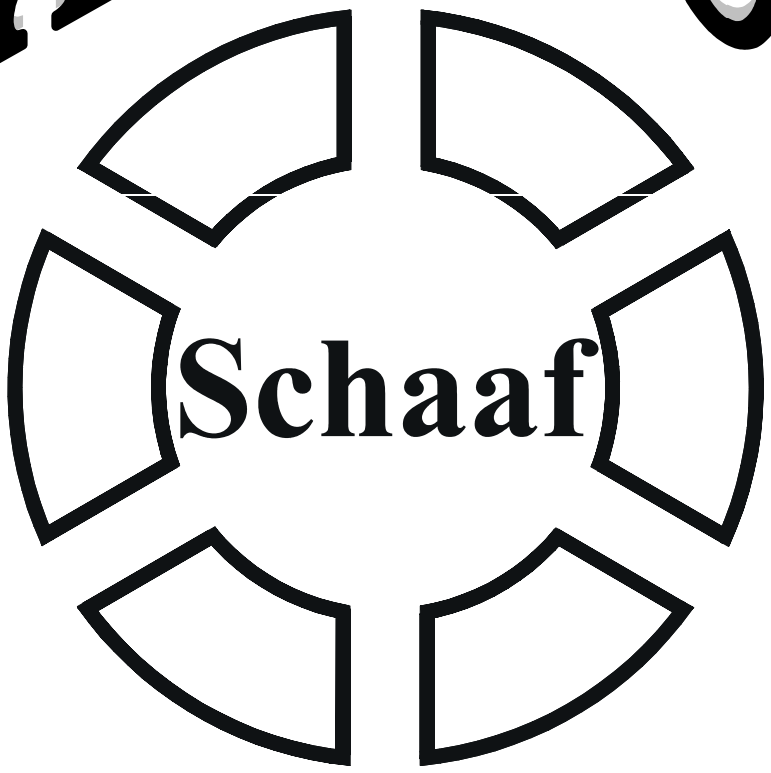
Schaaf Technologie GmbH

BASICS "EXTRUSION"



BETRIEBS- UND WARTUNGSANLEITUNG / OPERATING MAINTENANCE

C O N T E N T S

Basics Extrusion

Extrusion should be defined as a cooking-extrusion process with the aim of producing a voluminous, expanded, crispy product resembling somewhat a baked product.

There is no principle limitation in terms of the raw materials which can be used for extrusion. In the following passages an attempt will be made, sometimes simplified, to analyse the important characteristics of the building blocks of the organic raw materials along with their effects on the process and the results of extrusion.

The plant based raw materials, which are important from the viewpoint of extrusion, can be considered in a simplified form to be comprised of the building blocks:

Starch
Protein
Fat
Sugar
Fibre (Cellulose)

Cereals, Leguminous materials and seed based products are made of these basic building blocks in various ways.

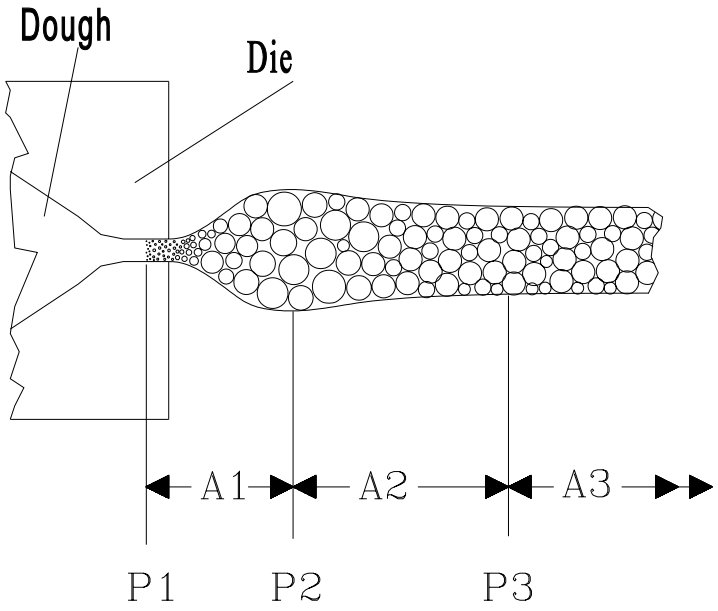
The process of extrusion, with the aim of obtaining an expanded, texturized product, is in principle made of simple physical effects which are influenced mainly by:

Dough characteristics
Presence of water
Temperatures higher than 100 deg C
Pressure

A dough which has to show particular **characteristics**, depending again on the presence of water, is brought to a **temperature** of more than 100 deg C, whereby the high **pressure** build-up prevents the **evaporation of water** in the machine itself.

The dough, pressed through a die into a pressure free room, blows up mainly due to water evaporating at a very high speed, expands as per its **elasticity**, cools down however due to the heat loss suffered by it in **evaporating out the water**, hardens up due to the **cooling** as well as due to the loss of water and retains, depending on the grade of hardening, its form and volume, which it has obtained due to its earlier mentioned expansion.
From the above mentioned principle it is possible to draw inferences about simple repeatable relations, the importance of which cannot be underestimated in terms of the results of extrusion and for the practical work with the extruder.

Let us now divide up the process of the expansion and the processes immediately following it into individual phases and take a look at the dough shortly before the expansion in terms of its state and characteristics.



The expansion can be seen as a phenomena limited by time, starting from the point of time, where the still existing pressure has just su nk down to such a level that water, which is present in the dough in an overheated state, begins to evaporate.
Let us call this as the point of time P1.
The next phase A1 is characterized by an increase in the steam volume to a maximum of P2, simultaneously ending the process of expansion.
Exactly at this point of time the pressure of steam inside the expanded dough (upto the elastic limit of the dough) is equal to the outside air pressure.
In the following phase of A2 the steam pressure inside tends to reduce even further due to further cooling, resulting in a more or less evident shrinking of the dough, reduction in its volume upto a point of time P3, which ends this phase, characterised by the, more or less, evident hardening of the dough.

During the phase A3 the dough cools down further, looses moisture and hardens itself upto the point of time P4 when room temperature is achieved.

Condition:	**Result:**
High temperature of dough	- Earlier setting in of expansion - Violent expansion - Steep increase in volume - Higher steam volume - Higher moisture loss - Stronger hardening - Lower specific weight of the extrudate - Soft product
High dough moisture level	- High elasticity of the dough - Large, rough pores in the product - Lower viscosity of the dough - Lower hardening of thedough - Strong shrinking tendency A2 - Crunchy texture of the extrudate - High final moisture level at P4

Let us examine the characteristics of the dough more closely

It can be seen very easily that under the condition of a very violent evaporation of water, the dough must posess an important characteristic, i. e. of elasticity, to be able to convert the increase in the volume of the steam into an incr ease in its own volume. If this elasticity is absent, then the stage of formation of bubbles is never reached, i.e. the bubbles break down even while in the stage of A1, without causing a remarkable increase in the volume.

To ensure that this dough posseses the required elasticity, it should be made out from raw materials which posess the principle capability of forming an elastic dough. Thus fat and fibre disqualify as such raw materials. Sugar is, under certain special circumstances, plastic though never elastic.
What remain are **proteins** and **starch**. Both these raw materials form under certain conditions elastic masses, specially in case of starch where particularly the gelatinization is an important pre-condition for development of elastic characteristics.

Starch alone and protein alone have, depending upon the source and characteristics, remarkable elasticity properties. In mixes comprising of both, the dough characteristics, in terms of elasticity, are surely worse.
Protein and starch tend to work against each other in terms of the maximum attainable elasticity.

Maximum elasticity is reached when the dough is as far as possible homogenous. This is valid for mixtures of starch and protein, specially in the presence of other, elasticity reducing components like fat, sugar and fibres.

As fine the "disturbing" components fat, sugar and fibre materials are distributed into the dough, as less "disturbing" are their effects in terms of the elasticity.

Maximum expansion, along with the loss of crispiness, sensitivity to moisture and of all the taste of the extrudate is however under no condition the exclusive aim of extrusion.

To know the above discussed relations, to understand them and to use them specifically for desired product characteristics is the aim of every work with the extruder.

The composition in terms of the raw materials decide primarily the development of certain characteristics of the dough and thereby the major product characteristics.

The moisture level of the raw material causes besides the direct effect on the extrusion process significant influence on the dough characteristics and thereby on the expansion and the texture of the end product.

The dough characteristics shortly before the die passage together with the factors temperature and pressure determine exclusively the characteristics, i.e. the quality of the end product.

Influence of the extrusion conditions on the characteristics of the dough and the extrudate:

It has been discussed till now that the composition in terms of the raw materials must fulfill certain conditions for the development of certain dough characteristics.
It has also been shown that it is necessary to carry out a particular treatment of the raw materials to achieve the so important elasticity of the dough.
Important aims of this treatment of the raw materials are:

- Gelatinization of the starch
- Denaturizing of the protein
- Heating above 100 deg C
- Homogenizing
- Development of pressure

It can be easily seen that inspite of the fact that one can realise all these process requirements also by other processes and techniques, the list of the above process steps covers also the characteristic process areas of a screw machine, specially when one considers a correspondingly optimized cooker-extruder.

For homogenizing/mixing of raw materials it is necessary to exert mechanical work. This is also valid for the development of pressure.

This work follows simultaneously with heating of the material.
Heating is desirable and even very necessary for gelatinization of the starch and the denaturisation of the protein.

Homogenization, gelatization, denaturization and heating exist in a forced and sometimes complex changing relation with each other, influenced further very strongly by the moisture level of the material.

Gelatinization of the starch and denaturization of the protein is, at least as per the general definition, not possible in absence of water , in the same way as the formation of a dough, nothing to talk about an elastic dough.

The moisture content of the material determines the viscosity of the dough formed. If the moisture level is high it results into a dough of low viscosity and vice-versa.

Schaaf short-screw extruders workexclusively under the principle of **"autotherm"**, i.e. the process heat is generated exclusively by the conversion of mechanical energy i.e. by the rotation of the screw together with the torque applied by the screw.

The control of the process conditions takes place mainly in 3 stages:

- Moisture of the extrusion material
- Pressure build-up before the die
- Screw rpm and its relation to the mass dosing rate

The development of the pressure with the help of the die and the various pressure elements cannot be changed during the operation of the extruder, whereas the moisture level of the raw material as well as the screw rpm can be varied.

Effect of the extrusion moisture

Higher moisture levels cause lower viscosity.
The dough viscosity shows its effect on the torque to be applied by the rotating screw and thereby on the load uptake, i.e. on the functions of kneading, homogenizing, and heating in the extruder.
Lower dough viscosities cause lower pressure at the die and pressure elements.
At lower viscosities one observes lower dough temperatures and hence lower expansions.

High moisture levels on the other side promote the important processes of gelatinization and denaturization and thereby the developement of elastic characteristics of the dough.
Higher moisture contents allow easy homogenizing of the fat, sugar and the starch-protein complex, is however of negative effect on the homogenizing of the fibre materials, requiring intensive mechanical size reduction.

It has been already established that the moisture of the raw material has direct influence on the dough characteristics in terms of minimal required moisture addition to cause gelatinization and denaturation together with the homogenizing. The moisture addition is on the other side limited to a maximum level due to the necessary hardening required for retaining the form after the expansion process.

Further in consideration of the direct influence of the moisture on the porosity and the texture of the extrudate, only a limited range of moisture level changes is available to regulate the extrusion process without causing direct, undesirable influence on the extrudate quality.

Influence of die pressure

Under the term "die pressure", one has to understand the total flow resistance caused due to pressure and die elements.

An extruder screw as a unit has minimum working efficiency from the viewpoint of pure transportation and pumping effect.

The theoretical pumping effect which is necessary to transport a certain mass flow against a certain pressure is surprisingly small. If one considers the actual power uptake of an extruder screw and compares it with a pure pumping load, one realises that the transportation efficiency is very low.

On the other hand it is specially this lost power, performing the important functions of kneading, homogenizing and conclusively heating, which makes the screw machine into a cooker extruder.

Every change in the die pressure causes although only a small increase in the required pumping capacity due to the lower efficiency, causes however a significant increase in the desired kneading and homogenizing capacity or an increase in the temperature of the dough.

It is possible to influence in many ways the extrusion conditions and hence the results of extrusion with the help of the construction, nature and the form of the dies and the pressure elements.

Even when the die tools are fixed due their basic form, a purposeful use of one or more pressure plates or such other flow elements are very important for a successful extrusion process.

Influence of the screw-speed
(or relation screw RPM : mass dosing rate)

By changing the dosing of raw materials in the extruder screw as well as with the help of change in the screw speed at constant material dosing, the transport relations in the extruder can be changed significantly in portions.

Completely filled screws result into a highest possible transport efficiency.

If the dosing of the raw material is increased in a partly filled screw, it causes an increase in the moment load on the screw and hence a higher power is demanded.
Though this situation can be easily visualized, an accompanying effect of much higher importance requires availability of some other basic knowledges also:

Due to the higher extent of fill of the screw, the transport efficiency also increases, i.e. the lost power used for kneading work and temperature decreases in comparison to the transport load. Hence, it follows that the specific energy input into the material decreases and hence the temperature of the dough also reduces.
In opposite direction it means that a reduction of the material dosing at unchanged screw speed leads to a lower filling of the screw, i.e. the transport effective length of the screw is reduced and hence the transport effectivity. This results into a greater kneading and homogenizing function and higher dough temperatures.

Out of these described relations, one of the most important tools of an efficient and above all a fast reacting control of the extrusion process during the operation is created.
Also the following relations can be derived from the above considerations:

Condition:	**Result:**
Increase of the screw	- Reduction of transport speed at same dosing efficiency - Increase of kneading and homogenizing activity - Increase of the energy input - Increase of the temperature - Increase of the expansion - Reduction of the moment - Reduction of the current uptake

The reduction of the angular moment or the current uptake is so far not a contradiction to the above described points, as this reduction is not proportional to the screw speed increase and only the difference of the product of sc rew speed and the angular moment cause the described effect.)

Increase in the dosing at same srew rpm	- Increase of the transport efficiency - Decrease of kneading and homogenizing work - Decrease of the energy input - Decrease in the dough
Temperature	- Decrease of the degree of expansion - Increase of the angular moment - Increase in the current uptake

Naturally the transport capacity of the screw reaches its limit when the screw is already filled, indicated by a filling of the feeding hopper.

Transport capacity as well as transport efficiency reduce with increasing wear of the screw. Due to increased wear the diameter of the screw gets reduced, resulting in higher backflow of the material over the screw threads. Hereby the transport efficiency reduces with all of the following consequences: Increase in the kneading activity, temperature, transport capacity and hence the discharging capacity of the machine.

This influence of the wear conditions of the parts on the extrusion conditions is not exclusively negative. It occurs quite often that particular end-product characteristics can be achieved only through increased kneading activity, i.e. through tools which have already undergone a certain extent of wear.

Hence a conclusion: *Never throw away screws or sleeves but keep them safely to enable their usage while producing special products, thus improving their overall utilisation !*

Conclusions:

The operating tools configuration, i.e. the combination of the pressure and flow elements, is the first and the most important measure to be undertaken for a specific influence on the process of extrusion.

With the help of a suitable configuration one sets the framework of the extrusion conditions in which the following control possibilities are to operate.

The variation of the extrusion moisture is the next instrument for the control of the extrusion conditions.

Limited at the lower end by the moisture requirement for gelatinising, danaturising and under certain conditions homogenising and at the upper end by undesirable texture changes of the final product or insufficient expansion due to energy deficit or insufficient hardening of the dough after the expansion (shrinking). The moisture level is chosen so as to have sufficient control possibilities by changing the extruder parameters (e.g. by making the screw speed higher or lower).

With the help of the screw speed or the relation between the screw speed and the dosing rate, one has the last and the most elegant control possibility, during the operation, for temperature and expansion.

The specific and properly considered setting and use of these three control methods are pre-conditions for a successful extrusion with the result of a constant product quality.