described a counter-flow solid–liquid reactor to remove boron by fractional extraction in a semi-continuous process in a patent assigned to Elkem ASA of Norway.

It has been demonstrated that phosphorus could be evaporated from a silicon melt under vacuum conditions [74, 75]. Miki *et al.* [76] have explained the thermodynamics of this process by reactions involving mono- and diatomic phosphorus in the gas phase:

$$P_2(g) = 2\underline{P}(1\% \text{ inSi (l)}) \tag{5.39}$$

$$P(g) = \underline{P}(1\% \text{ inSi (l)}) \tag{5.40}$$

Underscored symbols refer to dissolved element in liquid silicon as already defined in Section 5.3.2.

Silicon produced by carbothermic reduction is so to speak supersaturated in SiC when tapped from the furnace and may contain as much as 1000 to 1500 ppm(w) C. As this silicon is cooled down to the solidification temperature, the majority of this carbon precipitates out as SiC particles leaving around 50 to 60 ppm(w) in liquid silicon. Carbon removal from liquid silicon is therefore a two-step operation:

1. the removal of precipitated SiC as close to the solidification temperature as possible
2. the removal of dissolved $\underline{C}$ by oxidation to CO(g).

As already mentioned, SiC particles become effectively captured by the slag phase during oxidative refining in which the main objective may be to remove Al and Ca as industrially practised today or in a similar operation with the purpose of removing B or P. Depending on the temperature and the degree of slag/molten silicon intermixing, this treatment may give a product with 80 to 100 ppm(w) C. Other methods, which have been applied and proved effective at a temperature closer to the solidification temperature, are filtration, centrifugation or settling combined with slow cooling. Several studies have provided valuable contributions suggesting several methods, for example, settling in combination with directional solidification [77], filtration combined with oxidation [78], oxidative plasma [70–72] and decarburisation by inert gas purging or under vacuum [14, 78]. Klevan [14] has developed a mathematical model, which describes the kinetics of decarburisation when inert purging is applied. Mechanical removal is, however, not efficient enough to affect the substitution carbon. Stronger methods able to displace the equilibria, such as oxidative plasma and vacuum vaporisation, are believed to be more powerful techniques.

It is worth noting that these types of operation can all be carried out in carbon-lined ladles. The several steps dealing with the removal of dissolved carbon $\underline{C}$ from liquid silicon Si(l), however, has to be carried out in the absence of C and at a highest possible temperature in order to optimise the equilibrium and the kinetic conditions for the reaction:

$$\underline{C} + \tfrac{1}{2}O_2 = CO(g) \tag{5.41}$$

A parallel reaction, which affects the silicon yield, unfortunately, also takes place:

$$Si(l) + \tfrac{1}{2}O_2 = SiO(g) \tag{5.42} = (5.14)$$