carried out by adding slaked lime in order to flocculate or precipitate the majority of the water-soluble contaminants and even decompose a small proportion of them. When carbon dioxide is subsequently bubbled through the solution it precipitates the excess calcium hydroxide from the slaked lime in the form of calcium carbonate. This is then filtered off together with the precipitated non-sugar substances.

The clarified weak sugar solution produced in this way has a solids content of approximately 15% and is subsequently evaporated to about 70% dry solids. This solution is then further concentrated under vacuum until crystallisation starts. Cooling this syrup–crystal mix leads to further crystallisation of the sugar. The separation of the sugar from the first molasses or mother syrup is frequently performed in a centrifuging process. Crystallisation always requires several processing stages, since it is not possible to recover all of the sugar in a single step. White sugar therefore has to be crystallised in three or four different steps. Raw sugar factories produce brown raw sugar as an interim product by a simplified crystallisation process. This type of sugar contains impurities that are removed by means of further recrystallisation in sugar refineries. A by-product, called molasses, is the syrup obtained during the final crystallisation step, from which sugar can no longer be crystallised because of the high concentration of non-sugar substances. Beet molasses with about 83% dry solids contains about 50% sucrose and up to 11% inorganic substances, 4–5% organic acids and about 13% nitrogenous organic compounds. In addition, about 1–2% of the trisaccharide raffinose and traces of invert sugar may be found (Hoffmann *et al.*, 1985).

Sugar cane has a sucrose content of 11–17%. The raw juice in this case is manufactured by squeezing the crushed stalks on roller mills or by means of extraction equipment in combination with roller mills. What remains is the so-called bagasse, which serves either as fuel or as raw material for the production of paper, cardboard, hard particle board and so on. Since raw juice from sugar cane contains more invert sugar than the equivalent beet juice, a more gentle treatment is required to clarify the juice. A lime treatment, as used for the beet, would degrade the invert sugar, leading to the formation of undesirable brown colours. The chemical treatment required may be carried out by one of the following methods:

- A gentle lime treatment,
- A lime treatment plus "sulfitation" with sulfur dioxide,
- A lime treatment plus "carbonation" with carbon dioxide. This resembles juice clarification in the beet sugar industry, without, however, using the high temperatures normally employed in the latter.

The chemical juice clarification is preceded by a mechanical separation of suspended plant particles, for example by using hydrocyclones and bow-shaped sieves. Evaporation and crystallisation closely resemble the procedures used for the production of beet sugar. However, special purification, as well as the above clarification steps, are necessary in the refining of raw cane sugar because of the different composition of the non-sugar contaminants. These include carbonation with slaked lime and carbon dioxide or phosphatation, that is a slaked lime phosphoric acid treatment as well as a special colour removal with activated carbon.

Cane molasses of 75–83% dry solids contain about 30–40% sucrose as well as 4–9% glucose, 5–12% fructose, 1–4% other reducing substances (as invert sugar), 2–5% other carbohydrates, 7–15% inorganic substances, 2–8% organic acids and 2–5% nitrogenous organic compounds (Chen *et al.*, 1993).

4.3 Sugar qualities

The sugar industry supplies a wide range of crystallised and liquid sugars. Crystallised sugar is graded according to its purity and crystal size. The purity of all types of white crystallised sugars is extremely good. The sucrose content is generally more than 99.9% and only rarely falls below 99.7%. Any differences in quality result from minute quantities of non-sugar substances, which are mostly present in the syrup layer surrounding the sugar crystals.

In Europe, the quality criteria for sugar are determined by European Union (EU) market regulations and national legislation on sugar types. The EU sugar market regulations break crystallised sugars down into four categories, the quality criteria of which are summarised in Table 4.1.

The degree of optical rotation is a yardstick for the sugar purity. Refined sugar, as a rule, gives values of 99.9°S (this is a purity measurement, not degrees of rotation). The water content must not exceed 0.06% and in general does not exceed 0.03% in good quality crystallised sugar. The amount of invert sugar present should be not more than 0.04%. Once again the values obtained in practice are frequently much lower. Colour in solution is measured in a

Table 4.1 Quality criteria of white crystallised sugar according to EU market regulations.

Category	1 Refined sugar	2 White sugar (standard quality)	3	4
Optical rotation (°S, min.)	—	99.7	99.7	99.5
Water (%, max.)	0.06	0.06	0.06	
Invert sugar (%, max.)	0.04	0.04	0.04	—
ICUMSA colour type colour type unit (max.	(2)	(4.5)	(6)	—
points, 0.5 units = 1 point)	4	9	12	
Ash by conductivity (%); (max. points,	0.0108	0.0270	—	—
0.0018% = 1 point)	6	15		
Colour in solution; ICUMSA units, max.	(22.5)	(45)		
points (7.5 units = 1 point)	3	6	—	—
Total score according to EU Point score (max.)	8	22	—	—