeter. In some cases the liquid will fall too fast to take any measurement, and in others it will probably spend too much time. Avoid these liquids.

4. Write down the existing atmospheric pressure and temperature in that moment in the laboratory. With the aid of the data and expressions given hereafter, complete the following table:

Barometric Pressure .... mm Hg

Temperature .... º C

Car Motor oil density (depending on the manufacturer) ....g/cm³

Glycol density 1.25 g/cm³

Castor oil density 0.95 g / cm³

5. Write down in next table the values obtained with solutions of known viscosity and density.

Liquid	Viscosity (cP=10^{-2}g/cm·s)	Density (g/cm³)	Time (s)
A (range 0.6-3 cp)			
B (range 2-10 cp)			
C (range 10-50 cp)			
D (range 60-300 cp)			

6. Now, repeat again the experience, with the problem samples, and fill next table with the obtained values, using previous obtained data and equations.

Liquid	Time (s)	Density (g/cm^3)	Viscosity (cP=10^{-2}g/cm·s)
Motor car oil			
Glycerol			
Castor oil			

Experiment -2.2

Viscosity measurement with falling body method

Falling Sphere Method

The falling sphere viscometer is one of the earliest and least involved methods to determine the absolute shear viscosity of a Newtonian fluid. In this method, a sphere is allowed to fall freely a measured distance through a viscous liquid medium and its velocity is determined. The viscous drag of the falling sphere results in the creation of a restraining force, F, described by Stokes' law:

$$F = 6\pi\eta r_s U_t$$

where rs is the radius of the sphere and Ut is the terminal velocity of the falling body. If a sphere of density ρ_2 is falling through a fluid of density ρ_1 in a container of infinite extent, then by balancing the below equation with the net force of gravity and buoyancy exerted on a solid sphere, the resulting equation of absolute viscosity is:

$$\eta = 2gr_s^2\frac{(\rho_2 - \rho_1)}{9U_t}$$

The above equation shows the relation between the viscosity of a fluid and the terminal velocity of a sphere falling within it. Having a finite container volume necessitates the modification of this equation to correct for effects on the velocity of the sphere due to its interaction with container walls (W) and ends (E). Considering a cylindrical container of radius r and height H, the corrected form of given equation can be written as:

$$\eta = 2gr_s^2\frac{(\rho_2-\rho_1)W}{(9U_tE)}$$

$$W = 1 - 2.104\left(\frac{r_s}{r}\right) + 2.09\left(\frac{r_s}{r}\right)^3 - 0.95\left(\frac{r_s}{r}\right)^5$$

$$E = 1 + 3.3\left(\frac{r_s}{H}\right)$$

The wall correction was empirically derived and is valid for 0.16 ≤ rs/r ≤ 0.32. Beyond this range, the effects of container walls significantly impair the terminal velocity of the sphere, thus giving rise to a false high viscosity value. The following figüre contains a schematic diagram of the falling sphere method and demonstrates the attraction of this method — its simplicity of design. The simplest and most cost-effective approach in applying this method to transparent liquids would be to use a sufficiently large graduated cylinder filled with the liquid. With a distance marked on the cylinder near the axial and radial center (the region least influenced by the container walls and ends), a sphere (such as a ball bearing or a material that is nonreactive with the liquid) with a known density and sized to within the bounds of the container correction, free falls the length of the cylinder. As the sphere passes through the marked region of length d at its terminal velocity, a measure of the time taken to traverse this distance allows the velocity of the sphere to be calculated. Having measured all the parameters of the corrected equation, the shear viscosity of the liquid can be determined. This method is useful for liquids with viscosities between 10–3 Pa·s and 105 Pa·s. Due to the simplicity of design, the falling sphere method is particularly well suited to high pressure–high temperature viscosity studies.

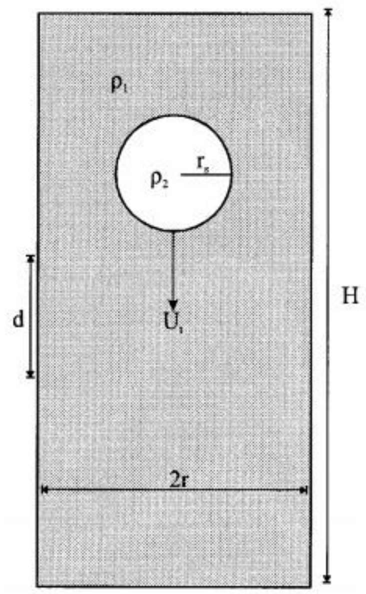


Figure: A schematic demonstration of falling sphere viscometer.

Experiment -4

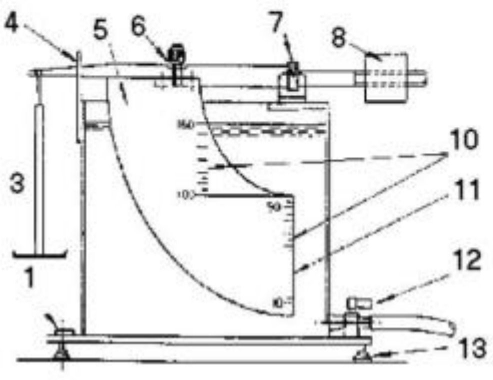
Pressure center in a smooth surface

Aim of this Experiment

To determine the position of the pressure center on the rectangular face of the float

Necessary devices

Hydrostatic Pressure device or hydrostatic device.



1..-Receiver
3.- Pan
4.- Balance indicator or pointer
5.- Quadrant
6.- Set screw
7.- Arm
8.- Support;
9.- Adjustable counterweight
10.-Graduated scale
11.-Font flat surface
12.-Cock
13.- support feet

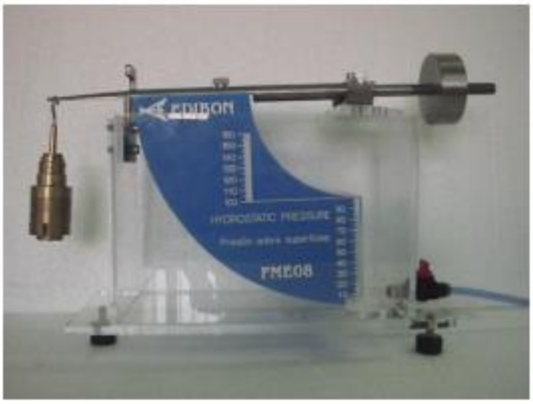


Figure 5. Hydrostatic Pressure device or hydrostatic device

Procedure

1. Measure and note down the dimensions designed as a, L, d, and b; the last corresponding to the flat surface placed at the end of the quadrant.
2. With the receiver placed on the bench, place the balance arm on the support (sharp profile). Hang the pan at the end of the arm.
3. Connect a length of flexible hose to the receiver draining cock and connect the other end to drain.
4. Level the receiver by properly acting on the support feet, which is adjustable, while the "bubble level" is observed.
5. Displace the counterweight of the arm until getting the arm to be horizontal.

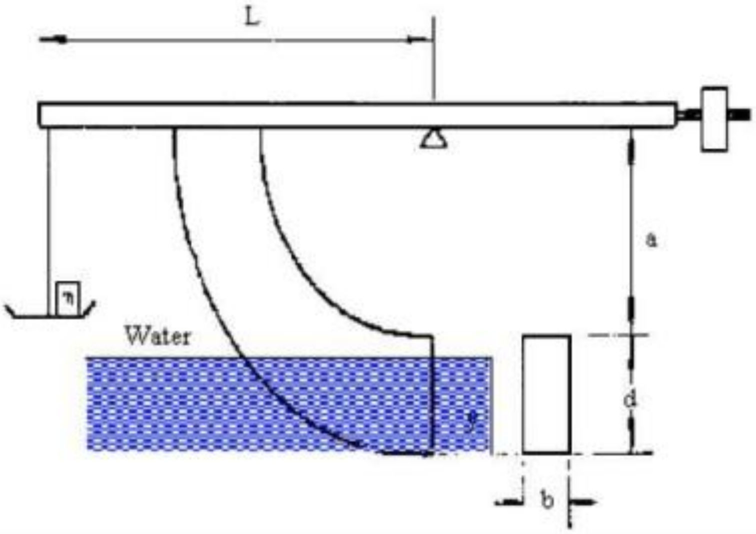
6. Close the drain cock in the bottom of the receiver.

7. Introduce water in the receiver until its free surface is tangent to the lower edge of the quadrant. The fine adjustment of that level can be achieved by slightly overreaching the established filling and then slowly draining through the cock.

8. Place a calibrated weight on the balance pan and slowly add water until the balance arm recovers the horizontal position. Record the water level, indicated in the quadrant, and the value of the weight placed on the pan.

9. Repeat the operation above several times, increasing progressively the weight in the pan until, the balance arm is at level, the level of the free water surface becomes flush with the upper edge of the flat rectangular surface that the end of the quadrant presents.

10. From this point on, and in the order inverse to the operation above of placing the weights on the pan, the weight increments given in each step are removed, the arm is leveled (after every removal) by using the drain cock and the weight in the pan and the water level values are recorded.



For $y < d$ (partial immersion), calculate the practical ant the theoretical value of m/y^2 using the equation:

$m/y^2 = \rho.b/2L\ (a+d-y/3)$.

The slope of this graph must be $-\rho.b/2L$, and its intersection with the coordinate axis $\rho.b\ (a+d)/2L$.

See the discrepancies in a reasoned way, if any, between the average values measured and the values obtained with the equations above

Weight	Height (y)	y/3	m/y²

Appendix – I Useful Data

Table 1. Table of the atmospheric pressure in function of the height

HEIGHT (m)	LEVEL OF THE VARIABLE	HEIGHT (m)	LEVEL OF THE VARIABLE	HEIGHT (m)	LEVEL OF THE VARIABLE
0	760	680	700.8	1360	645.2
20	758.2	700	698.9	1380	643.6
40	756.4	720	697.3	1400	642
60	754.6	740	695.5	1420	640.4
80	752.9	760	693.9	1440	638.8
100	751	780	692.4	1460	637.2
120	749.2	800	690.7	1480	635.6
140	747.4	820	689	1500	634
160	745.7	840	687.2	1520	632.5
180	744	860	685.5	1540	630.9
200	742.1	880	683.9	1560	629.4
220	740.2	900	682.4	1580	627.9
240	738.4	920	680.7	1600	626.4
260	736.8	940	679	1620	624.9
280	735	960	677.2	1640	623.3
300	733.4	980	675.6	1660	621.8
320	731.8	1000	674	1680	620.3
340	730	1020	672.4	1700	618.8
360	728.3	1040	670.8	1720	617.3
380	726.5	1060	669.1	1740	615.7
400	724.7	1080	667.5	1760	614.2
420	723	1100	666	1780	612.7
440	721.3	1120	664.3	1800	611.2
460	719.5	1140	662.6	1820	609.7
480	717.7	1160	661	1840	608.2
500	716	1180	659.3	1860	606.6
520	714.2	1200	657.9	1880	605.2
540	712.5	1220	656.4	1900	603.6
560	710.9	1240	654.8	1920	602.1
580	709.3	1260	653.2	1940	600.6
600	707.5	1280	651.6	1960	599
620	705.8	1300	650	1980	597.5
640	704.1	1320	648.3	2000	596
660	702.5	1340	646.7		