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Design, research and development of surface tension equipment with teaching purpose

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ABSTRACT

The importance of the experimental study of surface phenomena is not sufficiently reflected through the experiments carried out in teaching laboratories. The possibility of having cheaper equipment would be of great value for science and applied technologies students. The main objective of this project is the design of a piece of equipment measure the surface tension of liquids for teaching purposes, using the Du Noüy ring technique. Data acquisition will be based on the loading cell and HX711 module. Measurement tests of three different liquids are taken: water, olive oil and fuel. Then, a budget will be made, a basic comparison with the Krüss K20 equipment, and finally the conclusions. Necessary studies have been done to verify the design. Regarding the manufacture of some of the designed components, the tool used was UltiMaker Cura, where the characteristics of the parts were programmed for the 3D printing. Electronic components chosen to carry out the automation of the equipment; an Arduino UNO board, a Nema 17 engine with EasyDriver controller and a Loading Cell with an HX711 amplifier for data acquisition. The system implementation is done through 3 different software. Loading cell calibration and equipment operation are programmed in Arduino IDE.

Keywords: Surface tension; Liquids; Cellular membrane; Load cell

1. Introduction

In this introduction we will first define the following concepts of surface tension, the Du Noüy ring method and the working principle of the Load Cell will be explained and strain gauges. Once these concepts have been described, we will proceed to detail in the "Design and manufacturing", firstly, the software used in this section, chosen materials and their properties. Then the tools used to manufacture the equipment will be shown.

Finally, this chapter will deal with the automation of the equipment, in this section. The software used will also be made known, the chosen components will be specified and assembly scheme of the same.

1.1. Surface tension definition

In physics the surface tension of a liquid is the amount of energy required to increase its surface per unit area, this leads to the liquid having a resistance to increase its surface. Property only available in liquids as they are the only ones in have a free surface. It is a tension force distributed along the surface of a liquid. This force per unit length is tangential to the surface and tends to reduce its expansion, your units in the System International are N/m [1].

1.2. Properties of surface tension

As explained previously, the molecules inside the liquid are attracted equally in all directions due to

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neighbouring molecules and therefore are in equilibrium. Without, the surface molecules are not in equilibrium as they are more attracted to the molecules interiors than by gases in the atmosphere or material that is in contact with the surface [1,2].

The main properties of surface tension are as follows:

- If any line is drawn on the surface of the liquid, the surface force normal to this line per unit length is the surface tension.

$$\sigma = \frac{\partial F}{\partial L}$$

- It depends on the nature of the two phases that are in contact, which will normally be liquid–solid or gas–solid.
- It depends on the intermolecular forces within the liquid, in this way when the greater the cohesion forces of the liquid, the higher its surface tension.
- The temperature decreases due to the increase in thermal agitation, thus causing a decrease in intermolecular forces.
- The value of the surface tension will tend to zero as the temperature approaches the critical temperature of the compound. At this point the liquid is indistinguishable from vapor and therefore both will form a continuous phase where there is no different surface between the two [3–5].

It is shown in Table 1 the surface tension of different well-known liquids.

1.3. Capillarity

Concept derived from surface tension, which can be defined as a property in by virtue of which the free surface of a liquid in contact with a solid rise or falls in the vicinity of it, depending on whether the liquid is wet or not. Its effects are especially apparent in the inside a capillary tube or between two very close sheets. When a liquid rises through a capillary tube, it is due to the force or cohesion intermolecular, between its molecules is less than the adhesion of the liquid with the tube material [6–8].

1.4. Wettability and contact angles

Wettability can be defined as the tendency of a fluid to adhere to the surface solid. It is determined from the angle formed when a drop is deposited on a surface flat, it spreads forming a certain angle which is known as the "contact angle". The value of the angle depends on the relationship between the adhesive forces between the liquid and the solid, and the cohesive forces of the liquid. As can be seen in Fig. 3, the angle is between the solid–liquid interface and the liquid–vapor interface, at the vertex of which are the three interfaces, called the triple point [9–11].

Table 1
Surface tension of liquids

Liquid	Surface tension (mN/m)
Water	72.8
Acetone	23.7
Benzene	28.9
Acetic acid	27.8
Glycerol	63.4
Ethanol	22.3
Olive oil	33.1

2. Materials and methods

Du Noüy ring method is based on measuring the surface tension from the force necessary to separate a ring from the surface of the liquid. For the measurement, the ring is first completely wet and then we proceed to lift it up to the start.

The material used in the ring is usually platinum, it must also be completely clean so that it lies flat on the liquid (contact angle 0) and must have the surface with the least possible roughness [12–15].

2.1. Load cell

A load cell or load cell is a transducer that converts the force applied on her into a measurable electrical signal. Despite the existence of several types of sensors, load cells they are the most common force sensor on the market [16–19].

2.2. Operating principle

Strain gauge load cells convert the load acting on them into signals electrical. The meters themselves (strain gages) are attached to a beam or element structural that deforms when applying a weight. When applying a weight, the tension changes the resistance meters in proportion to load [20–24].

2.3. Strain gauges

Strain gauges or strain gauges are used as force transducers or deformation, based on the piezoresistive effect.

2.4. Parameters of a gauge

On a practical level, is considered the point of measurement at the geometric centre of the gauge. It is assumed a homogeneous metal wire of length l and diameter d held between two points according to, resistance associated with this will be proportional to its length and inversely proportional to its section [25–30].

2.5. Design and manufacturing

2.5.1. Introduction to design and manufacturing

In the design and manufacturing chapter, first, the software will be released used for 3D modelling and conducting relevant studies and the software used to manufacture certain components using 3D printing.

2.5.2. Design and manufacturing software

In this chapter, a description of the equipment design made by means of the CAD software has been with the "Solidworks" program.

2.5.2.1. Solidworks

Is a 3D CAD design software The software offers a range of solutions to cover the aspects involved in the product development process. It allows to create, design, simulate, manufacture, publish and manage the data of the design process.

2.5.2.2. UltiMaker Cura

UltiMaker Cura is a free and open-source 3D printing software, where allows you to configure the printing parameters and then transform them into G code. Contains an integrated CAD plug-in workflow with software such as Solidworks.

2.5.3. Materials

2.5.3.1. Krion Solid surface

It is a solid surface It is a material that is warm to the touch and like natural stone, composed of two thirds of natural minerals, it is a 100% ecological material recyclable.

2.5.4. Tools

Anet A8 Plus, angle grinder, eccentric dander, circular saw, driver drill, sergeants, precision screwdriver, multimeter.

2.5.5. Solution adopted

The designed equipment consists of 3 threaded legs for levelling, a triangular base where the Nema 17 motor and the bracket are coupled with the rods, and the load cell bracket. Its basic operation is as follows, the stepper motor rotates the threaded rod which, depending on the direction of rotation of the motor, lowers or raises the load cell support (subgroup 3), said cell oversees taking the voltage values.

2.5.6. Components

Subgroup 1:

- Levelling feet
- Base
- Bubble level
- Screws

Subgroup 2:

- Nema 17 motor (stepper motor)
- Flexible coupling
- Support
- Threaded rod
- Non-threaded rods
- Bearing
- End of stroke supports
- Screws

Subgroup 3:

- Load cell support
- Load cell
- Bearings
- Threaded nut
- Hook and hook support
- Screws

2.5.7. Computational calculation

To carry out the static study, the most unfavourable point has been taken, being this at the maximum height, for this the load cell support will be placed 21 mm from the top of the support, because the position of the limit switch support assembly must be and it has been carried out with two different loads, first, a load with a value of 1 N will be taken, due to the fact that the loads of the surface tension with which it will be worked are around the interval 0.7–1 (N). Second, the study will be carried out in the worst possible situation being this at the same height but with a force of 49 N, this being the maximum supported by the load of 5 kg.

2.6. Automation

2.6.1. Introduction

The different sections to be dealt with in this chapter are in the first place the software to be used for automation and data acquisition.

2.6.1.1. Arduino software (IDE)

Is an open-source electronics creation platform, which is based on free hardware and software, and easy to use consisting of a board with a reprogrammable microcontroller and an IDE integrated development environment.

2.6.1.2. Processing

Processing is a simple, open-source, java-based programming environment that was created to facilitate the development of visually oriented applications, with an emphasis on animation and providing users with instant feedback through interaction.

2.6.1.3. Scilab

Scilab is free and open-source software for computing that provides a powerful computing environment for engineering applications and scientific.

2.6.2. Components

Stepper Motor (2.4 kg/cm), Nema 17, arduino UNO board, power supply, EasyDriver controller, Load Cell (5 kg) + HX711 amplifier, Mini limit switch, Protoboard, DuPont Cables.

2.6.3. Interface

To achieve the interaction of the Arduino through a computer, you must use the program previously named "Processing". For this, the sketch has been made, which will be shown in the Annex in the section corresponding

to the Processing Sketch. Once this sketch is executed, the interface will start graphical user (GUI).

2.6.4. Calibrated

Calibration is one of the most important factors to consider when making use of the load cell. First, the ring will be placed on the holder, then the sketch of Arduino "Calibration", which can be found in the Annex, section Sketch Arduino Calibration. Next, two known loads will be placed, and the reading data obtained by the HX711 module obtained for each weight.

2.6.5. Functioning

Once opened in the Processing console, the following messages will appear:

- Reading the ADC value
- Do not put any object on the scale
- Stressing
- Place a known weight

3. Results

3.1. Computational calculations

This section presents the results of the computational calculations obtained for the static test of the simplified assembly established in section 2.5.7, for this the static study will be carried out for the 1 N load and for the 49 N load. Next, the development of the hypotheses will be shown continue in this section of which the first three the program will execute by default:

- Von Mises tension
- Displacements
- Deformed
- Safety factor

3.2. Measurements

It should be noted that, for the measurements, it was not possible to have the standard ring due to its high cost, this being €826.00 (without taxes), so they have carried out one made of homemade form from a bronze tube and as a thread support method, this being another section essential when making a conclusion about the measurements. Below, it is shown in Fig. 1 the difference between the rings.

In Figs. 2–4 it is shown the contact angle of the ring in the maximum point of surface tension of them.

Fig. 5 presents the interpretation. Follow the measurements made about surface tension and number of data:

In Fig. 5, three red boxes are observed, they are the most important points to keep in mind. The sequence followed in each trial is as follows:

- First the ring is in the air and goes down until it enters the liquid.
- Second when the ring has been introduced into the liquid to the required depth, there is a change of direction of the motor, or what is the same, the ring begins to rise.
- Finally, the ring comes out of the liquid, breaking the limit of surface tension.

Firstly, the rings are in the air, until reaching the first red square of Fig. 5, where a stress peak is observed due to the adsorption of the ring by the liquid, subsequently suffering a drop in tension due to the thrust exerted by the liquid on the ring.

Fig. 1. Difference between the rings.

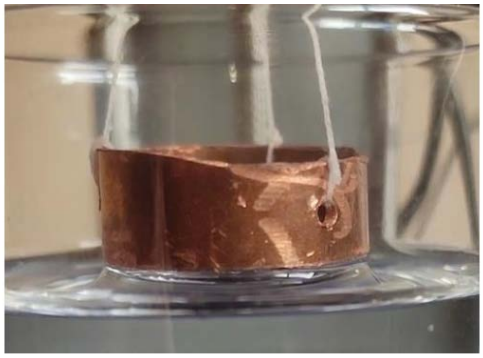

Fig. 2. Water contact angle.

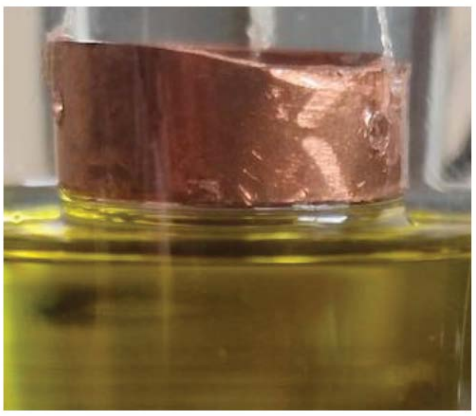

Fig. 3. Olive oil contact angle (AOVE).

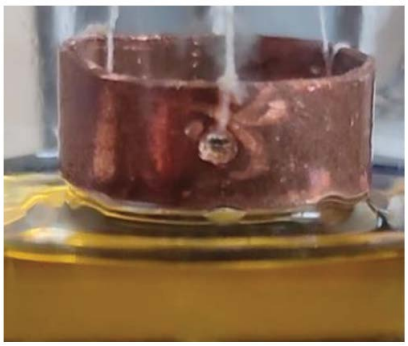

Fig. 4. Fuel contact angle.

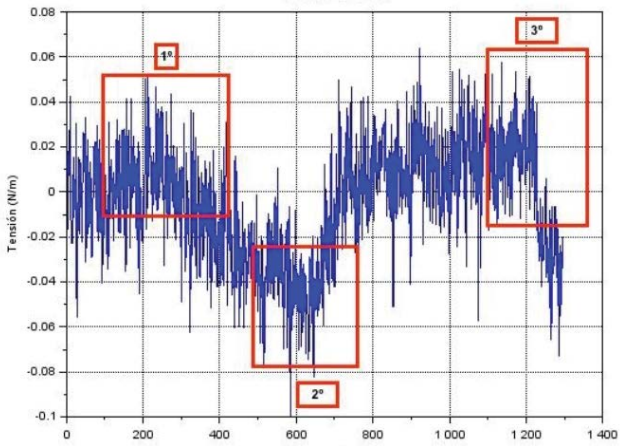

Fig. 5. Figure example.

As can be seen in the 2nd red box, there is another peak, but of opposite sign, this is due to the realization of the change of direction of rotation of the motor and therefore, of the ring (it begins to rise).

Finally, in the 3rd box, a abrupt change is observed that is due to the surface tension breakdown.

Next, two tests carried out for each of the three liquids will be shown in Figs. 6 and 7 (water measurements), in Figs. 8 and 9 (olive oil measurements) and Figs. 10 and 11 (fuel measurements):

Water measurements about surface tension and number of data:

- Test 1:
- Test 2:

Olive oil measurements about surface tension and number of data:

- Test 1:
- Test 2:

Fuel measurements about surface tension and number of data:

- Test 1:
- Test 2:

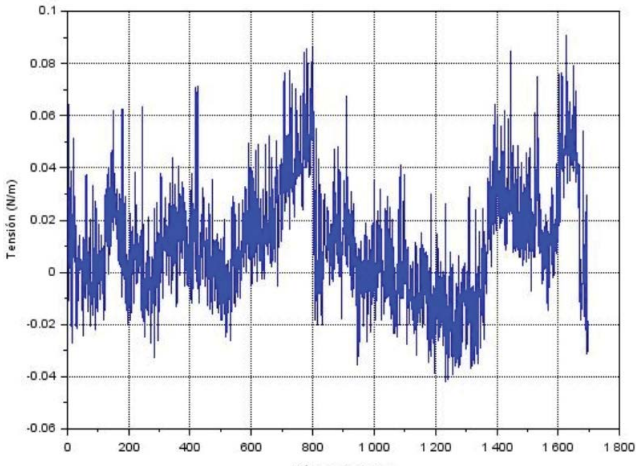

Fig. 6. Test 1 (water).

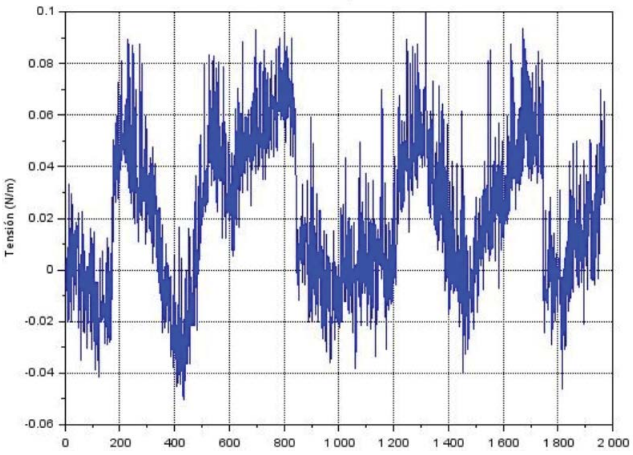

Fig. 7. Test 2 (water).

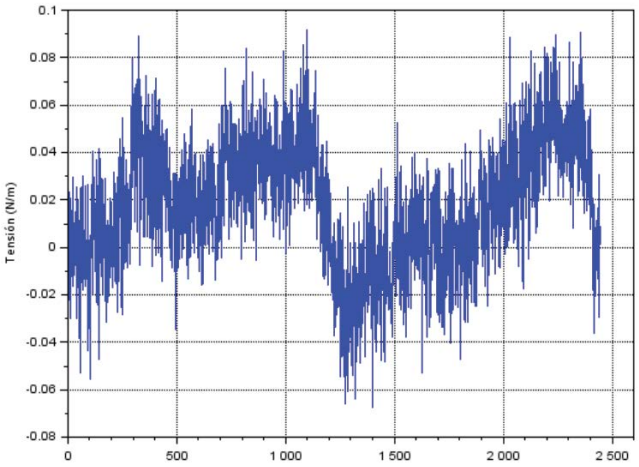

Fig. 8. Test 1 (olive oil).

Visualizing the previous graphs, it is observed how the measurements in the case of oil and of the fuel are not as abrupt as in the case of water, being in the measurements

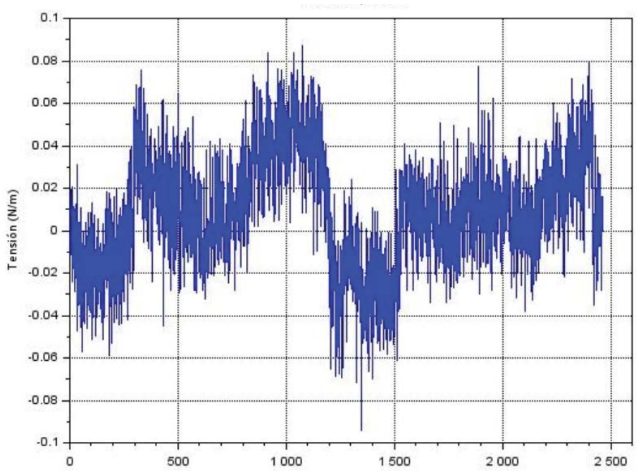

Fig. 9. Test 2 (olive oil).

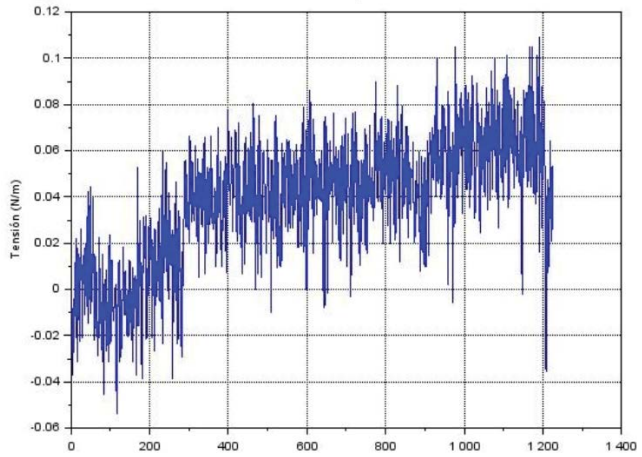

Fig. 10. Test 1 (fuel).

of the fuel much more constant than in the measurements of the other liquids.

4. Conclusions and future lines

In the first place, regarding the design, it is worth highlighting the value of the safety factor obtained for the studies being in the case of the study with the load of 1 N of 94 and for the load of 49 N of 2.2 and with this it is obtained that for the efforts to be made in our tests, a long durability in mechanical components. Highlight that the team will normally be working with loads less than 1 N and the high safety factor is due to the stresses so low.

Regarding the chosen design, although with some drawbacks due to vibrations created by the movement of the Nema 17 motor that are transmitted through the spindle until reaching the load cell that is converted to noise in measurements, this design allows some versatility to carry out other types of tests, such as material fatigue tests. It also allows you to modify heights in components, such as the position of the ends of stroke, leg levelling, ring height and varying sizes of liquid containers.

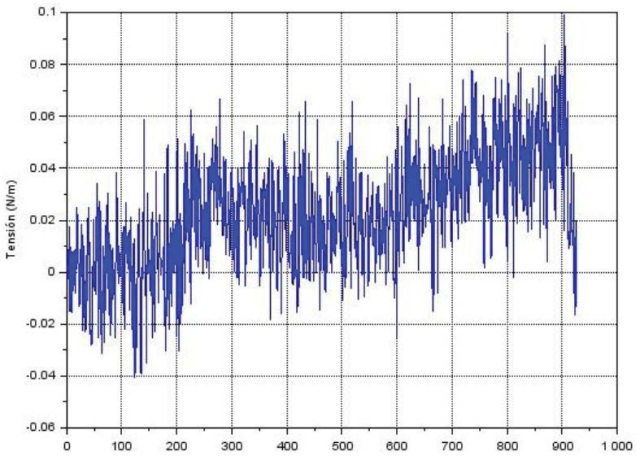

Fig. 11. Test 2 (fuel).

Regarding the measurements, as can be seen in section "3.2. Measurements" in different graphs shown, follow the same methodology which was explained in said section, there are repeatability and the results for each of the liquids are constant. As seen there a level of noise in the sampling due to the vibrations mentioned above, as well as, due to the connections between the electronic components being through pins (DuPont cables) and not by fixed welding.

As future lines for this project it could be summarized the following:

- Implementation through mobile application.
- Change the Arduino UNO board, for the Arduino Nano 33 IoT, equipped with Bluetooth, Wi-Fi, 256 kb flash memory, 32 kb SRAM memory, one inertial measurement unit 6-axis (IMU) with accelerometer and gyroscope and with cryptographic chip for the storage of certificates and pre-shared keys.
- Adding a camera to capture photos of the process and store them using processing.
- Creation and implementation of measurement and control of liquid temperature.
- Equipment vibration measurement.
- Improvement of the graphical user interface (GUI).
- Improvements in the design of the equipment.
- Regarding programming, a possible operation could also be programmed of multiple load cells if required, for surface tension comparisons of different liquids at the same time.
- Implementation of the equipment for its operation for the measurement with the method of the WHILHELMY plate and other types of assays.

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