Iron Making and Steel Making
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Module – 08
Lecture – 39
Homogenization and gas stirred ladle

In this lecture we will discuss about bath homogenization by gas stirring. Basically, the gas stirred ladle is used to homogenize the bath to remove thermal and compositional stratification.

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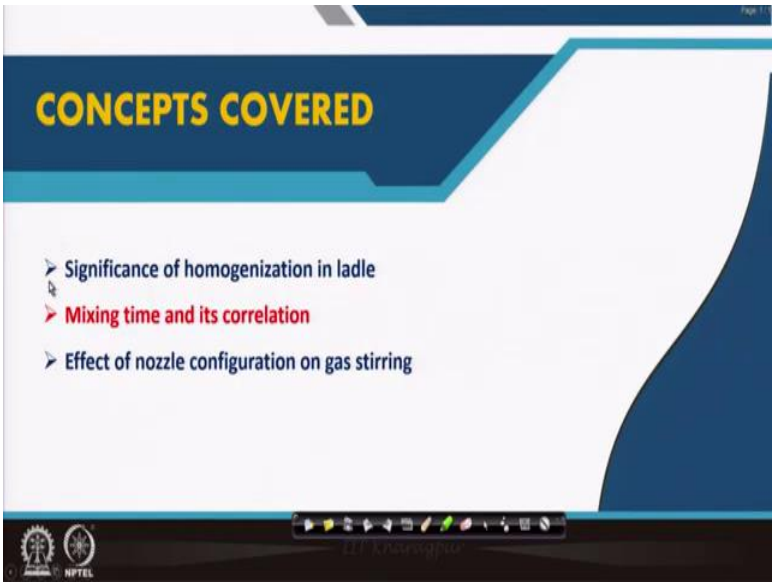

The topics covered will include the importance of homogenization in ladle, followed by characterization of bath mixing by mixing time and its correlation and finally the effect of nozzle configuration on gas stirring in the bath.

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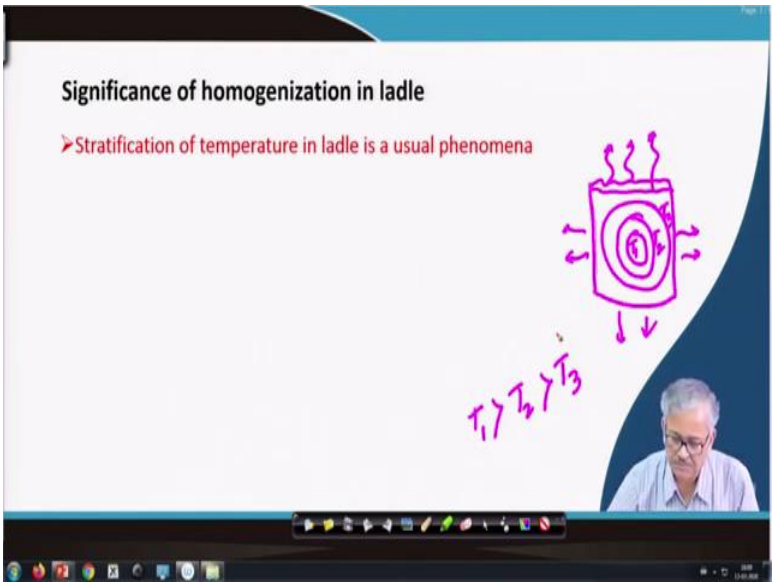

Why homogenization in the ladle is important? By homogenization, we mean both thermal and compositional homogenization. Stratification of temperature in ladle is a usual phenomenon. Liquid in ladle remains in transit for a long time before it reaches to the caster. Heat is continuously lost through surface walls by convection and from mouth by radiation, developing some temperature stratification with maximum temperature at the core of the liquid and minimum near the ladle wall. So, we need to get rid of this variation in the liquid temperature before it is put into caster. High speed casting like continuous caster cannot withstand variation in the bath superheat. Variation of superheat has to be adjusted with heat extraction rate through mold wall; but mold is designed with heat extraction at a fixed rate commensurate with fixed superheat and casting speed.

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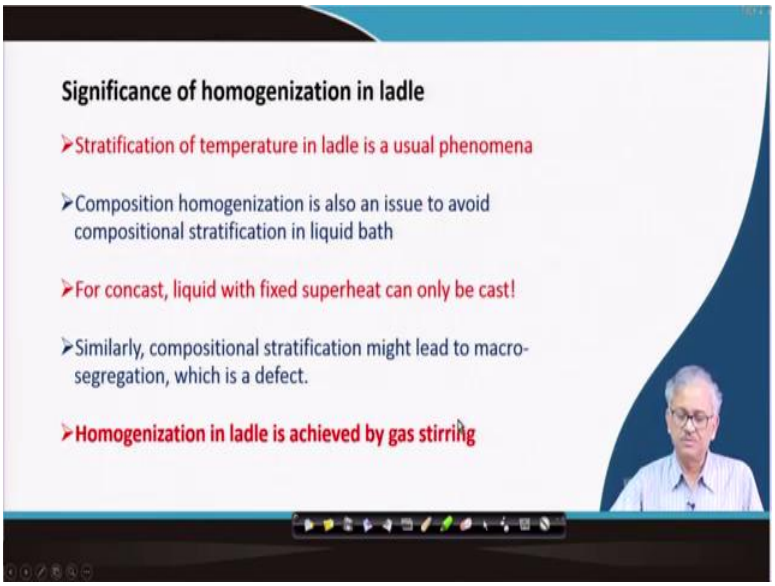

So, stratification of temperature in the ladle is a usual phenomenon. Also the compositional homogenization is also an issue to avoid compositional stratification in liquid bath during alloying. Such stratification will promote segregation and precipitation during solidification. Therefore homogenization of the bath both thermally and compositionally is an important issue.

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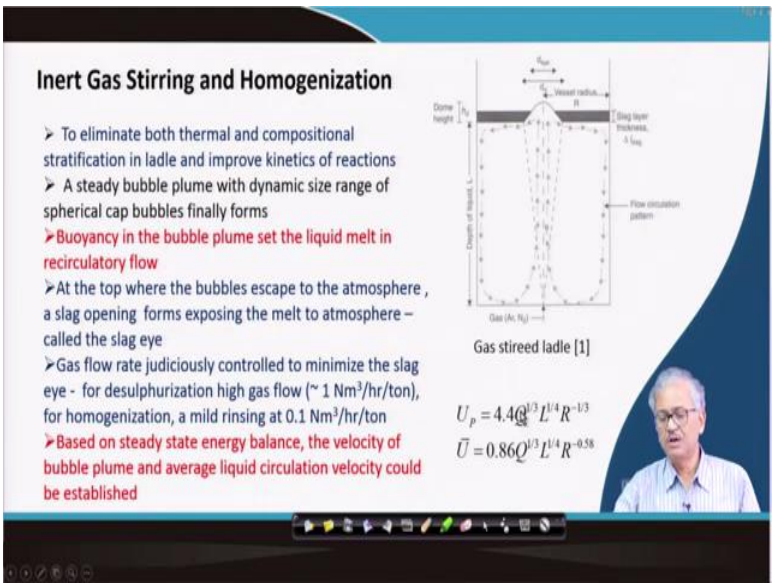

Inert gas stirring is usually done to mitigate stratification and homogenize the liquid bath. Gas stirring is done by purging inert gas from the bottom of the ladle. After some time of

onset of bubbling, a steady state bubble plume with a dynamic size distribution of the spherical cap bubbles is achieved. During gas purging, bubbles are generated at the nozzle and during their ascent there is a continuous breakup and coalescence of the bubbles and finally, forming a dynamic equilibrium between breakup and coalescence and a fixed bubble size distribution is obtained in the bubble plume under steady state.

Buoyancy in the bubble plume sets the liquid melt into recirculatory flow. Bubble plume may be conceived as a region of lower effective density due to presence of large amount of gas in the form of gas bubble; while outside liquid is heavier in absence of bubble. This sets the driving force for liquid movement; plume region being lighter rise up and the surrounding liquid being heavier sink.

Bubbles finally escape to the atmosphere by breaking the slag layer, where the liquid metal get exposed to the ambient atmosphere; the exposed surface of the slag layer is called the plume eye. So, slag eye is not a good idea and always attempt is made to reduce slag eye; increase in the gas flow rate, increases the slag eye.

So, gas flow rate from the bottom should be judiciously used. Obviously, higher gas flow rate intensely stirs the bath; and in some cases it is also required. For example, in case of desulphurization using synthetic slag, high bath stirring (~ 1 Nm^3/hr.ton) favors kinetics of desulphurization. However, in case of the homogenization of the temperature and composition a mild stirring (~ 0.1 Nm^3/hr.ton) is sufficient, which also will keep the bubble plume eye to a minimum.

Based on the steady state energy balance, the velocities of the bubble plume and liquid recirculation could be estimated using some empirical correlations obtained from laboratory scale simulation experiments.

$$U_P = 4.4 Q^{1/3} L^{1/4} R^{-1/3} \tag{39.1}$$

$$\bar{U} = 0.86 Q^{1/3} L^{1/4} R^{-0.58} \tag{39.2}$$

Where, Q, L and R are the gas flow rate ($Nm^3/hr.ton$), length and radius of the vessel, respectively.

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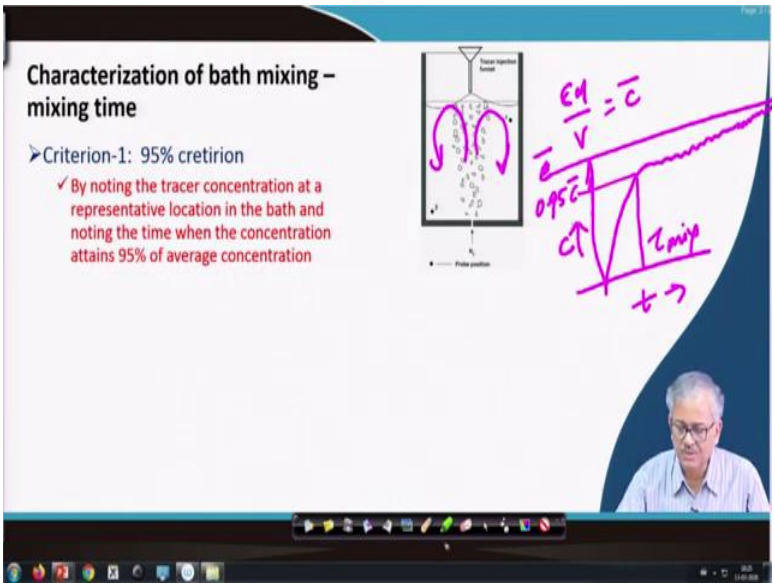
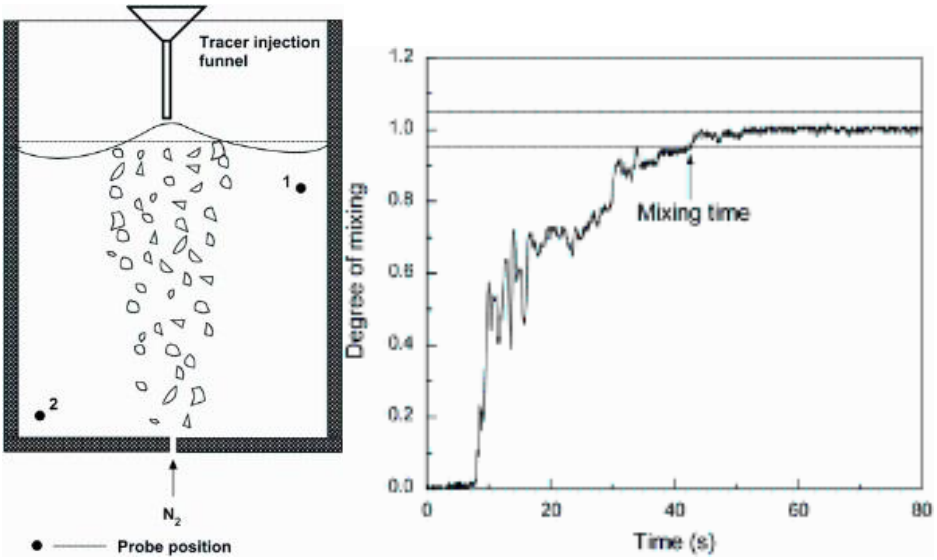


Now, it is required to device a parameter to measure the extent of mixing in a liquid bath. Usually, mixing time is used as a yard stick to measure the extent of bath mixing.

Theoretically, mixing time means the time at which the bath will attain uniform average composition everywhere. It is usually measured by putting some tracer in a moving liquid bath and monitoring the concentration of the tracer at a certain representative location or at several locations in the bath.

There two criteria to measure the mixing time. The first one is called the 95% criterion; where tracer concentration at a representative location is measured and noting the time when the 95% of the average concentration is achieved (Figure 39.1). In fact attaining 100% average concentration at a certain location takes infinite time; whereas 95% of average concentration may be attained at a reasonable time, which basically represents the process kinetics.



(a) **(b)**

Figure 39.1: (a) Positions of tracer monitoring (b) evolution of tracer concentration with time [1]

The probe positions are mentioned in Figure 39.1(a). Concentration can be monitored at the point 1 and 2. Obviously the location 2 lies in a dead zone near the vessel corner and it does not represent the overall vessel mixing time; rather location 1 is moderately stirred and can represent the vessel mixing time. However if one want to know the maximum mixing time point 2 can be monitored. Figure 39.1(b) represent the tracer concentration evolution at location 1. It is found that 95% of average concentration is achieved by 40 seconds and thereafter concentration becomes almost steady. Therefore 40 seconds may be considered as the mixing time. If we take the average of two mixing times at locations 1 &2, the resultant mixing time might represent a time which is much higher than a mixing time representative of the most of the reactor space.

The second criterion is defined in such a way that several location can be taken into account to represent an average mixing time. The second criterion is called the mixing intensity criterion where the rate of change of concentration is measured at several locations and average rate of change of concentration is noted and the time when such value goes below 1 %, is declared as mixing time (Figure 39.2).

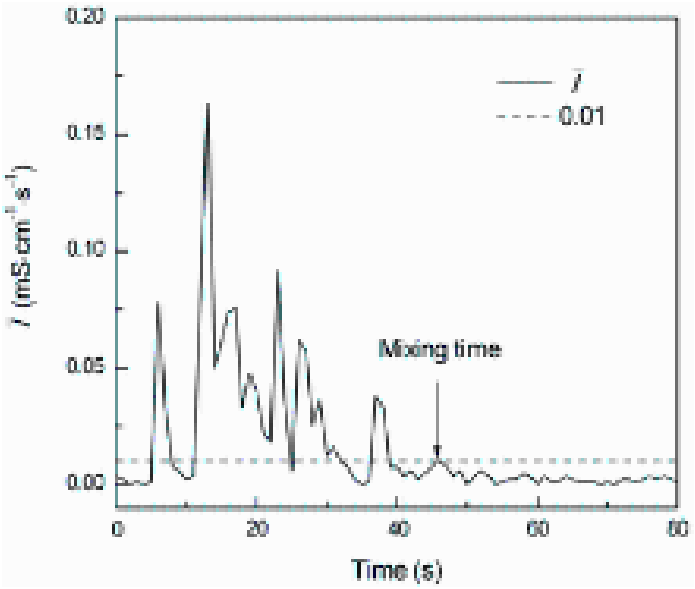


Figure 39.2: Evolution of average rate of change of concentration with time[1]

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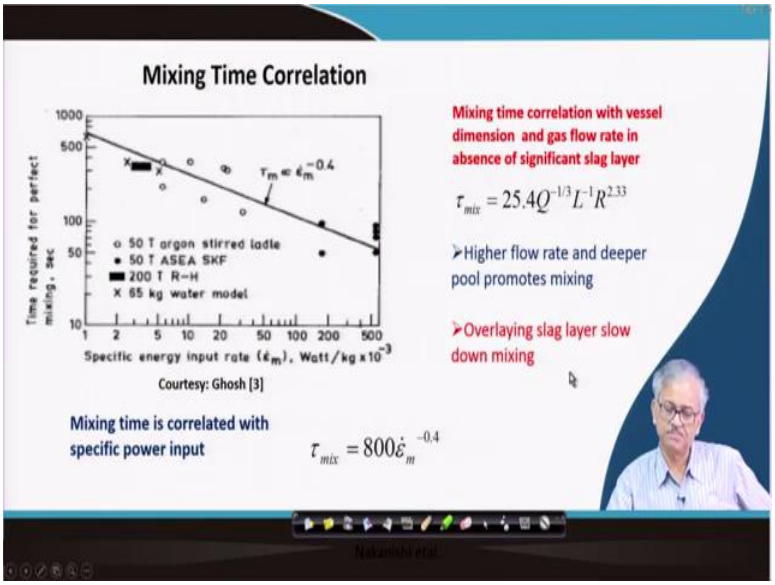

Once we have defined the mixing time, it is equally important to define the mixing time correlation with operating parameters of gas stirred ladle.

There are some semi-empirical correlation base on laboratory scale physical simulation experiments (Equation 39.3). Such experiments are carried out in scale down model in laboratory using low temperature analogues water and mineral oil for steel and slag, respectively.

$$\tau_{mix} = 25.4 Q^{-1/3} L^{-1} R^{2.33}$$

(39.3)

So, it is observed that higher flow rate and deeper pool promotes mixing. It has also been found that overlaying slag layer slows down the mixing.

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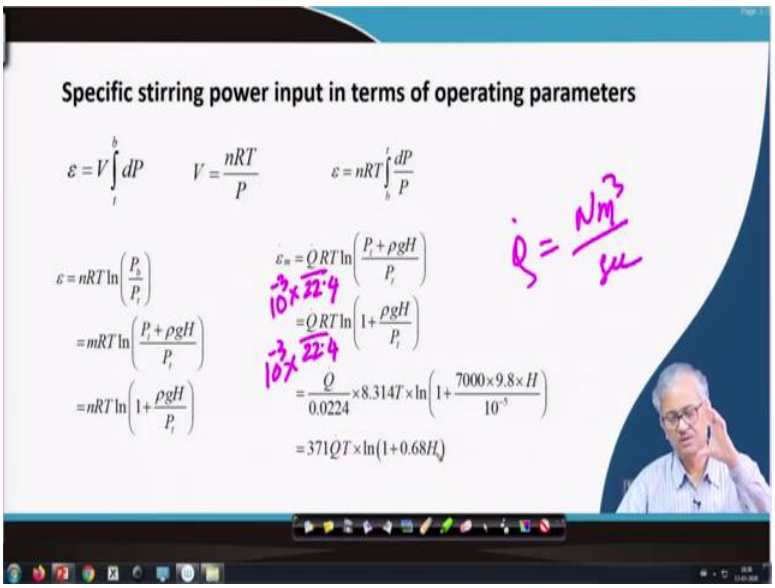

Mixing time can be more elegantly be correlated with the specific stirring power input. Energy input into the bath can be considered as volume work done by the bubbles as it ascent under a decreasing pressure (Equation 39.3).

$$\varepsilon = V\int_t^b dP$$

(39.3)

Where volume may be represented in terms of moles, temperature and pressure using gas law (Equation 39.4):

$$V = \frac{nRT}{P}$$

(39.4)

Combining equation (39.4), equation 39.3 can be rewritten as (equation 39.5):

$$\varepsilon = nRT\int_{b}^{t}\frac{dP}{P}$$

(39.5)

After integrating equation (39.5) from bottom to top, we get:

$$\varepsilon = nRTln\left(1+\frac{\rho gH}{P_t}\right)$$

(39.6)

Now, correlating number of moles with specific volume flow rate, the specific power input can be defined as (Equation 39.7)

$$\dot{\varepsilon} = 371\dot{Q}Tln(1+0.68H)$$

(39.7)

Where, $\dot{Q}$ is the specific volume flow rate (Nm^3/sec.ton), H is the depth of the bath in m, T temperature in Kelvin.

The mixing time is correlated with the specific power input as given by equation (39.7), which is based on laboratory experiments as well as pilot scale plant data (Figure 39.3)

$$\tau_{mix} = 800\dot{\varepsilon}_m^{\ -0.4}$$

(39.8)

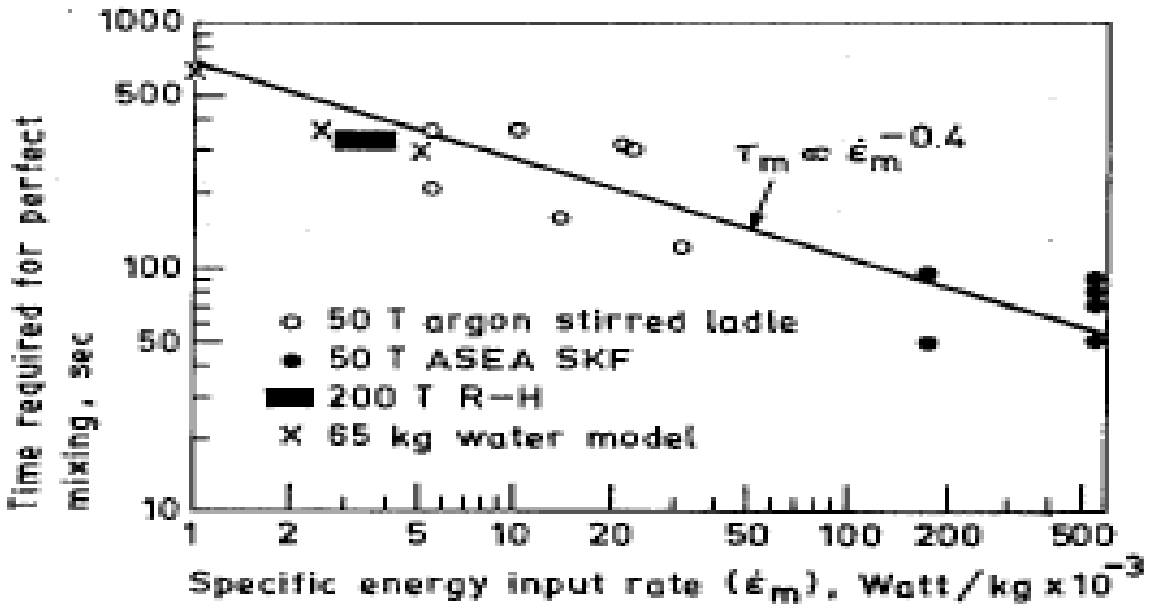

Figure 39.3: Correlation of mixing time with specific energy input[1]

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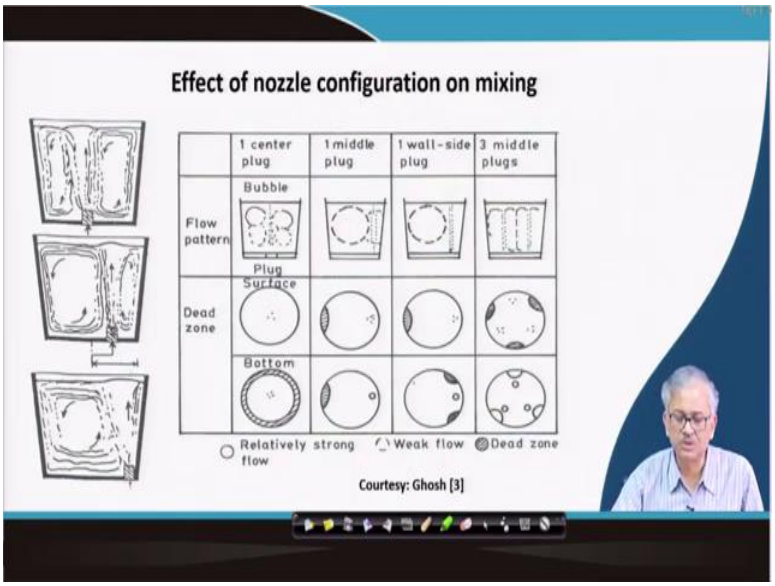
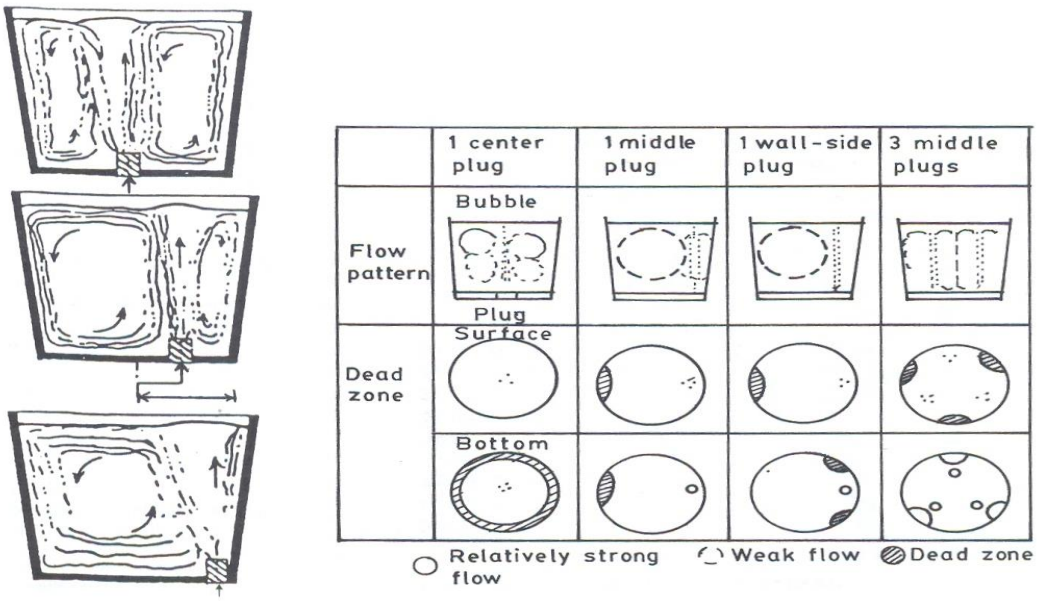


Various nozzle configurations have been studied extensively to understand its effect on flow pattern and dead zone. Figure 39.4 shows three different nozzle configuration and its effect on flow pattern and dead zones.



(a) **(b)**

Figure 39.4: (a) various nozzle configuration, (b) various flow pattern and dead zones under various nozzle configuration[3]

Four nozzle configurations are considered: one centric nozzle, one eccentric nozzle (at the middle between wall and center), one nozzle at the side wall, and three middle plug (4^{th} option in igure 39.4(b). In case of centric purging, two strong velocity loops on either side of the axis in the upper part of the ladle is observed; while two similar but weak loops are also observed at the lower part of the ladle. This type of flow pattern results in a very non-uniform kinetic energy distribution; most of the kinetic energy being located in the upper part of the ladle. Consequently, such flow pattern develops a ring dead zone along the periphery at the bottom of the ladle.

In case of eccentric purging with one eccentric nozzle, only two liquid circulation loops are observed. A big but comparatively weak loop exists that covers most of the volume of the ladle. The other is much smaller but comparatively stronger loop. Also since most of the momentum is confined in a bigger pool, the energy distribution is more uniform. This type of flow pattern is found not to generate big dead zone. It may be observed that only one and small dead zone exists at the wall end (at higher distance from the nozzle) of the big circulation loop both at the top and bottom surface.

In case of the one wall side plug, only one moderately stirred big loop is there. Such flow pattern develops one dead zone at the rear wall end of the loop on the top surface; while it also generates two dead zones on the bottom surface near the wall, closer to the nozzle.

In case of three middle plugs, four weak axial circulation loops on either side of the nozzles are observed and such flow pattern develops three dead zones on the top surface, as shown in the Figure 39.4(b).

Dead zone represents location where the momentum of the liquid is very low or the velocity is very low; such that the movement of the liquid may be negligible compared to the movement of the liquid in the other parts; that is called the dead zone, where heat and mass transfer is very weak.

In case of one eccentric middle plug the dead zones are limited to a very small area and liquid flow is also more uniform. Only one circulation loop is there and although it is mild but the distribution of energy is more uniform. This is the most favored plug configuration in the Industry.

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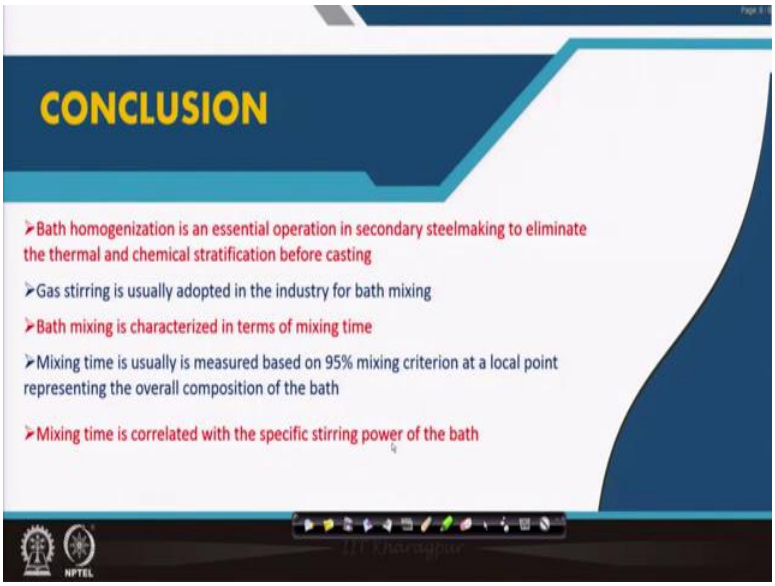

Conclusion: Bath homogenization is essential operation in secondary steelmaking to eliminate the thermal and chemical stratification before casting.

Gas stirring is usually adopted in the industry for bath mixing.

Bath mixing is characterized by the mixing time. And mixing time is usually measured based on 95 percent criterion at a local point representing the overall composition of the bath. Here, the time is noted when the tracer concentration at the representative location attained the 95% of the average concentration of the tracer in the bath. It can also be measured in terms of average change of tracer concentration less than one percentage based on measurements at several locations. Semi empirical correlations are available to measure the mixing time.

The nozzle configuration in the gas stirred ladle influence the flow pattern as well as dead zones in the ladle. It has been found that a single eccentric nozzle at the middle of the center and the wall, provides the best flow field with one big circulation loop with more uniform distribution of energy and with minimum dead zones. Such nozzle configuration is popular in the industry.