5. Calendaring

Calendering is a method of producing plastic film and sheet by squeezing the plastic through the gap (or 'nip') between two counter-rotating cylinders. The art of forming a sheet in this way can be traced to the paper, textile and metal industries. The first development of the technique for polymeric materials was in the middle 19th century when it was used for mixing additives into rubber. The subsequent application to plastics was not a complete success because the early machines did not have sufficient accuracy or control over such things as cylinder temperature and the gap between the rolls. Therefore acceptance of the technique as a viable production method was slow until the 1930s when special equipment was developed specifically for the new plastic materials. As well as being able to maintain accurately roll temperature in the region of 200°C these new machines had power assisted nip adjustment and the facility to adjust the rotational speed of each roll independently. These developments are still the main features of modem calendering equipment.

Calenders vary in respect of the number of rolls and of the arrangement of the rolls relative to one another. One typical arrangement is shown in figures 1 and 2. Although the calendering operation as illustrated here looks very straightforward it is not quite as simple as that. In the production plant a lot of ancillary equipment is needed in order to prepare the plastic material for the calender rolls and to handle the sheet after the calendering operation. A typical sheet production unit would start with premixing of the polymer, plasticizer, pigment, etc in a ribbon mixer followed by gelation of the premix in a Banbury Mixer and/or a short screw extruder. At various stages, strainers and metal detectors are used to remove any foreign matter. These preliminary operations result in a material with a dough-like consistency which is then supplied to the calender rolls for shaping into sheets.

However, even then the process is not complete. Since the hot plastic tends to cling to the calender rolls it is necessary to peel it off using a high speed roll of smaller diameter located as shown in Fig. 2. When the sheet leaves the calender it passes between embossing rolls and then on to cooling drums before being trimmed and stored on drums. For thin sheets the speed of the winding drum can be adjusted to control the drawdown. Outputs vary in the range *0.1-2 m/s* depending on the sheet thickness.

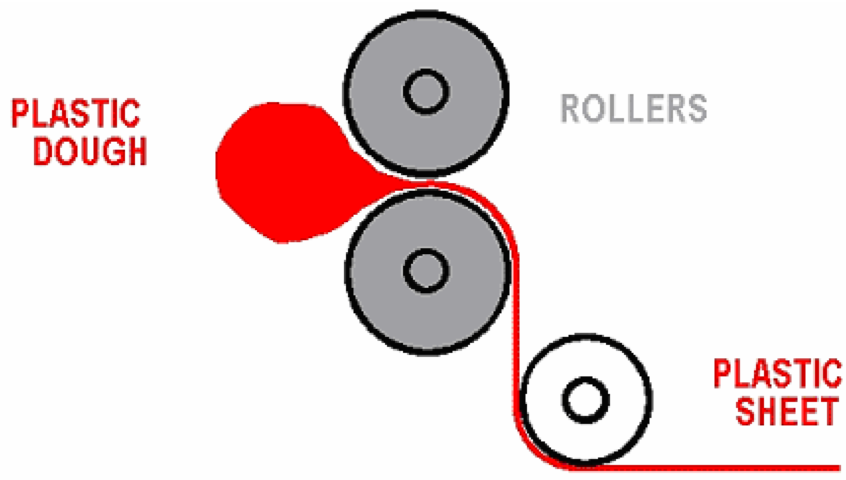

Fig. 1 Typical arrangement of calender rools

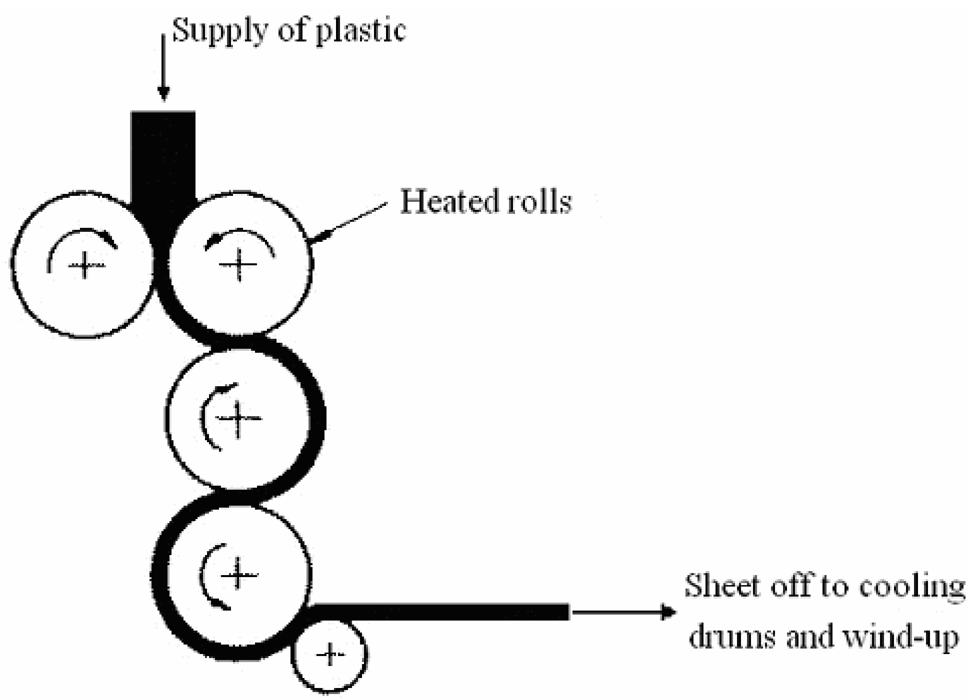

Fig. 2 Inverted L-type arrangement of calender rolls

Calendering can achieve surprising accuracy on the thickness of a sheet. Typically the tolerance is ±0.005 mm but to achieve this it is essential to have very close control over roll temperatures, speeds and proximity. In addition, the dimensions of the rolls must be very precise. The production of the rolls is akin to the manufacture of an injection moulding tool in the sense that very high machining skills are required. The particular features of a calender roll are a uniform specified surface finish, minimal eccentricity and a special barrel profile ('crown') to compensate for roll deflection under the very high pressures developed between the rolls.

Since calendering is a method of producing sheet/film it must be considered to be in direct competition with extrusion based processes. In general, film blowing and die extrusion methods are preferred for materials such as polyethylene, polypropylene and polystyrene but calendering has the major advantage of causing very little thermal degradation and so it is widely used for heat sensitive materials such as PVC.

Analysis of Calendering

A detailed analysis of the flow of molten plastic between two rotating rolls is very complex but fortunately sufficient accuracy for many purposes can be achieved by using a simple Newtonian model. The assumptions made are that:

(a) The flow is steady and laminar

(b) The flow is isothermal

(c) The fluid is incompressible

(d) There is no slip between the fluid and the rolls.

If the clearance between the rolls is small in relation to their radius then at any section x the problem may be analyzed as the flow between parallel plates at a distance h apart. The velocity profile at any section is thus made up of a drag flow component and a pressure flow component.

For a fluid between two parallel plates, each moving at a velocity V_d, the drag flow velocity is equal to V_d. In the case of a calender with rolls of radius, R, rotating at a speed, N, the drag velocity will thus be given by $2\pi RN$.

The maximum pressure may be obtained as:

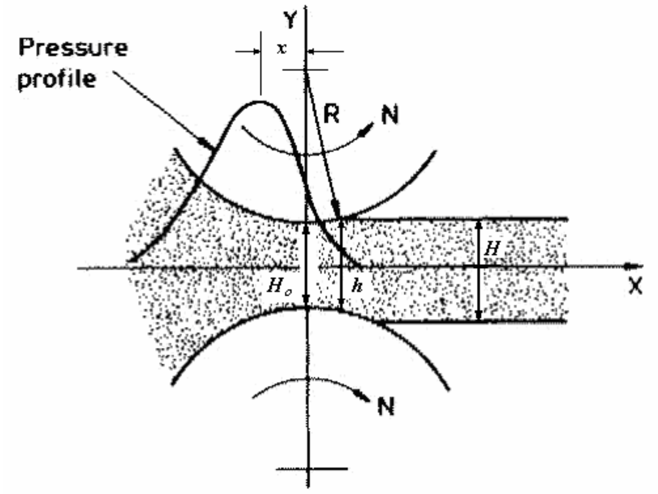

Fig. 3 Melt flow between calender rolls

$$P_{\max} = \frac{3\eta V_d}{H_o}\left\{2\omega - \frac{(4H_o - 3H)}{H_o}\left[\omega + \sqrt{\frac{R}{H_o}}\tan^{-1}\sqrt{\frac{H - H_o}{H}}\right]\right\}$$

$$where:\ \omega = \frac{x}{H} = \frac{\sqrt{(H - H_o)R}}{H}$$

Example

A calender having rolls of diameter 0.4 m produces plastic sheet 2 m wide at the rate of 1300 kg/hour. If the nip between rolls is 10 mm and the exit velocity of the sheet is 0.01 m/s estimate the position and magnitude of the maximum pressure. The density of the material is 1400 kg/m^3 and its viscosity is 10^4 *Ns/m^2*.