(rubber), and every component is expressed relative to the 100 parts of rubber (PHR).

2.3.2 Plant Recipe

The plant recipe is the base with which the compounds are developed and optimized in the plant. It is proportional to the calculated theoretical recipe and is expressed in kilograms instead of PHR.

To calculate the plant recipe one should consider:

- Volume of the mixing chamber
- Capacity of the mill mixer
- Fill factor
- Density of the different components

2.3.3 Recipe Expressed as Percentage by Weight

Using the plant recipe, it is quite simple to compute the percentage by weight of each of the components. Table 2.1 shows a typical plant recipe.

For a 160 liter capacity internal batch mixer and a fill factor of 0.72 the available volume (V_a) is 160 l (0.72) = 115.2 l.

The compound quantity becomes

$$\rho_{compound}\, V_a = (1.138\ \text{kg/l})(115.2\ \text{l}) = 131.1\ \text{kg}$$

The quantity of each ingredient is calculated below. For example, for the SBR 1502:

$$\text{kg of SBR 1502} = \frac{80 \text{x} 131.1}{183} = 57.31$$

For each ingredient the percentage by weight can easily be computed.

For example, for the SBR 1502:

$$\text{\% in weight of SBR 1502} = \frac{57.31}{131.1} \text{x} 100 = 43.72\%$$

Table 2.1 Typical Plant Recipe

Ingredient	PHR	Density (g/cm^3)	Volume (cm^3)
SBR 1502	80.0	0.93	86.02
BR	20.0	0.91	21.98
Plasticizer	12.0	0.94	12.77
Antioxidant	1.5	1.17	1.28
Antiozonant	1.5	0.91	1.65
Carbon black	60.0	1.84	32.61
Stearic acid	2.0	0.92	2.17
Zinc oxide	3.0	5.60	0.54
Sulfonamide	1.2	1.30	0.92
Sulfur	1.8	2.07	0.87
TOTAL	183.0		160.81

ρ compound = (compound weight / volume compound)
Compound ρ = 183.0 / 160.81 = 1.138 g/cm^3

Table 2.2 Percentage by Weight for Typical Plant Recipe

Ingredient	PHR	ρ (g/cm^3)	Volume (cm^3)	Plant recipe (kg)	Weight %
SBR 1502	80.0	0.93	86.02	57.31	43.72
BR	20.0	0.91	21.98	14.33	10.93
Plasticizer	12.0	0.94	12.77	8.59	6.56
Antioxidant	1.5	1.17	1.28	1.07	0.82
Antiozonant	1.5	0.91	1.65	1.07	0.82
Carbon black	60.0	1.84	32.61	42.98	32.79
Stearic acid	2.0	0.92	2.17	1.43	1.09
Zinc oxide	3.0	5.60	0.54	2.15	1.64
Sulfonamide	1.2	1.30	0.92	0.86	0.66
Sulfur	1.8	2.07	0.87	1.29	0.98
TOTAL	183.0		160.81	131.1	

2.4 Mixing Equipment and the Mixing Process

2.4.1 Mixing Equipment

The most common systems for the compounding of rubber formulations are the two-roll mill and the internal batch mixers, such as the Banbury mixers.

Two Roll Mills

The two-roll mill is an external mixer whose main components are two counter-rotating rolls that circulate and stretch the compound. Table 3.3 presents specifications for various standard two-roll mills.

Table 2.3 Specifications for Various Standard Two-Roll Mills

Roll size (mm) (diam. x length)	Batch size (kg) (density = 1.0)	Motor (H.P.)
152 x 330	0.5 to 1.0	7.5
203 x 406	1.0 to 2.0	10-15
254 x 508	2.0 to 4.0	15-20
305 x 610	4.5 to 8.5	30-40
355 x 762	9 to 14	40-50
406 x 1067	14 to 23	70-75
457 x 1220	20 to 32	75-100
560 x 524	34 to 57	125-150
610 x 1829	57 to 90	150-200
660 x 2134	68 to 110	150-200
710 x 2134	80 to 136	200-250

Roll Mill Capacity

The mill capacity can be computed using:

$$C = \frac{\pi\ dhl}{(1 - B)100}$$

where d = Mill diameter (cm), l = Length (cm), h = Thickness (cm), B = Bank ratio (upside of the rolls).

Example

We have a roll mill with 36 cm diameter and 76 cm length. Working with a thickness of 0.5 cm and a bank of 60% of total weight of the compound (ρ = 1.13 g/cm^3), the total weight is:

$$W = pc = \frac{p\,\pi\,dhl}{(1-B)1000}$$

$$\mathrm{W} = \frac{1.13 \text{ x } \pi \text{ x } 36 \text{ x } 76 \text{ x } 0.5}{(1-0.6)1000} = 12\,\mathrm{kg}$$

Internal Batch Mixers

Internal batch mixers such as the Banbury mixer are composed by an internal double lobed cavity, each with a mixing head that counter-rotates with respect to its neighbor at a slightly different speed. Table 2.4 presents specifications for standard internal batch mixers.

Table 2.4 Standard Internal Batch Mixers

Capacity (kg) (ρ = 1.0)	Motor (H.P.)	Capacity (kg) (ρ = 1.0)	Motor (H.P.)
0.30	7.5	80.00	235-940
0.41	7.5	90.00	220-895
1.00	0-25	105.00	280-1110
1.200	8.5-25	112.00	335-1340
1.57	8.5-25	120.00	200-400
1.70	17	130.00	250-500
3.00	0-60	158.00	450-1810
3.20	15-30	160.00	250-1600
3.60	30	170.00	300-600
4.32	15-30	182.00	250-500
7.20	44	185.00	540-2160