THEORETICAL AND EXPERIMENTAL STUDY ON THE GAS FLOWING THROUGH THE NOZZLES OF OXY-FUEL CUTTING EQUIPMENT

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Abstract. *The paper analyzes theoretically the elements conditioning the performance of the manual oxygen and acetylene-based cutting equipment and presents original proposals for performance improvement after verification on the test stand.*

Keywords: *flow, flame, nozzle, cutting*

1. INTRODUCTION

This paper proposes measures justified theoretically and verified experimentally to enhance the performance of the oxy-fuel equipment intended for manual metal cutting.

Using the ratios:

$$Q_m = \frac{A \cdot p_1}{\sqrt{T_1}} \cdot \sqrt{\frac{2 \cdot \chi}{R(\chi - 1)} \cdot \left[\left(\frac{p_2}{p_1}\right)^{\frac{2}{\chi}} - \left(\frac{p_2}{p_1}\right)^{\frac{\chi+1}{\chi}} \right]} \quad kg/s \qquad (1.)$$

where:

A - is the effective passing area m^2

T_1 - is the absolute temperature of the gas above the slot *K*

R – the gas constant *J/kg · K*

- ***for the overcritical, or subsonic flow regime, when*** $\beta > \beta_{cr}$

and:

$$Q_{m\,max} = \frac{A \cdot p_1}{\sqrt{T_1}} \cdot \sqrt{\frac{\chi}{R} \cdot \left(\frac{2}{\chi + 1}\right)^{\frac{\chi+1}{\chi-1}}} \quad kg/s \qquad (2.)$$

- ***for the subcritical, or supersonic, flow regime, when***

$0 < \beta < \beta_{cr}$

where: $\beta = p_2 / p_1$

and p_2, p_1 -pressure values down and up the slot [1], [2]

there resulted Table 1, which contains the values of the gas flow based on β, and the comparative chart $Q = f(\beta)$ shown in figure 1, for the oxygen and acetylene, which are the gases used in the oxy-fuel cutting.

Table 1

Gas	Chemical formula	β_1 Nm³/h	Q_1	β_2 Nm³/h	Q_2	β_3 Nm³/h	Q_3	β_4 Nm³/h	Q_4	β_{cr} Nm³/h	Q_{cr}
oxygen	O_2	0,9	0,136	0,8	0,184	0,7	0,208	0,6	0,221	0,528	0,223
acetylene	C_2H_2		0,123		0,164		0,184		0,191	0,557	0,193

Considering that the pressure down the slot (channel) p_2 decreases to a critical value, p_{2cr}, the gas flow passing through the slot (channel) increases from 0 to Q_{max}, a value that is called saturation flow and represents the maximum gas flow that can pass through the slot considered, in this situation the gas exit speed being the critical speed, that is equal to the speed of sound.

On further reducing, below the critical pressure, the p_2 value of the pressure down the slot, mathematically the gas flow Q_{max} should decrease [3].

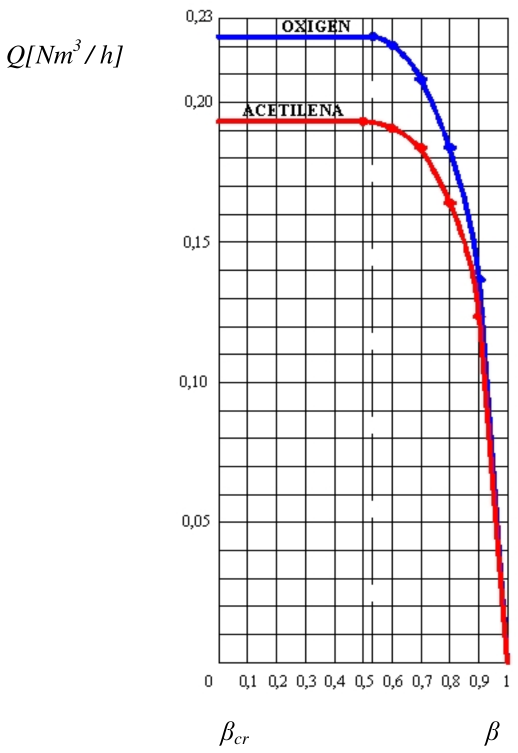


Figure 1. Chart $Q = f(\beta)$ **for oxygen and acetylene**

However, experimentally, it is found that, in the subcritical flow regime (i.e. β <βcr), the gas speed on exiting the slot maintains its critical value and the flow rate remains at the constant value Q_{max}

The fact that, at exit pressure values of $p_2 < p_{2,cr}$, the flow $Q = Q_{max}$, is explained by the fact that the critical speed, equal to the speed of sound, installed in the slot section, does not allow the perturbation created by the pressure fluctuation down the slot to propagate to the slot section at the speed of sound as well [1], [2].

2. THE STAND FOR TESTING THE CUTTING CAPACITY OF THE MANUAL OXY-FUEL CUTTING MACHINE

The test stand presented in Figure 2 is a special stand designed to measure the cutting capacity of manual oxy-fuel (oxy acetylene; oxy methane; oxy propane) cutting machines; the stand is provided with fuel gas and oxygen sources and flareback protection systems [4].

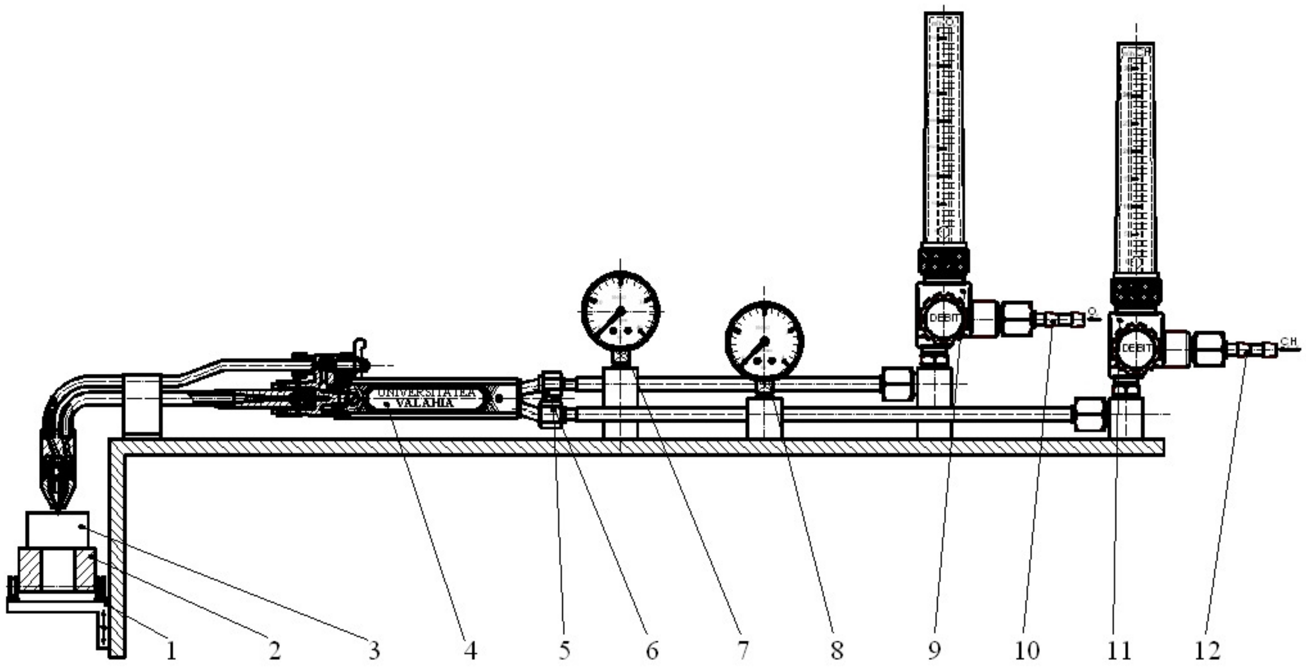


Figure 2. Test stand basic components

Legend: 1 mobile holder; 2 - part holder; 3-the part to be cut; 4-manual cutting device; 5- oxygen connecting pipe; 6- acetylene connecting pipe 7- oxygen manometer; 8- acetylene manometer; 9- oxygen flow meter; 10- oxygen source connection; 11-acetylene flow meter; 12-acetylene source connection.

The basic elements of the stand are mentioned in Figure 2, the only missing elements being the flareback protection components. The cutting process is carried out by moving piece to be cut; the cutting device and the other components of the test stand are mounted on the stand table using brackets. In order to improve the vertical position accuracy of the cut parts, we decided to move the parts using slideways.

3. INNER AND OUTER NOZZLES DESIGN SOLUTIONS

Presented below are the design solutions adopted for making the outer nozzles (Figure 3,4):

-The roughness of the nose radius of *min. R1,5* on entering the *Ød1* diameter must be of *max. 1,6*.

-The roughness of the nose radius of *max. R0, 01* on exiting the diameter *Ød1* must be of *max. 1.6* (detail A).

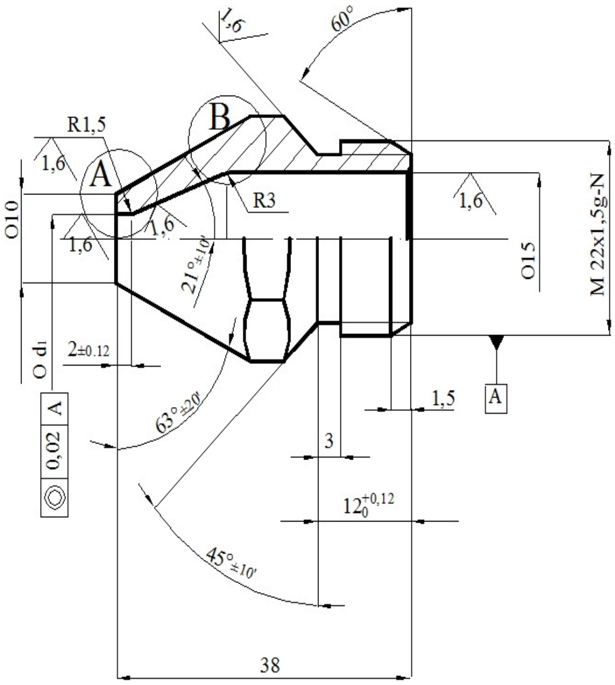
-The roughness of the nose radius of *min. R3* on exiting the *Ø15* diameter must be of *max. 1,6*.

4. EXPERIMENTS ON THE GEOMETRIC SHAPE OF THE GAS JET FOR THE PROPOSED SOLUTIONS

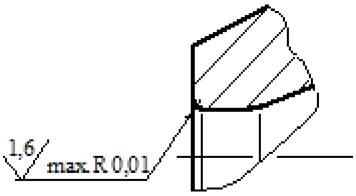
4.1. The jet shape when the device operates without cutting oxygen

Analyzing the shape of the burning gas mixture jet, there result the following conclusions:

- Because of the edge of the inner nozzle outlet (Figure 5. a), the flame will be directed outwards, taking the shape of a flare; at the same time, the area of the section perpendicular to the jet axis increases. This causes the area that needs to be heated to the melting temperature to increase before the cutting oxygen jet is triggered (before oxidation).



Detail A
Scale 2:1



Detail B
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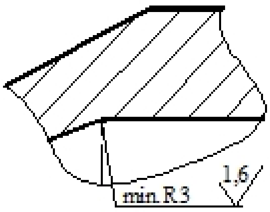

Figure 3. Outer nozzle outline

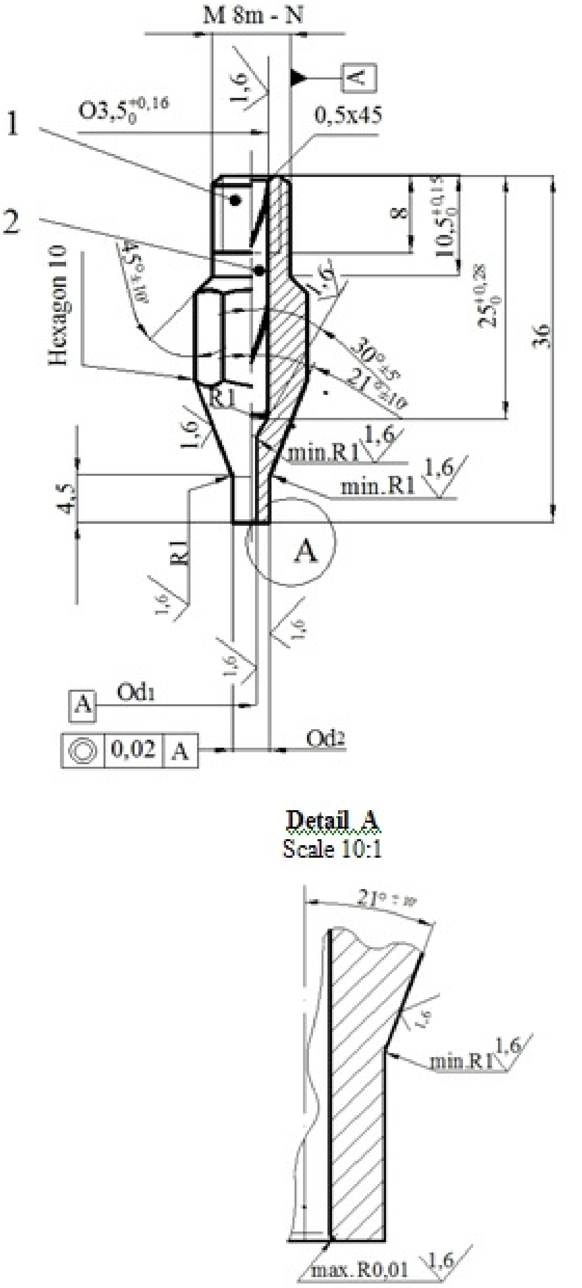

Figure 4. Inner nozzle outline

1- inner nozzle; 2- variable thickness twisted blade.

- Because of the outer edge of the inner nozzle's head (Figure 5. a), the flame tends to concentrate in the central area thus increasing the risk that the flame flows back on the cutting oxygen path. At the same time, the caloric power in the area decreases due to dispersion.

In both cases, this phenomenon occurs because the gas jet tends to follow the rounded edges.

- Figure 5. b shows the longitudinal section shape of the flame coming out of a set of nozzles where the two edges are sharp.

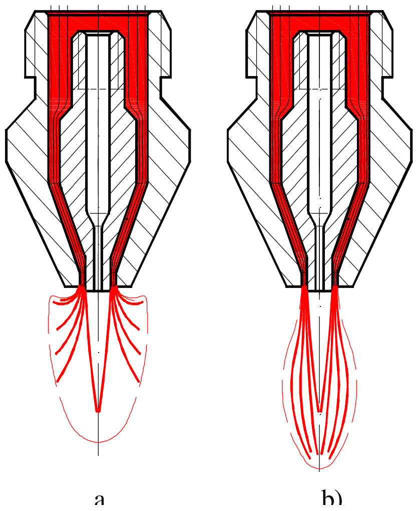

Figure 5. Jet shape on the outer nozzles

a) normal outer nozzle; b) designed outer nozzle

4.2. The shape of the jet coming out of the set of nozzles when the device operates on cutting oxygen

Figure 6. a) and b) shows the longitudinal section shapes of the flame when the device operates on cutting oxygen, so during the cutting process.

Figure 6. a) shows the shape of a jet produced by a cutting device with re-designed nozzles, where the dimensions of the edges radii indicated in the manufacturing documentation are observed.

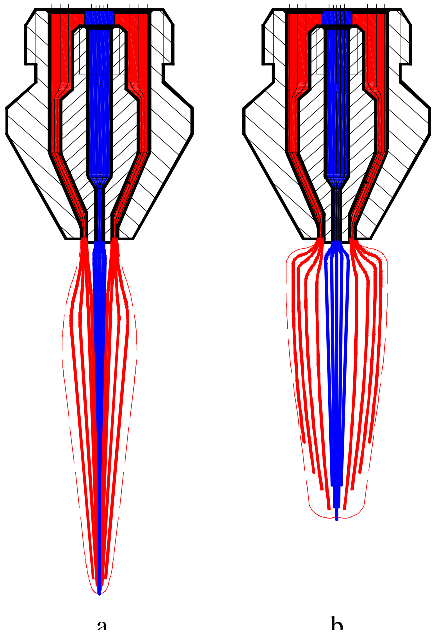

Figure 6. The jet shape when the cutting oxygen is triggered

a) the set of the re-designed nozzles; b) the set of normal nozzles

In Figure 6. b), the longitudinal shape of the jet corresponds to a set of nozzles where the edges radii have not been checked after the passivation operation prior to surgery chroming.

As can be seen, in case a) the jet shape is long and narrow, which leads to a greater penetrating power and therefore an improved cutting performance. In case b), because of the larger area of the jet's cross section, the oxidation and penetration capacity decreases.

4.3. The shape of the jet produced by the nozzles proposed in this paper

Further to the experiments performed on the test stand, the following observations were made:

-The radii used in rounding the edges of the gas nozzles' outlets (both the outer and the inner nozzles) have a major impact on the jet's longitudinal section shape and cross-section area. So, the lower the value of the radii (therefore, the sharper the edges), the longer is the gas jet and the smaller the area of its cross-section. A low value of the cross-section means a higher rate of heating and thus a shorter heating time until the metal reaches the melting temperature, and a high value of the jet length, especially when the cutting oxygen supply is on, means implicitly a higher pressure of the cut material. During the experiments we have noticed that if the gas jet direction is not perpendicular to the direction of the unconnected crossing edges (Figure 7.), the effect of these edges on the shape of the gas jet is considerably diminished.

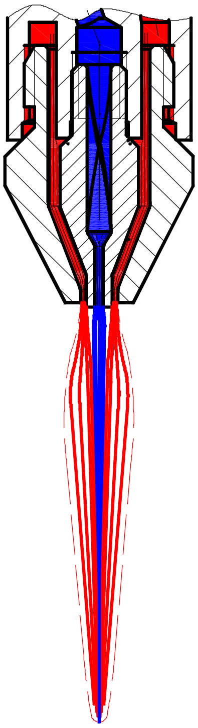

Figure 7. The jet shape with the proposed set of nozzles

This observation led to searching for a viable technical solution that allows the deviation of the flow direction, especially of the cutting oxygen jet which has very high speed rates, from the longitudinal axis of the inner nozzle outlet.

To obtain this result there was adopted the solution presented in Figure 8. This solution consists in twisting a brass plate at an angle of 180°, irrespective of the twisting direction, and, pressing gently, inserting it along the larger diameter inner hole of the inner nozzle.

The result of this was a deviation of the cutting oxygen jet of about 20° from the axial direction, forcing it to move following the direction of an elongated propeller.

As can be seen in Figure 8, the plate does not have a constant thickness over its length, but is convex on both sides, therefore is thicker at the center.

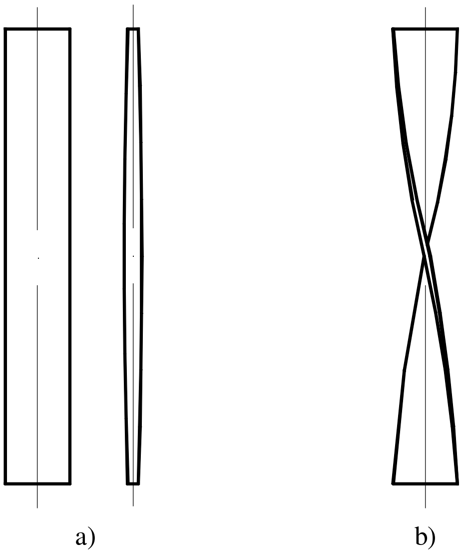

Figure 8. Outline of the twisted plate used for the inner nozzle
a) before twisting; b) after twisting

Applying the above-mentioned technical solutions, the jet has taken a much elongated shape, and the value of the cross-section area in the thickest part was much reduced. For calculations there are used the relation (1.), valid for the subcritical flow regime, and the relation (2.), valid for the critical flow regime; the results are presented in Table 1.

The calculations for determining the values of flow rates Q depending on the value of the ratio β for the gases used, for which the curves $Q = F(\beta)$ shown in Figure 1 have been raised based on the data in the Table 1, have been performed using the measurements of the resized nozzles. The maximum flow rate Q_{max}, which can pass through a nozzle's orifice corresponds to the critical ratio $\beta_{cr} = p_2/p_1$. Below this value, therefore when $\beta < \beta_{cr}$ and $p1$ exceeds a certain value, the flow rate $Q = Q_{max} = ct$, consequently it can no longer increase, ensuring the speed of sound at the exit.

5. OF THE MANUAL OXY-FUEL CUTTING DEVICE

The proper functioning of a set of nozzles depends largely on the following factors:

- the quality of the material the nozzles are made of, in terms of how compatible are its mechanical and chemical characteristics with the gases used.
- the smoothness and processing of the surfaces that come into contact with gaseous agents flowing at high speeds.
- the capacity of the nozzle's material to quickly convey the stored heat resulting from the combustion process.

5.1. Measurements on the cutting capacity of the device equipped with redesigned nozzles

Examining the values shown in Table 2, the conclusions on the cutting capacity of the manual device equipped with the proposed set of nozzles can be drawn.

Table 2.

Set of nozzles	3÷25	25÷50	50÷100	100÷200	200÷300
	Outer nozzle No.1			Outer nozzle No.2	
	Inner nozzle No.1	Inner nozzle No.2	Inner nozzle No.3	Inner nozzle No.4	Inner nozzle No.5
STAS thickness [mm]	3÷25	25÷50	50÷100	100÷200	200÷300
Effective cut thickness [mm]	2÷35	25÷60	50÷120	100÷235	200÷350

5.2. Comparative graph illustrating the cutting capacity

The graph shown in Figure 9 illustrates in a suggestive manner the comparative numerical data in Table 2. Examining the two curves there can be easily noticed that the better quality of processing has led to performances superior to those of the manual oxy-fuel cutting devices equipped with STAS nozzles.

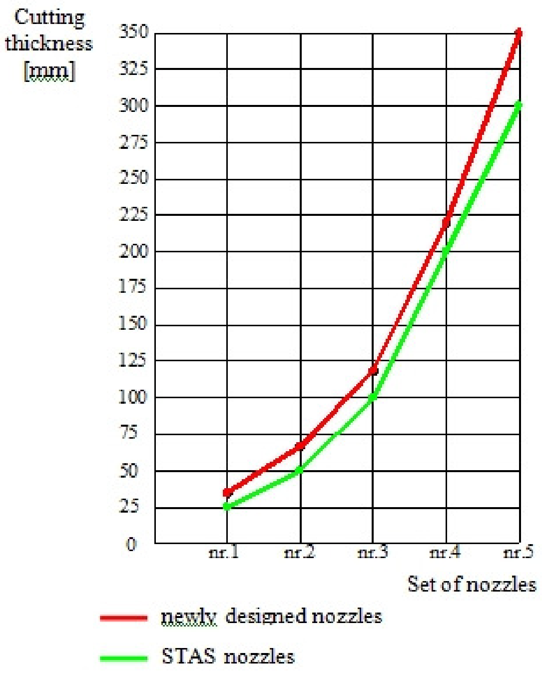

Figure 9. Comparative graph illustrating the consumptions of the two types of devices

6. CONCLUSIONS

The cutting capacity of the device equipped with the sets of newly designed nozzles is superior to that of the device provided with STAS nozzles.

The oxygen consumption is 5% lower.

The quality of the cut surface is far better.

For the future we have in mind making the variable thickness plate, which allows simulating a convergent-divergent nozzle in the area where it is inserted.

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