**The important role of the oxygen gun in the oxygen furnace**

Oxygen Blowing Guns and their Role in Basic Oxygen Furnaces

In Basic Oxygen Furnace (BOF) steelmaking， a water-cooled lance is used to inject a high velocity (supersonic) stream of oxygen into the liquid melt pool for refining. The speed or momentum of the oxygen injection results in the penetration of the liquid slag and metal to promote oxidation reactions in a relatively small area. The speed and penetration characteristics of the oxygen jet are a function of the nozzle (lance head) design.

The top blow gun oxygen jet of a blast furnace converter is the source of oxygen input and the source of energy for stirring the metal liquid in the molten pool. The main phenomena involving the BOF converter are the formation of cavities due to the physical interaction between the oxygen jet and the liquid metal， the stirring of the liquid metal， the generation of spit and dust， and the afterburning of CO gas produced by decarburization and reaction with oxygen. In order to optimize the operation of the converter and to control the above mentioned phenomena， different devices and improvements have been made in the design and operation of the top-blow lance. Examples of these include the use of Laval nozzles capable of efficiently converting pressure energy into jet flow energy to facilitate the stirring of liquid metal， and the use of multi-hole lances to enable high speed oxygen delivery while suppressing spitting and dust generation by dispersing the oxygen jet.

With the introduction of combined blowing in the BOF converter， the role of the top blowing lance jet as a source of energy for stirring the liquid metal iron was reduced and the flexibility of design and operation was significantly improved.

The primary reason for blowing oxygen into the liquid bath is to remove carbon from the bath to endpoint specifications. As a result of oxygen blowing， the primary reaction that results is the removal of carbon from the bath to CO. This is an exothermic reaction that adds heat to the system. Small amounts of carbon dioxide (usually less than 10%) are also produced as this carbon dioxide reacts with oxygen in the converter and burns (called afterburning). Other reactions that occur as a result of oxygen blowing are the oxidation of other elements such as silicon (Si)， manganese (Mn) and phosphorus (P). These elements are oxidized and absorbed into the slag layer. These reactions are also exothermic， further contributing to the heat required for the liquid bath and raising the temperature of the bath to the desired level. The oxidation of silicon is particularly important because it occurs early in the oxygen blowing process and the resulting silica combines with the added lime to form the liquid slag. The oxidation reactions that occur due to oxygen blowing are given below. The free energy change of the reaction (given in parentheses) at 1600 degrees C is given in kcal/mol.

C + 0.5 O2 = Co (- 66)

2CO + O2 = 2CO2 (- 57.4)

Si + O2 = SiO2 (-137.5)

Mn + 0.5 O2 = MnO (-58.5)

2P + 2.5 O2 = P2O5 (-148.5)

The oxidation reaction occurs in the impact zone of the oxygen jet. This impact zone is called the cavity and is created by the impact of oxygen. The depression in the liquid bath is a function of the momentum or thrust of the oxygen jet and is calculated by the following equation

F = W (Ve/g)

where F is the force， W is the mass flow rate， Ve is the exit velocity， and g is the acceleration of gravity. The jet thrust and impact angle were optimized by designing the nozzle of the oxygen gun to achieve the desired chemical reaction and bath agitation.

The nozzle of the oxygen gun is designed for a certain oxygen flow rate， usually in N cum/min， producing a certain exit velocity (Mach number) with the required jet profile and force to penetrate the liquid slag layer and react with the liquid metal bath in the cavity region.

The high-momentum oxygen jet leaves the Laval nozzle exit at approximately twice the speed of sound. The characteristic parameter is the Mach number， which represents the ratio between the local gas velocity and the speed of sound. Due to the expansion inside the nozzle， the oxygen cools to about -100 degrees Celsius on its way to the nozzle exit， thus concentrating the cooling of the nozzle in both water and oxygen.

A Laval nozzle consists of a convergent inlet and a divergent outlet duct. The term often used is convergent-divergent (CD) nozzle. Supersonic jets are generated with convergent/divergent (Laval) nozzles. A stagnant oxygen reservoir is held at pressure， Po. The oxygen accelerates in the converging section and reaches the speed of sound (Mach number = 1) in the cylindrical throat region. The oxygen then expands in the divergent section. The expansion reduces the temperature， density and pressure of the oxygen and the velocity increases to supersonic levels (over Mach 1).

As the oxygen jet leaves the nozzle and enters the BOF converter， it spreads and decays. A supersonic core remains at a certain distance from the nozzle. The supersonic jet spreads at the angle of the Laval nozzle， usually in the range of 10 to 16 degrees， but rising to 23 degrees in some gun nozzle designs.

Proper nozzle design and proper operation are both necessary to effectively produce the desired steelmaking response and to maximize gun life. If the nozzle is blown too far， meaning that the oxygen jet does not fully expand as it leaves the nozzle， shock waves will be generated as the jet expands outside the nozzle. Useful energy is lost in these shock waves， and an over-expanded jet impacts the liquid metal tank with less force than an ideally expanded jet.

When the oxygen jet expands to equal the surrounding pressure and then stops expanding before leaving the nozzle， the nozzle is underblown. In this case， the oxygen stream separates from the inner surface of the nozzle. The hot gas from the BOF converter then burns back or erodes the exit area of the nozzle. This erosion not only reduces the life of the gun nozzle， but also leads to a loss of jet force， resulting in a soft-blow condition. Figure 1 shows the mechanics of supersonic jet formation as well as the overblow and underblow conditions.

Fig. 1 Mechanics of supersonic jet formation and conditions of over-blow and under-blow

The main components of BOF's oxygen gun include the oxygen inlet fitting， the oxygen outlet (gun head)， which is designed from highly thermally conductive cast/forged copper with precisely machined nozzles to achieve the desired flow rate and parameters of the oxygen jet. The gun tube is a series of concentric tubes consisting of an outer tube， an intermediate tube and a central tube for oxygen supply. The oxygen lance is designed to compensate for thermal expansion and contraction. The lance's outer tube is exposed to the high temperatures of the converter. As the temperature rises， it expands. The entire internal structure of the lance uses O-rings and various joints， but can accommodate thermal expansion and contraction during use. The lance also has to have a stress-free design， and it must be built with the construction quality of a steel mill so that it can withstand the normal operating conditions of a steel melting shop.

Cooling water is necessary in the lance to prevent it from burning up the oxygen lance in the BOF converter. Both the copper gun nozzle and the steel gun are cooled by circulating water at a pressure of about 6 kg/cm2. An important component of the gun is the water cooling channel， where the cooling water flows through the center of the nozzle and out through the outer tube of the gun. It is designed to obtain the maximum cooling water velocity in the nozzle area， which is exposed to the highest temperatures.

It is important to design the Laval nozzle for the oxygen gun so that the process variables during blowdown are consistent with the design parameters. When the nozzle is operated at a higher inlet pressure than the design pressure， the blowdown jet is simply inefficient. When nozzles are operated at lower inlet pressures， they are worn out quickly and the supersonic jet is inefficient.

Factors Affecting BOF Gun Performance

There are many factors that affect the performance and efficiency of an oxygen gun. The performance of the gun depends on the conditions present in the furnace. The Si content in the hot metal is a very important parameter. This affects the amount of slag formed and the amount of slag that must be penetrated by the oxygen jet， and also controls the amount of tilt in the furnace. The operating height of the gun is also very important and it is necessary to include it in the nozzle design calculation. If the height of the gun inside the furnace is too low， then it is exposed to extremely high temperatures. In this case， the heat transfer from the cooling water is not sufficient to keep the surface of the gun from melting or burning off prematurely. If the height of the gun is too high， the thrust of the oxygen jet becomes less， the refining time of the liquid bath becomes longer and more oxygen is required to achieve the necessary decarburization and bath temperature. Oxygen flow rate is a design parameter that is sometimes limited by the oxygen supply system， and/or emission problems. The Mach number exit velocity is also a factor used when designing the gun. Oxygen injection is usually more vigorous if the Mach number value is higher.

The number of nozzles and the angle of the nozzle holes are also important considerations for oxygen guns. In the early stages of the development of the BOF steelmaking process， single-nozzle guns were used that blew directly into the liquid bath. This caused a large amount of tilting and the liquid material was sprayed directly onto the converter nozzle. Slightly angled three-hole nozzles were developed to minimize tilting and thus achieve high process yields. Many BOF converters are now using guns with 4， 5 or 6 nozzle configurations.

The impact area is a function of the number of nozzle holes and the nozzle angle. The following will compare the effect of increasing the number of nozzles and the nozzle exit angle on the impact area in the liquid bath for oxygen lances with 3-hole nozzles， 4-hole nozzles and 5-hole nozzles. For this comparison， the oxygen flow rate is considered to be 565 ml/min. The impact area of the gun is 1.41 m2 for a 3-hole nozzle with a 12 degree angle， 1.52 m2 for a 4-hole nozzle with a 12 degree angle， 1.61 m2 for a 5-hole nozzle with a 12 degree angle， and 1.67 m2 for a 5-hole nozzle with a 14 degree angle.

As the nozzle angle increases， more lateral force components are generated rather than vertical force components. This contributes to more stirring and agitation in the liquid bath of the BOF converter. However， if the lateral component of the oxygen injection is too high， higher refractory wear can occur.

Factors affecting nozzle life

A longer lance life is beneficial for the economic operation of the converter. However， in normal converter operating practice， many individual parameters have an influence on the process， such as hot metal chemistry， slagging method， lime quality， lance pattern， dynamic or static lance control， oxygen supply pressure limitations， and the shape and volume of the converter. These factors also vary considerably from plant to plant， so only general rules can be given based on more or less ideal working practices to describe the general relationship between converter process parameters and lance nozzle life.

The most vulnerable part of the nozzle is the so-called nozzle head crown， which is exposed to temperatures above 2000 degrees Celsius during use. Therefore， the nozzle crown must be made of copper with a conductivity close to 100%. Typically， only forged copper can provide such high conductivity. Due to the limitations of casting， the minimum conductivity of cast copper gun nozzles is usually around 90%. Electrical conductivity is directly proportional to thermal conductivity.

Gun life varies from shop to shop and depends on various operating methods. Typical gun life may be 200 cycles， but there are some shops that have guns that last up to 400 cycles. There are also some steel melting shops that do not even reach 100 heats. Cooling water is critical to maintaining a high gun life. The flow rate must be maintained at the design rate. The outlet temperature of the cooling water should not exceed 60 degrees C to 65 degrees C. Water quality is also an important parameter. If the water is contaminated with oxides or dirt， deposits will typically form in the gun piping and nozzle， negatively impacting heat transfer， which will reduce gun life. The operating height is critical to achieve penetration of the oxygen jet in the liquid bath. However， if the nozzle height is too low， there is a risk of erosion or melting of the nozzle face of the nozzle.

Insufficient blowing of the BOE converter can lead to erosion of the nozzle outlet and failure of the lance nozzle. Excessive floating ash on the nozzle needs to be removed mechanically or burned off. Both of these practices can cause damage to the nozzle.

The service life of the gun is influenced by two factors.

For oxygen blowing， the static pressure that is important to the gun nozzle design is adjusted at the valve station rather than at the nozzle inlet. This creates the volume flow of oxygen required for metallurgical reactions. The pressure loss between the valve station and the gun nozzle， due to friction and deflection losses， is an unknown. The pressure loss is usually between 0.3 kg/cm2 and 1.5 kg/cm2， depending on the geometry of the oxygen line. In order to design the nozzle， the pressure loss is estimated and the inlet pressure is determined. It is not easy to calculate the true pressure loss theoretically， because a compressible pressure loss calculation covering all gas network components is required. For the design and for the static pressure in the converter， the inlet temperature is also necessary， which is also unknown. Therefore， the process variables required for nozzle design are considered to be approximations. If the nozzles operate in a different mode than originally designed， they can quickly show signs of wear. In addition， the blowing conditions become unstable and ineffective.

During BOF converter operation， specific process variables may be changed by the operator in response to unforeseen events (liquid metal and slag slipping out of the converter， pressure fluctuations in the oxygen network， addition of cooling ore during the main blowing stage) and current process events (sampling through the sub lance during blowing operation). Accordingly， the nozzle flow differs from the ideal design conditions for a more or less long period of time. Inside and outside the nozzle， complex and undesired flow patterns， called diamond ripples， appear in the form of compression and/or expansion waves， which lead to wear of the nozzle edges.

New Developments in Kyocera Guns

The first recent development is the post-combustion gun. Since 90% of the gas produced by the melt pool oxidation reaction is carbon monoxide， it is desirable to burn this carbon monoxide further to form carbon dioxide. This reaction is highly exothermic and brings additional heat to the steelmaking process. This is a practice being used in some converter shops with a high ratio of scrap to hot metal. This practice requires a dual flow oxygen lance which has two oxygen outlets. In such a lance， the main oxygen supply is distributed through the lance tip， similar to a conventional lance， while the auxiliary oxygen is controlled separately and blown out at a high point in the converter. The auxiliary oxygen serves to react with the carbon monoxide flowing from the liquid metal bath， thereby generating additional heat that can be used to melt more scrap and help control slag buildup at the mouth of the converter.

A second recent development in oxygen lances is for sputtering a protective layer of slag containing high concentrations of magnesium oxide onto the walls of BOF converters. This process is often referred to as slag sparging. This is done after the steel has been tapped out of the converter and the residual slag is left in the converter. The composition and temperature of the residual slag are then regulated. The two parameters slag composition and slag temperature are important parameters for successful slag sparging. The oxygen supply is switched off and the nitrogen supply is switched on. The sparging gun is lowered to a position about 1 m from the bottom of the converter. The nitrogen is then turned on and the liquid slag is sputtered onto the converter wall， forming a protective slag coating on the refractory. This slag coating has been successful in increasing the typical refractory lining life to over 20，000 heats per shot. In addition， the shelling requirement has been reduced to less than 0.5 kg per ton of molten steel.