

Agitation and Mixing

Measure of the Energy Transferred during Kneading

For the past several years VMI has carried out research regarding the control of various parameters during kneading operations. In most cases, for small businesses or industrial manufacturing, the baker relies on criteria gathered by the sensorial examination of the dough to determine the optimum length of the kneading process. Efficiency and more specifically duplication factors have recently led some bakers to request a real time follow-up of the kneading process that takes into account the rheological characteristics of the dough being produced as well as the various operational parameters of the kneaders. The energy generated by the kneader and transferred to the dough is one of the physical values which meets this goal and can, with some precautions, provide precious benefits in the follow-up and optimization of a variety of settings.

Some Fundamental Principles

Energy is the capacity of a system to generate an action which leads to movement, illumination or heat. Energy is a concept created to quantify the interaction between very different phenomena; in some ways it is the representation of the exchange that is produced between physical phenomena. These exchanges are controlled by the laws and principles of thermodynamics. When a phenomena leads to another phenomena, the intensity of the latter is conditional to the intensity of the first phenomena. As an example, the chemical reactions on the muscles of a cyclist give him the energy to set the bicycle in motion. The quantifiable value is the intensity of movement (speed) that is conditional to the intensity of the chemical reactions on the cyclist's muscles. The concept of energy allows the calculation of the intensity of the various phenomena (ex. the speed of a car) in respect to the initial phenomena (the quantity of gas and heat generated by the chemical reaction of combustion in the engine). To create mechanical energy an action by a mechanical force is required.

Force:	Physical phenomena which causes the deflection, movement, stop or change of direction of a body. The Newton (N) is the unit of force. 1 N equals the intensity of force required to generate an acceleration of 1 ms^{-2} for a body having a mass of 1 kg.
Energy:	The Joule (J) is the unit used to express energy (also called work). 1 J equals the work generated by a force of 1 N when the point of application moves over a distance of 1 meter in the direction of the force or due to the force.
Power:	Power expresses the transfer of 1 J of energy during 1 second. In the field of mechanics, Power = Energy (J) / Time (s). The unit of power is the Watt (W). $1 \text{ W} = 1 \text{ J/s}$, and $1 \text{ J} = 1 \text{ W/s}$. Very often energy is presented in W/h (= 3600 J).

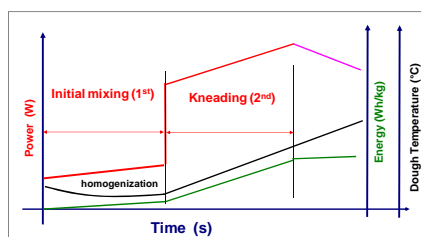
Energy Generated during Kneading

A kneader must transfer enough energy to the dough in order to encourage the production and structural development of the gluten network. The stretch, compression and shearing forces activated by the various components of the kneader generate the energy for which a part of this energy causes a transformation in the consistency of the dough and the other part the increase of the dough's temperature. Several parameters have an influence on these forces:

- The shape and size of the tools and the tank,
- The rheological characteristics of the dough (viscosity, elasticity, speed of discharge), which are themselves influenced by the basic elements (water, flour, salt, ...) and the reaction to the input of power,
- The reaction of the dough in respect to its exterior environment (friction, adhesion),
- The relative quantity of dough in the kneader

This explains the reason why even if the same input in energy is used for identical ingredients, the quality of kneading will differ from one kneader to another. In the case of a single kneader an equivalent input in energy will not always produce the same quality of dough throughout the life cycle of the kneader. The kneader will undergo a certain level of wear during its life cycle therefore modifying the effects of the mechanical forces in respect to the return of energy.

A profile of specifics for the progress of the transfer of energy to the dough during kneading was defined thanks to recent research:



Naturally, the relative values of these curves are conditional to the type of kneader used, the characteristics of the raw material and the rotation speed of the tools. However, they do show that it is possible to establish a correlation between the kneading time, the energy (or power) generated by the kneader and the temperature of the dough during the kneading process.

Some have specifically used these correlations relatively in order to establish the expected values in energy with regard to the desired quality of the dough. It is the case for the Englishmen of the *Flour Milling and Baking Research Association* who by developing what they called the "Chorleywood Bread Process" (CBP) defined a reference point for the level of energy required to obtain the quality of dough needed using specific ingredients and conditions in temperature. 40 kJ/kg of dough is the recommended value for this type of bread.

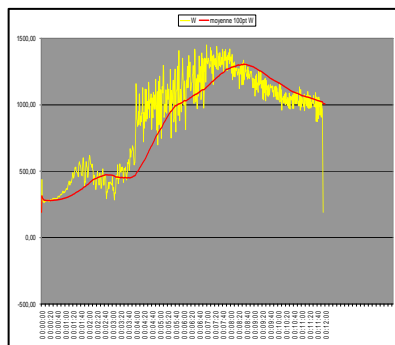
The large-scale diversity of French bread does not allow the establishment of a single value for energy. Several experimental results show that when using the intense French kneading process the "optimum" values in energy are positioned between 7 and 15 kJ/kg for kneaders equipped with a diagonal axe and approximately 25 kJ/kg for kneaders with spirals.

This notion of "optimum" energy can be understood using the concept of over-kneading. If the dough is shaped by the development of a network of fibers and proteins linked together by mechanical joining and supported by the input of energy originating from the kneading

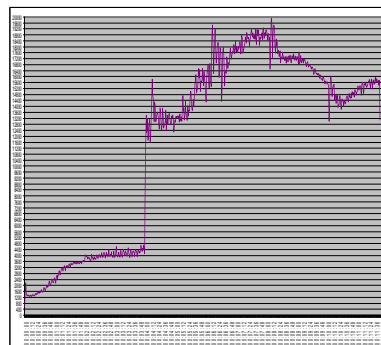
procedure, an input that is too strong will lead to the rupture of the links that were initially formed. These ruptures are augmented by an increase in temperature and a thinning of the protein film when it reaches its maximum expansion. The dough reaches levels of viscosity and resistance that no longer allows it to be properly handled, resulting in over-kneading. The decrease in the internal mechanical links of the dough leads to the breakdown of its overall resistance. The kneading tools require a much lower mechanical power to continue the exertion of the required force at a constant speed. A point of inflexion in the progress of power is then noticed, an indication that energy is being transferred to the dough by the kneader. This point of inflexion can give an indication of the "optimum" length of kneading time. However, this time period can be seen as a maximum period that must not be exceeded, and not the optimum length of time observed using sensorial criteria which would indicate the quality of dough that must be reached in a shorter kneading time.

Implementation of the Measure of Energy

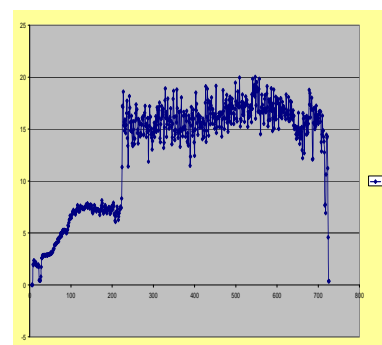
VMI kneaders allowing the measure of energy in real time are equipped with a wattmeter measuring electric energy consumption by the kneader motors. Several trials show that the progress in the consumption of electric power during kneading corresponds to the theoretical characteristic profile of the power curve, indicating that energy is transferred to the dough.



Measures performed on kneaders with spirals SPI53
5.6 kg flour, 3.3 kg water, 16.5g salt (added at 10'30)
Initial mixing first speed (110 rpm) for 4 min
Kneading second speed (220 rpm) for 8 min



Measures performed on kneaders with spirals 400 AVI
100 kg flour, 150 kg water
Initial mixing first speed (96 rpm) for 4 min
Kneading second speed (192 rpm) for 8 min



Measures performed on fork kneaders 1595
10 kg flour, 15 kg water
Initial mixing first speed (40 rpm) for 6 min
Kneading second speed (80 rpm) for 12 min

The electric power consumed by the kneader is, as illustrated in the various experiments performed, tainted by the uncertainty associated with the instability of an electric network, the non homogeneity of the resistant consistency of the dough being produced, the cyclical aspect of the global rotation efforts of the dough within the tank and the inaccuracy of measures performed spontaneously through sampling. These uncertainties are also illustrated by the fact that under vacuum, power consumption by the kneaders is not constant in time mainly due to the different performances and the rise in temperature of the internal mechanical parts of the kneaders. However, trials have shown that these measures are replicated in identical kneading conditions. We can therefore state that the measure of electric power consumed, even if it does not provide an absolute value of the energy ultimately transferred to the dough, allows the verification of a certain number of parameters by comparing relative values of power from one production to another. In fact, a variance in power can result from modifications associated to the ingredients (characteristics of the flour, forgotten ingredients, error in the order of incorporation of ingredients, difference in temperature, ...), or signals a modification in the performance of the kneader itself (wear, improper settings).

Energy and Temperature

It is important to link the expression of the energy consumed and in part transferred to the dough by the kneader, to the temperature of the dough. There is in fact a direct relation between the energy transferred to the dough and its increase in temperature. This relation is established through the specific heat of the dough that gives the quantity of heat (associated to a form of energy) which must be released in order to produce the increase of the given temperature. The official unit of specific heat (C_p) of a body is expressed in $J/kg/^\circ K$, but is often expressed in $cal/kg/^\circ C$ ($1 J/kg/^\circ K = 0.24 cal/kg/^\circ C$). The relation between energy (E) and temperature variation (ΔT), for a quantity of a given matter (M) is therefore simply $E (J) = C_p (J/kg/^\circ C) \times \Delta T (^\circ C) \times M (kg)$. This relatively simple relation unfortunately does not lead to the linear demonstration of the increase in temperature according to the input of energy because the specific heat of the subject we are dealing with, the dough, varies according to its state which changes from a relatively liquid state ($C_p = 410 cal/kg/^\circ C$) to a solid state ($C_p = 640 cal/kg/^\circ C$) during the procedure. The measure of the increase in temperature of the dough, performed in parallel with the power consumed by the kneader, allows an initial approximation of the absolute values for the energy transferred to the dough.



Example of measures performed in real time under vacuum on a horizontal kneader VeryMix III

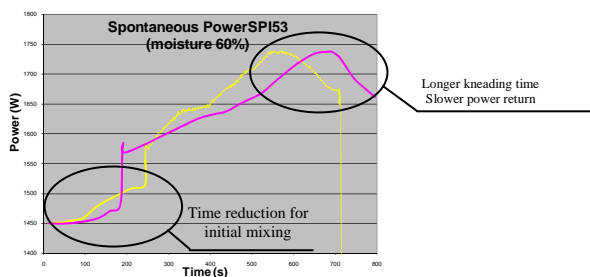
Benefits and Limits of the Readings of Kneader Energy

Traditionally, the baker relies on sensorial criteria in order to define the proper parameters for kneading. He will produce the proper dough after the multiple trials that will allow him to establish the optimum time of kneading. This time becomes the only control method of the kneader. He will configure the kneader settings in a manner that will stop the kneading process after a certain period of time. We can observe that this control parameter is completely uncorrelated from any physical reality that would allow the characterization of the state of the dough. The impact of any change in the conditions of kneading (ingredients, temperature, parameters of the kneader) cannot be evaluated by a simple measure of time. That is why it might be interesting, specifically for replication and tracking considerations, to have a method of follow-up for the kneading procedure which takes into account the rheological characteristics of the dough being produced and the various operation parameters of the kneaders. Energy transferred to the dough is one of the physical values that meet this objective as explained previously.

However, this measure of energy presents some difficulties and limits:

- At what value of energy does the user consider his kneading procedure "optimum"? Bread making methods throughout the world are extremely diversified, varied and use ingredients (flour and others) of extremely variable properties. Consequently, it is very difficult to define beforehand an optimum value of energy to reach. This value can only be defined by a battery of trials unique to each type of dough.
- The signal emitted during spontaneous measure of the power consumed by the kneader is very noisy and fluctuates. This fluctuation has no direct impact on the calculation of the corresponding energy, but is a major inconvenience for the calculation of the point of inflexion that indicates the moment of "over-kneading". Hinting algorithms with averaging must be used, but they lead to significant delays in the detection of slope reversal. They do not yet allow the possibility of stopping the kneader when this point of inflexion is reached, if this is what is really expected.

During the multiple trials conducted by VMI, the measure of energy allowed us to underline the importance of the initial mixing of ingredients. This step is required to enhance the absorption of starch and gluten by the stream of water through rigorous mixing of the flour with the water. It is executed upstream from the kneading process at lower kneading rotation speeds and prepares the blend of ingredients for mixing. Bakers know its importance since it has an impact on the final quality of the dough. The measures of energy performed using various parameters allowed VMI to quantify its impact.



We verified that a shorter time of initial mixing of ingredients leads to a delay in power return to the dough and ultimately leads to an increase in the global time of kneading.

What's next? ...

Yesterday, the baker had only the Time variable to adjust his kneaders - a variable for which the measure only does not consider the real and effective state of the dough. It is a parameter that is completely uncoupled from the characterization of the dough.

Today VMI offers the possibility of measuring the energy consumed by the kneader and in this manner providing the baker with a variable that globally considers the state of the kneader/dough group through a report in energetics. It is a parameter that is in part associated to the characteristics.

In the future, VMI will work in collaboration with a certain number of partner researchers, to develop a method of measuring that will allow the adjustment of kneading, taking into account a parameter that is solely associated with the characterization of the dough and entirely separated from the mechanical or thermal phenomena of the kneader itself.

The measure of energy generated during kneading, by the energy of the spontaneous electric power consumed by the kneader, is a method used to quantify the state of the dough during kneading. It is mainly useful for tracking and identifying variations in a well established process. It is a complement to other parameters, temperature as an example, which now allows the control of the proper operation of the kneaders while taking into account the state of the dough being produced. This measure being a global report of the energy implemented by the kneader/dough group, integrates parameters specific to the kneader itself while limiting the interpretation of its absolute values.

For more information:

Suggested reading:

- *Les Pains Français – Philippe Roussel, Hubert Chiron (Editions Maé-Erti)*