Continuous Solvent Extraction of Sunflower Seed, Groundnuts, Palmkernels, Rapeseed, and Copra

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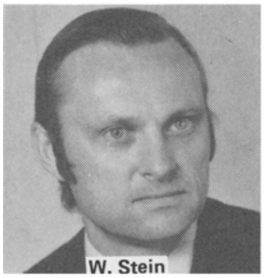
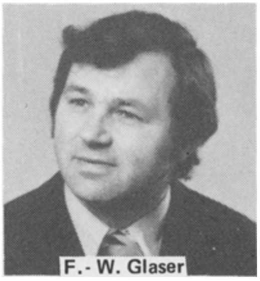




ABSTRACT

In principle, the oil milling process is straightforward. The wide variety of equipment in use reflects, however, a multiparametric process. The main limiting parameters are kind of seed, oil content, particle strength, particle structure, temperature, moisture, particle size, residence time, mechanical forces, etc. Additionally, the seed specific parameters vary not only between kinds of seed but also for the same seed, due to different conditions in climate, soil, and harvesting. Therefore, equipment design must be widely based on statistical averages of the limiting parameters. In other words, exact precalculation of the single technological steps is impossible. As a consequence, for more than 5,000 years, the oil milling process has been in the stage of being optimized. The actual technical standard is very satisfying, but there is still a strong need for further research and development. Currently, as in the past, the oil milling process seems to be not so much a science as an art.

INTRODUCTION

Two general questions must be answered when talking about the processing of a given selection of oilseeds:

- What do the seeds in question have in common, and what are the specific features in comparison to other seeds?
- Do the seeds in question call for specific process steps which are basically different from those for other seeds?

As far as seed selection is concerned, the five seeds under consideration do not match with any usual method of classification, i.e., soft seeds (rape, groundnuts, copra) and hard seeds (palmkernels, sunflower), or seeds from multiannual trees (palmkernels, copra) and seeds from uniannual plants (rape, groundnuts, sunflower). All that they have in common is an oil content in the range of 40-70%, which is appreciably higher than the ca. 20% for soybeans (Fig. 1). No specific characteristics of these seeds in comparison to other seeds can be deduced from the method of processing. The basic technological steps of the oil milling process are still the same for all seeds as they have been since the first written record on oil milling from the Chinese nearly 5,000 years ago. These basic steps, shown in Figure 2, are as follows:

- Size reduction
- Heating
- Separation

} Preparation

The separation of crude oil and solid matter can be achieved either by means of mechanical forces in any kind of press, or by means of mass transfer because of concentration gradients with solvent extraction. Actually, there is not only a choice of either pressing or solvent extraction, but the two technologies may well be combined. However, any choice of single process steps is, in the first place, not tied to seed specific characteristics but is a matter of optimization, including economic aspects as well as availability of solvents, skill of workers, etc.

This paper will not deal with technical details of equipment. These are basically the same for all oilseeds and are well covered in other papers. On the contrary, it will stress some physical and biochemical aspects involved in the single technological steps according to Figure 2, the knowledge of which is a prerequisite of proper design and optimization. At the same time a great number of important research activities may be derived from these aspects.

PREPARATION

In Figure 2, the two steps of seed preparation are listed. To comprehend what shall be achieved and what the physical background is, one has to first visualize the microscopic structure of oilseed (Fig. 3). The single seed is composed of cells, which are enclosed by fairly strong cell walls. The cells contain the oil as well as the protein. The cell wall is nonpermeable for the oil, and it is also supposed to be nonpermeable for any solvent used in solvent extraction processes. Consequently, preparation means breaking the cell walls to get the oil out of or solvent into the cells. From the standpoint of equipment design, each cell must be treated by the necessary mechanical forces to break the cell wall. This requires size reduction of the seeds first,

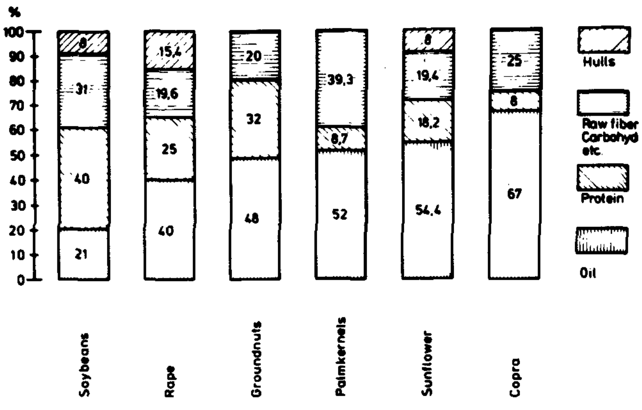


FIG. 1. Composition of prepared seeds (dehydrated basis).

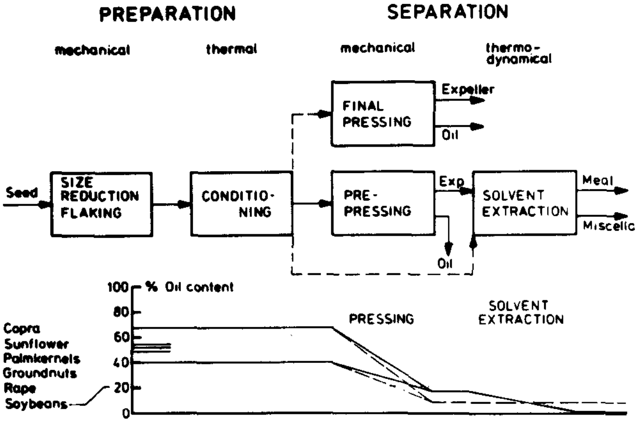


FIG. 2. Oil milling process.

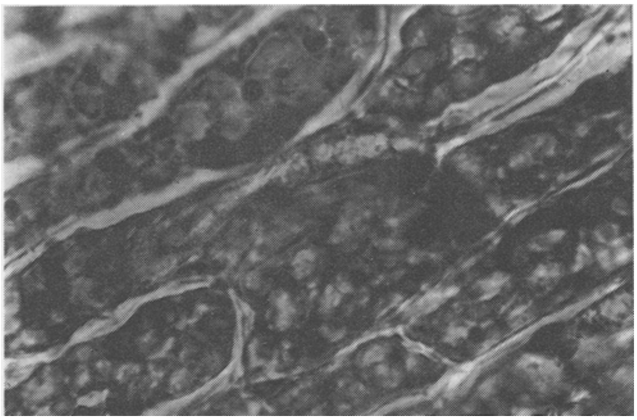
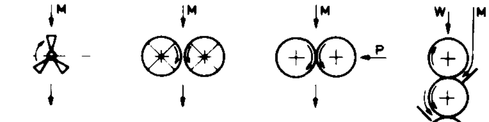
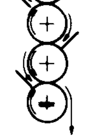


FIG. 3. Seed structure.

Equipment (schematic)





	Cutting	Breaking	Flaking
Sunflower	—	—	1 passage
Groundnuts	—	1 passage	—
Palmkernels	—	3 passages	4 passages
Rape	—	—	1 passage
Copra	1 passage	3 passages	1 passage

FIG. 4. Size reduction and flaking (number of passages).

which is normally performed in fluted roller mills. The optimal size distribution for any kind of seed must still be adjusted empirically. The actual breaking of cells is achieved through roller mills, where each seed is exposed to the necessary pressures to break its cell walls. However, getting an access to each cell is not alone sufficient to easily separate crude oil and solid matter. In the separation process, i.e., in mechanical presses or in extractors, the solid matter must form a porous structure which allows transport of the oil or miscella. It is known from fixed bed systems that free cross section and pressure drop depend on particle size and size distribution. In any case, the size distribution should be as narrow as possible, and the particle itself must be stable. Consequently, the roller mills must also deform and compress (to flake the single piece in an adequate manner), which is also still a matter of experience.

However, there is an easy test to determine what percentage of cells is open. The ratio of extracted oil from any probe determined by solvent extraction, and the maximum oil content to be extracted from the same material which through very fine milling is surely prepared completely, indicates the percentage of open cells. The respective number may be defined as degree of treatment X_T, where

$$X_T = \frac{x_o - x}{x_o - x'}$$

$$\lim_{x' \to 0} X_T = 1 - \frac{x}{x_o}$$

x_o = oil content of seeds

x = oil content after separation

x' = minimum oil content after separation

To achieve the technological prerequisites of size reduction, breaking, and flaking in a suitable way, the machines in use are equipped with one, two, or three passages, the slot and pressure being adjustable (Fig. 4).

Besides the mechanical steps, preparation mostly includes a thermal step, which is referred to as conditioning. This procedure is reported from the old Chinese and, in the first place, must reduce the viscosity of the oil. Today, however, when the high protein content of different seeds is to be used for animal feed and human food, certain biochemical reactions, as coagulation of the protein or toasting, must take place. These, indeed, are temperature and time dependent. So far, one can only check whether these reactions have gone far enough, while the optimal temperature over time curve is still unknown for the different seeds. It may also be assumed that such cell walls, which are damaged during the mechanical process but which are not yet broken completely, may finally tear through thermal tensions. The actual share of this process is also unknown.

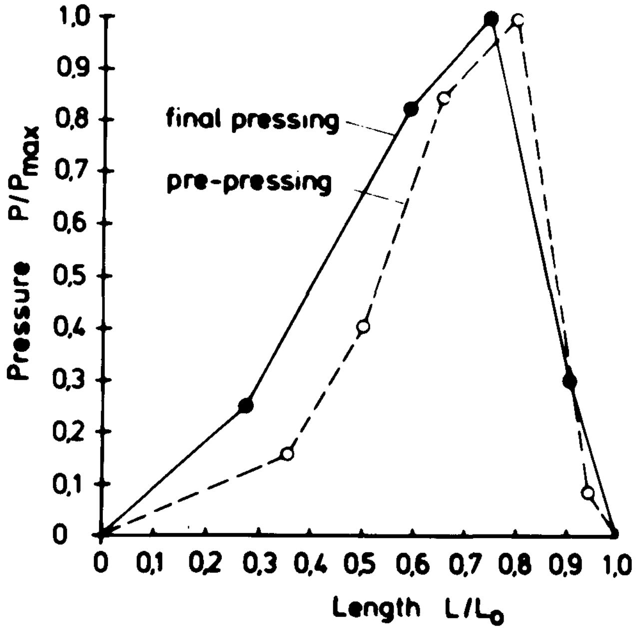


FIG. 5. Requirements for pressing.

Another important aspect of conditioning is to control humidity. There is a strong influence of humidity on the coagulation of protein and on the stability of flakes, as well as on the bed structure in the press or in the extractor. Again, the optimal moisture content cannot be calculated but is a matter of experience depending on the kind of seed and equipment.

Two common types of conditioners are in use: the multistage cooker with six or more horizontal heated plates and the externally heated rotary conditioner consisting of one or more cylindrical drums. In both apparatuses, the material is moved through special kinds of agitators to achieve good contact of the material with the heated areas as well as a narrow residence time distribution of the single particles.

SEPARATION

The properly prepared seed passes through a separation process, which may be either pressing or solvent extraction (Fig. 2). It must be kept in mind that any separation process is just as effective as was the foregoing preparation of seeds.

In our days, pressing is done by means of continuously operated screw presses. Aside from technical details of the different designs, they are basically the same, as they have to meet the same requirements (Fig. 5):

- Drawing in the material

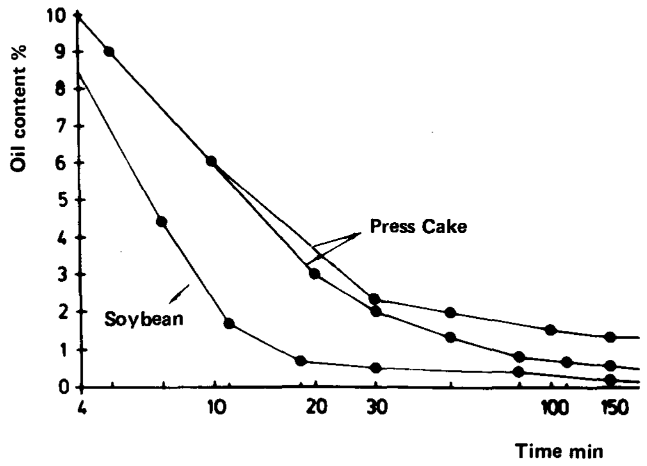


FIG. 6. Requirements for extraction.

- Compressing the material
- Forming a porous structure in the solid material
- Self-filtration of the oil through the fines of solid material
- No overheating of organic matter at any place in the press

The performance of any kind of screw press can be characterized by a pressure over length of the cage curve, which indicates the effectiveness of the pressing process. Clearly, for reasons of transport phenomena in the porous structure to be built up, the process should run at the lowest pressures possible to achieve good deoiling. Again, pressing is a very complicated multiparametric process that is affected by the kind of seed, flake size and stability, temperature, moisture, geometry and speed of worm, etc. So far, there is no sure way to precalculate.

The average figures of residual oil content, which may be achieved by single and final pressing, are in the range of 5-6% (Fig. 2). Much lower figures, down to 0.5%, can be achieved by solvent extraction. Here, the process requirements are as follows (Fig. 6):

- Free access of solvent or lower concentrated miscella to each cell
- Free exit of higher concentrated miscella from the single flake into the bulk flow
- Suitable separation of miscella and solid matter

The overall effectiveness of the process with respect to transport phenomena is reflected by a residual oil over time curve. From this curve, the necessary extraction time to achieve a required residual oil content can be read. A given capacity and extraction time lead directly to the size of the extractor. As can be seen from the curves, there are seed specific differences which result in different sizes of reactors at the same throughput of seeds. Reactor size depends also on suitable separation of miscella and solid matter.

There are basically two different designs of extractors: the percolation type and the immersion type. With the percolation type, the solid material forms a fixed bed, where good drainage of the fluid phase is a main requirement. Therefore, size reduction of the seeds must not go too far, so that the pressure drop may be kept low. With the immersion type, the solid material is dispersed in the fluid phase, which means perfect contact between the solvent and each single particle. For reasons of a big specific surface of the solid material, size reduction must go as far as possible. However, there is the problem of quick separation of the two phases after extraction. In principle, the two ways of solvent extraction may be set in line with the percolation step first and the immersion step second. Size reduction then is also applied in two steps, thus allowing for optimal adjustment to the above requirements.

As far as the residual oil content is concerned, approximately the same figures can be achieved in either type of extractor, while the foregoing treatment in the preparation process has to be modified.

Experience so far has proved an oil content of ca. 20% to be an upper limit for extraction directly after preparation. This figure does not, indeed, mean a physical barrier but simply reflects the technical standard. Consequently, it is common practice to combine pressing and solvent extraction (Fig. 2).

In a pre-pressing step, the high oil content of seeds is brought down to ca. 16-20%, the expeller cake then being exposed to solvent extraction. This procedure adds another requirement to the pressing process, i.e., to form a suitable structure and stability of the expeller. As this is normally achieved with modern screw presses, no further preparation before extraction is necessary. Recent developments seem to allow for direct extraction of seeds with an oil content >20%. This brings up the question of whether there is a preference for either direct extraction or the combined process of pre-pressing and extraction. As indicated above, the choice of process steps is, in the first place, a matter of economics, besides such other aspects as availability of solvents, skill of workers, etc. Economic factors, among others, include fixed costs (investment cost), energy cost, and maintenance parts. Because of the wide range of limiting quantities, an optimization has to be achieved from case to case.