Sugar production in CR and in the world

Start of industrial sugar production in Czech - year 1831
Sugar production in CR - 370-500 thousands t per year
- domestic consumption 400 thousands t per year

Production costs - 16.000 CK/t (640 EUR/t)

The important costs:
- price of sugar beet 53 %
- transport of beet 7 %
- production costs in sugar factory 36 %
- storage of sugar 4 %
World production of sugar
20 % from sugar beet

P.Kadlec, E. Šárka - Erasmus - sugar12
World sugar production (mil.t) 2010/11

- Europe: 26.4 million tons (16%)
- South America: 40.5 million tons (24%)
- Asia: 65.8 million tons (39%)
- North-Centr. America: 19.9 million tons (12%)
- Africa: 10.1 million tons (6%)
- Oceania: 4.9 million tons (3%)

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World prices of sugar do not reply to production costs
- prices follow instructions of market, mechanism of supply and demand
- prices are affected by world storage of sugar

<table>
<thead>
<tr>
<th>Year</th>
<th>Range (USD/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>185 – 244</td>
</tr>
<tr>
<td>2004</td>
<td>202 – 241</td>
</tr>
<tr>
<td>2005</td>
<td>258 – 330</td>
</tr>
<tr>
<td>2006</td>
<td>378 – 481</td>
</tr>
<tr>
<td>2007</td>
<td>330 – 387</td>
</tr>
<tr>
<td>2008</td>
<td>330 – 395</td>
</tr>
<tr>
<td>2009</td>
<td>379 – 650</td>
</tr>
<tr>
<td>2010</td>
<td>450 – 815</td>
</tr>
</tbody>
</table>

Movement of world prices of sugar during the last 30 years - from 100 to 800 USD/t

Ney York, raw sugar, cent/lb
2011/2012
<table>
<thead>
<tr>
<th>State</th>
<th>Quota before the reform (t) (%)</th>
<th>Added quota (t)</th>
<th>Referred quota (t)</th>
<th>Quota 2008/2009 (t) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>3 288 747 19,3</td>
<td>352 695</td>
<td>683 655</td>
<td>2 956 786 22,8</td>
</tr>
<tr>
<td>Germany</td>
<td>3 416 896 20,0</td>
<td>238 560</td>
<td>757 200</td>
<td>2 898 256 22,3</td>
</tr>
<tr>
<td>Poland</td>
<td>1 671 926 9,8</td>
<td>100 551</td>
<td>366 869</td>
<td>1 405 608 10,8</td>
</tr>
<tr>
<td>Great Britain</td>
<td>1 138 627 6,7</td>
<td>82 847</td>
<td>165 000</td>
<td>1 056 474 8,1</td>
</tr>
<tr>
<td>Netherlands</td>
<td>864 560 5,1</td>
<td>66 875</td>
<td>126 457</td>
<td>804 978 6,2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10 380 756 60,8</td>
<td>840 528</td>
<td>2 099 181</td>
<td>9 122 103 70,3</td>
</tr>
<tr>
<td>Spain</td>
<td>996 961 5,8</td>
<td>0</td>
<td>366 375</td>
<td>630 586 4,9</td>
</tr>
<tr>
<td>Belgium</td>
<td>819 812 4,8</td>
<td>62 489</td>
<td>206 066</td>
<td>676 235 5,2</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>420 746 2,5</td>
<td>31 720</td>
<td>80 083</td>
<td>372 383 2,9</td>
</tr>
<tr>
<td>Denmark</td>
<td>387 326 2,3</td>
<td>18 486</td>
<td>54 785</td>
<td>351 027 2,7</td>
</tr>
<tr>
<td>Austria</td>
<td>368 262 2,2</td>
<td>17 722</td>
<td>92 798</td>
<td>293 186 2,3</td>
</tr>
<tr>
<td>Sweden</td>
<td>1 557 443 9,1</td>
<td>0</td>
<td>1 049 064</td>
<td>508 379 3,9</td>
</tr>
<tr>
<td>Italy</td>
<td>5 005 412 29,3</td>
<td>150 487</td>
<td>1 951 644</td>
<td>3 204 255 24,7</td>
</tr>
<tr>
<td>Hungary</td>
<td>401 684 2,4</td>
<td>5 000</td>
<td>301 264</td>
<td>105 420 0,8</td>
</tr>
<tr>
<td>Greece</td>
<td>317 502 1,9</td>
<td>0</td>
<td>158 800</td>
<td>158 702 1,2</td>
</tr>
<tr>
<td>Slovakia</td>
<td>103 010 0,6</td>
<td>8 000</td>
<td>21 838</td>
<td>89 172 0,7</td>
</tr>
<tr>
<td>Ireland</td>
<td>199 260 1,2</td>
<td>0</td>
<td>199 260</td>
<td>0 0,0</td>
</tr>
<tr>
<td>Finland</td>
<td>146 087 0,9</td>
<td>0</td>
<td>65 088</td>
<td>80 999 0,6</td>
</tr>
<tr>
<td>Portugal</td>
<td>109 164 0,6</td>
<td>0</td>
<td>104 689</td>
<td>0 0,0</td>
</tr>
<tr>
<td>Lithuania</td>
<td>66 505 0,4</td>
<td>0</td>
<td>66 505</td>
<td>0 0,0</td>
</tr>
<tr>
<td>Latvia</td>
<td>52 973 0,3</td>
<td>0</td>
<td>52 973</td>
<td>0 0,0</td>
</tr>
<tr>
<td>Slovenia</td>
<td>109 164 0,6</td>
<td>0</td>
<td>104 689</td>
<td>0 0,0</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>4 752 0,0</td>
<td>0</td>
<td>0</td>
<td>0 0,0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1 678 087 9,8</td>
<td>21 605</td>
<td>1 039 163</td>
<td>651 302 5,0</td>
</tr>
<tr>
<td>European Union</td>
<td>17 064 255 100,0</td>
<td>1 012 620</td>
<td>5 089 988</td>
<td>12 977 659 100,0</td>
</tr>
</tbody>
</table>

Main points of the reform:
Sugar production in EU is need to decrease about 6 mil. t
Compensation (offset) for producers who finished sugar production
Sugar price decreased about 36 % from 632 to 400 EURO/t at 2009/10
Sugar beet price decreased from price 43 to 26 EURO/t at 2009/10
Reform started as for July 2006 and will take time to 2014/15
## Sugar producers in CR

<table>
<thead>
<tr>
<th>Company</th>
<th>Sugar factory</th>
<th>Capacity t/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tereos TTD, a.s.</td>
<td>Dobrovice</td>
<td>14000</td>
</tr>
<tr>
<td></td>
<td>České Meziříčí</td>
<td>7000</td>
</tr>
<tr>
<td>Moravskoslezské cukrovary, a.s.</td>
<td>Hrušovany n.Jev.</td>
<td>4900</td>
</tr>
<tr>
<td></td>
<td>Opava</td>
<td>3500</td>
</tr>
<tr>
<td>Cukrovar Vrbátky, a.s.</td>
<td>Vrbátky</td>
<td>2000</td>
</tr>
<tr>
<td>Hanácká potr. spol., s.r.o.</td>
<td>Prosenice</td>
<td>2000</td>
</tr>
<tr>
<td>Litovelská cukrovarna, a.s.</td>
<td>Litovel</td>
<td>2300</td>
</tr>
<tr>
<td><strong>Total capacity (t/d)</strong></td>
<td></td>
<td><strong>35700</strong></td>
</tr>
<tr>
<td><strong>Average capacity (t/d)</strong></td>
<td></td>
<td><strong>5100</strong></td>
</tr>
</tbody>
</table>
## Chosen characteristics of sugar beet and sugar production in CR

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>CR</th>
<th>(best)* EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar beet yield (t/ha)</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Area on 1 farmer (ha)</td>
<td>65</td>
<td>10</td>
</tr>
<tr>
<td>Content of sugar (%)</td>
<td>17-18</td>
<td>19</td>
</tr>
<tr>
<td>Yield (%)</td>
<td>90,5</td>
<td></td>
</tr>
<tr>
<td>Yield of refined sugar (t/ha)</td>
<td>10,3</td>
<td>13,4</td>
</tr>
<tr>
<td>Capacity of sugar factory (t/d)</td>
<td>5000</td>
<td>10000</td>
</tr>
</tbody>
</table>
SUGAR and its use

- in human nutrition
- to chemical and biochemical transformations

Very long time of storage (years)
Relative low price

SUGAR

- ensures the significant portion of total energy income
- is widely used in foods produced in food factories or in workrooms
  - is used for home consumption

function of sugar:
- sweetener
- flavouring agent
- preservation media
- increasing of food volume
- improving of food texture
- substrate for fermentation

Consumption of sugar in CR - 40 kg per person and year
The basic direction in nutrition – decrease of sugar consumption about 30 %
High sugar consumption and health diseases
SUGAR AS RAW MATERIAL FOR CHEMICAL AND BIOCHEMICAL TECHNOLOGIES

• only 5% of sugar world production is used for non-food use
• products of chemical or biochemical transformations of sucrose are biological degradable and are not toxic

The possibilities of production coming out from sucrose:
• fermentation to bioethanol, the following use as fuel or additives to fuel
• classical fermentation production (spirit, yeasts, organic solvents and acids (citric, lactic), vinegar, aminoacids)
• products of chemical transformation of sucrose (sorbitol, vitamin C, gluconic acid, 5-hydroxymethylfurfural, …)
### BASIC ANALYTICAL TERMS

<table>
<thead>
<tr>
<th>Term</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry substance</td>
<td>$S \ (%)$</td>
</tr>
<tr>
<td>Sucrose content</td>
<td>$P \ (%)$</td>
</tr>
<tr>
<td>Nonsugar content</td>
<td>$N = S - P \ (%)$</td>
</tr>
<tr>
<td>Purity</td>
<td>$Q = 100 \times \frac{P}{S} \ (%)$</td>
</tr>
<tr>
<td>Ash content</td>
<td>$A \ (%)$</td>
</tr>
<tr>
<td>Reducing substances, Invert sugar</td>
<td>$RL \ (%)$</td>
</tr>
</tbody>
</table>
Sugar beet

- is grown to have maximal content of sucrose
- requires a high quality soil
- is grown in mild climatic areas
- requires long vegetation time
- the area of land suitable for growing of sugar beet in CR 700 thousands ha
- is grown on the area of 60 000 ha
- close to the rivers Labe, Vltava, Ohře; region Haná, south Moravia, Opavsko (Silesia)
## Composition of sugar beet

<table>
<thead>
<tr>
<th>Dry substance</th>
<th>Marc</th>
<th>Sucrose</th>
<th>Soluble nonsugars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 %</td>
<td>16 – 18 %</td>
<td>2,5 %</td>
</tr>
<tr>
<td>Cellulose</td>
<td></td>
<td></td>
<td>Monosaccharides</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td></td>
<td></td>
<td>Oligosaccharides</td>
</tr>
<tr>
<td>Arabans</td>
<td></td>
<td></td>
<td>Organic acids</td>
</tr>
<tr>
<td>Pectin substances</td>
<td></td>
<td></td>
<td>Saponin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Proteins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Amino acids</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Amines</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Betaine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inorganic salts</td>
</tr>
</tbody>
</table>

- Dry substance: 23 – 25 %
- Sucrose: 16 – 18 %
Modern sugar beet laboratory

determination of soil content (mineral matters) and trash
analytical determination sucrose (sugar)
sodium and potassium
amidic nitrogen
assessment of the yield of refined sugar, resp. losses of sugar in molasses from composition of sugar beet
Sugar technology
Beet storage

Stone and trash separation

Stones, sand

Trash

Washing

Water treatment

Water

Production of cossettes

Water

Extraction

Pressing

Disinfectants

Raw juice

Pressed pulp

Q=90-93 %

S=20-29%,

P=0.6-2.5%

Conditions of extraction: temperature < 80 °C, time < 120 min, pH 5.8

Soil mud

P.Kadlec, E. Šárka - Erasmus - sugar12
Juice purification

Main objectives:

1) To remove about 30 - 40 % of nonsugars
2) To neutralize the acid reaction of raw juice
3) To minimize sucrose degradation
4) To disinfect the juice
5) To remove fine pulp particles

For the juice purification is used:
- milk of lime (hydrated suspension Ca(OH)$_2$ and CaO in water)
- kiln gas (content 30-40 % vol. CO$_2$)
Raw juice, Q=90-93 %

- Preliming - pH 11
  - Lime milk
  - Lime milk
  - Kiln gas – CO₂

- Main liming – pH 12.5
  - Kiln gas – CO₂

- 1st carbonation – pH 11
  - Thickening of slurry
  - Filtration

- 2nd carbonation – pH 9-9.5
  - Kiln gas – CO₂
  - Filtration

Carbonation lime; mud

P<1 %; S=60-70 %

Thin juice, Q=93-94.5 %
Preliming

0.25 – 0.30 % CaO per beet

- Removing of colloidal matters
- Precipitation of insoluble calcium salts
- Aggregation and dehydration of sediment

Progressive preliming

- gradual increase pH value up to 11
- precipitation, dehydration, coagulation
- stabilization of sediment particles
- repeptization of colloids
- temperature 50-65 °C or 85-90 °C

Protein precipitation during preliming

![Graph showing protein precipitation during preliming](image)
Main liming

**objective:** decomposition of amides, of reducing substances, and of oxalogenic substances

- Addition of lime milk: 0.7 – 1.1 % CaO per beet
  - Sum for juice purification: 1.0 – 1.4 % CaO per beet
- Temperature: 82 – 85 °C
- Time: 10 - 20 min
- pH higher than 12

**Formation of saccharates**
**Precipitation of insoluble calcium salts**
1st carbonation

Main objective – precipitation of crystalline calcium carbonate, adsorption of color substances, surface active matters and the others nonsugars

Basic precipitation reaction

\[
\text{Ca(OH)}_2 + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + 2 \text{H}_2\text{O}
\]

Hydration of CO₂

physical chemical purification

precipitation and crystallization of calcium carbonate
adsorption of nonsugars on surface of calcium carbonate
dissolving of gas carbon dioxide
temperature 82 – 84 °C
end of 1st carbonation pH 11
Separation of carbonation precipitate

1st carbonation juice

clarifier

thickening filter

carbonation slurry

juice

vacuum rotary filter

filter press

mud 50 %

juice

mud 65-70 %

juice
2nd carbonation

Main objective: to minimize the content of soluble calcium salts in juice, to improve purity of juice

• chemical purification
• protection before scale formation (encrustation)
• 2nd carbonation slurry – pure calcium carbonate
• temperature 95 °C
• optimal alkalinity (pH 9 – 9.5)
Juice evaporation

The main goal of evaporation station:

1. to concentrate thin juice to 60 - 65 %
2. to supply production units with needed heating steam (vapours)

Amount of evaporated water $m_w$ (% per beet)

$$m_w = m_1 \left(1 - \frac{S_1}{S_2}\right)$$

For $m_1 = 120$ % per beet, $S_1 = 16$ %, $S_2 = 65$ %, then $m_w = 90$ % per beet.

The needed heat $Q_w$ for evaporation of $m_w$ kg water is:

$$Q_w = m_w \cdot r \text{ (kJ)}$$

where $r$ is heat of evaporation at temperature $t$ (kJ/kg)

Rough estimate: for evaporation of 1 kg water from juice you need 1 kg of steam
Scheme of evaporator

Thin juice $S=15\%$

130 °C

124 °C

122 °C
do kotelny

to steam boiler plant

17 %

115 °C

113 °C

104 °C

102 °C

teplá voda

Thick juice $S=65\%$

90 °C

88 °C

17 %

to barometric condenser

hot condensate

P. Kadlec, E. Šárka - Erasmus - sugar12
Crystallization

1) nucleation (creation of nucleus)
2) crystals growth
   - nucleation and crystal growth requires that the sugar solution is supersaturated
   - driving force of nucleation and crystal growth is the difference between actual concentration and concentration of saturated sugar solution (supersaturation)

Supersaturation of sugar solution is expressed as **supersaturation coefficient** $K_p$, defined

$$K_p = \frac{H}{H_1},$$

$H$ - ratio P/W in solution
$H_1$ - ratio P/W in saturated solution
Metastable zone

- no creation of new nucleus, only growth crystals
- zone of supersaturation suitable for evaporation and cooling crystallization
- limits of metastable zone are influenced chiefly by temperature, purity and presence of crystals
- the lower limit correspond to saturated solution
Theory of crystals growth from solution

Crystallization process is composed from these steps:

a) transport of sucrose molecules from solution to the diffusion layer
b) diffusion of sucrose molecules through the diffusion layer
c) surface diffusion of sucrose molecules in the reaction layer and arrangement in the crystal grid

dm/dτ = A . D/d . (c - cr) = A . k_d . (c - c_r)
dm/dτ = k_r . A . (c_r - c_0)r

Crystal growth in steady state

v = dm/(dτ . A) = (k_d . k_r)/(k_d + k_r) = K . (Kp - 1)
Scheme of sugar boiling house

1-reservoirs, 2-vacuum pan, 3-barometric condenser, 4-crystallizer, 5-distributing trough, 6-centrifuge, 7-syrup, 8-sugar

Concentration of syrup
Evaporation crystallization
Cooling crystallization

massecuite
Vacuum pan with stirrer

Equipment of pan:
- Measurement and control of pressure, temperature, level, electric conductivity, viscosity
- Control systems for feeding of sirups, steam, crystal seed
Boiling of masssecuites

1) preparation of the boiling
   - vaporising, test of tightness
   - set up of syrups - 85 °C, 70 - 75 %, alkalinity

2) concentration of the syrup
   - boiling point increases with higher concentration
   - at pressure 67 - 80 kPa is boiling point 78 - 82 °C

3) seeding
   - Kp 1.10 – 1.25
   - microseed - suspension of sucrose crystals
     (size 1 - 10 μm) in ethanol or propanol

4) stabilization of seed
   - transition from period of seed formation to period of crystal growth
   - metastable zone, Kp is decreased to 1.08 – 1.12
5) boiling - crystallization
Kp 1.10, sucrose crystallizes from supersaturated mother syrup; this syrup is exhausted; the further syrup is fed to the pan and this procedure is repeated until the top level of massecuite in pan is reached

6) concentration
concentration of massecuite to dry matter 92 %

7) drainage of massecuite
massecuite is drained to crystallizer, where is mixed with heated mixed syrup, supersaturation of mother syrup is decreased
Automatization of sugar boiling

the controlled value – supersaturation coefficient
other values – crystal content, level in a pan

For supersaturation measurement:
  electric conductivity
  viscosity (consistence)

is used.

Course of viscosity during sugar boiling
Magma system boiling

Advantages:
Better granulometry of boiled crystals
Saving of heating steam during the shortened time of boiling
Simplification of boiling scheme

Course of magma boiling
1) preparation
2) feeding of magma-seed – low grade sugar + thick juice or syrup
3) boiling – crystallization
4) concentration
5) drainage of massecuite
Crystallization scheme
Raw sugar (B, C)

Magma preparation

Affination

Liquor preparation

Filtration

Decolorization

Liquid sugar

Boiling of massecuite

Centrifugation

Drying

_end moisture 0.05 %

Classification of crystals

Milling

Packaging

Pressed cube

Scheme of refinery
## Types of sugar according Czech Food Law

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar extra</td>
<td>fine mixture of smaller crystals or pulverized crystals, bulk material</td>
</tr>
<tr>
<td>white</td>
<td>crystals mixture of crystals, bulk material</td>
</tr>
<tr>
<td>Sugar white</td>
<td>fine crystals</td>
</tr>
<tr>
<td></td>
<td>powder mixture of fine pulverized crystals, bulk material</td>
</tr>
<tr>
<td>Sugar semi-white</td>
<td>fine crystals</td>
</tr>
<tr>
<td></td>
<td>powder</td>
</tr>
<tr>
<td>Powdered sugar</td>
<td>can include (max. 3 %) anti caking agent</td>
</tr>
<tr>
<td>Pressed cube sugar</td>
<td>(cube, bridge, loaf)</td>
</tr>
<tr>
<td>Sugar with additives</td>
<td>Sand, granular, light yellow crystal, slightly sticky</td>
</tr>
<tr>
<td>Natural sugar</td>
<td>Sand mixture of big crystals, yellow – brown color</td>
</tr>
<tr>
<td>Candys</td>
<td>Liquid products</td>
</tr>
<tr>
<td></td>
<td>invert syrup</td>
</tr>
<tr>
<td></td>
<td>caramel</td>
</tr>
</tbody>
</table>