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OXYGEN SUPERSONIC BLOWING LANCES IN BOF: A COMPARISON OF SKULLS3® TECHNOLOGY AND OUTER STRAIGHT AND CONICAL TUBES OF STEEL AND COPPER*

Ismar Antônio Sardinha[1]

Abstract

Usually outer straight steel tubes are used to blow supersonic oxygen into LD converters (BOF) to make liquid steel, although conical tubes are used too. Inner tube for oxygen blow and intermediary tube for water IN and water OUT are normally straight steel tubes. Present paper shows the influence of outer tube shape and metal used to in lance cooling and, consequently, a skull retention on lance surface. There are two parameters more important related to lance cooling: velocity of water out and the total lance cooling by addition of thermal conductivity of outer tube metal to it. For this comparison outer tubes are made of carbon steel or copper, and can be straight or conical. As related to velocity of water OUT, outer straight tubes have bigger efficiency than conical tubes. As related to total lance cooling, outer tube metal made of copper has much bigger efficiency than steel because of its thermal conductivity 7 to 12 times more depending on work temperature. The lance cooling has much bigger efficiency for the patented SKULLS3® technology with no skulls on the lance and no skulls into the mouth of LD converters (BOF).

Keywords: Skull; SKULLS3®; PC module; Conical lance.

[1] *Metallurgical engineer, MBA FGV, ABM member, Business Director, S3 Technologies, Belo Horizonte, MG, Brasil.*

1. INTRODUCTION

Normal oxygen supersonic blowing lances for making liquid steel in BOF are composed of three steel tubes as figure 1. There are steel plants that also use conical steel lances as 400t BOF.
Inner steel tube is normally made of stainless or carbon steel to blow supersonic oxygen and intermediary and outer tubes are made of carbon steel.

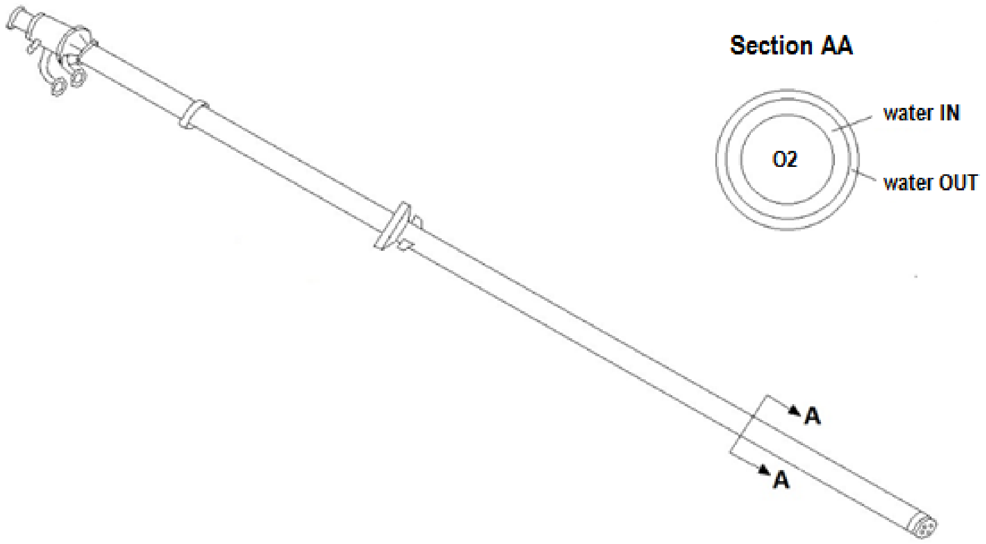

Figure 1 – Normal lance

The efficiency of a heat exchange tube depends mainly on material, geometric characteristic, thermal conductivity and fluid flow in evidence. Present paper has the objective to verify the influence of outer tube in lance cooling when it is modified in its shape, straight to conical; and/or replaced by copper metal. In case of copper tubes some inner van is considered and the cooling fluid is water.
Outer straight copper tube with a length of 3.20 m to 5.20 m long and composed of 3 modules (tip, cartridge and PC – Post combustion) has a patent named SKULLS3®. Figure 2 shows a normal lance modified by a SKULLS3®.

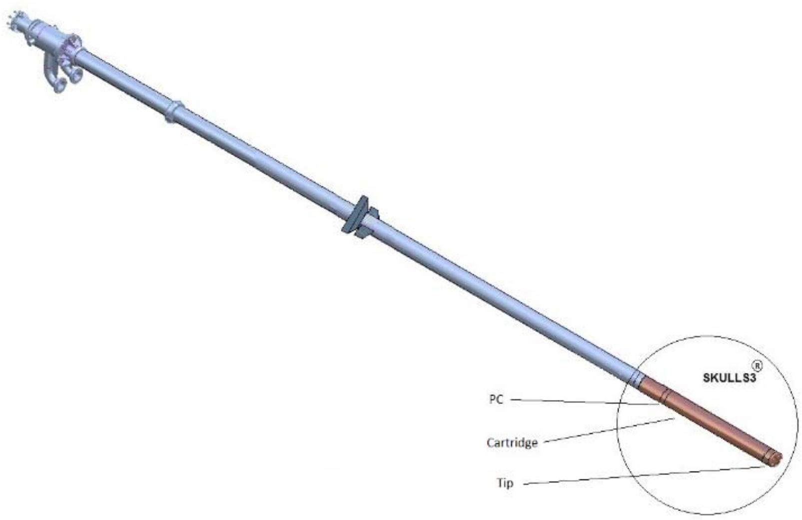

Figure 2 – SKULLS3® lance

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It can be composed by 2 modules only, tip and cartridge. Tip module can be exchanged, independently, same as done in normal straight and conical steel lances. Tip life is expected to have 400 heats and cartridge and PC modules are expected to have 2000 heats. PC module has the purpose to eliminate BOF mouth skulls.
In case of conical copper lance there is a need to exchange the cartridge and tip together normally. Practical results in 75t to 210t BOFs have shown a retention of skulls on lance for bigger BOFs (210 t). There is a cleanness need for 600 heats for 75t BOF to 250 heats for 210t BOF, while for normal straight and conical steel lances cleanness need is each 15 to 20 heats only [1] . For much bigger BOFs (300 to 400t) the frequency must be a number of heats lower.
Figure 3 shows various lances types.

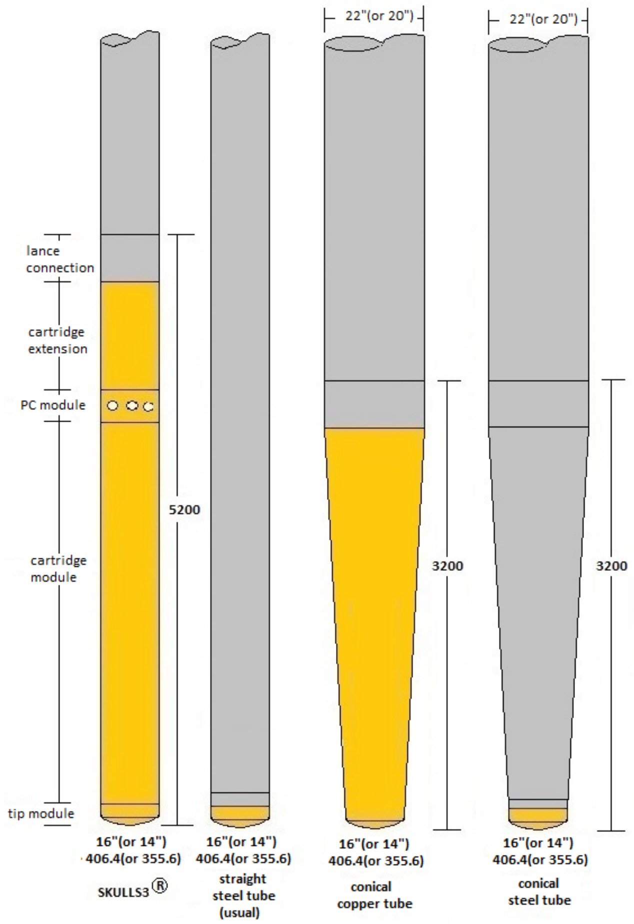

Figure 3 – BOF lances types – 300t to 400t

Using van has the advantage of promoting a stronger turbulence in fluid (water) and increasing the velocity of water OUT cooling. In this case considered van has an angle β of 40 degrees (factor of 1.42 times).
As water has a higher pressure, there is a “forced convection”, promoted by outer agents (pumps), to maintain the water movement with the surface of metal [2] [3].
For the influence of thermal conductivity and total lance cooling, by consequence, the multiply factor was gotten from the existent comparison curves for various metals and still considered at high work temperatures [4].
Field measurements have shown an outer temperature for steel tubes (no skulls) from 300 to 700 °C while for copper tubes from 150 to 250 °C (temperature measured on surface of lance just after end blow) [5]. So in this range, based on curves of thermal

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conductivity for various metals as shown in table 1 and figure 4, the conductivity for copper is about 400 W/m.ºK and for steel (a litle bit less than iron) is about 40 to 50 W/m.ºK (and for practical effect it is considered a value of 45 W/m.ºK).

Table 1 – Thermal conductivities of various metals at 300 ºK [4]

THERMAL CONDUCTIVITIES

Metals	k (W/m.K)
Aluminium	205.0
Brass	109.0
Copper	385.0
Lead	34.7
Mercury	8.3
Silver	406.0
Steel	50.2

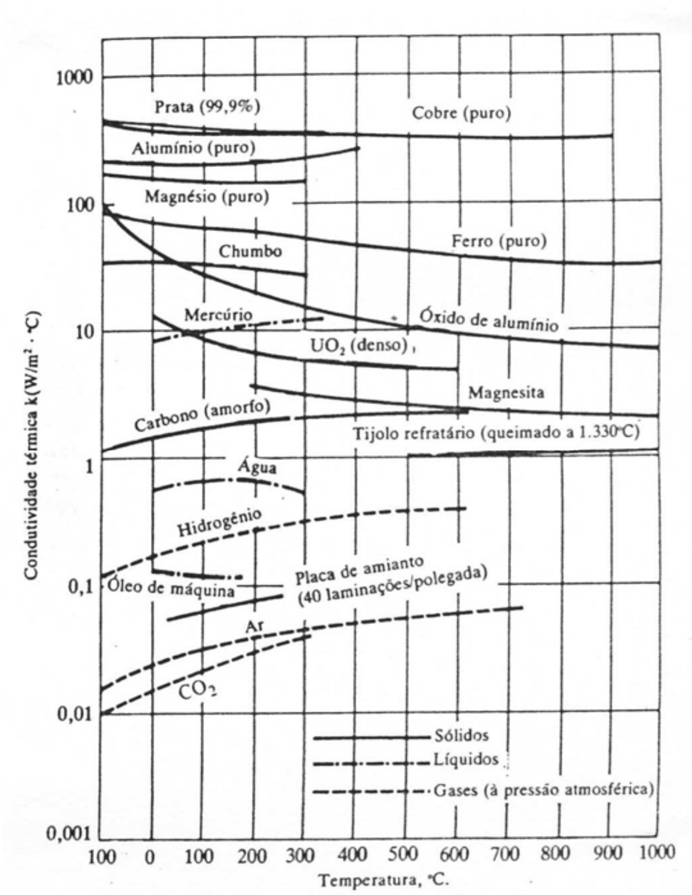

Figure 4 – Thermal conductivitiy curves of various metals in function of temperature [4]

The relationship of copper to steel is:

$$k_{copper} / k_{steel} = 400 / 45 = 8.9$$, or 9 times.

PC module has the objective to eliminate skulls in BOF mouth, and preliminary results have gotten in 210t BOF with 309 heats with no skulls in mouth. The issue at that time was the equipment itself, by erosion at the holes. Later on this issue was eliminated (75t BOF) and life was increased to more than 1000 heats [6]. The result is a benefit in productivity (to increase the amount of heats per month).

2. MATERIAL AND METHODS

By considering the influence of outer tube modified in its shape, some theoretical calculations are done in its essential cylindrical shape and in its modified conical shape. In this such case of conical shape there is an additional need to modify the outer diameter of lance to get the aimed α conical angle (figure 3 and 5).
The diameters of tubes are normally standardized and the calculations are done for lances of 300t BOF.

Considered shapes for comparison are:
- straight outer tube (steel and copper)
- conical outer tube (steel and copper)

Considered normal diameters for a 300t BOF are:
- outer tube: 16” (406.4 mm)
- intermediary tube: 14” (355.6 mm)
- inner tube: 10.75” (273.1 mm)

Figure 5 shows considered shapes: cylindrical and conical.

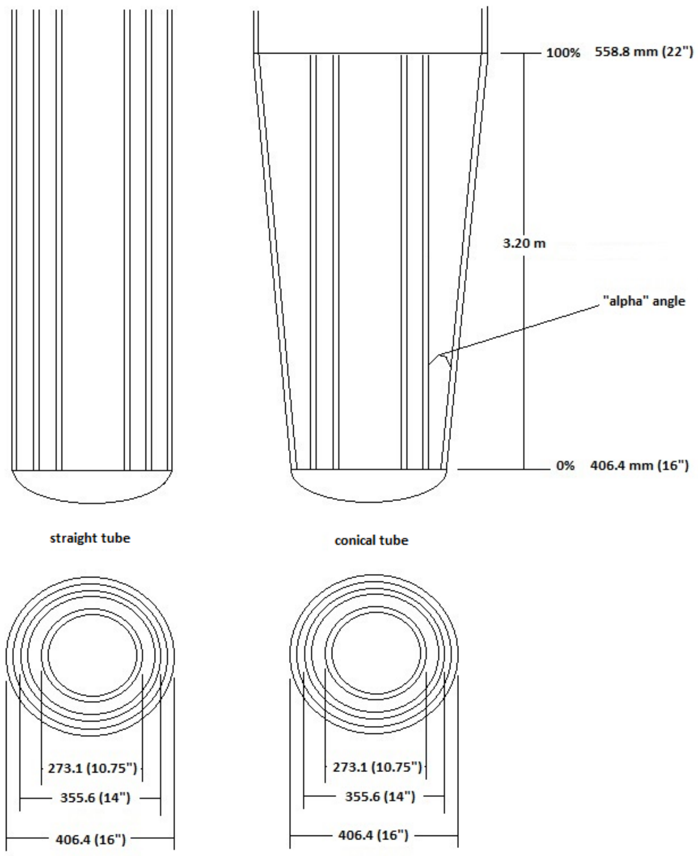

Figure 5 – Shapes and dimensions of tubes (conical α angle)

Considered normal thicknesses are:
- inner tube (stainless or carbon steel): 7.0 mm
- intermediary tube (carbon steel): 9.5 mm
- outer tubes: carbon steel – 9.5 mm
  copper – 15.0 mm

Length of outer tubes are:
- Steel and copper conical tubes: 3.20 m
- straight copper: 3.20 m and 5.20 m (PC module included)

Larger outer diameter of conical tube is 22” or 558.8 mm.
Other factors remained the same for inside and outside the vessel.

3. RESULTS AND DISCUSSION

3.1 Calculation of water OUT velocity

The exit velocity of water (water OUT velocity) can be calculated (figure 6), in function of tube outer diameter, and inner and intermediary tubes remained as original and straights.

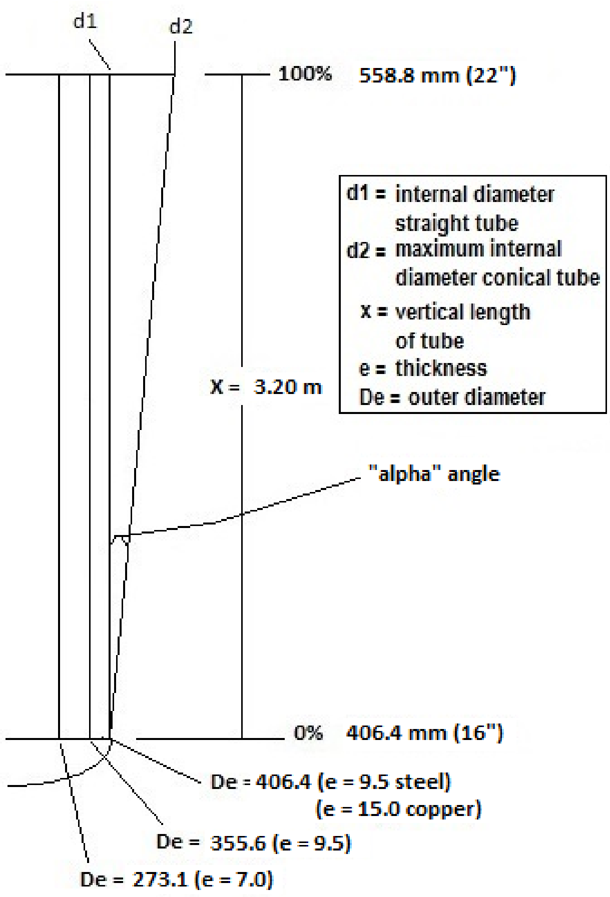

Figure 6 – considered dimensions

Cooling water flow rate is 300 m3/h (300t BOF) and 400 m3/h (400t BOF) and a pressure of 10 bar, approximately 10 kgf/cm^2.
This flow rate in m^3/s is in table 2.

Table 2 – Water flow rate (300 and 400t BOFs)

BOF (t)	Water flow rate (m^3/s)
300	0.083333
400	0.111111

For straight tubes (steel and copper) the cooling water OUT is constant. Charge loss is not considered.

For conical tubes (steel and copper) water OUT velocity varies along the length of lance with a reduction that is proportional to square diameters (or to water OUT area) as the α angle, where:

$$tg\alpha = (d_2 - d_1) / 2x \quad (1)$$

$$d_2 = 2x \cdot tg\alpha + d_1 \quad (2)$$

and:
x (m) = vertical length of conical tube (steel or copper)
α = conical angle (or tgα)
d_2 (m) = maximum internal diameter of outer conical tube
d_1 (m) = internal diameter of outer straight tube (steel=0,3874, copper=0,3764)

By calculation (function of diameters), tgα for steel and copper conical tubes are in table 3.

Table 3 – Tgα for conical tubes

Conical tube	tgα
steel	0.023813
copper	0.023813

The velocity V is the flow rate of water OUT (m3/s) over ΔS area where water flows (m^2), and for a 300t BOF is:

$$\Delta S = S_2 - S_1 \quad (3)$$

where: $S_2 = 0.7854\ (D_i)^2$ and D_i = internal diameter of outer tube
where: $S_1 = 0.7854\ (D_e)^2$ and D_e = outer diameter of intermediary tube
So:

$$V(m/s) = \text{water flow rate} / \Delta S = 0.083333 / \Delta S = 0.106103 / [(D_i)^2 - (D_e)^2] \quad (4)$$

For considered tubes diameters, the velocity of water OUT at the tip exit, with and without van in copper tubes and still considering the velocity of water OUT for the normal steel tube (normal lance) as 1, is proportional as table 4.

Table 4 – Proportional velocities of water OUT at the exit tip

BOF (t)	Tube	Velocity water OUT (m/s)	
		Without van	With van (β = 40°)
300	steel	1.00	
	copper	1.82	
			2.59

Still considering no charge loss along the tube and varying the tube length “x” from 0 (zero) to 3.20 m (or 5.20 m), and, as in table 4, changing the velocity of water OUT of straight steel tube (normal lance) equal 1, the velocity of water OUT in function of copper tube length, for different technologies, is in table 5.

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Table 5 – Velocities of water OUT along lance length for different technologies (300t BOF)

x (m)	Steel conical no van	Copper conical no van	Copper conical with van	Steel Straight no van	Copper straigth no van	Copper straigth with van
0	1.00	1.82	2.59	1.00	1.82	2.59
0.2	0.73	1.07	1.51	1.00	1.82	2.59
0.4	0.57	0.75	1.06	1.00	1.82	2.59
0.6	0.47	0.57	0.81	1.00	1.82	2.59
0.8	0.39	0.46	0.66	1.00	1.82	2.59
1.0	0.34	0.39	0.55	1.00	1.82	2.59
1.2	0.30	0.33	0.47	1.00	1.82	2.59
1.4	0.26	0.29	0.41	1.00	1.82	2.59
1.6	0.24	0.25	0.36	1.00	1.82	2.59
1.8	0.21	0.23	0.32	1.00	1.82	2.59
2.0	0.20	0.21	0.29	1.00	1.82	2.59
2.2	0.18	0.19	0.26	1.00	1.82	2.59
2.4	0.17	0.17	0.24	1.00	1.82	2.59
2.6	0.15	0.16	0.22	1.00	1.82	2.59
2.8	0.14	0.14	0.21	1.00	1.82	2.59
3.0	0.13	0.13	0.19	1.00	1.82	2.59
3.2	0.13	0.13	0.18	1.00	1.82	2.59

3.1.1 Comparative curves of velocity of water OUT

Table 5 is changed in comparative curves of velocity of water OUT and is shown in figure 7.

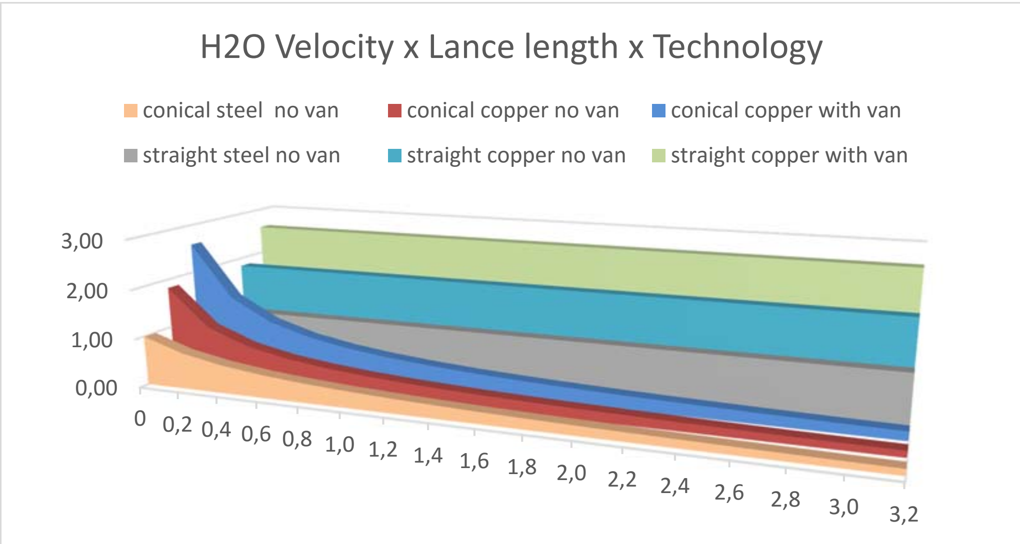

Figure 7 – Comparative curves of velocity of water OUT

For a distance of 1.60 m (50% of tube length), the difference of velocity of water OUT in conical steel tube (no van) and in conical copper tube (no van) is practically none (zero) and at beginning the difference is 1.82 times for the conical copper tube.

In case of straight steel tube (no van) for a distance of 0.40 m only the difference of velocity in conical copper tube with van is practically none (zero), and practically none (zero) for a distance of 0.20 m in conical copper tube (no van).
For a distance of 3.20 m the velocity becomes too small in conical tubes related to straight steel tubes (0.13 to 0.18 times), that means 7.7 to 5.6 times lower.
Straight copper tube (no van) has a velocity of water OUT greater than in conical copper tube with van for a distance of 0.20 m only.
Straight copper tube with van has a velocity of water OUT greater than in conical copper tube with van next the exit of the tip.
In another words straight outer tubes show much bigger efficiency than conical outer tubes.

3.2 Calculation of total cooling lance

Based on curves of thermal conductivity for various metals as shown in figure 4 and table 1, the relationship of copper conductivity to steel is 9.
With this multiplyer factor of copper to steel equal 9, (called C Factor), related to table 5 (velocity of water OUT), the total lance cooling is shown in table 6 for various technologies.

Table 6 – Total cooling lance fator (C Factor) for various technologies

X (m)	conical steel no van	straight steel no van	conical copper no van	conical copper with van	straight copper no van	straight copper with van
0	1.00	1.00	16.42	23.32	16.42	23.32
0.2	0.73	1.00	9.60	13.63	16.42	23.32
0.4	0.57	1.00	6.73	9.55	16.42	23.32
0.6	0.47	1.00	5.15	7.31	16.42	23.32
0.8	0.39	1.00	4.16	5.91	16.42	23.32
1.0	0.34	1.00	3.47	4.93	16.42	23.32
1.2	0.30	1.00	2.97	4.22	16.42	23.32
1.4	0.26	1.00	2.58	3.66	16.42	23.32
1.6	0.24	1.00	2.28	3.24	16.42	23.32
1.8	0.21	1.00	2.05	2.91	16.42	23.32
2.0	0.20	1.00	1.85	2.62	16.42	23.32
2.2	0.18	1.00	1.68	2.38	16.42	23.32
2.4	0.17	1.00	1.53	2.18	16.42	23.32
2.6	0.15	1.00	1.41	2.01	16.42	23.32
2.8	0.14	1.00	1.30	1.85	16.42	23.32
3.0	0.13	1.00	1.21	1.72	16.42	23.32
3.2	0.13	1.00	1.13	1.61	16.42	23.32

3.2.1 Comparative curves of total lance cooling

The table 6, when it is changed to comparative curves of total lance cooling (C Factor), is shown in figure 8.
There is no doubt that the worst result is for conical steel tubes (no van) and if compared with straight steel tubes (normal lance) the total cooling for a distance of 3.20 m becomes very small (0.13 times only), that means 7.7 times lower.

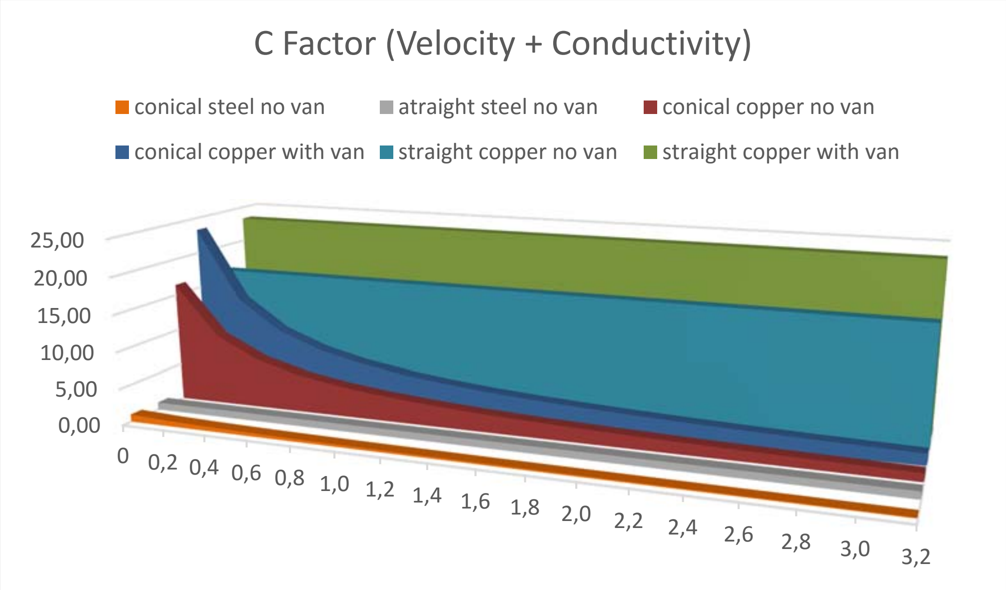

Figure 8 – Comparative curves of C Factor or total cooling lance

Conical copper tube (no van) has a bigger efficiency at small distances from tip when compared to straight steel tube (16.42 times to 2.05 times only for a distance of 1.80 m) and reduces drastically for a distance of 3.20 m (1.13 times only).
Conical copper tube with van compared to straight steel tube has a similar efficiency as conical copper tube (no van), but with a bigger efficiency. At next distances of exit tip, the total cooling is reduced from 23.32 times to 2.01 times for a distance of 2.60 m and reduces a lot for a distance of 3.20 m (1.61 times only).
Straight copper tube (no van) has a total cooling lance higher than in conical copper tube with van at a distance of 0.20 m only (13.63 times conical one to 16.42 times straight one).
Straight copper tube with van has a total cooling lance higher for the entire length, and compared to straight steel tube (no van) is 23.32 times. When compared to conical copper tube with van for a distance of 3.20 m, total cooling is 23.32 times to 1.61 times, that means about 14.5 times more efficient.
In another words conical copper outer tubes, due to the metal copper, have shown to have more efficiency than steel outer tubes, but less efficiency than straight copper outer tubes.

3.3 Conical angle (α) of outer tube

In case of conical tubes, the conical angle (α) can be measured by tgα, figure 4. This conical angle (α) may be determinant to get a better performance through the length of outer tube. This means, smaller the conical angle α (smaller the tgα) and bigger will be the length of copper outer tube (for a defined copper outer tube diameter as said diameters are standardized) which may become impracticable to be used due a higher cost.
Figure 9 shows the relationship for conical copper tubes, based on table 7, what means, smaller the angle bigger the length. If α angle is “zero” the tube will be straight.

Table 7 – α conical angle versus conical tube length

	α (degrees)	x (m)
1	0.20	21.83
2	0.30	14.55
3	0.40	10.92
4	0.50	8.73
5	0.60	7.28
6	0.80	5.46
7	0.95	4.60
8	1.10	3.97
9	1.36	3.21

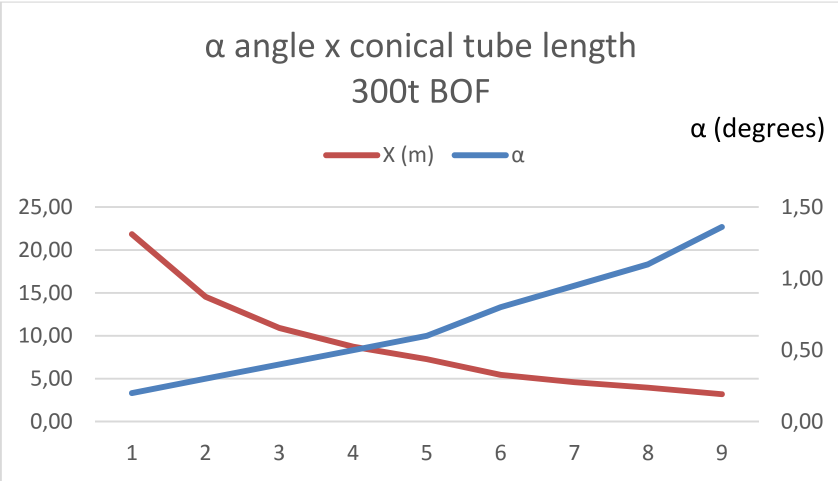

Figure 9 – Influence of conical tube length with α conical angle

A practical data is that the best result is for a smaller BOF (75t) where the α conical angle is very small (α = 0.39, tgα = 0,006807) with a copper tube length of 3.00 m and the skull retention with a frequency of about 600 heats, that means no cleanness is need. Curves in figures 10 and 11 show the differences in velocity and total lance cooling for a conical copper tube of 3.20 m and 5.20 m in a 300t BOF.

The difference of efficiency of total lance cooling is very small. To get a bigger efficiency the tube length must be much longer than 5.20 m, that means, to get an efficiency similar for a 600 heats cleanness frequency (α = 0.39), the length might be 11.20 m long.

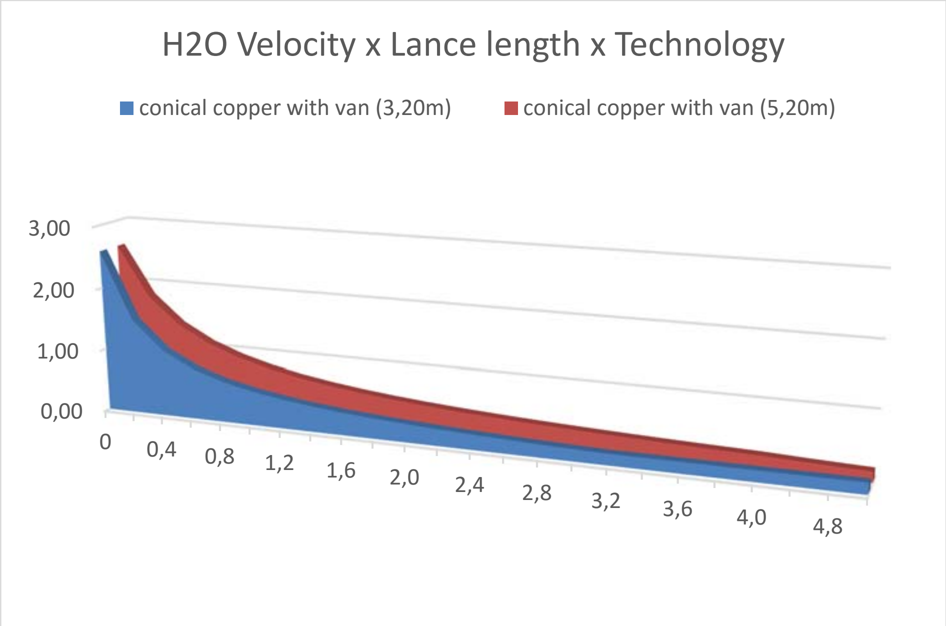

Figure 10 – Comparative curves of conical copper tubes with length of 3.20 m and 5.20 m (velocity)

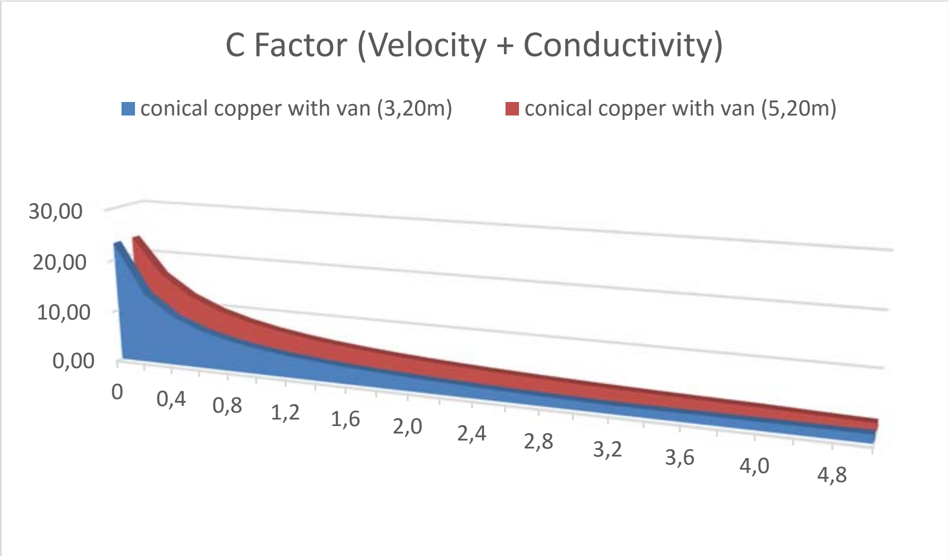

Figura 11 – Comparative curves of conical copper tubes with length of 3.20 m and 5.20 m (Lance total cooling – C Factor)

3.4 Comparison of conical copper tubes with van and length of 3.20 m with SKULLS3®

Related to figure 3 and the calculated curves bellow, the basic difference is in velocity of water OUT (figure 12), as the metal copper is the same. Figure 13 shows the comparison for total lance cooling (C Factor).

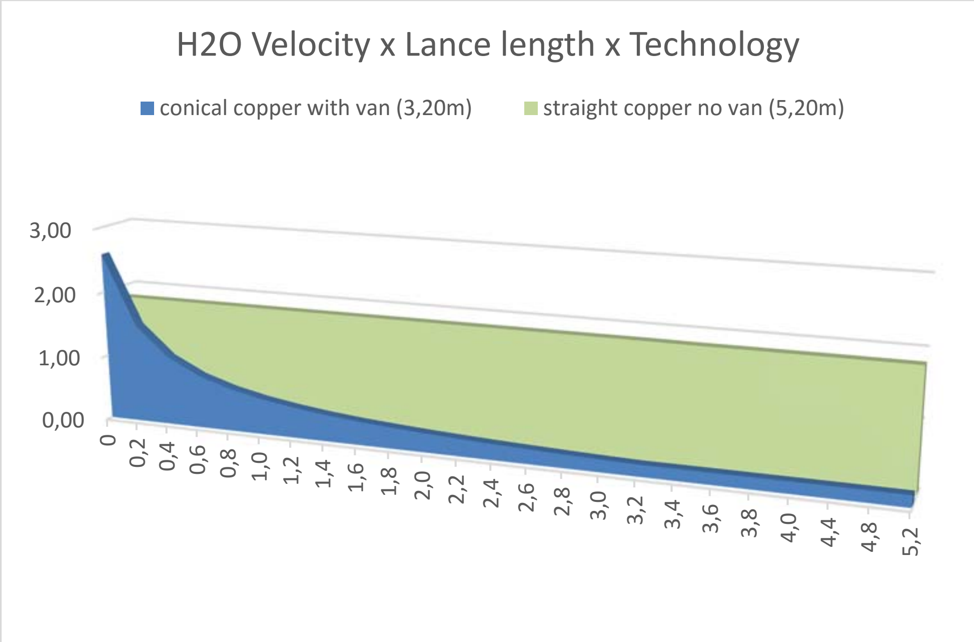

Figure 12 – Comparison of velocity of water OUT for a conical copper tube with van and 3.20 m and a straight copper tube (no van) and 5.20 m

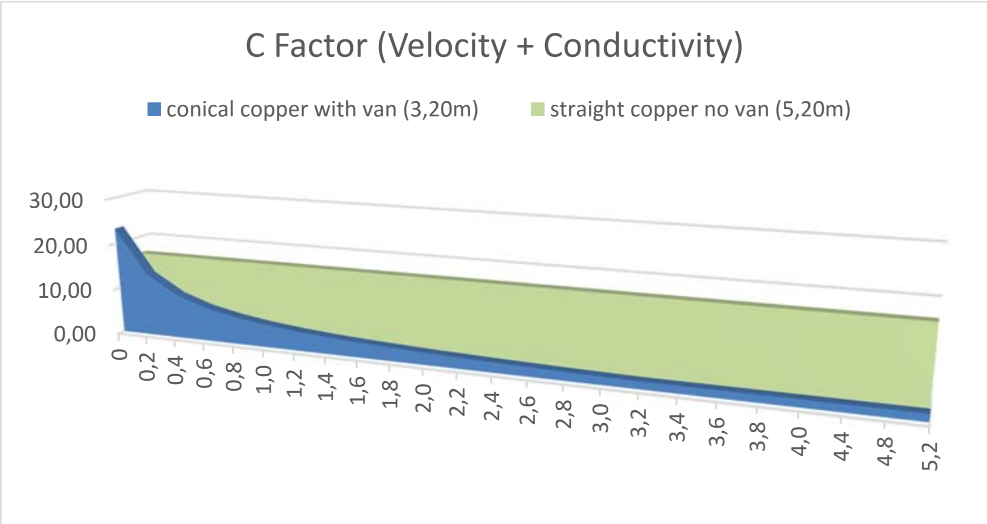

Figure 13 – Comparison of total cooling lance for a conical copper tube with van and 3.20 m and a straight copper tube (no van) and 5.20 m

Beginning from a tip distance of 0.20 m, total lance cooling for straight copper tube (no van) has much bigger efficiency than conical copper tube with van as seen before. In this case α angle is 1.36.

To get a better efficiency in total lance cooling of conical copper tubes, even with van compared to SKULLS3•, the length of conical copper tube has to be much longer than 5.20 m (figure 9), as 11.20 m (α = 0.39) which will have a very high cost.

By getting a comparison of curves, SKULLS3• lance, having pretty bigger efficiency than a conical copper lance (even with van), will have less retention of skulls. By consequence, the expectation is to get no skulls for 400 heats which is equivalent to change only the tip (tip with low erosion on it). The lance will get out for an exchange of tip only and no more because of skulls need for cleanness.

PC module has a life of 2000 heats (same for Cartridge module) and will eliminate skulls in BOF mouth all time long.

Another consequence, as tip cooling is better with copper tubes, the expectation also is to get more metallurgical benefits (with lower height of lance blow at the end of a heat). It is possible to increase the metallic yield and also save the addition of Fe-alloys.

4. CONCLUSION

It is very clear that the velocity of water cooling OUT for straight tubes has pretty more efficiency than for conical tubes. When straight tube is made of copper, the efficiency is much bigger with van and even with no van.
Related to lance total cooling (C Factor), due to higher thermal conductivity of copper, copper tubes lances have bigger efficiency than steel tubes lances.

When it is compared a straight copper tube, SKULLS3•, and a conical copper tube, the straight copper tube lance (even with no van) has much bigger efficiency than a conical copper tube lance with van.
A conical copper tube lance to get an approach to an efficiency of a straight copper tube, it is necessary a very small conical angle (α), and so a conical copper length pretty longer, for the same outer conical diameter, which can become unpractical its competitiveness due to a very high cost.
In phase of a trial, SKULLS3• lance must be validate to:

- no more need to be get out for cleanness, but for tip exchange only.
- no more BOF mouth need to be cleanness, with a PC module, and get the benefit of productivity.
- get more metallurgical benefits (metallic yield and save some addition of Fe-alloys), by an operation with a lower lance height at the end of blow (because the tip life is higher).

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