FUNNEL AND THE BALL

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ABSTRACT

Funnel and ball is an educational experiment in which by placing a ball inside a funnel while a stream of air is flowing through it, it can be observed that in correct conditions a pick up force will be implied onto the ball, which makes the ball to levitate inside the funnel. In this research we are going to investigate the parameters which affect this experiment and what relation between this parameters cause a better result in an ideal system. The pick-up force is caused due to the difference of pressure which is implied onto the ball and to have a successful pick up there is an important relation between physical properties of the ball (e.g. mass, volume) and air flow (e.g. velocity, stability).

1 Introduction

Funnel and ball is an educational experiment in which by placing a ball inside a funnel while a stream of air is flowing through it, a suction force will be created which happens due to the difference of pressure created inside the funnel, this suction force might be strong enough to keep the ball inside of it even though the direction of air flow is against it. In this article you will read an explanation behind why this phenomenon happens, what are the parameters which affect this experiment and what relation between this parameters can cause a better result in an ideal system (Fig. 1) .

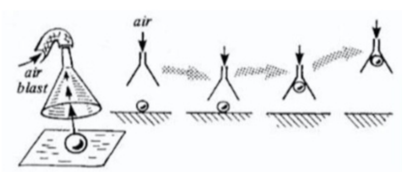


Fig. 1: Funnel and the ball

2 Experimental Setup

For performing this experiment, we need a funnel, a light ball (e.g. Ping-pong ball) and a stable source of stream of air.

Considering the properties of these equipment, it is best to use a ball with a high volume and low mass along with a funnel with a low angle in order to be able to work easily with different varieties of air velocities.

3 Theoretical Analysis

In fluid mechanics, Bernoulli's principle states that fluids with higher velocity will have less pressure; this principle gives us the relation between pressure and velocity of the fluid in every cross section of the funnel. According to another principle, which is volumetric flow rate, fluids passing through a narrow pipe will have more velocity.

According to the continuity in the funnel when the ball is picked up with the air pressure, the air's velocity inside the funnel , which the ball is in middle of it, increases because the cross section is small there and the air's velocity decreases under the ball in funnel because the cross section is big there so according to this might be explained by Bernoulli principle or Coandă effect. According to the Bernoulli's law when the air's velocity decreases , under the ball in the funnel, the pressure increase and help the ball to pick up (Fig.2).The Coandă effect is the tendency of a fluid jet to stay attached to a solid surface (Fig.3) [1 & 2].

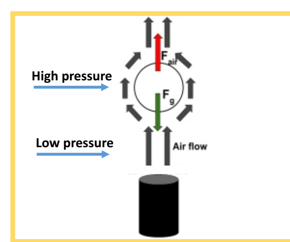


Fig. 2: Bernoulli's principle

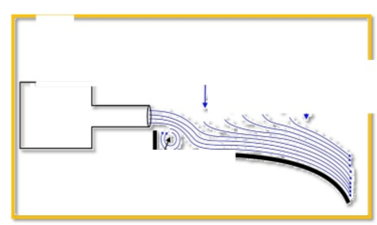


Fig. 3: Coandă effect

We can analyze the movement of the ping-pong ball in the funnel by plotting the X and Y components of the position of the ball versus time. Some of the important parameters which should be considered are the weight and size of the ball, airflow rate, and the shape of the funnel.

In the following diagram (Fig.4), the main forces, which are applied to the ball are shown.

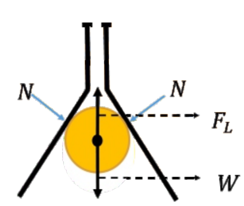


Fig. 4: The main forces applied to the ball in the funnel

Theoretically the data which will be gathered using this information will show that the sum of pressure above the ball is lower than from its below, this difference of pressure in some conditions might create enough suction force for it to be able to keep the ball inside of it.

3-1 Upwards force(F_{up})

This force is formed because of the difference in pressure below and above the ball, which makes the ball to get lifted upwards. Upward force is measured by the equation (1).

$$F_{up} = 4c\pi^2R^2 - \frac{\rho V_0^2 A_0^2 R^2}{\pi} \int \frac{\cos\varphi \, d\varphi}{(y - R\sin\varphi)^2 \tan^2\theta - R^2\cos^2\varphi} \quad (1)$$

$F_L > W \rightarrow$ *ball sticks to te funnel.*

$F_L = W \rightarrow$ *ball levitates in the funnel.*

$F_L < W \rightarrow$ *ball falls down.*

This force has the same properties of lift force but the direction of pick-up force is not perpendicular to the direction of airflow, so it could not be considered as a lift force (Eq. 2-5) (Fig.5) .

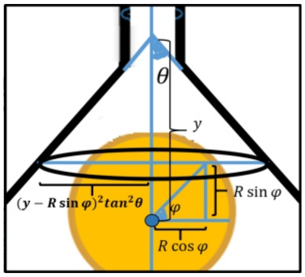


Fig. 5: The components of the main forces applied to the ball in the funnel

$$A = \pi((y - R\sin\varphi)^2 \tan^2\theta - R^2\cos^2\varphi) \quad (2)$$

$$V = \frac{V_0 A_0}{\pi((y - R\sin\varphi)^2 \tan^2\theta - R^2\cos^2\varphi)} \quad (3)$$

$$P = c - \frac{1}{2}\rho(V_0^2 A_0^2 \frac{1}{\pi^2((y - R\sin\varphi)^2 \tan^2\theta - R^2\cos^2\varphi)^2}) \quad (4)$$

$$F_L = \int \mathrm{PdA} \longrightarrow F_L = \int PdA \longrightarrow F_L = 4c\pi^2R^2 - \frac{\rho V_0^2 A_0^2 R^2}{\pi} \int \frac{\cos\varphi \, d\varphi}{(y - R\sin\varphi)^2 \tan^2\theta - R^2\cos^2\varphi} \quad (5)$$

In Coandă effect Stream lines are connected to the solid objects are walls of the funnel and surface of the ball (Fig.6).

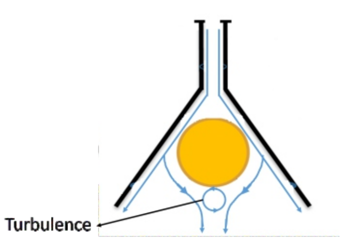


Fig. 6: Turbulence causes in Coandă effect

3-2 Drag force(F_D)

This force is formed by the friction and the momentum created between the ball and the gas particles at the moment of impact which makes the ball to get pushed downward. This force is measured by equation (6).

$$F_D = \frac{1}{2}\rho A V^2 C_D \quad (6)$$

3-3 Weight force (F_W)

This force is created as a result of the gravitational force exerted to the ball's mass. Weight force is measured by the equation (7).

$$F_W = \mathrm{mg} \quad (7)$$

Using these three main equations, we can predict if in any case the ball's levitation will be successful; in order the ball be able to levitate inside the funnel, amount of the lift force must be equal or above the amount of drag and weight force (Eq. 8).

$$F_{up} \geq F_D + F_W \rightarrow \textit{ball levitates in the funnel.} \quad (8)$$

4 Experiments and Results

The parameters which are effective in this experiment are explained in more details.

Mass of the ball: by increasing the mass of the ball with a constant volume, amount of weight force will get increased which in correct amounts it will make the addition of drag and weight force to get higher than the amount of upwards force which in this case the ball would not levitate.

According to the results in our experiment by increasing the mass of the ball (Fig.7), minimum velocity of the ball is increased and levitation force will be decreased (Table 1) and (Fig. 8).

Table 1: Velocity of different balls in the funnel

Mass: 2.30 g ⟶	minimum velocity: 1.74 m/s
Mass: 6.39 g ⟶	minimum velocity: 2.05 m/s
Mass: 11.08 g ⟶	minimum velocity: 2.31 m/s

Fig. 7: Balls with different masses

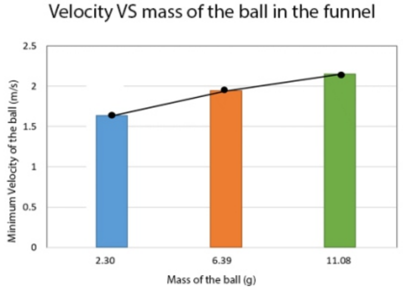


Fig. 8: Minimum velocity of the balls with different masses in the funnel

Volume of the ball: by increasing the volume of the ball with a constant mass (Fig. 9), the distance between top of the ball and its bottom will get increased which according to volumetric flow rate and Bernoulli's principle the difference of pressure above and below the ball will get increased which makes the ball to levitate with more stability (Fig. 10) (Eq. 9 and 10).

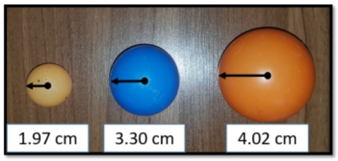


Fig. 9: Balls with different radius (volume)

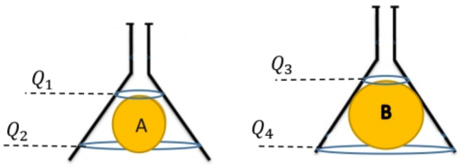


Fig. 10: Balls with different volumes inside the funnel

$$Q = A.V \xrightarrow{A_1=A_3,\ V_1=V_3,\ A_2<A_4,\ V_2<V_4} Q_1 + Q_2 < Q_3 + Q_4 \qquad (9)$$

$$\xrightarrow{\frac{v^2}{2}+gh+\frac{p}{\rho}=const.} P_1 = P_3,\ P_2 < P_4 \longrightarrow \Delta P_A < \Delta P_B \qquad (10)$$

According to the results in our experiment, by increasing the volume of the ball , its velocity decreases so the levitation force will be increased (Table 2) (Fig. 11).

Table 2: Velocity of different volumes of the balls

Radius: 1.97 cm ⟶ minimum velocity: 1.39 m/s
Radius: 3.30 cm ⟶ minimum velocity: 1.08 m/s
Radius: 4.02 cm ⟶ minimum velocity: 0.94 m/s

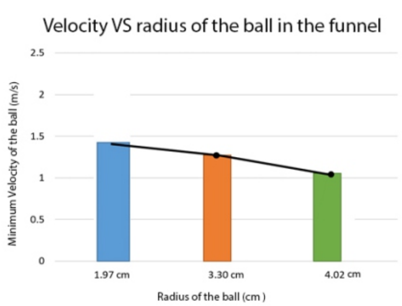


Fig. 11: Minimum velocity of the balls with different volumes

Angle of the funnel: as angle of the funnel changes, the difference of cross section above and below the ball will change (Fig.12). According to volumetric flow rate by increasing the angle, difference of velocity in the funnel will increase which according to Bernoulli's principle difference of pressure inside the funnel will increase which makes the ball to levitate inside the funnel with more stability (Fig. 13) (Eq.11).

$$A_2 - A_1 > A_4 - A_3 \longrightarrow V_2 - V_1 > V_4 - V_3 \qquad (11)$$

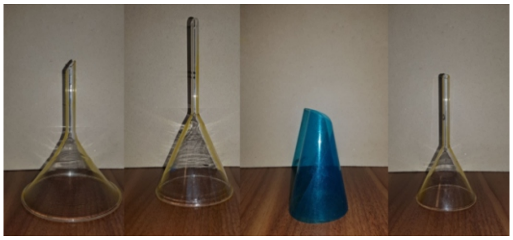


Fig. 12: Different shapes of the funnel with different angles, curves and heights

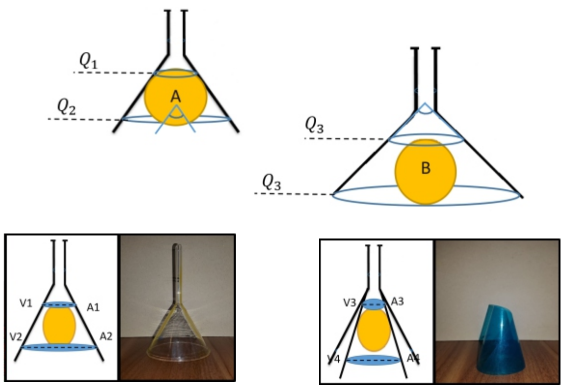


Fig. 13: Funnels with two different angles

Different shapes of funnels are compared with each other; a flat funnel with a curved one and also two different heights (Fig. 14 , a and b ;c and d).

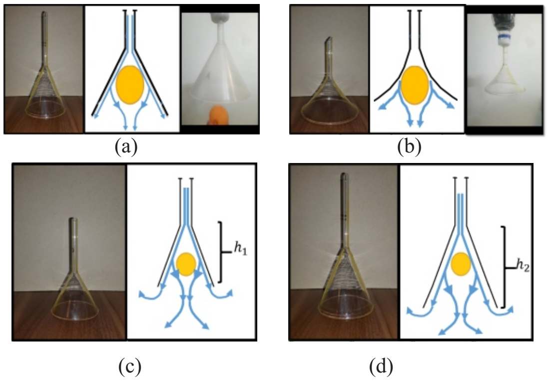


Fig. 14: Different funnels, flat (a) and curve sides (b); short (c) and tall height (d)

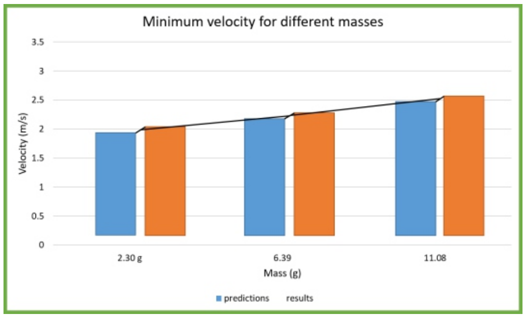
5 Results and Conclusions

We have compared our prediction by theory and the results from the experiments both in different masses and different volumes (Fig. 15 a and b).

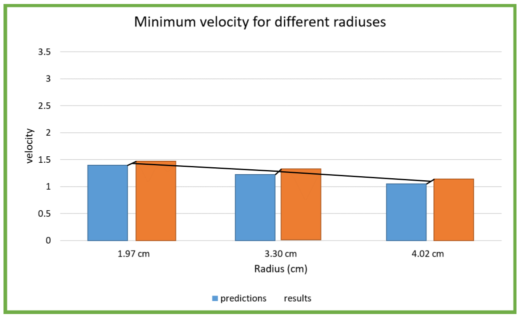
The basic reason why this phenomenon happens is the difference of pressure created inside the funnel.

Ideally, the main forces, which are applied to the ball, are upwards force, drag force and weight force.

According to the experiments we can understand that to improve results of this experiment is best to use a ball with higher volume and lower mass.



(a)



(b)

Fig. 15: Comparison between theory and experimental results in balls with different masses (a) and different radiuses(b)

References

[1] Weltner K., (1990), "Aerodynamic lifting force". Phys. Teach. 28, 2, 78-82

[2] Weltner K., (1990) ,"Bernoulli's law and aerodynamic lifting force". Phys. Teach. 28, 2, 84-86