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**Vitenskapelig artikkel**

# Thermoregulation of planetary mills

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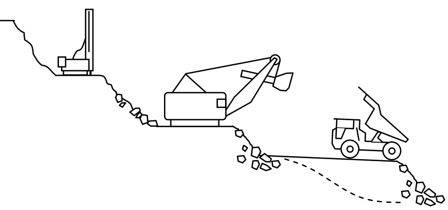
**ABSTRACT**

This paper proposes the use of a copper disc (i.e. a heatsink) as a simple thermoregulation device for planetary mills in order to limit or slow down the temperature increase during prolonged grinding. Two different experimental series were conducted in both the dry and the wet grinding mode; a reference series without the heatsink, and a corresponding series where the heatsink had been given an initial temperature of 25 ºC. Using the heatsink during 30 min of high intensity dry grinding resulted in an 11% temperature reduction at the floor of the grinding bowl, whereas the corresponding 30 min of wet grinding produced an 18% reduction in the slurry temperature. Larger reductions can be achieved by cooling down the heatsink prior to grinding. The effect is of a magnitude that can be of considerable practical importance, and the concept can be employed on most planetary mills where the grinding bowl holder is designed to accommodate different bowl sizes.



## 1. INTRODUCTION

Thermodynamically speaking, mechanical comminution devices are notoriously inefficient as almost all the energy input is converted to heat and only a few percent are contributing to size reduction, production of new surface area and the breakage of crystal lattices. Planetary mills are no exception and are characterised by very high energy intensities (Baláž 2000). When such mills are used for mechanical alloying or mechanical activation, applications that require prolonged grinding, the temperature of the system will increase rapidly during grinding and could reach problematic levels (Kleiv et al. 2006, Kleiv and Thornhill 2007).

Heat accumulation during grinding in planetary mills could pose two main problems. Firstly, facing excessive temperatures over a long time interval, the integrity of the seal between the grinding bowl and its lid could be compromised, potentially causing the product to escape from the bowl contaminating the mill and the surroundings. Secondly, a number of applications could require or would benefit from a lower or more stable temperature during the grinding process. This could be the case when the mill is used as a combined chemical and mechanical reactor to promote chemical reactions that are thermodynamically favoured at lower temperatures, or when excessive temperatures could cause the substances that are being ground to decompose, evaporate or ignite (i.e. unwanted physical or chemical reactions). For such applications the temperature of the system could be a limiting factor.

Due to the complex rotational motion of the grinding bowl in a planetary mill it is difficult to employ a conventional cooling mantel with a circulating cooling fluid. This paper investigates the effect of implementing a much simpler solution; a solid heatsink in the shape of a disc that could be placed in contact with the grinding bowl thus dissipating its thermal energy by direct conduction. Even though such a solution would have a limited capacity it could provide sufficient thermal buffering for a number of applications. Furthermore, as demonstrated in this paper, it could be implemented easily in most common planetary mills at a very low cost.

## 2. MATERIALS AND METHODS

### *2.1 The planetary mill and the heatsink*

The experiments conducted in this study were performed using a *Fritsch Pulverisette P6* planetary mono mill, equipped with a 250 ml stainless steel grinding bowl containing twenty ∅20 mm stainless steel grinding balls. A standard *Teflon* seal was used between the lid of the grinding bowl and the bowl itself. The weight of the lid, bowl and the grinding balls were 763 g, 2532 g and 638 g, respectively.

The heatsink consisted of a turned slightly tapered copper disk with a total volume of 253 $cm^3$ and a weight of 2260 g. Copper was chosen due to the combination of the metal's superior thermal conductivity (approx. 400 W/m°C) and high volumetric heat capacity (approx. 3.45 $J/cm^3{}^\circ C$).

Figure 1 shows the dimensions of the disk and its integration with the grinding bowl and grinding bowl holder of the planetary mill. When in place, the grinding bowl and the heatsink were held together by the mill's original clamping arrangement. Here, both the contact surface of the thrust piece and the grinding bowl holder consist of *Viton*$^{TM}$ to minimize the heat transfer from the mill.

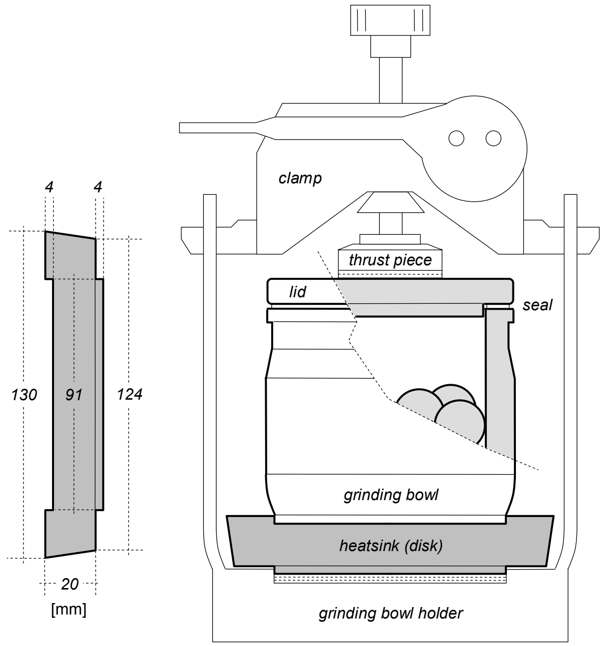



**Figure 1.** The heatsink, grinding bowl and grinding bowl holder.

## *2.2 The grinding experiments*

The grinding experiments were performed by dry grinding of 50.0 g of quartz sand (-586 µm/+147 µm) at 500 rpm for various lengths of time, ranging from 5 min to 45 min. Both dry and wet grinding were investigated. Wet grinding was conducted by adding 100 ml distilled water to the system. The grinding was performed at room temperature (i.e. 22 ± 1 ºC).

Prior to grinding, the lid, grinding bowl, grinding balls and the distilled water were given an initial temperature of 25 ºC using a thermostatic water bath. Two different experimental series were then conducted for both the dry and the wet grinding mode; a reference series without the heatsink, and a corresponding series of experiments where the heatsink had been given an initial temperature of 25 ºC. Triplicate runs were conducted at 30 min grinding time.

Once each batch had reached its pre-set grinding time, the grinding bowl was removed from the planetary mill and a series of instant temperature measurements were performed. The surface temperature of the heatsink and the various parts of the grinding bowl were determined using a *FLUKE 561 HVACPro* infrared thermometer, whereas a *Testo 925* digital probe thermometer was used to obtain the temperature of the slurry.

Between each batch the grinding bowl and grinding balls were rinsed by grinding 50 g of coarse quartz sand (+1 mm) for 30 s at 500 rpm before the individual components were brushed clean, wiped with alcohol and allowed to dry.

## 3. RESULTS AND DISCUSSION

Figures 2 and 3 illustrate the effect of the heatsink by presenting the average measured surface temperature for different parts of the system after 30 min of dry and wet grinding, respectively. The corresponding standard deviations, based on the triplicate runs, are also shown.

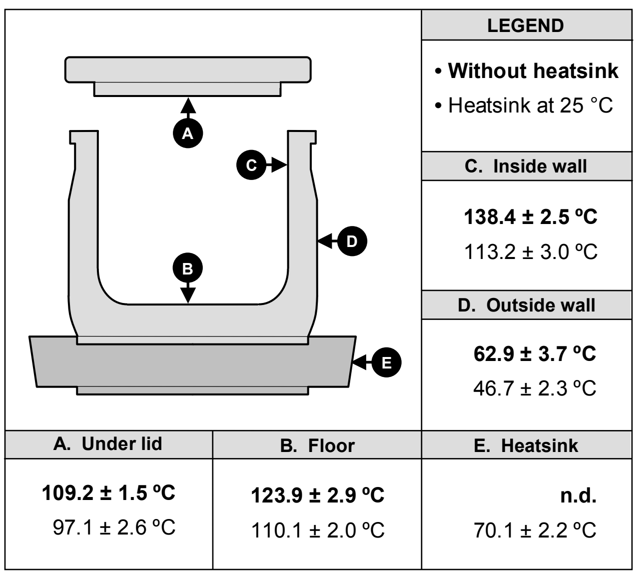



**Figure 2.** Average measured surface temperature (±1 SD) after 30 min of dry grinding.

As expected, the highest surface temperatures are obtained in the dry grinding mode in the absence of the cooling and dissipating effect of water. As the volumetric heat capacity of water is approximately 4.18 $J/cm^{3}$ºC, the heat capacity of the 100 ml added prior to wet grinding corresponds to 48% of the theoretical heat capacity of the copper heatsink. During the 30 min of wet grinding the 100 ml of water is heated from 25 ºC to 53.9 ºC. This requires some 12 kJ. At the same time the heat sink reaches a surface temperature of 40.3 ºC, which corresponds to a heat transfer of approximately 13 kJ (making the very simplifying assumption that its core temperature is identical to its surface temperature). In addition, some heat could also be lost to evaporation. For each millilitre (ml) that evaporates during the grinding experiment approximately 2.3 kJ is transferred, assuming a heat of evaporation of 40.65 kJ/mol.

It is interesting to note that the observed surface temperatures also depend on the geometry of the grinding bowl. This is illustrated by the data given in figure 2. Not surprisingly, the highest recorded temperature occurred at point C where the thickness of the grinding bowl wall changes and the heat from the lower part of the bowl is channelled into a smaller volume.

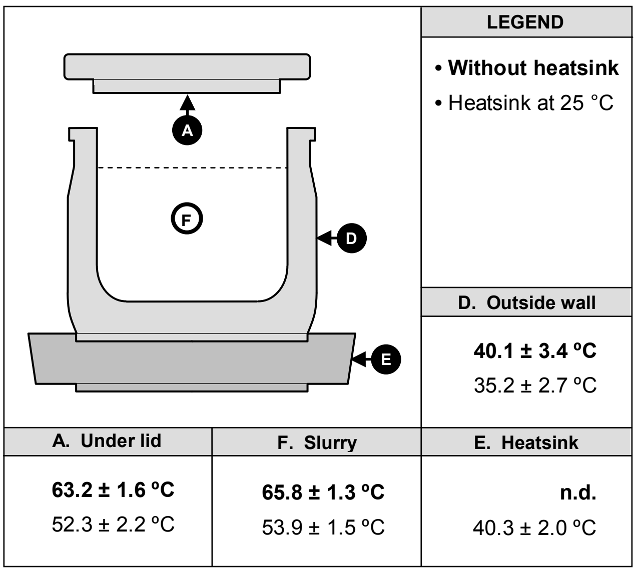



**Figure 3.** Average measured surface temperature (±1 SD) after 30 min of wet grinding.

Figure 4 presents the development of the surface temperature at the grinding bowl floor (point B) during dry grinding as a function of grinding time, whereas a similar curve is presented for the slurry in figure 5. Both figures display the same trend; an initial rapid temperature increase is followed by a decrease in the temperature/time gradient with the temperatures, at least in the dry mode, approaching a stable level.

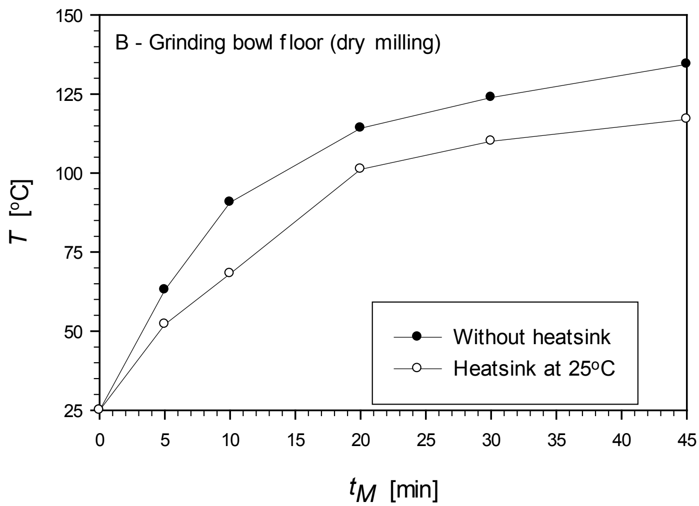



**Figure 4.** Surface temperature at the grinding bowl floor as a function of grinding time.

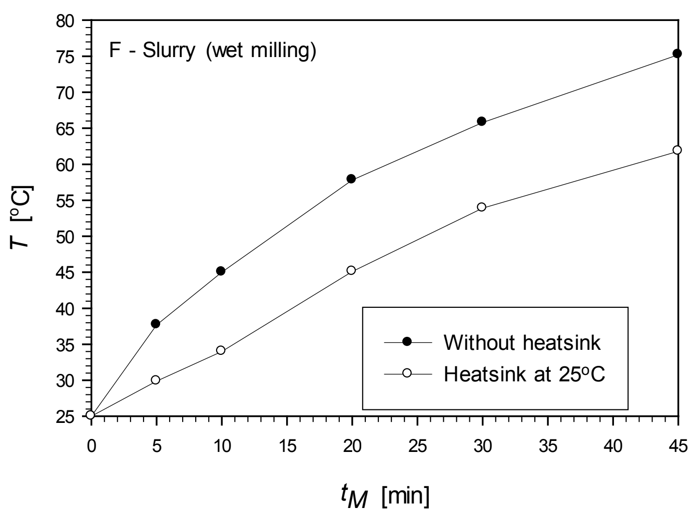



**Figure 5.** Temperature in the slurry as a function of grinding time.

As shown in figures 2–5, the heatsink has a significant effect on the temperature development of the system, and the effect is of a magnitude that can be of considerable practical importance. When using the heatsink with an initial temperature of 25 ºC, the measured surface temperature in the slurry following

30 min of wet grinding is lowered from 65.8 ± 1.3 ºC to 53.9 ± 1.5 ºC (i.e. an 18% reduction). If a temperature limit of 50 ºC is required, it can be seen from figure 5 that the grinding time could be increased from approximately 14 min to 26 min. The same effect is observed in the dry grinding mode. Here, the use of the heatsink at 25 ºC resulted in an 11% temperature reduction at the grinding bowl floor (point B) after 30 min of grinding. Furthermore, as shown in figures 4 and 5, using a heatsink could allow significantly longer grinding times before a pre-set or critical temperature level is reached, especially if the critical temperature is in the region where the temperature/time gradient is low.

It is clear that even larger temperature reductions than those demonstrated by figures 2–5 can be obtained by lowering the initial temperature of the heatsink, e.g. by first placing it in a fridge or a freezer unit. If the initial temperature is lowered to –20 ºC this would correspond to an additional heat storage capacity of approximately 39 kJ. Theoretically, this is the same amount of heat required to warm up the heatsink from its initial 25 ºC to the 70.1 ºC reached after 30 min of dry grinding.

The temperature regulation concept proposed in this paper would work on most planetary mills where the grinding bowl holder is designed to accommodate different bowl sizes (e.g. Fritsch 2008, Retsch 2008). The heatsink disk could be made by local workshops at a low cost.

## 4. CONCLUSIONS

The experimental results demonstrate how the use of a copper disk as a simple heatsink during prolonged grinding in planetary mills represents a cheap but effective way of thermoregulation by limiting or slowing down the temperature increase that takes place in the grinding bowl. Using the heatsink (with an initial temperature of 25 ºC) during 30 min of high intensity dry grinding resulted in an 11% temperature reduction at the floor of the grinding bowl, whereas the corresponding 30 min of wet grinding produced an 18% reduction in the slurry temperature. Larger reductions can be achieved by cooling down the heatsink prior to grinding.

The effect is of a magnitude that can be of considerable practical importance, either by allowing longer grinding times or by enabling the use of temperature sensitive reagents. The concept can be employed on most planetary mills where the grinding bowl holder is designed to accommodate different bowl sizes.

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