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# Modern Approaches to Rubber Processing Problems*

Rubber processing is nowadays considered with a sound scientifical approach to the problems involved, namely by taking into consideration the heterogeneous nature of rubber compounds, their strong viscoelastic character and the pecularities of their flow process. It is now recognised that, within an uncured rubber compound, besides the free mobile rubber molecules whose entanglement level is known to control the flow behaviour, it exists a soft three-dimensional network of fibrous elements of carbon black and bound rubber, which brings singular rheological properties. The flow mechanisms of rubber compounds therefore involve a number of concomitant phenomena, certains common to all macromolecular systems, certains typical of such heterogeneous materials. When submitted to the appropriate strain field, a rubber compound flows through disentanglement processes of macromolecules in the free mobile rubber region and the displacement of complex rubberfiller flow units.

The motion of such flow units not only requires the disentangling of the interface but also involves various stretching/relaxation processes of the filaments arising from rubber-filler interactions. Such an interactive network description of rubber compounds allows to understand their particular flow properties.

Progress in rubber processing has benefited from the unit operation analysis of the overall process, which considers the various stages as a sequence of unit steps, in order to establish the relationships between the input and output flux of material, by understanding the various physical, chemical and rheological phenomena involved. Despite its complexity, this approach allows major processing steps such as mixing and extrusion to be analysed in details and the key operational factors to be identified.

When the key operational factors have been identified, the appropriate testing equipments can be developed in order to specifically address the relevant processing properties. Internal mixers are now being equipped with control systems to measure and record all relevant mixing parameters.

Experiments with various compounds demonstrate that the actual position of the ram is a key factor of the process. It has been observed that the higher the fill factor, the longer this time, with clear differences due to the nature of the filler. An important consequence of observations is that, at the beginning of the process, only a part of the total batch volume is involved in the mixing, since a significant portion remains in the inlet duct until the ramp has reached its equilibrium position. The actuel mixing energy must then be corrected for the effective batch volume concerned. When such a correction is applied, it is seen that the true specific mixing energy is not depending on the fill factor but is a characteristic of the batch nature (and depending on the other mixing parameters).

By analysing the extrusion process as a series of sequential unit operations, two major parts are identified, i.e. the screw component and the die component. The later can be studied via experiments with capillary rheometers. The screw component can only be approached using instrumented extruders. For instance, it has been used to study the extrusion behaviour of various rubber compounds by paying a particular attention to the process stability over long period of time.

Results so far obtained show that the feeding of the extruder has a strong effect, as well as the set temperature profile along the barrel. It is clear that such information cannot be obtained using standard laboratory test equipment.

Modern approaches of rubber processing problems consist thus in correctly addressing the particular aspects of rubber compounds, the filler-elastomer interactions and the resulting viscoelastic character combine as to give significant slippage and elastic memory effects, which monitor the processing performances of rubber compounds. Using the appropriate unit operation analysis of the various processing stages, the most likely sources of variation can be identified and the suitable controls installed with respect to the desired process stability. In order to study the relevant aspects of rubber processing rheology, appropriate testing instruments are now being developed to consider real flow situation rather than the ideal conditions generally achieved in classical test equipment.

*Montedison, Nivelles, Belgique.*
* *Extrait du numéro spécial de* Caoutchouc et Plastiques *consacré à Europlast 90/IRC Exhibition (n° 696, mai 1990).*

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# The Use of New Thermo-Dynamic Methods in the Rubber Industry*

Many rubber processing technologies are connected with exchange of thermal energy as well as with changes of the thermal state. There also many rubber products used in conditions different from the ambient temperature. Therefore, it is surprising that relatively

*Rubber and Plastics Technology Research Institute and* Journal of Plastics and Rubber, *Zlin-Louky, Czechoslovakia.*
* *Extrait du numéro spécial de* Caoutchoucs et Plastiques *consacré à Europlast 90/IRC Exhibition (n° 696, mai 1990).*

little attention is paid to the problems of heat transfer in rubber processing.

In the rubber industry the thermal energy is present virtually everywhere, i.e. in rubber processes, new and somewhat outdated rubber processing machinery and equipment and also in testing of rubber products. The same applies to the tyre industry.

The are also many thermodynamic methods available for the description of the above phenomena. We have concentrated our attention to the following ones :

- exergy balance and measurement of exergy by thermovision.
- application of the Pinch method.
- fuzzy modelling including the development of expert systems for rubber processing.

Exergy can be measured directly by thermovision. In exergy, just like in thermovision, a reference temperature is involved, i.e. the ambient temperature in case of exergy. By setting the same temperature as the comparative level in thermovision, temperatures on which the determination of exergy flow are based, are visualized directly. This connection between a theretical method and a measuring instrument used in practice is an important benefit of the procedure adopted. The thermal radiation in a selected wave length range and in a fairly wide temperature range is scanned and visualized by the thermovision camera ; for an absolutely black body and our camera AGA 780 this temperature range is between –20 °C and +1600 °C. The above maximum range can be modified by suitable adjustable partial range scales and there is no problem to measure temperature differences of a few degrees of centigrade. The accuracy of measurement in the narrowest temperature range is between 0.1 and 0.2 °C. Temperature fields are visualized as coloured surfaces and a given temperature in K can be assigned to each boundary.

Thermovision diagnostics is used for the investigation of rubber technologies, evaluation of rubber processing machines and equipment and testing of rubber products. Tyres are checked by thermovision during the production stage, as final products and in practical tests on testing or racing cars.

A few more examples :

- A thermogram of closed moulds in a press for the production of sealing rings.
- A thermogram of a press for the vulcanization of passenger tyres.
- Another interesting experience was the investigation of the function and especially of higienic aspects of milking sets (machines) used in large capacity cowsheds.
- Thermovision measurements of the behaviour of tyres during production, testing and driving.
- A thermogram of a tyre fitted on a racing car, at the end of the speed test.
- A thermogram of a natural rubber sample under tensile load on the Instron tester.

Another method, investigated at our institute, is the Pinch method. At ICI in England, it has been developed under the name Tensa. The method includes several parts, e.g. the one designed for investigation of heat exchanger networks is called HEN. In Czechoslovakia it came to be called Pinch method.

The result of application of the Pinch method to a given system are substantial savings of costs with simultaneous improvement of efficiency of the thermal (heat exchanger) installation and very short return of investments.

The Pinch method is very developed for continuous processes. In case of discontinuous processes, like the majority of those employed in the rubber industry, this method should be modified and that is exactly what we are aiming at. For better illustration I have chosen a continuous process, namely the recovery of DMFA from the production of synthetic leather.

In this overview I should not forget to mention one more method, i.e. the fuzzy method. Although it does not belong to thermodynamic methods it can be used for the solution of thermal problems.

The fuzzy method is based on linguistic modelling. It summarizes and processes a multitude of valuable information concerning a given process, (e.g. the production of rubber conveyor belts) used by the operator of a machine according to his accumulated experience over many years. The operator is usually unable to formulate this experience in mathematical or physical terms ; he can, however, describe it in his own words, not quite unambiguously, i.e. in a fuzzy way.

In the field of the rubber industry we have tested the fuzzy oriented expert system in designing rubber compound formulations and extending service life of rotating shaft seals.

As the method is not generally know I have restricted myself only to a basic information to say that such a method exists and is used in the rubber industry.