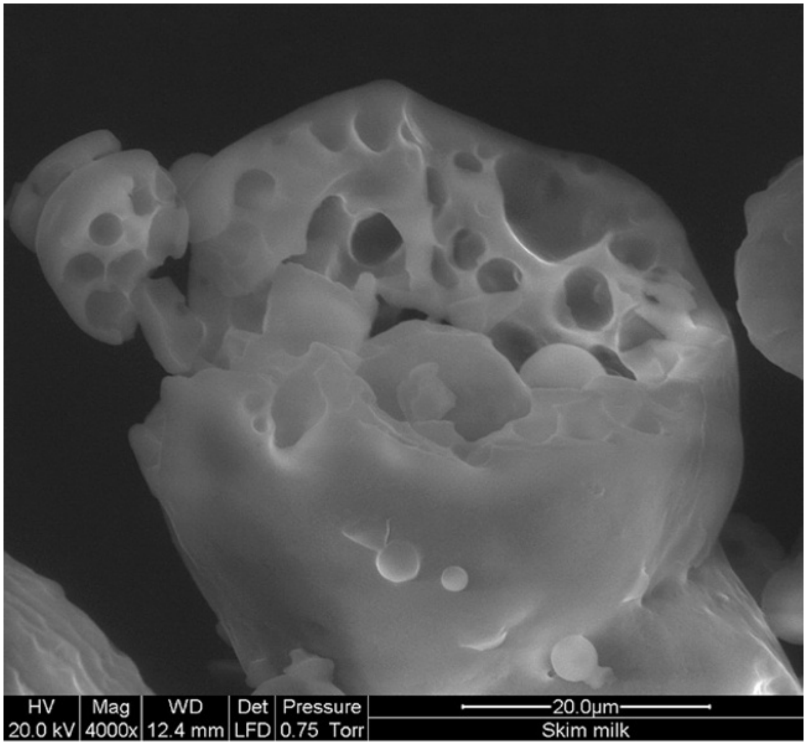
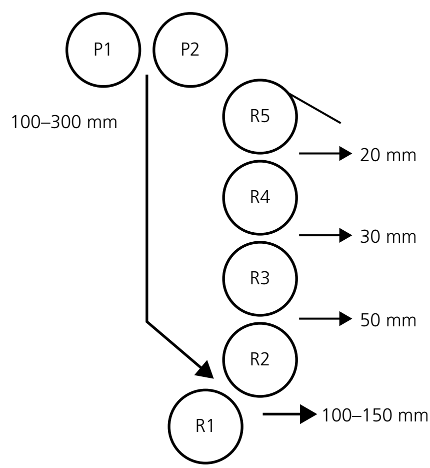


Figure 9.8 Fragment of refined spray-dried skim milk powder.

Figure 9.9 Schematic diagram of a five-roll refiner.



grinding, instead forming an even film of chocolate mass across the length of the rolls. The rotational speed of the rolls gets progressively faster from the bottom (R2) to the top (R5), as the gap gets correspondingly narrower (Table 9.1). The roll refiner is essentially a series of single-pass devices. The film of product

Table 9.1 Example of operating conditions for a five-roll refiner (Peter, 1994).

Roll	RPM	Temperature[1]	
		°C	°F
R1	<58	35–40	95–104
R2	58	35–40	95–104
R3	155	42–48	108–118
R4	268	50–60	122–140
R5	380	35–40	95–104

[1] Recommended for low-fat mixes; subtract 5–10 C (9–18 °F) for high-fat mixes.

exiting each gap is transferred to the faster roll, moving upwards, until it is scraped off the final roll by a stationary knife. Hydraulic pressure is applied to the roll stack to compress the camber (uncompressed, the rolls are barrel shaped) and obtain an even coating across the roll length. Loeser (see Chapter 24) has proposed roll refiner control based on machine vision to monitor roll coverage. Counter-pressure built up by the product ensures a stable roll gap, but alterations in pressure do little to affect the size reduction.

Size reduction occurs as a combined result of compression and shear. The *degree of reduction* in a five-roll refiner is generally 5–10, resulting in a final product with a maximum particle size of in the range 15–35 μm ($6–14 \times 10^{-4}$ in). The relationship between final maximum particle size and specific flow rate (kg h^{-1} m^{-1}) is linear (Fritzsche, 1994), with the theoretical fineness being defined by Equation 9.1,

$$S_o = 2\dot{m}/\rho\left(v_i + v_{i+1}\right)b \tag{9.2}$$

where S_o = theoretical maximum particle size equivalent to the film thickness or gap, $\dot{m}$ = mass flow rate, ρ = chocolate density (approximately 1.2 kg m^{-3}), v = speed of circumference for rolls i and i+1, and b = roll length. This equation has been used to predict actual particle size measured by micrometer with a relatively high degree of accuracy (Fritzsche, 1994), and can be rearranged and used to estimate throughput at a given particle size.

Temperature has a significant effect on the rheology of the chocolate film and thus influences the refining process. Temperature is maintained by circulating water in the interior of each roll. The relative size of the cooling zone (one-half the circumference of the roll) compared to the gap width (a few microns) allows for effective temperature control. The properties of the material being broken may change substantially with temperature and thereby alter the milling process.

The proper consistency for transfer of product from roll to roll is maintained by the appropriate fat content. It is normally advantageous to roll refine chocolate at the lowest fat content possible – in the range of 24–27%. It is said that