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ENERGY CONSUMPTION DURING EXTRUSION-COOKING OF PRECOOKED PASTA

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Summary. The paper presents results of specific mechanical energy consumption (SME) and process stability during the extrusion-cooking of precooked pasta. The raw materials were semolina and common wheat flours type 450, 500, 550 moistened to 28, 30, 32% of moisture content. Precooked pasta was processed in a single screw extrusion-cooker TS-45 (Polish design) with L/D=16 at the temperature range of 65-95°C. SME values depended mostly on a screw rotational speed used during the extrusion-cooking, raw materials used and its moisture content. Thanks to intensive cooling of the last barrel section before the die, satisfactory stability of extrusion-cooking process was achieved during pasta production.

Key words: extrusion-cooking, precooked pasta, energy consumption, wheat flour.

INTRODUCTION

The main source of heat energy in the extrusion-cooking process is the energy obtained during transformation of mechanical energy, generated by the shearing forces to heat energy in the processed material. Total energy of extrusion-cooking includes: heat energy along the screw as a shearing effect, energy used for increased pressure of the viscous dough, the kinetic energy, increasing heat energy in the space between a screw and a barrel, but also the energy created during physiochemical changes of processed materials dependently on residence time distribution inside the barrel [Davidson *et al.* 1983, Janssen *et al*. 2002, Le Roux *et al*. 1995, Mościcki, Mitrus 2001, 2002].

Specific mechanical energy (SME), depends mostly on the moisture content of raw materials, process temperature and the die diameter. Lowering the moisture content from 20 to 14% influenced an increase of SME values from 0,16 to 0,20 $kWh\cdot kg^{-1}$ at the temperature 60°C and die diameter 2 mm. SME values could be reduced during the increasing of the process temperature from 0,16 to 0,09 kWh/kg for 60 and 260°C, respectively. A small decrease of SME could be observed when a lower die diameter was used [Le Roux *et al*. 1995, Meuser *et al.* 1987, Singh *et al*. 1994, Wiedman, Strobel 1987].

During processing the dough is kneaded, cooked and transported along the screw, which is contributed with temperature and pressure increase. A screw motion is consuming a considerable part of the energy provided to the process. Cooking and shearing processes inside the extruder can be controlled by steer equipment according to the process parameters. The process parameters changing profiles during extrusion-cooking are presented in Fig. 1 [Mercier *et al.* 1998, Wiedman, Strobel 1987].

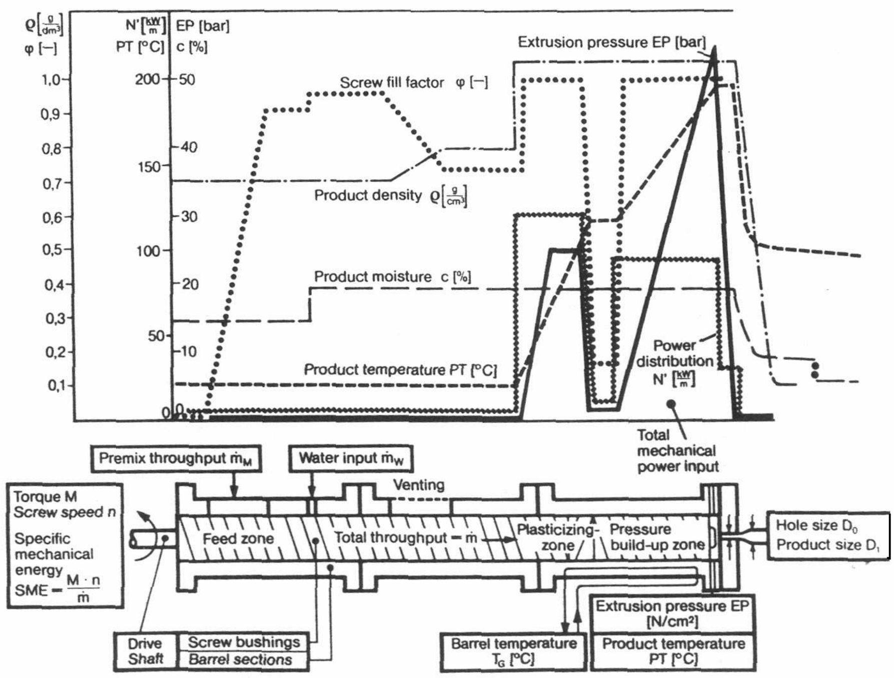

Fig. 1. The process parameters changing profiles during the extrusion-cooking along the screw sections [Mercier *et al.* 1998]

The thermo-mechanical treatment connected with the presence of high pressure during the extrusion-cooking of pasta gives an opportunity to use different raw materials: durum semolina, common wheat flour, unconventional materials like legumes at wide range of granulations [Huber 1988, Mercier *et al.* 1998, Obuchowski, Michniewicz 2002, Obuchowski 2002, Pagani 1986, Wang *et al.* 1999, Wójtowicz 2006a, 2005, 2001]. The extrusion-cooking allows for an increase of the versatility of extruded products e.g. convenience instant or precooked pasta, subjected to short-time microwave treatment or hydration for a few minutes' period of time in hot or cold soups or sauces. Due to the extrusion-cooking treatment the further conditioning and seasoning operations became simpler. There is shorter drying time at lower temperature (40 min., 80°C), and costs reduction in comparison to the traditional process of pasta manufacturing. Other significant advantages are easy operation and production. There is no need for high energy drying, hot water baths or steam cooking to achieve precooked properties [Huber 1988, Obuchowski 2002, Mościcki *et al.* 2007, Wójtowicz, Mościcki 2000]. Better texture and short hydration time can be formed by addition of protein components like gluten, eggs, milk or surfactants and emulsifiers. Precooked pasta is a thin-wall product, easy for hydration and can be processed from finely ground raw materials, flour like.

Conventional pasta processing requires the dough moisture range from 27% to 34% of d.m. A similar moistening level was used in our investigations. For processing the simple-shape pasta products the moisture content should not exceed 28-29%. Products with more complicated shapes require higher moisture content of dough of 30-32%. That allows for a fluent dough flow inside the extruder and guarantees its proper viscosity and texture. Too high dough moisture, especially in short extruders creates low pressure and faster dough flow, which may cause unstable texture after drying and increase the cooking losses during hydration. The proper pressure formation depends on dough characteristics and suitable relation of the screw capacity to the total surface of open dies, which can be regulated by die openings, proper gap between the screw spine and inside barrel surface. Design of the barrel should avoid slipping of adhesive materials, especially in case of the single screw extruders [Abecassis *et al*. 1994, Debbouz, Doetkott 1996, Le Roux *et al.* 1995, Mościcki *et al.* 2007, Wójtowicz, Mościcki 2000]. Production of precooked or instant pasta requires application of the so-called long extrusion-cookers with L/D≥16, equipped with intensive cooling section before the die [Mościcki *et al.* 2007, Wójtowicz 2006a,b, 2005, 2001].

MATERIALS AND METHODS

In the experiments standard common wheat flour with different extraction rate: type 450, type 500 and type 550 together with durum wheat semolina – the traditional pasta raw material, were used. The prepared samples were moistened with 20°C water to 28%, 30% and 32% of dough moisture content, mixed and rested for 0.5 h. The extrusion-cooking process was carried out with a modified single screw extrusion-cooker type TS-45 (Polish design) equipped with 12 openings die head (0.8 mm). Modification of the extruder involved the barrel elongation from L/D=12 to L/D=16 and additional barrel cooling section before the die. The mentioned modifications have been designed and performed in the Department of Process Engineering.

Precooked pasta was produced with the screw rotation range from 60 to 120 rpm using thermal treatment ranged from 65°C to 95°C.

Stability of the process, its effectiveness and energy consumption were carefully observed, dependently on the used process conditions.

Power consumption was measured using standard register connected to the extruder's motor. After the consideration of motor load and its efficiency, the SME values were calculated according to the method described by Singh and Smith [1997]:

$$SME = \frac{\text{Screw speed x Power [kW] x Torque [\%]}}{\text{Max. Screw speed x Throughput } [kg \cdot h^{-1}] \text{ x } 100} \quad [kWh \cdot kg^{-1}].$$

The throughput of the extruder processing of tested raw materials at different conditions was measured for each sample by products collection after 10 minutes of regular production. The process stability was determined by temperature changes registration during the extrusion and temperature of ready products just after the forming die. The measurement of the barrel temperature was realized using thermocouples installed along the barrel connected to the registers in the extruder electrical panel. The product's temperature was registered using handy electronic thermometer CIE 370.

RESULTS

The use of die head with openings of 0,8 mm in diameter and the proposed process temperature enabled to achieve thin-wall products with low expansion ratio and compact structure, without any air bubbles inside the pasta strain. The products were ready to eat after few minutes hydration in hot water [Wójtowicz 2006a, b, 2005].

Application of a modified barrel section with an additional cooling system allows processing at desired thermal conditions (65-95°C). Small differences ± 5°C were measured in particular sections of the extruder during processing of different flour types. A significant influence of screw speed and raw materials moisture content was observed, especially in section II and in the die head of the extruder. A temperature increase was observed at higher screw rpm used (highest at 28% of dough m. c.). That was connected with more intensive shearing inside the extruder and exchanging the mechanical energy into the heat. The highest temperature of 86°C was recorded in section I during the processing of flour type 450 with 28% m.c. at 120 rpm of the screw. At the same conditions the highest temperature of 90°C was recorded in section II, at the same moment the final product's temperature was 88°C.

The typical direct single screw extrusion-cooking requires the raw materials moisture range 10 – 28% [Gallagher *et al.* 2000, Mościcki *et al.* 2007]. Higher moisture up to 48% is required for production of pellets or pasta products [Abecassis *et al*. 1994, Davidson *et al.* 1983, Mercier *et al.* 1998, Meuser *et al*. 1987, Singh *et al.* 1994]. As mentioned before, we processed the tested samples at the temperature range 65-95°C, which was connected with the highest effectiveness of starch gelatinization. The starch gelatinization temperature of common wheat is 59-64°C and for durum wheat 46-56°C [Mościcki *et al.* 2007, Wójtowicz 2006a]. The thermal treatment at a higher temperature used during the tests was predicted by presence of additional water and other chemical components (proteins, lipids) present in flour, which essentially differ in behavior during thermo-mechanical treatment together with starchy components.

The use of the longer screw and the barrel with cooling system caused stable, lower process temperature and prevented the stickiness of the products. The results of the temperature measurements during precooked pasta production suggested the tendency to stabilization temperature especially in section I connected with similar characteristics of the used raw materials. Fluctuations were distinct in section II of the extruder and the final product's temperature.

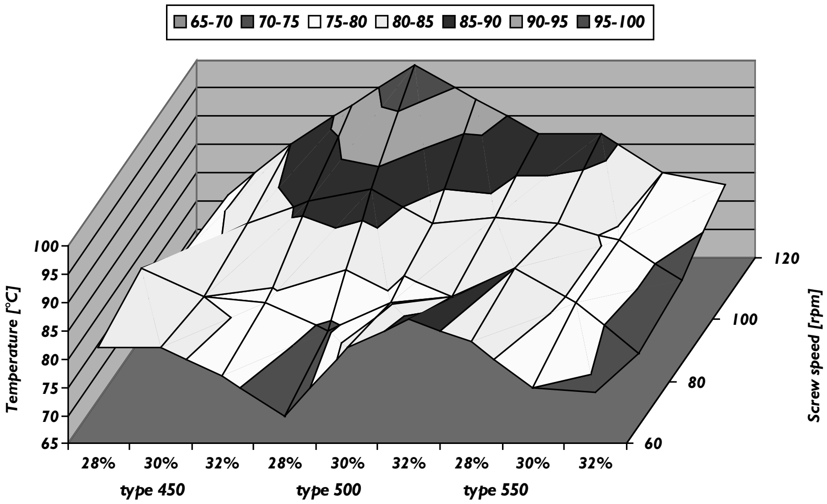

Fig. 2. The temperature of extruded pasta leaving the die head

The temperature changes in section II and final products were mostly dependent on screw rotational speed. Independently on the used raw materials or moisture content of the dough, the process temperature increased with the increase of screw rpm. A more dynamic progress was observed during the measurements of the product's temperature just after die, the temperature of the pasta extruded at 120 rpm was about 15-20°C higher than the one measured at 60 rpm.

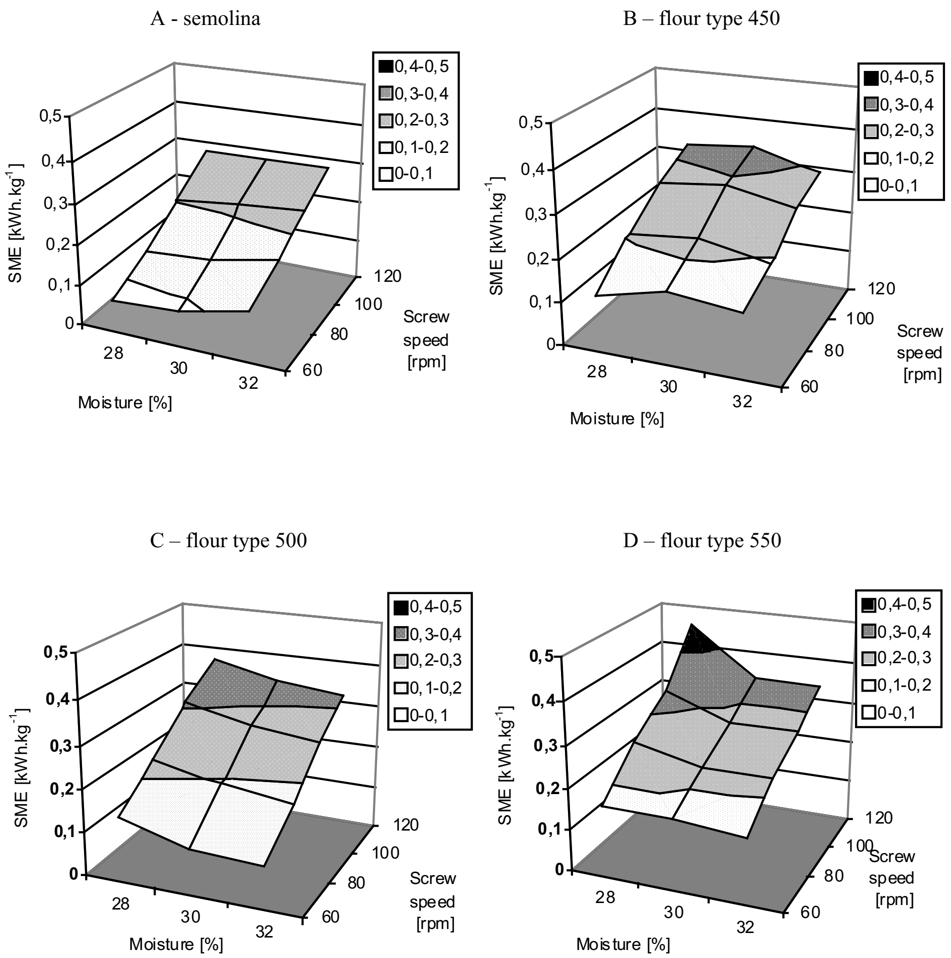

Fig. 3. SME values during the extrusion-cooking of precooked pasta

During the experiments a significant influence of the screw rpm on SME values was noticed. With an increase of the screw speed, an increase of SME was observed. Energy consumption was different for each raw material and its moisture during the extrusion-cooking. The lowest SME values were reported when processing semolina pasta (Fig. 3A). In the case of common wheat flour an increase of SME with an increase of extraction rate was observed. These results are similar to Singh and Smith [1997] and Mitrus [2005] observations They reported the SME values at the range from 0,07 to 0,13 $kWh \cdot kg^{-1}$ during the extrusion-cooking of wheat starch, whole wheat meal and oat flour using twin screw, co-rotating extruder, at the temperature range 30-175°C. SME decreased with an increase in moisture content and extrusion temperature. The extent of reduction in SME due to an increase in moisture was lower at a higher temperature in feed materials.

In the presented experiments SME values varied from 0,07 $kWh \cdot kg^{-1}$ during processing semolina pasta with moisture content of 28% d.m. at 60 rpm, to 0,45 $kWh \cdot kg^{-1}$ when wheat flour type 550 with moisture of 28% was processed at 120 rpm (Fig 3). These values seemed to be higher per kg of raw material compared to those reported in the literature. Total energy consumption during complete processing will be lower, because of unnecessary high energy drying and/or steam cooking process requirements. In the presented technological development the drying process is limited to short time, which has to result in the total energy balance.

Abecassis *et al*. [1994] reported that during conventional pasta pressing at the temperature about 50°C, semolina dough moisture content 44 – 48%, SME was ranged from 0,03 to 0,12 $kWh \cdot kg^{-1}$. Higher energy was required when additional filter plate was placed into the extruder. A significant influence of raw materials moisture and the temperature during the extrusion-cooking of wheat flour on SME values was also reported by Singh and Smith [1997] and Singh *et al.* [1994]. Higher level of these factors led to a decrease in energy consumption, but there are limits which may influence the quality of extrudates when exceeded.

Also it should be added that the presented experiments were performed on the extruder designed in the 80's, whose DC motor has the efficiency of 0,55-0,97, dependant on loading and rpm used. The old-fashioned construction probably raised the measurements. Nowadays, new generation DC motors installed in modern extrusion-cookers are less energy consumptive and more efficient. Nevertheless, SME values presented in this paper show overall trends depending on the used raw materials and the process conditions.

CONCLUSIONS

The obtained results allow to conclude the following:

1. Application of modified single screw extrusion-cooker TS-45 equipped with the barrel of L/D=16 and additional cooling section gave an opportunity of processing good quality precooked pasta using common wheat flour.

2. The most significant influence on the temperature changes during the extrusion-cooking of precooked pasta was exerted by the screw speed. Higher rpm caused a higher temperature in the last barrel section, the biggest effect was observed during the processing of raw materials with the lowest moisture content. An additional cooling system allowed proper stabilization of thermal treatment and satisfactory stability of the process.

3. The energy consumption during precooked pasta processing depended on both the used raw materials and their moisture level as well as the screw's rotational speed during processing. The lowest values of SME were noted during semolina pasta extrusion and the highest ones for common wheat flour type 550. An increase of the moisture level decreased the process energy consumption.

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