MEng. Dmitrij Sanne
Kautex Maschinenbau GmbH
53229, Bonn
Phone: +49 228 489 530
Fax: +49 228 489 88 530
E-mail: dmitrij.sanne@kautex-group.com

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Energy saving potentials in the single screw extrusion through the cooling of the feed zone

Introduction

In the last few decades, the field of polymer production developed enormously. As a material, plastics have become an indispensable part of our everyday live. In the 30s of the 20th century the large-scale industrial production of thermoplastics sets in. In 1949 the global production of plastics exceeded one million tons for the first time. With an average growth of 9 % per year the production increased up to 245 million tons in 2006 (Fig. 1).

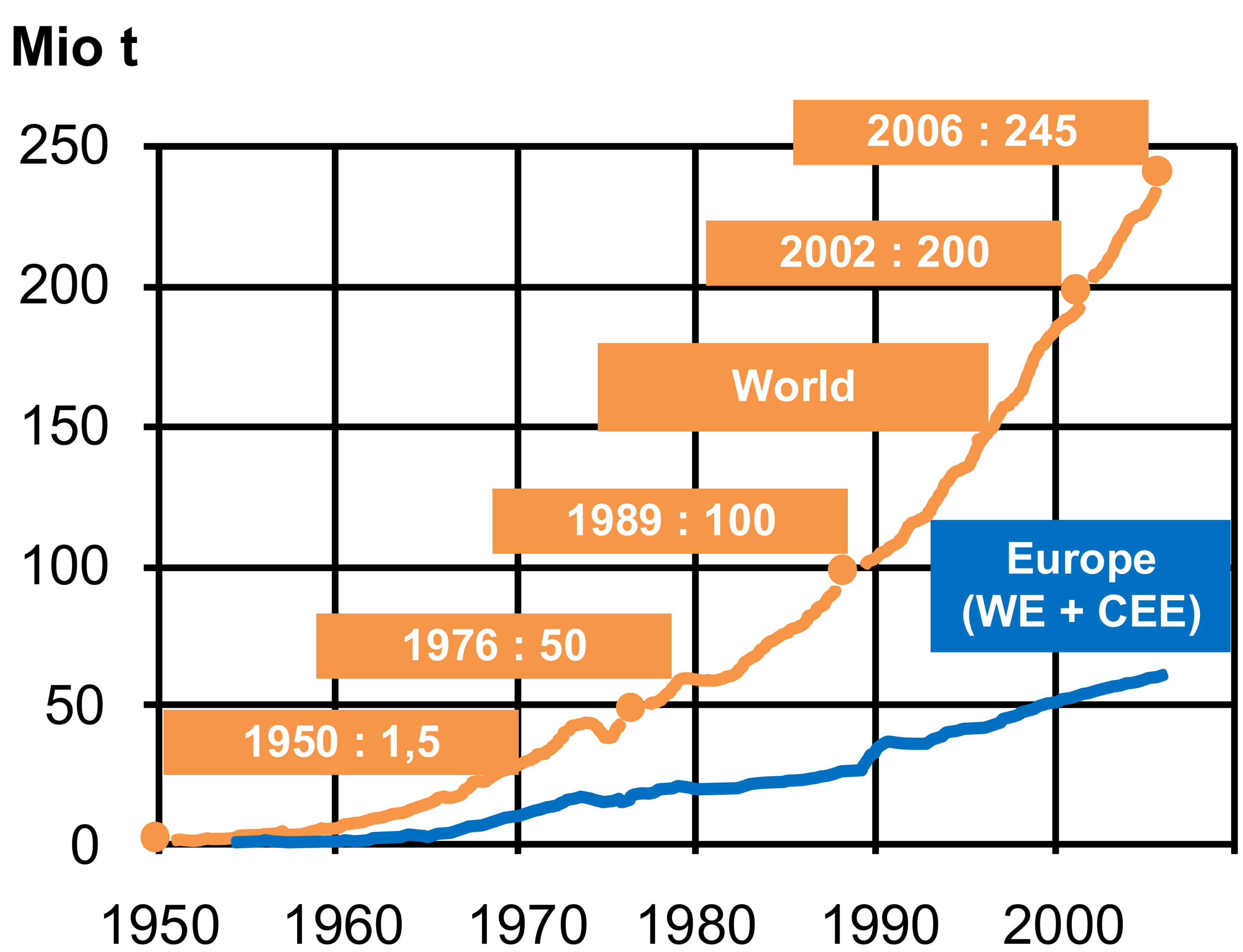

Figure 1: Diagram of the economic increase of plastics [1]

The extrusion of polymers employing single screw extruders is an established part of the current plastic industry. Particular extruders with grooved feed bushing (Fig.2) are widely used in Europe and increasing in importance because of their higher throughput rates and ensured back pressure independency.

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Axial grooves in the feed zone increase the solid friction on the inside surface of the extruder and prevent the rotation of granulate around the screw. To maintain the solid friction and to avoid melting film friction with increasing screw speed and pressure, a cooling of the grooved bushing is necessary (Fig.2). But the necessity of cooling is an additional loss in the overall energy demand.

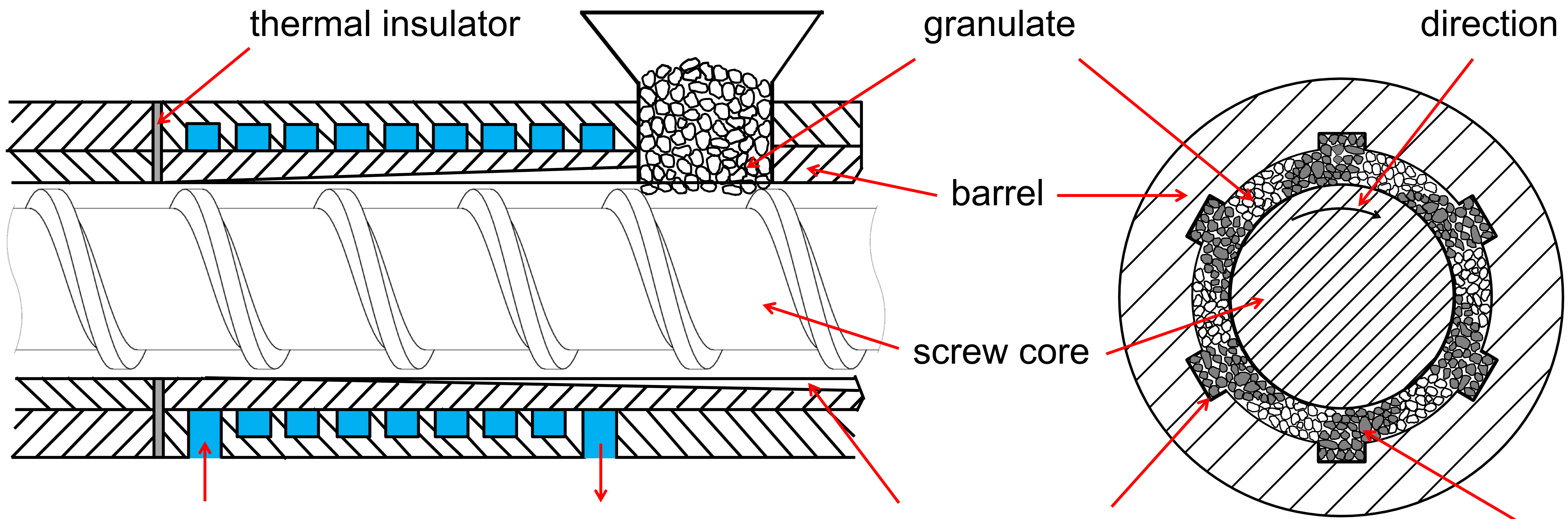

Figure 2: Schematic of a grooved feed section [2] [3]

To assign the cooling losses and other individual loss components of the extruder and to identify potential improvements several energy balance areas of the single screw extruder are considered.

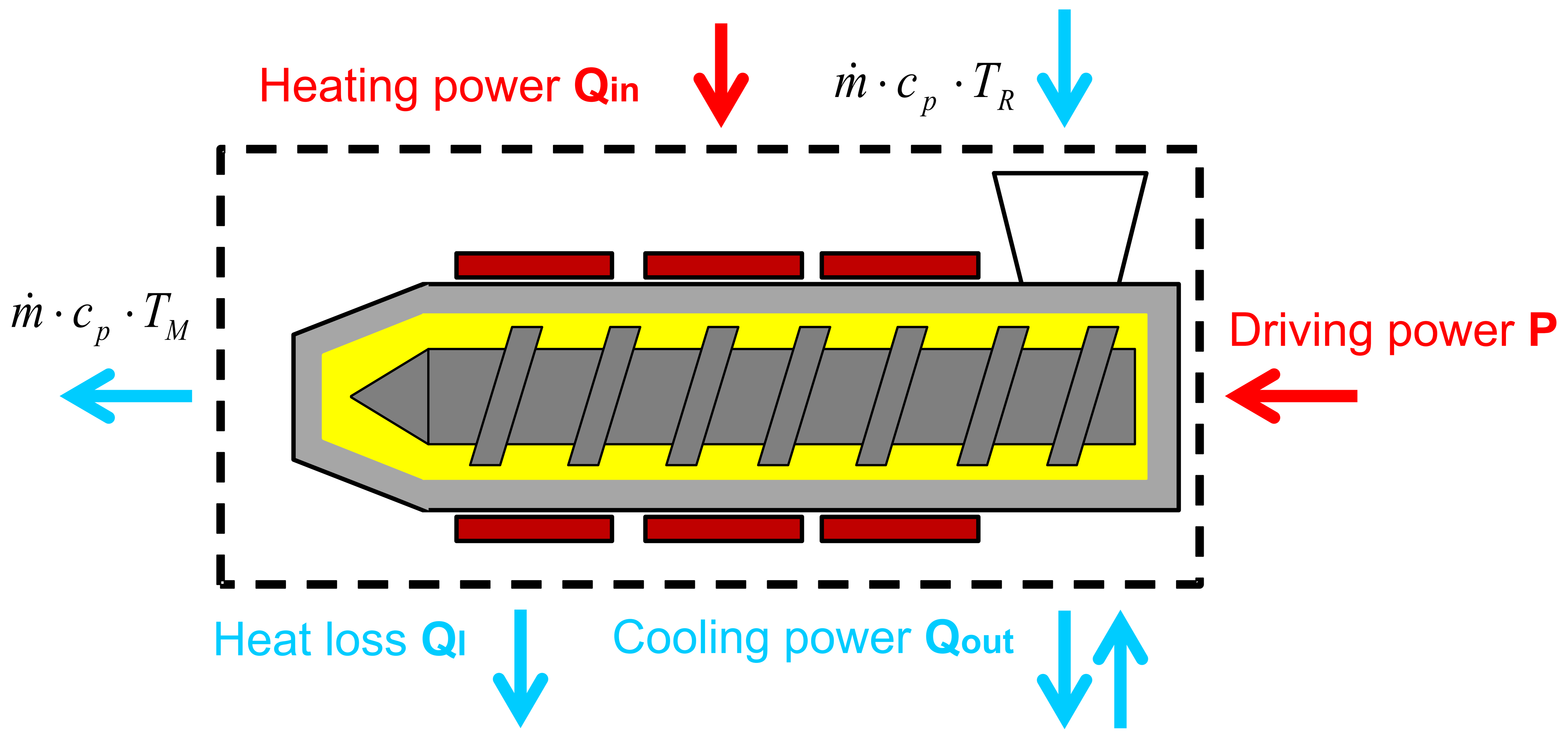

Figure 3: Energy balance of single screw extruder [4]

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Power distribution

For improving the energy efficiency in extrusion it is necessary to identify the current situation (Fig 4). The measured total electricity consumption is considered in relation to the amount of product produced per unit of time and thus forms the specific energy consumption:

$$e_{spez} = \frac{P}{\dot{m}} \left[\frac{kWh}{kg} \right]$$

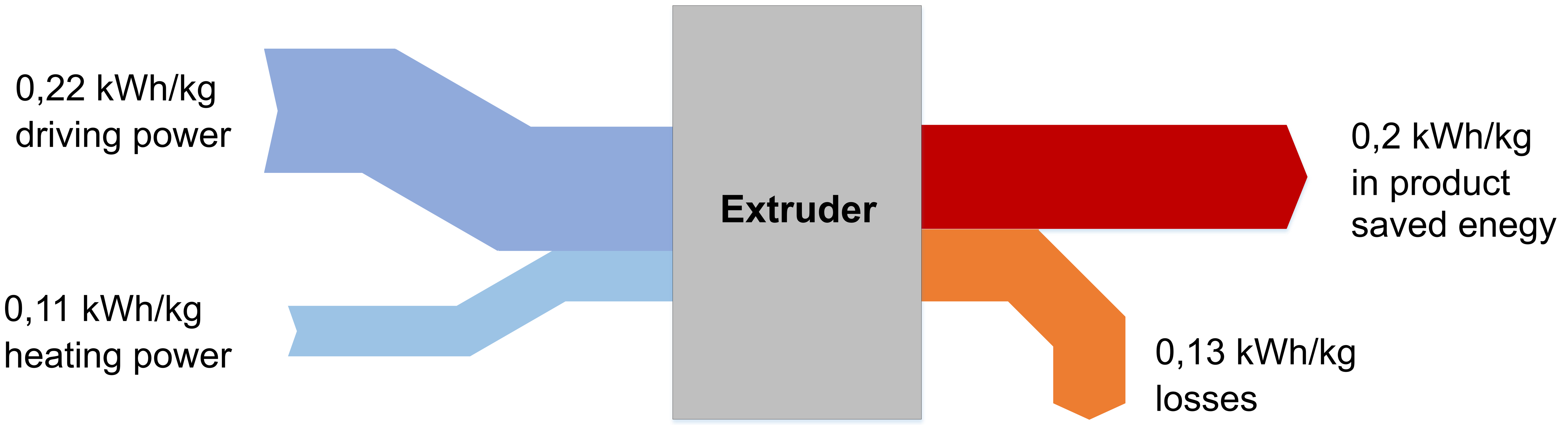

Figure 4: Driving power distribution of single screw extruders [5]

With the rising awareness of the finite nature of fossil fuels and because of the dramatic rise in electricity prices over the last years energy efficiency is becoming increasingly important. Assessing the individual energy consumption of the drive section one can see the engine has the highest energy content (Fig 5). Energy saving measures should be set first at this main consumer.

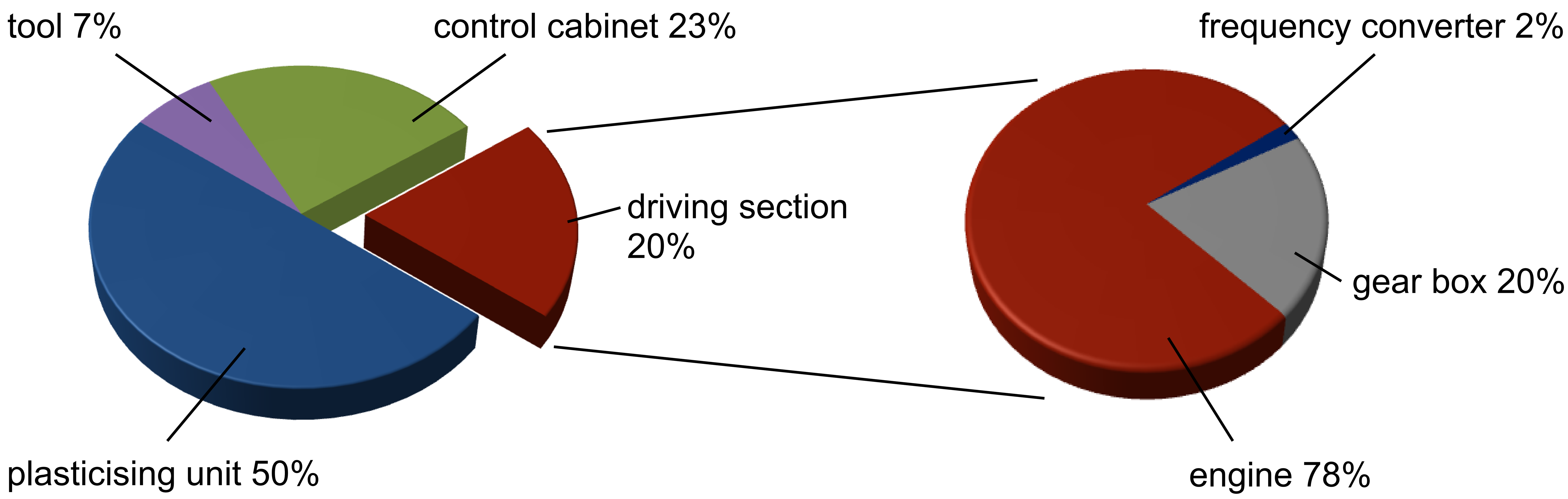

Figure 5: Composition of the total power loss [6]

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Methods and Experiment Equipment

In terms of technology maintaining the solid friction is achieved by cooling water in the feed zone. But an intensive cooling of the feed bushing possibly have an adverse effect such as increased wear of the grooved barrels, poor feeding behavior and poor energy efficiency.

The impact on the driving power and the throughput by the controlled increase of the temperature in the feed zone has to be investigated.

For this research, three sizes of extruders with L/D 25 were used (Table 1). The extruder exit was fitted with a valve adapter, which was used for back pressure monitoring.

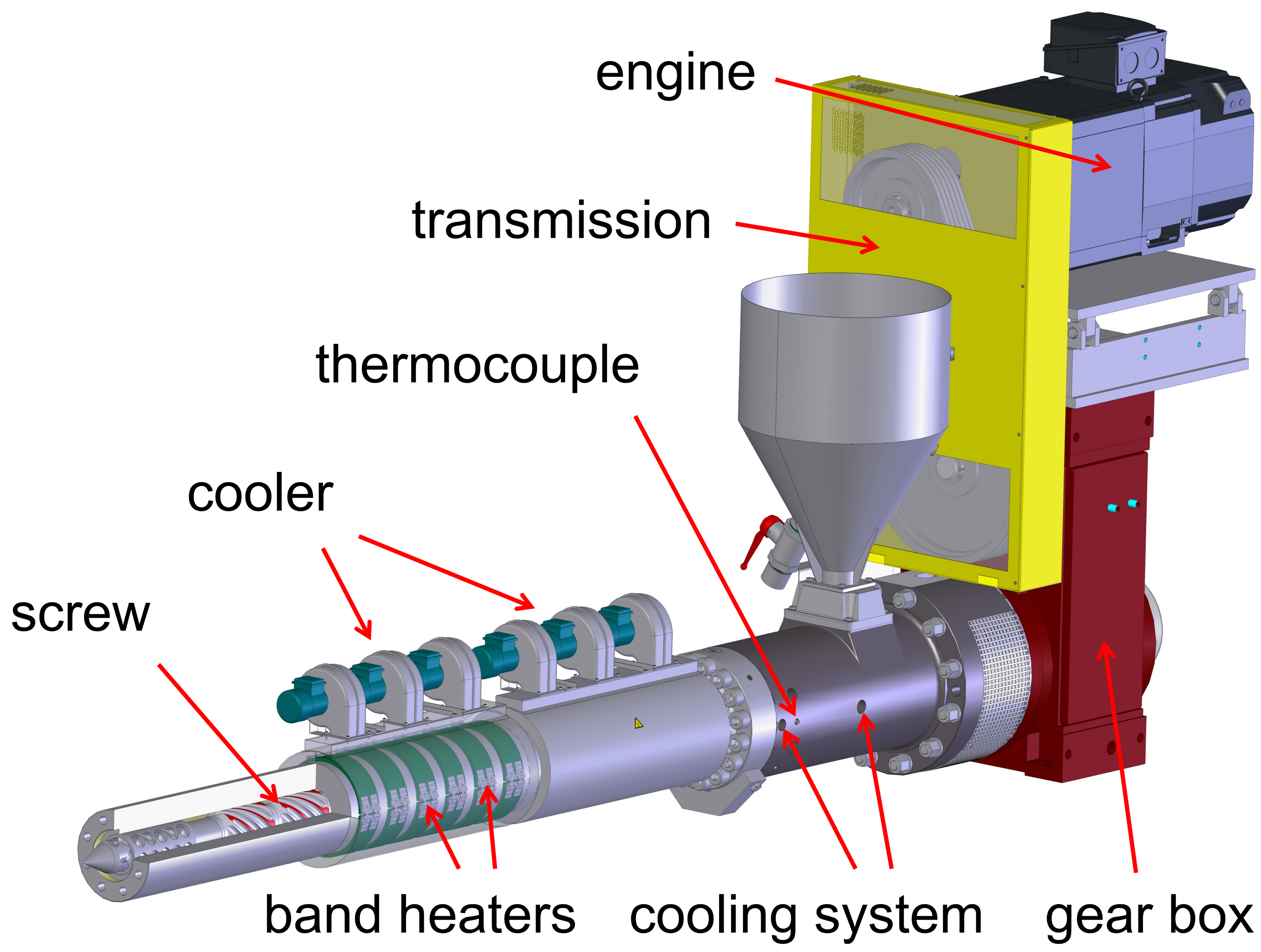

Figure 6: Component of typical single screw extruder

Extruder cize [mm]	Bushing grooves	Bushing deep [mm]	Bushing length [mm]	Driving power [kW]
60	6	3,2	12	36
90	10	2,8	10	75
100	12	4,2	10	81

Table 1: Summary data for grooved barrel feeding

Furthermore, it should be noted that the back flow temperature of the cooling water must be kept below 60 °C as an effect to avoid calcium deposits which can occur otherwise. As the result, the temperature in the grooved feed zone must not exceed this point.

Formation of calcium carbonate with temperature increase

Lime-carbonic acid equilibrium

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

1. Release of carbon dioxide by increasing the temperature

$$H_2CO_3 \rightarrow CO_2 + H_2O$$

2. Reproduction of carbonic acid

$$2HCO_{3^-} \rightarrow H_2CO_3 + CO_3^{2-}$$

3. Formation of calcium carbonate

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \downarrow$$

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Experimental Results

The total extrusion output rate was measured along with the driving power and grooved feed bushing temperature from 8 °C (max. cooling power) to 60 °C. This was done at zone 1 through zone 3 at barrel temperature from 190 °C to 210 °C. All the work was done at 25 to 75 % from max. RPM.

Figures 7 to 9 plot the data of specific driving power for the different extruder sizes vs. screw speed of this investigation.

Figure 7 plots the data from the measurement with the 60 mm extruder. Here we see a decrease in specific driving power at the hotter grooved feed section on the average by 0,005 kWh/kg.

Figure 8 shows the data from the measurement with the 90 mm extruder, the second experiment in this investigation. Here one can observe the reduction of the specific driving power on the average by 0,017 kWh/kg.

Figure 9 adds the data from the measurement with the 100 mm extruder, the last trial of this investigation. Here we see a decrease in specific driving power by up to 0,016 kWh/kg by the low screw speed.

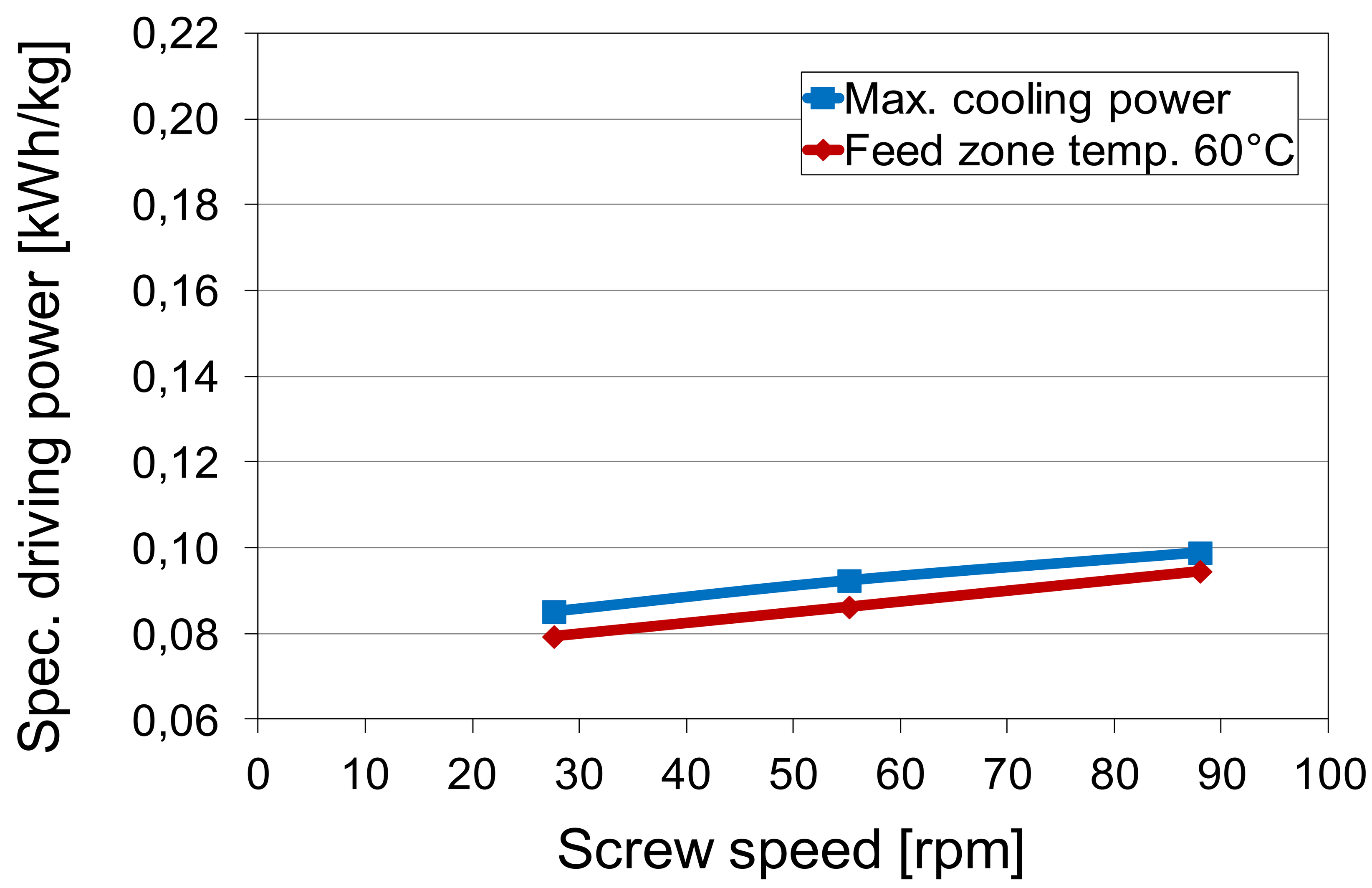

Figure 7: Spec. driving power vs. screw speed for 60 mm extruder

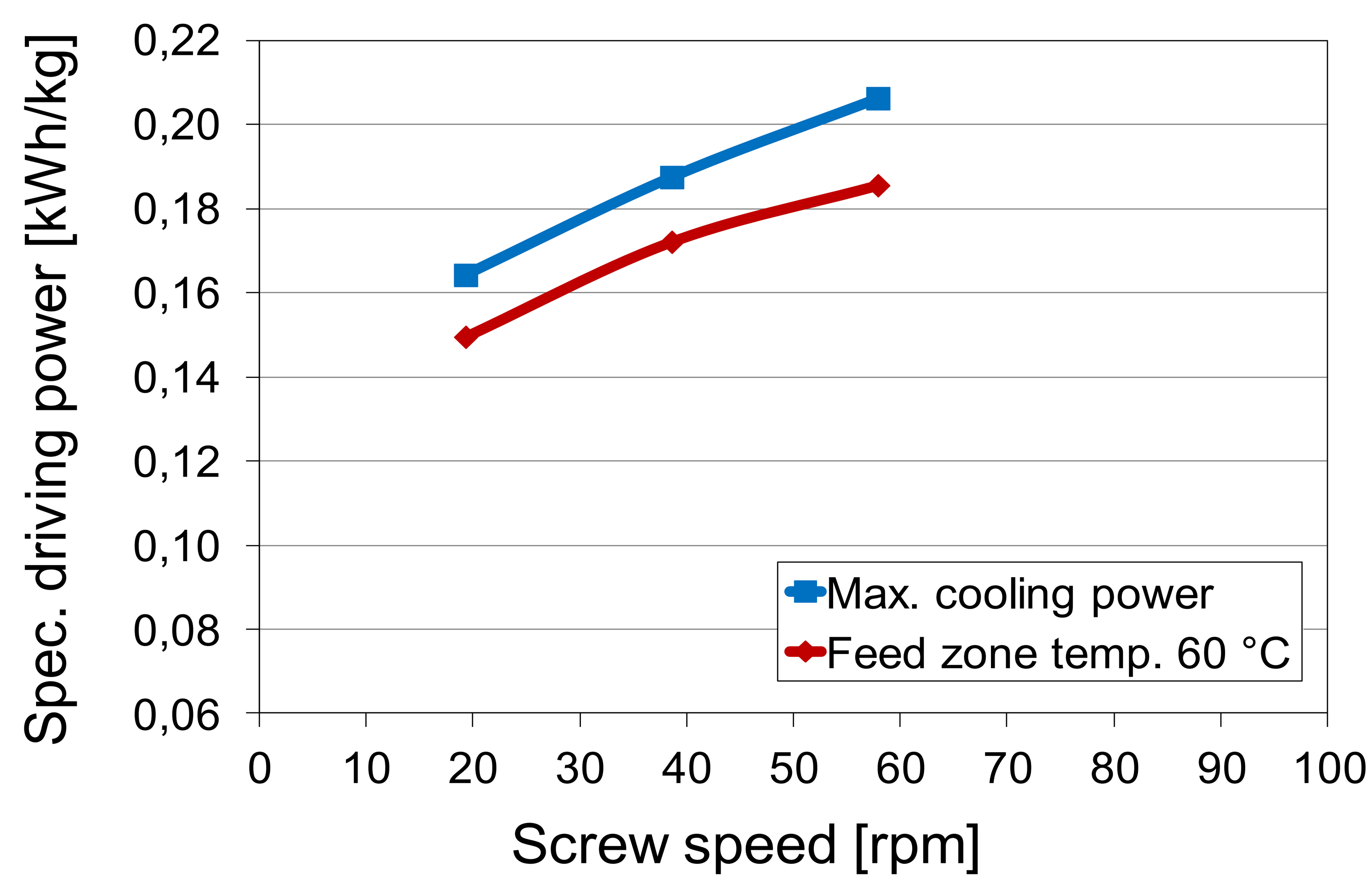

Figure 8: Spec. driving power vs. screw speed for 90 mm extruder

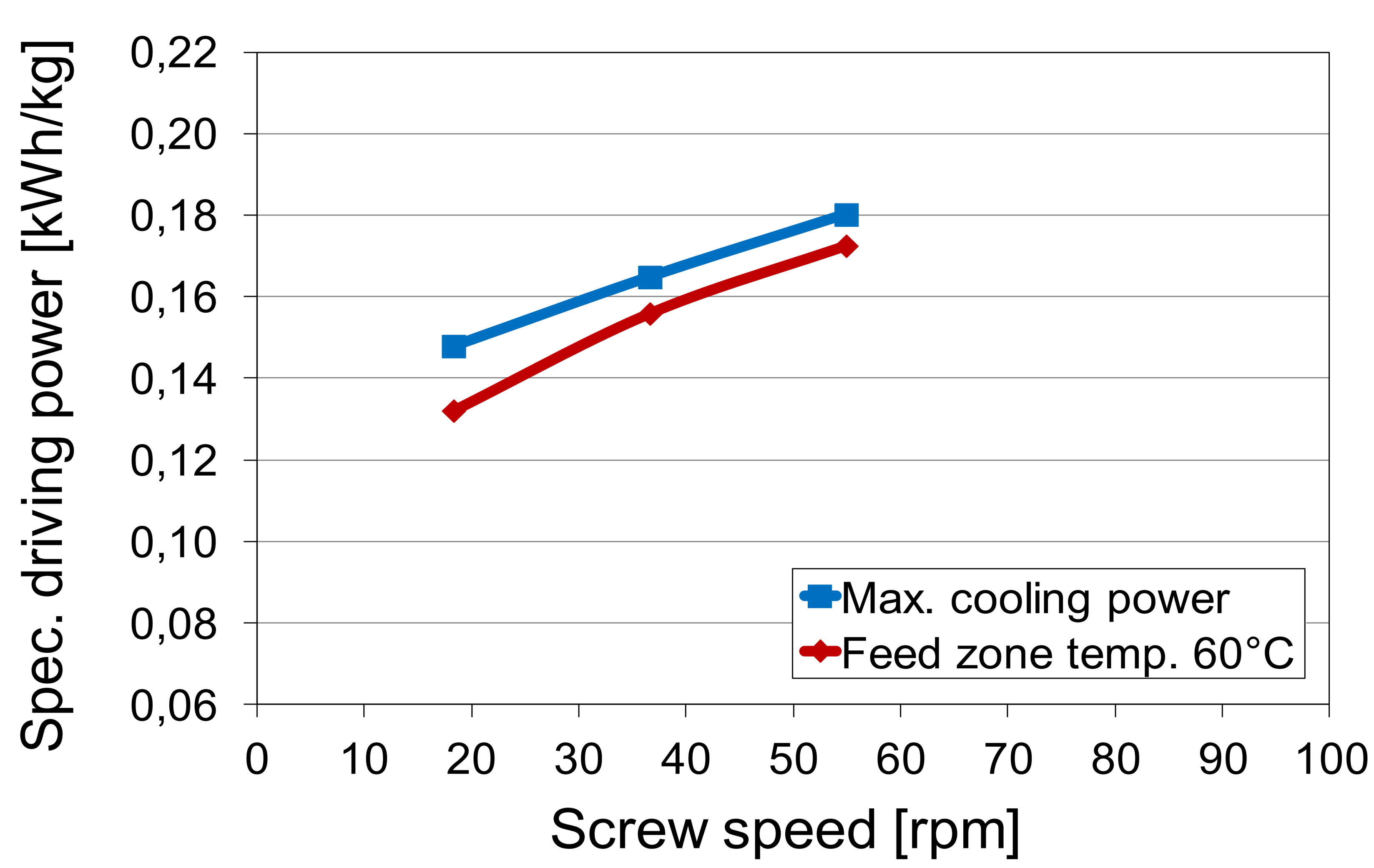

Figure 9: Spec. driving power vs. screw speed for 100 mm extruder

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Materials

Lupolen 4261 AG was used for this investigation. The resin had a melt flow index (MFI) of 6,0 and a solid density of 0,945 g/cm³. The coefficient of the friction μ between steel and plastic pellets is 0,2.

Discussion

The result illustrate that for high molecular weight polymers with typical coefficients of friction a controlled increase of the temperature in the grooved feed zone by up to 60 °C will not only result in a significantly reduced driving power furthermore a stable and higher throughput can be achieved. This relationship is shown in figures 7 to 9.

The driving power that rotate the screw and causes friction between the polymer pellets and the barrel wall and the screw itself generate via friction about 80 % of the energy to melt the polymer [7]. The lower cooling in the feed section increases the effect of dissipation from the screw into the row material and lowers the material viscosity. At the lower plastic viscosity less driving power at the constant screw speed required. Thus, the AC drive can operate very economical and more efficiently.

The higher temperature in the grooved feed bushing also reduces the heater power consumption because the screw will dissipate more energy for metering the polymer.

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