S. LANDA*, T. RODRÍGUEZ*, J.L. MUÑOZ*, J.J. LARAUDOGOITIA*

DYNAMIC CONTROL OF SLAG FOAMING AT SIDENOR BASAURI MELTSHOP

DYNAMICZNE STEROWANIE PROCESEM PIENIENIA ŻUŻLA W STALOWNI SIDENOR BASAURI

The melting process in the EAF is normally controlled via fixed operating patterns; the aim of this practice is to achieve the optimum conditions at the tapping. Industrial practice indicates that sometimes deviations appear, so it is not uncommon to obtain very high or low C contents at melt-down promoting bad slag foaming conditions, rising electrical consumption and tap-to-tap times. As a consequence the productivity decreases and the running cost increases.

The slag foaming process in the EAF has been studied analyzing process data, such as: EAF electrical consumption, steel oxygen activity, steel and slag composition, temperature, acoustic noise signal, Total Harmonics Distortion (THD) of arc voltage and current.

A dynamic model has been developed, with the aim of controlling the oxygen and carbon injection process in order to achieve the target of composition, O activity and temperature at tapping while maintaining a good foaming quality during the process leading to a lower electrical consumption and tap to tap time. The model starts working after the first C sampling measurement takes places, and from that time it controls the oxygen and carbon injection. This model has been integrated in the plant as part of the EAF automatic control system.

Keywords: Electric Arc Furnace, slag foaming, oxygen activity, acoustic noise, Total Harmonic Distortion, energy efficiency

Wytapianie w piecu łukowym zwykle sterowane jest przy użyciu wyznaczonych modeli; celem tej praktyki jest osiągnięcie optymalnych warunków przy spuście. Praktyka przemysłowa wskazuje, że mogą wystąpić odchylenia w zawartości węgla przy złych warunkach spieniania żużla podczas wytopu, wzrastającym zużyciu energii elektrycznej i czasie wytopu. Konsekwencją jest spadek wydajności i wzrost kosztów.

Proces pienienia się żużla w piecu łukowym zbadany został przez analizę danych takich jak, zużycie energii, aktywność tlenu w stali, skład chemiczny żużla i stali, temperatura, poziom sygnału dźwiękowego, całkowite zniekształcenie harmonicznych (THD) napięcia i prądu łuku elektrycznego. Model dynamiczny został stworzony, celem sterowania procesem wdmuchiwania tlenu i węgla, aby uzyskać odpowiedni skład chemiczny, aktywność tlenu i temperaturę przy spuście przez utrzymanie dobrego spieniania w trakcie procesu, przy niższym zużyciu energii i czasie wytopu. Model zaczyna funkcjonować po pierwszym pomiarze zawartości C i od tego momentu steruje wdmuchiwaniem węgla i tlenu. Model ten został zintegrowany z system automatycznego sterowania piecem łukowym.

1. Introduction

SIDENOR INDUSTRIAL S.L. is a steelmaking company which produces special and stainless steel long products, devoted to a high extent for automotive applications.

Production facilities at Sidenor Basauri plant include electric arc furnace (AC), secondary metallurgy station (two ladle furnaces sharing a vacuum tank degasser and VOD) and continuous casting process followed by direct rolling.

Some of the most important worries for every steelmaking company are energy consumption and productivity, therefore is compulsory to develop an optimum EAF process.

It is known that during the EAF process the foamy slag practice is very favourable, so it is important to make the slag foaming in good conditions [1].

This paper deals with two main items related to slag foaming practice:

– To develop optimum patterns to control oxygen and carbon in melting and slag foaming stages in order

* SIDENOR I+D S.A., BARRIO UGARTE S/N, 48970 BASAURI, SPAIN

to increase productivity and reduce energy electrical consumption.

– To find an optimal combination of control tools (bath/slag, Total Harmonics Distortion and acoustic noise measurement) that assure the quality of the EAF slag foaming stage, integrating the whole process in the EAF control network.

2. Slag foaming process control

At Sidenor Basauri EAF practically all the oxygen and graphite in melting and slag foaming stages are injected through the two wall injectors. A continuous oxygen and carbon injection through the door is only performed if there is a breakdown of the wall injectors.

Production of SBQ in EAF is characterised by the necessity to control oxygen activity at tapping in different ranges depending on steel grade produced. Therefore control of oxygen and C flow rates during the slag foaming stage is of paramount importance because a misbalance between C and O flow rate may lead to over- or undershoot oxygen activity levels in steel bath at tapping, Fig. 1, leading to compulsory final oxidation or reduction processes and, increasing of power off time as outcome [2]. Power off periods during the slag foaming stage lead to higher electrical consumptions and reduction of productivity.

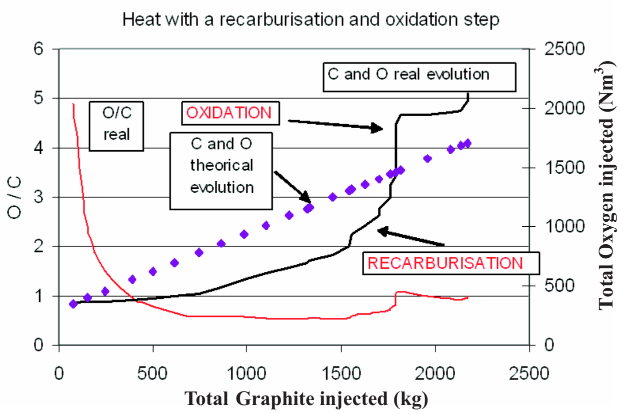

Fig. 1. Evolution of C and O injection in a heat showing unbalances of O/C flow rates producing extra recarburisation and oxidation during the slag foaming stage

Control of C and O in the bath is complicated because standard scraps mix change from heat to heat as it is common practice to cast CC sequences of different steel grades heats.

In order to improve O and C control during slag foaming stage a dedicated heat analysis has been developed to design different approach curves during the slag foaming stage that may lead O and C injection through the injectors. With the knowledge of C content at the initial stages of slag foaming and active oxygen content along the process, optimised C and O flow rate have been calculated for the standard times of the slag foaming stage. Slag sampling has also been used as additional tool.

Initially for the first control of this flow rate C analysis of molten steel is used as a tool. However due to a delay of 3-5 min in sampling chemical analysis and in order to speed up the control of O/C flow rate, an active oxygen Celox measurement will be used at the same time of C sampling to check the effectiveness of these tested O/C patterns. Close to the final of the slag foaming stage further Celox will be introduced in the bath for final approach.

The O/C injection during slag foaming is controlled by three different stages:

– Start of foaming: constant O/C flow rates.
– With 1st Celox / carbon analysis: application of O/C initial flow rate.
– With the following Celox before tapping: final O/C rate.

So, in this way it was defined an initial set of oxygen/carbon patterns for groups of steel qualities defined depending on oxygen activity conditions at tapping Fig. 2.

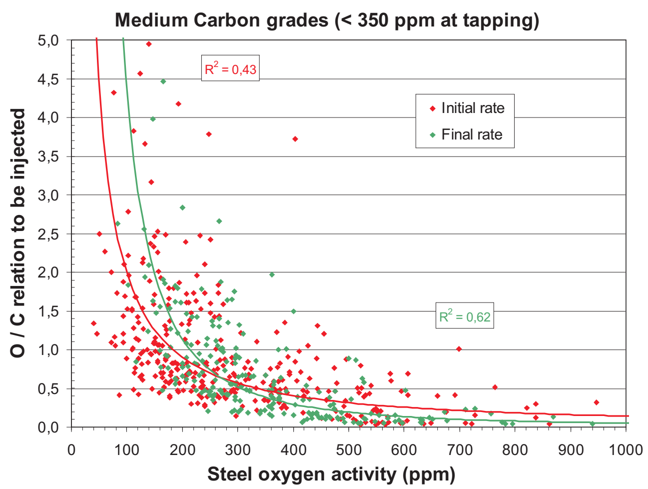

Fig. 2. O/C flow rates approach depending on oxygen activity steel control as calculated for medium carbon steel grades

The objective with this adjusted O/C patterns is to be effective on:

– Reduction of time off periods (oxygen activity adjustment with power off during the slag foaming stage).
– Homogenisation of the foaming stage looking for a reduction of transitories.
– To obtain a better energetic efficiency with influence on power on time.

3. Slag foaming quality assessment

Two different systems for foamy slag quality assessment are available in Sidenor Basauri EAF:

– Acoustic noise. EAF noise is measured via an Acoustic Slag Control ASC System 2000.
– Measurement of total harmonic distortions (THD) of the arc voltages and currents, accomplished with a portable Electric Power Quality Analyser.

These two systems will provide data of the slag foaming in the electrical and acoustic noise aspects which will complement the steel/slag chemical data. Thus, all the three slag foaming detection systems will be available to define the best solutions and optimum parameters to control the quality of the slag foaming stage [3].

In order to accomplish the slag foaming behaviour assessment, different approaches are being developed with ad hoc industrial heats process design:

– An initial set of O/C patterns has been defined for different groups of steel selected grades, depending on oxygen activity level at tapping.
– Definition of "indexes" for slag foaming behaviour assessment.
– Studies of the slag foaming steady state in which analysis of relationships between O/C injection rates and noise signals and harmonics are being looked for. Influence of chemical conditions and FeO in slag will also be considered.

Acoustic noise as slag foaming quality assessment

Interpretation of acoustic noise index non steady behaviour during the slag foaming stage (main cause, duration, type of signal...) gives information about process development.

Without a continuous chemical analysis of slag/steel it is difficult to avoid in certain cases the appearance of disturbances which may have duration of more than a minute. However, sometimes the increase of noise index is high (>10); and being generally its cause evident the EAF operators are able to stabilize slag foaming whenever injection conditions are restored. Due to no knowledge of on-line continuous C in steel, a possible automation of this stage is a difficult task.

Main transitories found are related to disturbances of the optimum oxygen/carbon patterns due to different situations. Normally a standard O/C practice of injection is performed since the moment of slag foaming start, but this practice may change due to each heat particular case. Fig. 3 shows a noise transitory (increase of noise index) due to stop graphite injection.

Non optimised O/C flow rate patterns can also affect steels with high C content at meltdown. For example Fig. 4 plots an increase of noise originated due to a sudden increase in the graphite injection flow rate which affected optimum O/C relation.

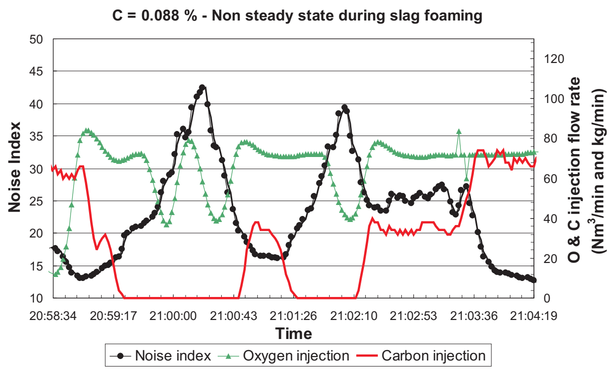

Fig. 3. Noise transitory in slag foaming stage depending on graphite injection

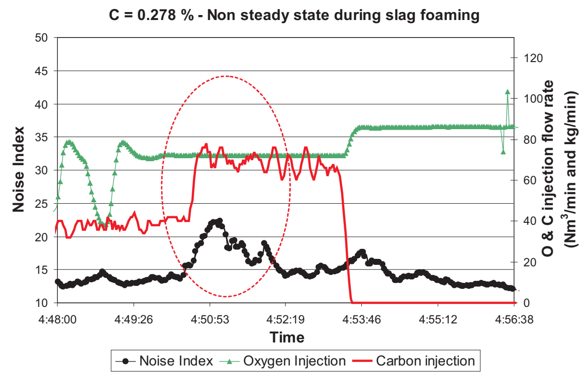

Fig. 4. Increase of noise originated due to sudden increase in the graphite injection flow rate

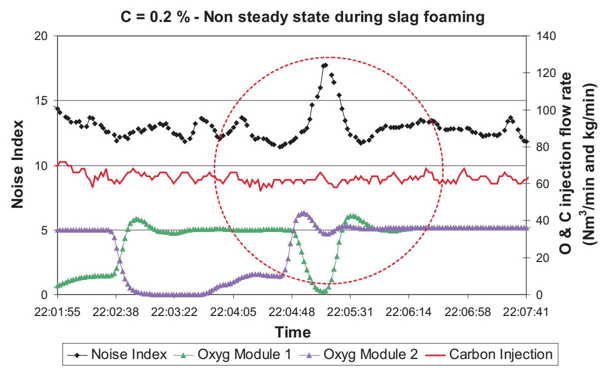

Fig. 5. Peak in noise index observed due to several operations of opening/closing of the primary oxygen injection of the modules in a short time

Operational practice with the injectors can also promote transitories in slag foaming. It has been detected that operations of aperture/closing of primary oxygen injection of injectors may create peaks in noise. This effect seems to affect more in heats with high C content, as an example, Fig. 5 shows noise peaks observed due to several operations of opening/closing of the primary oxygen injection of the modules in a short time.

Total Harmonics Distortion (THD) (V, I) as slag foaming quality assessment

In order to evaluate the possibility to use THD as a tool to assess slag foaming behaviour a group of heats were devoted. A continuous measurement of THD of the arc voltages and currents was done, accomplished with a portable Electric Power Quality Analyser.

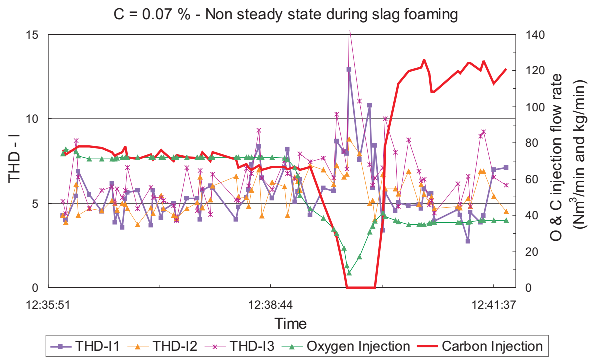

Fig. 6. Intensity THD transitories observed in the three phases during slag foaming stage due to a stop in oxygen and graphite injection

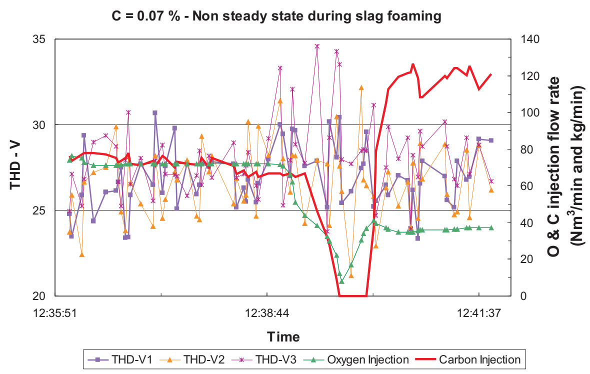

Fig. 7. Voltage THD distortion transitories observed in the three phases during slag foaming stage due to a stop in oxygen and graphite injection

According to trial results instabilities on slag foaming gave as result higher level of THD. It is shown in Fig. 6 and Fig.7 the effect in THD (I and V) of the interruption on oxygen and graphite injection.

Relationship between acoustic noise index and Total Harmonics Distortion (V, I)

Two different trials campaigns were designed with very different production electrical parameters in order to highlight differences. Considering all the heats of the sampling campaigns, good relationship have been found among THD V, noise index and THD I as shown in Fig. 8 (slag foaming stage), higher levels of THD V/I are related with higher acoustic noise as well as lower values of THD V/I correspond with low level of acoustic noise.

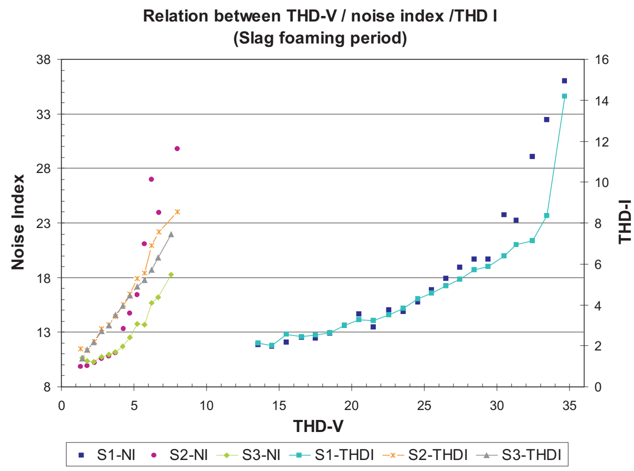

Fig. 8. Relationship observed among THD V, noise index and THD I

The same relationship between items of slag foaming assessment have been found in analysis of the whole heat as it is seen in Fig. 9.

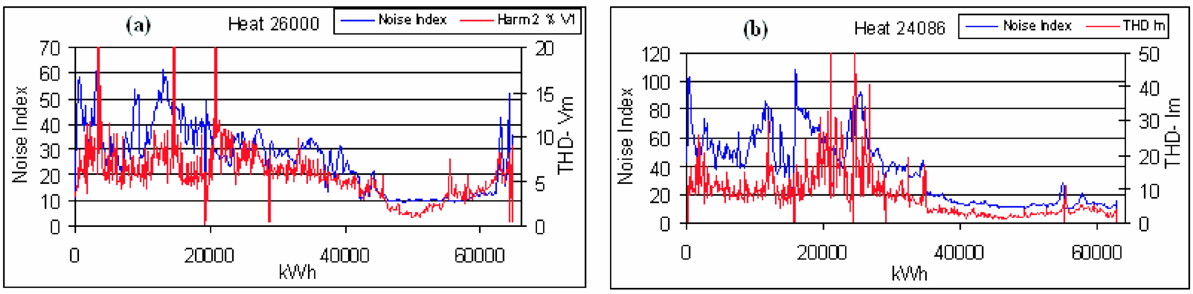

Fig. 9. Relation between noise index / THD-Vm (a) and between noise index / THD-Im (b)

4. Automatic foaming slag injection system

At the Sidenor AC EAF, O/C patterns defined were used to develop an automatic slag foaming injection system, fully integrated in the EAF control network. This system follows a multi-pattern oxygen and carbon flow rate control approach.

For slag foaming injection system the following control functions have been considered:

– Four different target values of bath oxygen activity levels at tapping will determine the slag foaming O/C injection flow rate patterns.
– From the first stage of slag foaming up to the moment of an initial sampling (C or oxygen activity), a fixed O/C pattern will be used.
– After each measurement of O activity, a designed multi-pattern O/C injection will be used.

Software and hardware for the automatic oxygen and carbon injection during slag foaming were installed, Fig. 10. Trials were performed to verify the system behaviour in industrial operation testing the multi-flow rate oxygen and carbon injection tables vs. standard conditions.

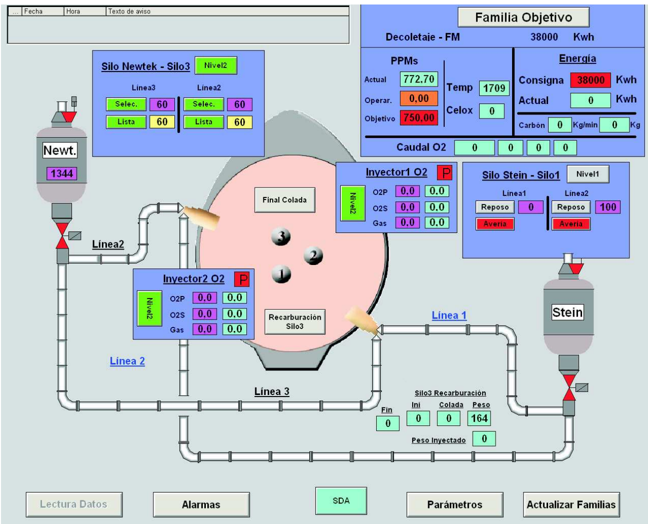

Fig. 10. Software for the automatic oxygen and carbon injection during slag foaming

The system integrated in the EAF control network follows a multi-pattern oxygen and carbon flow rate approach. The system control is based on:

– Target of steel oxygen activity level at tapping
– Oxygen activity / C measurement via Celox / sampling
– Electrical energy consumption
– Bath temperature
– Celox validity
– Adaptability to particular operation of C feeder bins, injection points and oxygen injection modules.

Depending on the EAF process stage and the oxygen activity, an optimised O/C approach is selected to reach a fixed range of oxygen activity at tapping depending on the steel grade produced. Data were collected for evaluation of the injection control system. The acoustic noise signal for slag foaming detection is used for checking the slag foaming quality.

Figure 11 shows the O/C injection control during the slag foaming stage of a heat with an oxygen activity aim value at tapping below 200 ppm, in which oxygen and carbon flow rates are controlled by the system depending on the oxygen activity measurement and the noise index of the heat during the slag foaming stage.

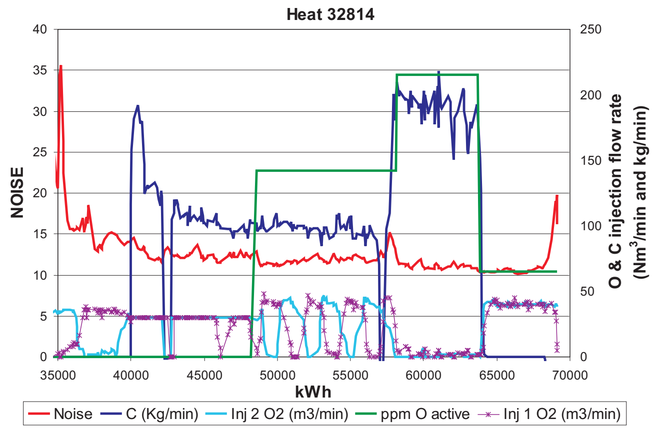

Fig. 11. Automatic O/C injection control which modifies flow rates depending on oxygen activity measurement during the slag foaming stage

The performance of the automatic vs. manual control of the standard O/C injection was compared. Automatic control showed an improvement of the main EAF parameters like power-on, power-off times and electrical consumption, Table 1. Power-off time was improved due to a reduction of stops needed for oxidation or recarburisation of the bath in final adjustment of oxygen activity at tapping. Furthermore there was an improvement of the noise indexes in the foaming slag stage.

Besides integration of the noise signal in the automatic system allows to reduce certain noise peaks that take place during slag foaming especially due to:

– No C injection assigned by the O/C programme when there is a very low O activity (high C content) in the bath. The noise signal determines if some C injection is needed.
– Unpredicted C / Non reliability of Celox measurement.

The use of several electrical programmes during the slag foaming stage in EAF have been monitored with the use of noise index signals as reference control. The objective was to define a stable programme for maximum active power / reduced power-on time with optimum noise index.

TABLE 1

Average EAF operational parameters and acoustic noise index with automatic and manual control of O/C ratio

	Power on (min)	Power off due to de-C or oxidation (min/heat)	Electrical consumption (Kwh)	Noise index	
				Average	Standard deviation
Automatic system	51.2	0.7	65121	12.3	4.2
Manual system	52.8	1.2	67023	14.4	6.4

TABLE 2

Average active power, noise indexes and average power on time for trial heats with different electrical programmes used during the slag foaming stage

	Active Power (MW)		Powern on (min)		Noise Index	
Electrical programme	Average	Stand dev	Average	Stand dev	Average	Stand dev
Tap 4 based	71.7	6.1	55.1	4.5	19.2	7.3
Tap 5 based	72.4	6.2	52.8	4.0	15.5	5.1
Tap 6 based	73.3	4.9	51.0	3.5	14.4	3.8

A certain average increase of the noise index was detected, which could be associated to the use of electrical programmes not optimally adapted for the EAF slag foaming conditions.

Trials have demonstrated the usefulness of the acoustic noise signal as a reference helping tool to obtain a better adapted electrical programme during the slag foaming stage, Table 2. In fact programmes with reduced voltage (maintaining average current) during the slag foaming stage gave a higher average active power during slag foaming, and a total reduction in power-on time, due to a more homogeneous behaviour of the slag foaming stage.

5. Conclusions

- Depending on the EAF process stage and the O activity, an optimised O/C approach is selected for the slag foaming period to reach an O activity at tapping depending on the steel grade produced.
- Noise index can be used as a qualitative/quantitative parameter of the slag foaming behaviour and its effect on EAF operational parameters and especially in electrical consumption and power on time.
- Relationships have been found between THD V, THD I and noise index for slag foaming and heat power on stages. Harmonics frequency analysis (V or I) could give a good complementary approach to noise index for slag foaming behaviour analysis.
- Noise index and THD transitories during slag foaming have been associated to unbalances of O/C flow rates in different steel C content and EAF operational performance.
- A basic integration of the noise signal in the automatic system has been implemented. Industrial practice has demonstrated the usefulness of the sonic signal as a reference helping tool to obtain a better slag foaming quality as well as adapted electrical programme for this period.

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