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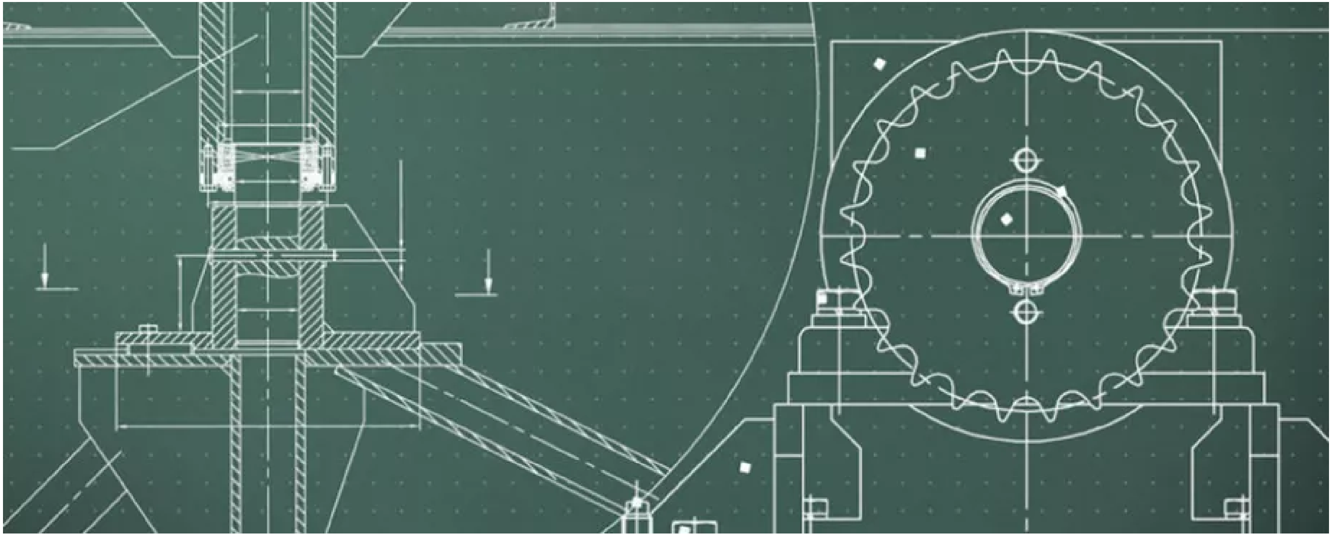

Technical Article

Feeding of Biomass: Design Experience with Wood Chips

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Part of the international struggle to reduce the carbon footprint in energy consumption is the utilisation of biomass instead of fossil fuels such as coal or oil. Although the basic approach is quite promising, as there is a huge amount of usable biomass, there are some problems to be solved with regard to its application due to the largely differing form of appearance of the various base materials. In the following, some research into storage and handling of different wood products including DEM measures are presented.

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Introduction

With its 2030 energy strategy, the European Union has set ambitious specifications for its climate and energy targets. One of these targets is to increase the share of renewable energy to at least 27% of the total energy consumption [1]. Within the share of primary energy generation from renewable energy, the vast majority is contributed by solid biomass. As can bee seen from the orange lines in Fig. 1, the generation of primary energy from solid biomass was just slightly short of 45% of the total renewable portion in 2014. The overall usage of solid biomass has been steadily increasing at least since 2005, whereas the lion's share is utilised for heat and power generation.

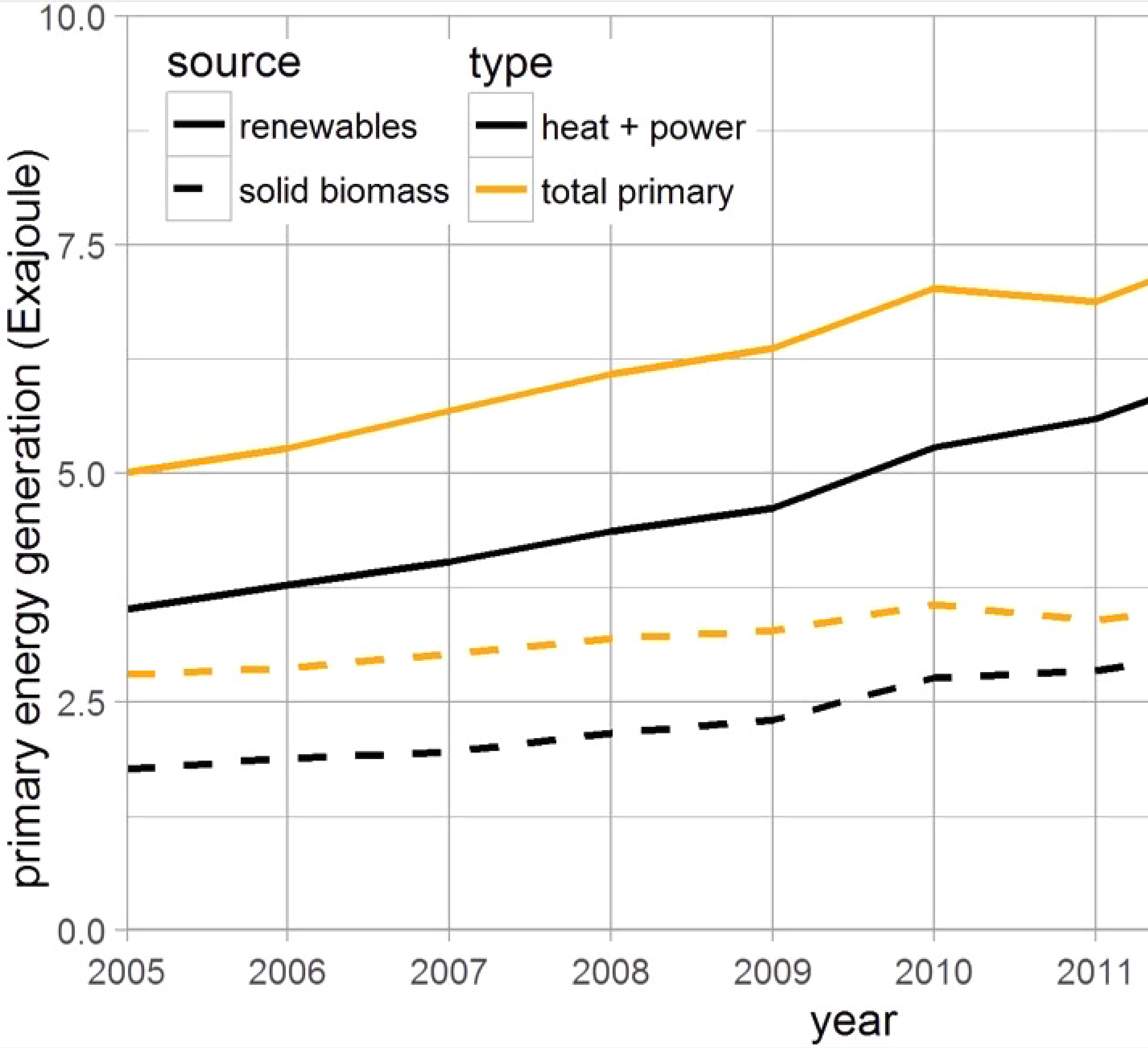

Fig. 1: Overall primary energy generation from renewable sources and solid biomass in particular, in the EU28 countries during the most recent years (solid biomass without charcoal). (Picture: © Eurostat [2])

Solid biomass will continue to contribute a large share in renewable energy generation in the future [3]. Its major advantage over other renewable energy forms such as solar or wind is its high availability, since energy retrieval does not depend on the time of the day or the weather. Furthermore, there are no special requirements for storage facilities with regard to environmental aspects or protection of labor. Nonetheless, solid biomass contains significantly less energy per mass and bulk density than fossil fuels. Thus, when replacing fossil fuels with solid biomass, considerably larger volumes need to be in place, which has direct implications for the capacity and size of storage, transport and handling facilities.Even though solid biomass has been utilised and handled for a long time, there still exist no (standardised) design guidelines for corresponding handling and feeding equipment. Relevant design considerations are typically restricted to trial-and-error and related experience and hence solely at the respective manufacturer's disposal. In addition to this, only a relatively small number of scientific studies are concerned with such issues. With this lack in published research – and hence openly discussed best practices – and knowing that most issues in biomass processing are related to handling and feeding [4], it falls into place that there is a considerable knowledge gap. It is important to address this gap for the growing demand for large-scale handling equipment for biomass.

1. State-of-the-art Feeding of Wood Chips

Although there is a large variety of biomass bulk solids, this article focuses on woody biomass and wood chips in particular. In addition, the last section of this article briefly summarises some projects concerned with other types of biomass fuels and introduces the EU-Project Flexifuel-CHX, which targets in innovative fuel-flexible heating technology.

1.1 General Properties of Wood Chips

Handling equipment is typically designed based on certain properties of the respective bulk solid. The most commonly used properties are the particle size distribution (PSD), particle or bulk density, angle of repose and the friction coefficient against the feeder wall material. The latter is almost always steel. **Origin of the Wood**Wood chips is the term for a broad range of particulate biomass, which is produced from wood by chopping with sharp tools. The wood species used, the particular production method and pre- as well as post-treatment can vary; however the most common sources for wood chip wood are forest and plantation wood as well as residual wood from industrial or domestic processes. An international standard [5] classifies the quality of graded wood chips into two property classes, A and B. Class A wood chips are defined as untreated with low moisture and ash content (A1) or higher moisture and ash content (A2) and produced from full trees without roots, stem wood, forest residuals or chemically untreated wood residuals. Class B1 extends the sources to short rotation forestry and B2 also allows untreated used wood and residual wood from industry.Three ungraded wood chip samples are depicted in Fig. 2. It can be seen that the samples differ in particle size and bark content. Among the three samples, the average particle size decreases from a to c. Sample c are wood chips from forest residues with a characteristically high share of fines consisting of bark as well as needles from conifers.

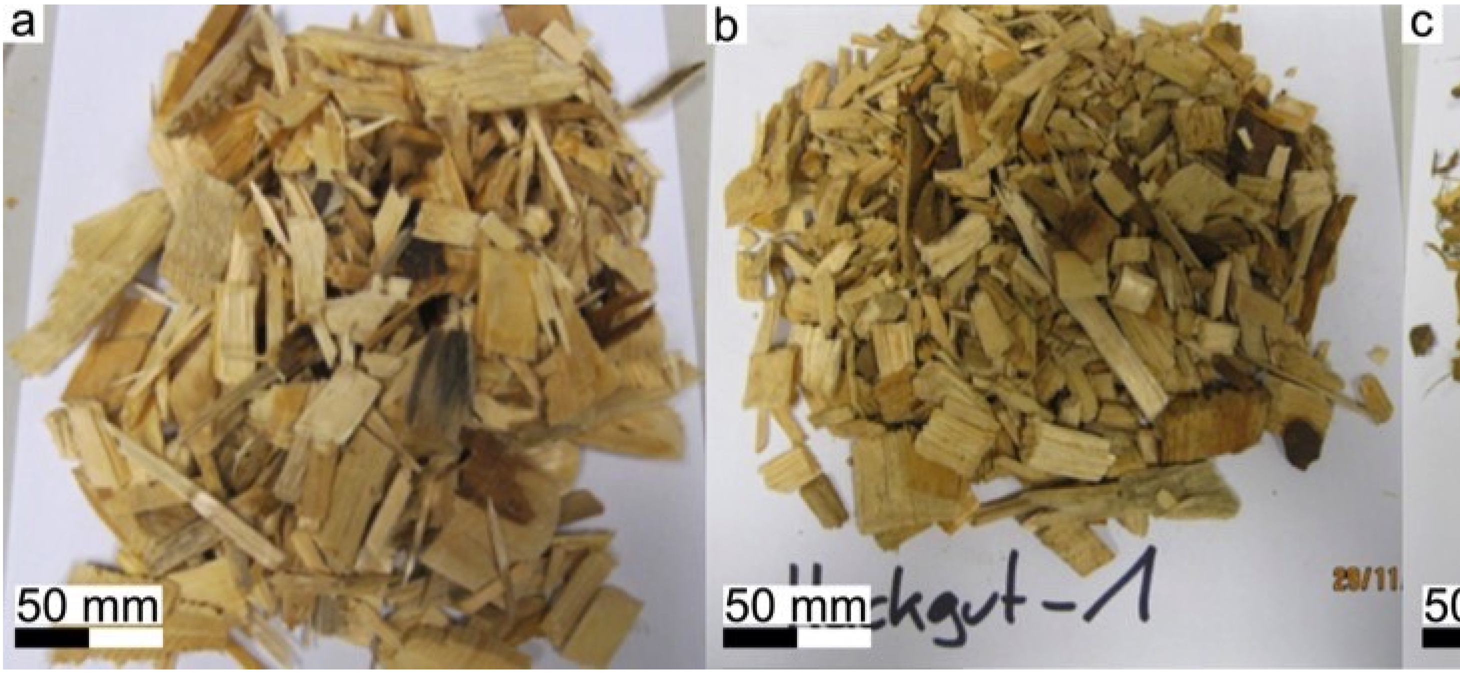

Fig. 2: Different ungraded wood chip samples, a: S1; b: S2; c: S3. (Picture: © Rackl, Günthner [6])

Particle Size Distribution The previously mentioned standard [5] specifies three distinct particle size distributions for wood chips based on passage of a round-hole sieve. The distributions are referred to as P16S, P31S and P45S. At least 60 mass percent of the particles must lie between the lower level of 3.15 mm and 16, 31.5 or 45 mm for P16S, P31S or P45S, respectively. A share of fines, smaller than 3.15 mm, of less than 10 to 15% is allowed and oversized particles, which are larger than 31.5, 45 or 63 mm, have to be limited to less than 6 to 10%. The maximum length of particles is restricted to 45, 150 and 200 mm. This means that for P31S and P45S wood chips with approximately 4.5 times the size of the largest particles of the main share are allowed to be present in the bulk. In combination with the share for fines, graded wood chips can feature a very wide particle size distribution, which has to be considered for feeding equipment design calculations.**Angle of Repose**The angle of repose is a commonly used value to characterise bulk solids for silo discharge design. It is defined as the angle between the lateral surface of a bulk solid formed under gravity and the ground, as shown in Fig. 3. According to the literature, it can be useful to categorise bulk solids from freely, easily, normally or poorly flowing to cohesive (p. 14, in [7]). With an angle of repose between 29° and 46° [6,8–10], wood chips can hence be categorised from normally to poorly flowing. The steep maximum angle of repose of wood chips arises from the combination of many different particle shapes and sizes and wood fibers. There is a strong tendency for wood chips to form bridges over orifices, because they can get tangled with each other. Thus, wood chips can cause severe problems in silo discharge [11,12] and other applications, like screw feeding, where they can cause blockage [6,13] which eventually leads to damage of the feeding system.

Fig. 3: Angle of repose β of a bulk solid heap. (Picture: © Rackl, Tan, Munich Technical University)

Friction Coefficient against Steel Handling equipment for wooden biomass is mostly manufactured from carbon steel or stainless steel. In silo discharge design, the outlet angle should be greater than the angle of repose of the bulk solid in order to grant mass flow and reliable draw down of material. The static friction coefficient between wood chips and mild or carbon steel can be considered equal [6] and its value typically ranges from 0.3 to 0.7 (p. 4-17 in [14]). However, the friction coefficient depends on surface roughness of steel, moisture content of wood chips and other micro-mechanical aspects and should always be measured in an application-oriented setup.**Remark on the Standardisation of Wood Chips**Even though international standards for wood chips exist, there are wood chip manufacturers who do not offer wood chips according to these specifications. Those manufacturers mostly are small enterprises, which mainly produce for domestic customers and forgo processes such as drying or sieving of their product in favor of a competitive price. Thus, wood chips from such sources are ungraded and large deviations in qualitative aspects and physical condition have to be expected among different batches. One should not rely on the characteristics described in the above subsections, unless there is a clear statement from the manufacturer that the provided wood chips are in accordance with such standards.

1.2 Wood Chip Feeding for Combustion

In context with energy generation, biomass is very often handled as particulate matter and the spatial dimensions of single particles range from a few millimeters for saw dust to about 100 millimeters for example for wood chips and elongated fibrous biomass. In addition, a certain share of dust is always present. Handling is carried out with stationary and mobile continuous or discontinuous bulk material handling equipment, e.g., grabs, belt conveyors, screw feeders or wheel loaders. Many of the handling devices which are used for biomass are designs, which had originally been developed for other bulk solids. Energy biomass (especially wood products) had mostly been used for domestic heat generation in the past and the transported quantities were rather small; hence there has only been limited demand for dedicated designs in the past.One typical application in small- and medium-scale combustion of wood chips is their transport from a bunker to the furnace. Fig. 4 shows a schematic of such a feeding system. Coming from a bunker, wood chips are fed into a hopper with a horizontally arranged agitator. The agitator’s task is to omit bridging above the hopper outlet and grant reliable mass flow from the hopper to the screw auger. After the trough of the screw auger, the wood chips pass a rotary gate valve before arriving at the stoker screw feeder. The rotary gate valve is a safety component for application in combustion to prevent backfire from the furnace to the bunker. This could occur if the feeding system was stopped, yet filled with fuel, and there were no spatial separation of fuel as provided by the valve. Finally, the stoker screw feeder transports wood chips directly into the furnace.

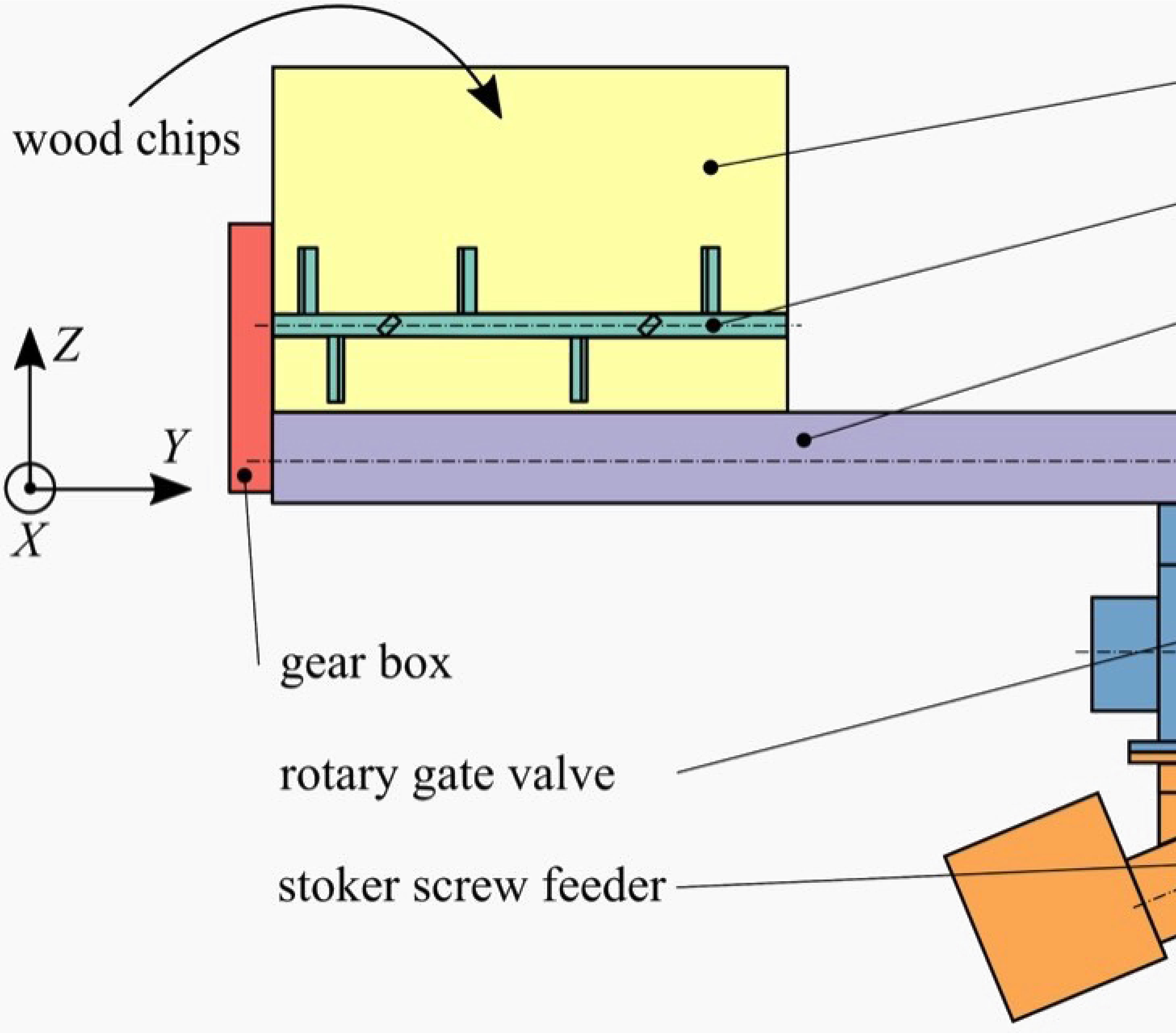

Fig. 4: Schematic of a feeding system for small- and medium-scale wood chip combustion. (Picture: © Rackl, Tan, Munich Technical University)

The three samples depicted in Fig. 2 were subject to experimental investigation by Rackl and Günthner ([6]; open access publication). Mass flow, combined driving torque of the agitator and screw auger as well as power consumption were measured with the setup depicted in Fig. 5. Apart from the basic wood chip samples S1, S2 and S3, two blends were investigated. Blend 1 consisted of 30 mass percent of S1 and 70 percent S3, whereas blend 2 consisted of 70 mass percent S1 and 30 percent S3. This means that the blends consisted of chunky wood chips and forest wood chips with a high share of fines.

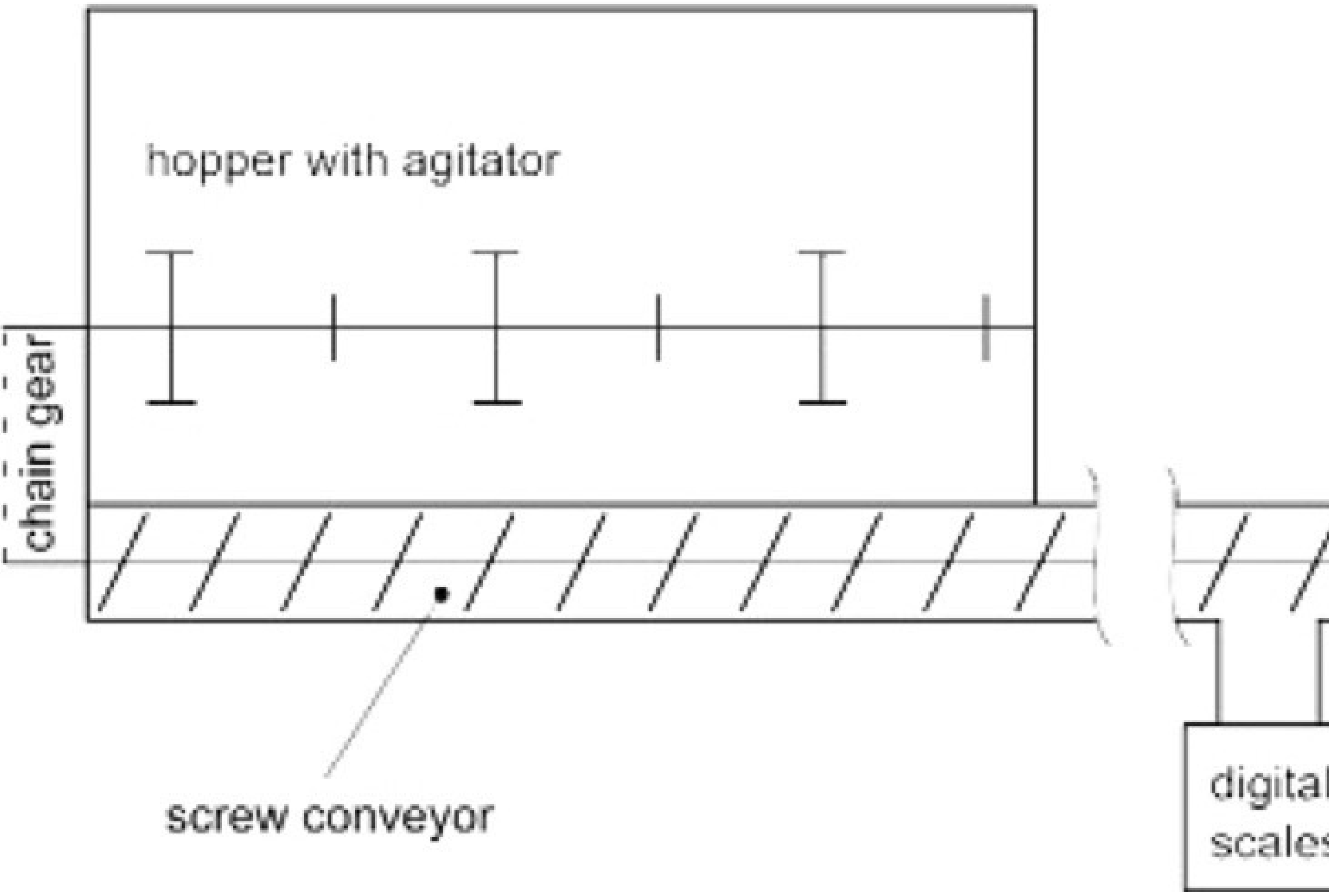

Fig. 5: Experimental setup. (Picture: © Rackl, Günthner [6])

The results in [6] revealed significant differences for the investigated wood chip samples. Fig. 6 presents the driving torque and mass-related energy consumption of the overall system for the different samples. Sample S1 led to jamming of the screw auger of the experiment and these results could not be further considered. The remaining results show clear differences between S2, S3 and the two blends. One conclusion from these experiments is that blending hard-to-feed wood chips with forest wood chips can omit screw feeder blockage. This is due to the fines of the forest wood chips acting as a solid lubricant between the larger particles of S1; adding high-fine-content wood chips can increase the flowability of a blend.

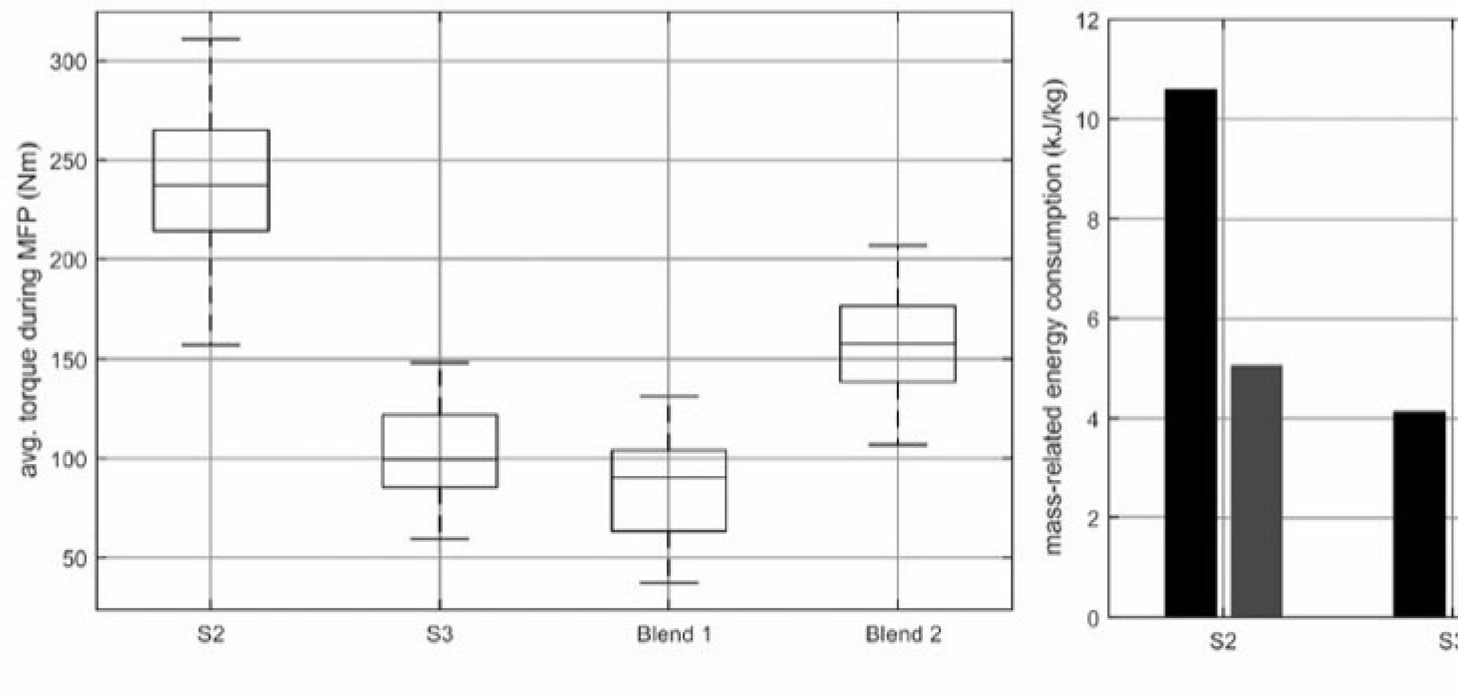

Fig. 6: Average driving torque and mass-related energy consumption of the feeding system. (Picture: © Rackl, Günthner [6])

2. Simulation of a Wood Chip Feeding System Using DEM

The discrete element method (DEM) is a numerical simulation method, which was developed by Cundall and Strack [15] to model rock mechanics. Over the last two decades it has been adopted to model the mechanical behavior of bulk solids for various applications, ranging from powder technology to mining industries.

2.1 Discrete Element Method Theory

A considerable part of DEM’s recent career can be attributed to the availability of ever affordable computer power, since this method is very demanding for central processing unit (CPU) power. DEM can describe the motion and interaction of thousands of particles in a simulation domain. Such interaction can occur between particle and particle as well as between particle and so called walls, where the latter could be mesh geometry of machinery. DEM can be especially useful to compute forces and loads acting on feeding equipment or to predict possible problems with the flow of bulk material at transfer points.Particles are modelled as spheres in classical DEM, because of the computationally cheap contact detection. More complex particle shapes can be accounted for by clumping several spheres together. For the soft-sphere approach, the Hertz-Mindlin contact model [16] is a widely applied model to describe the contact situation between two particles. It is a non-linear contact model and, as depicted in Fig. 7, based on normal und tangential contact stiffness and damping as well as Coulomb friction; various rolling friction models can be implemented, too.

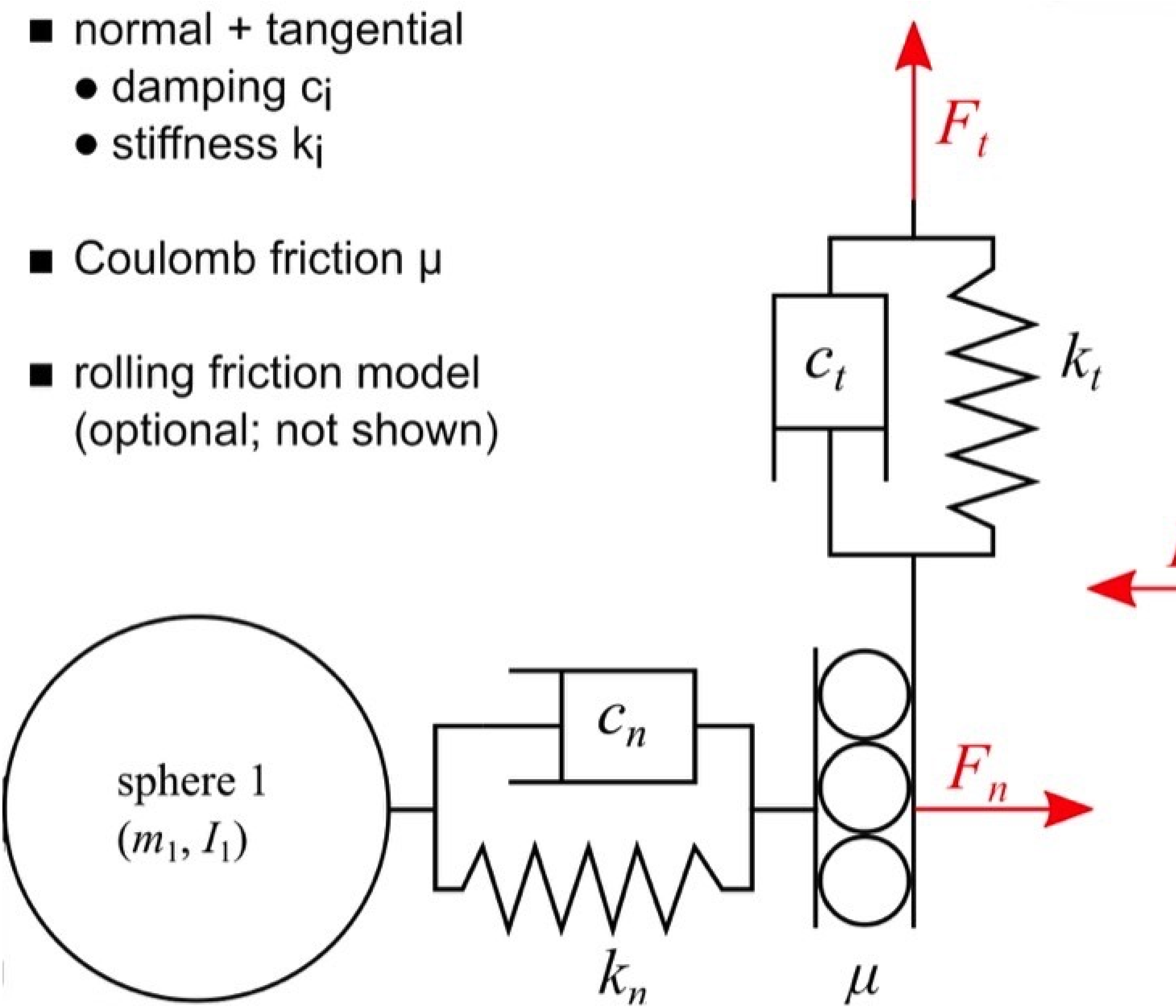

Fig. 7: Hertz-Mindlin contact model for soft-sphere DEM. (Picture: © Rackl et al. [18])

In DEM, the motion of particles is governed by Newton’s second law of motion and the forces acting on a single particle consist of two parts in case of a cohesionless bulk solid. In Eqs. 1 and 2, the temporal derivative of the ith particle’s velocity, v_i, times its mass m equals the sum of the gravitational force, $F_{i,g}$, and the contact forces, $F_{i,HM}$, from the Hertz-Mindlin contact model. Analogously, the rotational velocity depends on the rotational moment of inertia, I_i, and the torque, T_i, acting on the respective particle. [17]

$$m_i \bullet \frac{\mathrm{d}v_i}{\mathrm{d}t} = F_{i\,g} + F_{i\,HM} \qquad (1)$$

$$I_i \bullet \frac{\mathrm{d}\omega_i}{\mathrm{d}t} = T_i \qquad (2)$$

The following material data are required to parametrise a DEM simulation with one bulk solid and walls made from steel. For the bulk solid and wall: particle sizes, particle density, Poisson’s ratio, Young’s modulus. In terms of contact law parameters, the following quantities are needed: static friction coefficient, coefficient of restitution and rolling friction coefficient; each for particle-particle and particle-wall contact. Also note that the rolling friction coefficient is sometimes used to mimic particle shape [19].

2.2 Parameter Study on the Mounting Position of the Agitator

The commercial DEM software EDEM [20] was used to model the system depicted in Fig. 5. The main aim was to investigate the influence of the mounting position of the agitator, since the experimental investigation had indicated that a large part of the driving torque is taken up by the agitator to stir through the wood chips.The mass-related energy consumption of the feeding system was computed for a total of eleven configurations (Table 1), where the agitator’s axis of rotation was displaced vertically and horizontally [21]. Corresponding results were compared to the original mounting position, which was used as a reference.

Number	Displacement from reference configuration [mm]	
	X	Z
1 (reference)	0	0
2	0	-30
3	0	40
4	0	120
5	0	200
6	0	280
7	40	0
8	-40	0
9	40	40
10	-40	40
11	100	120
12	-100	120

Fig. 8 shows the results for the mass-related energy consumption in relation to the original mounting position of the agitator. Energy consumption of the feeding system can be reduced by as much as 30% when the agitator is mounted higher above the hopper outlet (no. 3-6 in Fig. 8). This effect is due to the agitator having a smaller amount of wood chips pushing down onto it. In addition to this, the agitator loses contact with the wood chips at an earlier stage, as the wood chip filling level inside the hopper decreases.

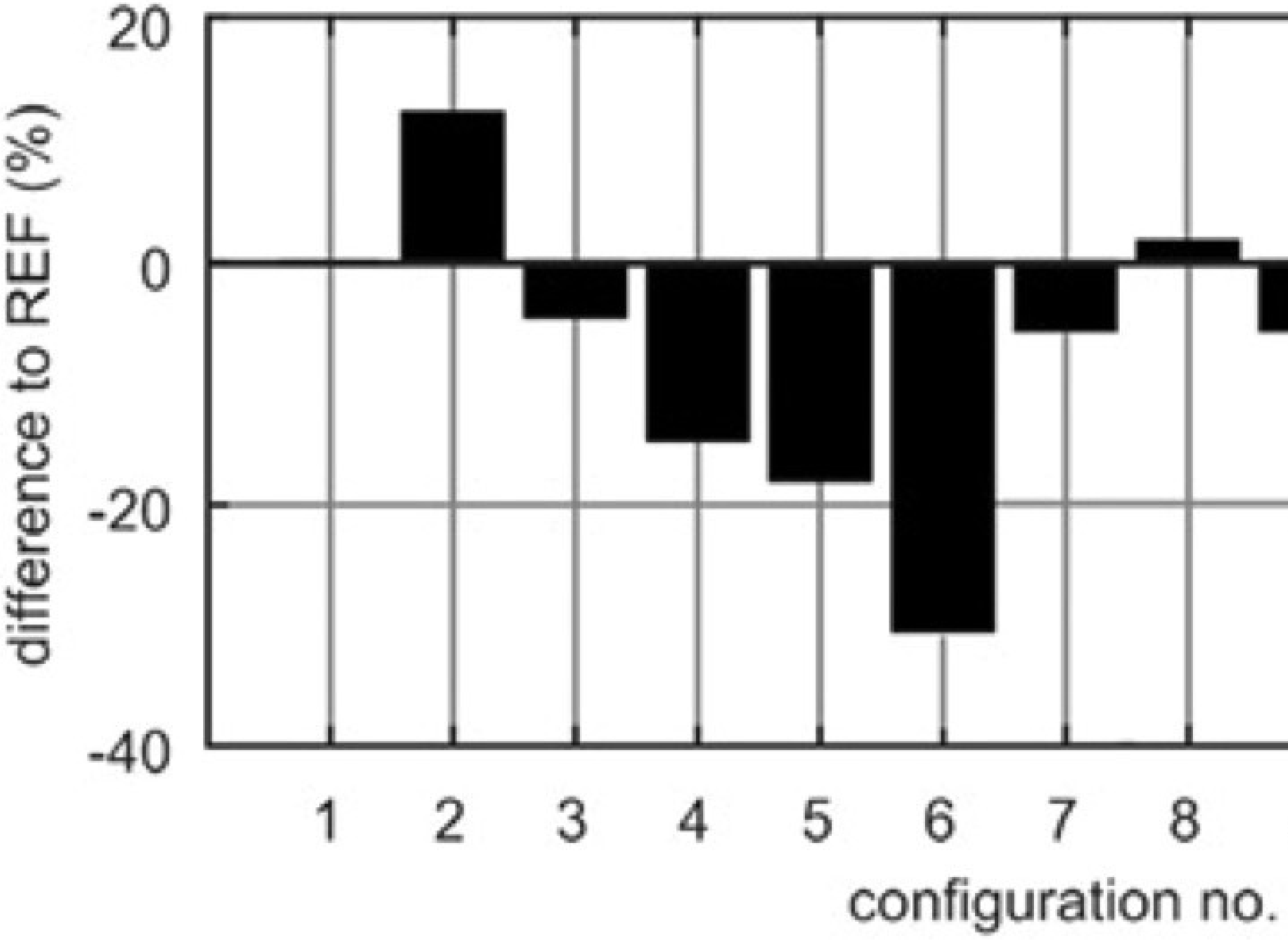

Fig. 8: Influence of vertical and horizontal displacement of the agitator mounting position. (Picture: © Rackl et al. [18])

The effect of shifting the agitator horizontally had less influence, however there could be other reasons to arrange the agitator’s axis of rotation asymmetrically. Fig. 9 shows the effect, when the agitator is displaced towards X+ (solid) and X- (dashed) including the direction of rotation of the agitator and screw auger. If the agitator is shifted towards X+, it tends to loosen wood chips above the screw auger, while in the X- configuration, it pushes down onto the latter.

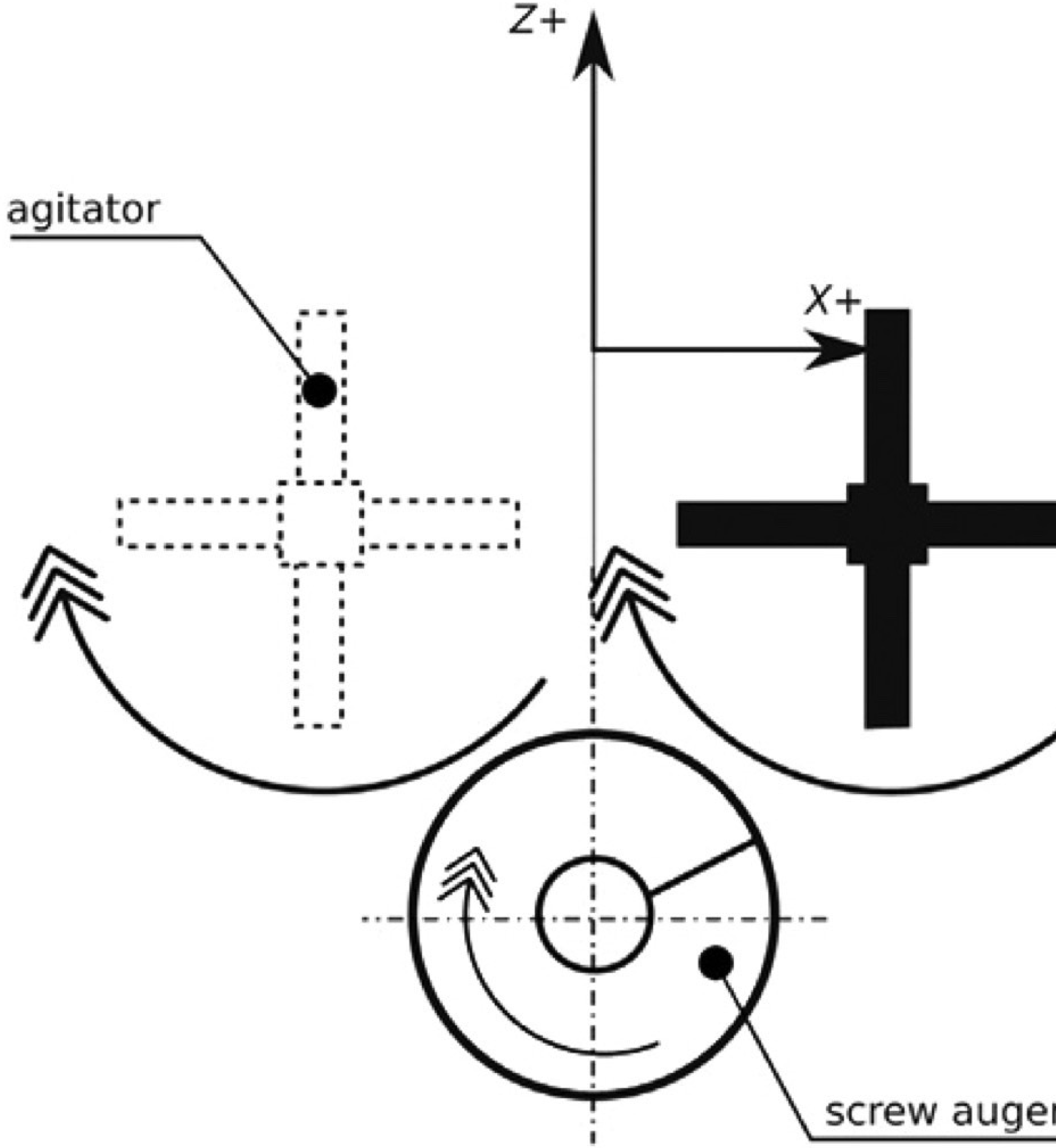

Fig. 9: Loosening effect, when mounting an agitator asymmetrically. (Picture: © Rackl et al. [18])

In conclusion, the mounting position of the agitator can have a significant influence on the mass-related energy consumption of a feeding system, i.e., the energy use per kilogram of transported wood chips. It could be demonstrated that even simple changes in assembly design may significantly reduce energy usage and that auxiliary feeding equipment can contribute a significant portion to the requirements for driving torque and connected load.

3. Ongoing Research Concerning Biomass and Biomass Feeding

As mentioned before, several other biomass materials, such as straw, miscanthus and lawn grass, are also available on the market. However, the physical nature and mechanical behavior of these materials usually differ a lot; particles can be elastic, fibrous, flaky, and even stringy naturally.In recent years, many research projects around the world, such as BioBoost [22] or DIBANET [23], were initiated to address previous difficulties in harvesting, pretreatment, storage, transport and feeding of biomass, so as to optimise small- and large-scale applications. Besides, other ongoing EU projects, like FlexiFuel-CHX [24], aim at developing a new and highly efficient residential biomass heating technology regarding fuel flexibility; for example utilisation of forest residues, short rotation forestry (SRF-willow, poplar), miscanthus, olive stones, nut shells and agro-pellets. One important step of this project is to develop a fuel-flexible fuel feeding system, including fuel extraction system and feedstock.It is well known that the physical conditions of biomass depend on their type. Fig. 10 shows large and irregular differences between them with regard to moisture content and bulk density.

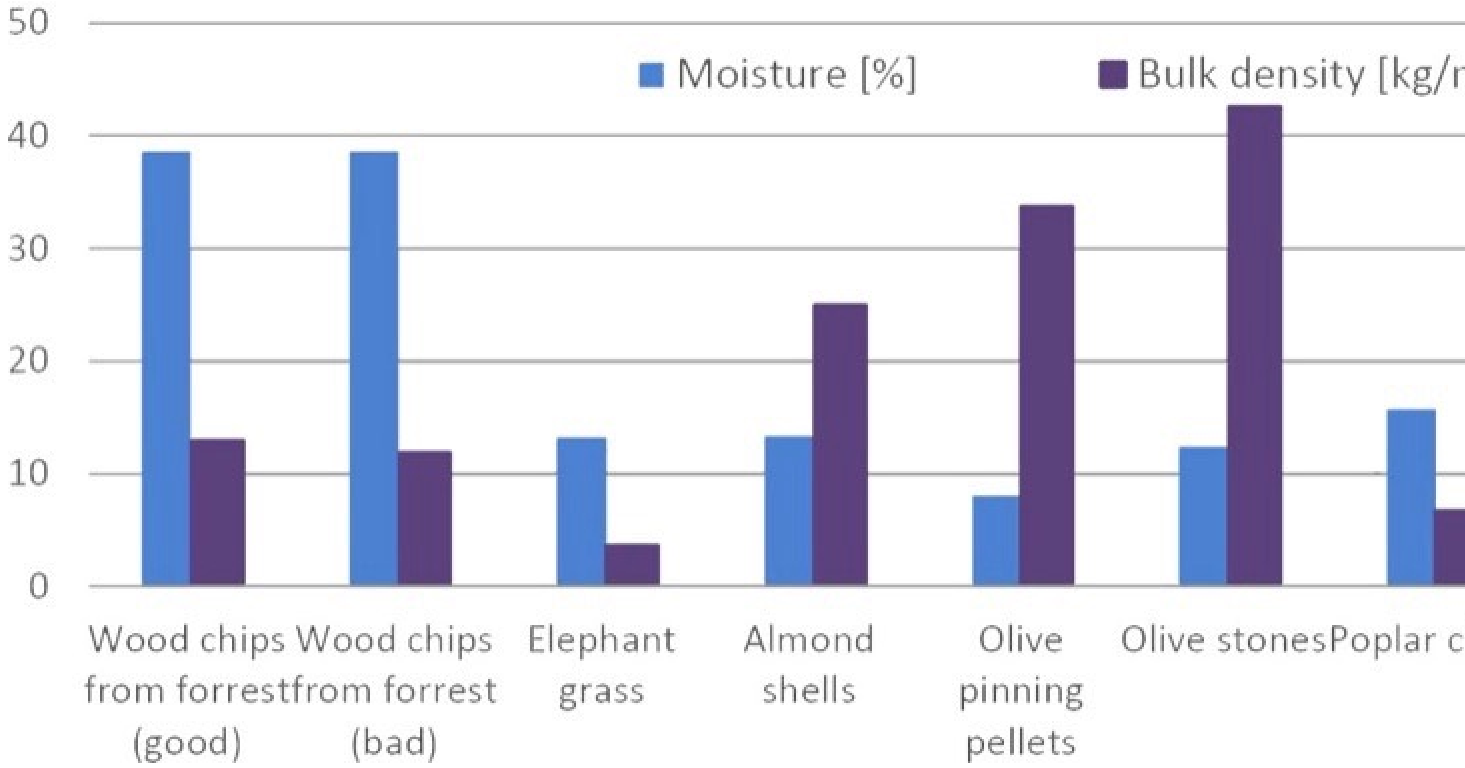

Fig. 10: Moisture and bulk density of ten types of biomass. (Picture: © Rackl, Tan, Munich Technical University)

According to the preliminary results from the FlexiFuel-CHX project, the feeding behavior varied significantly among different biomass fuels, such as forest residues, miscanthus and pellets, which were also discussed in similar studies [25]. It means that the various properties of biomass affect process features, including the flow rate, energy rate as well as torque. For example, the flow rates of these three fuels mentioned measured within 10 minutes were 0,002 kg/s, 0,0005 kg/s and 0.02 kg/s, respectively, when the screw auger ran under the same conditions. In addition, the recorded power fluctuations when feeding forest residues and pellets with the same rotational speed of the screw auger were clearly different from each other as well, even though the motor was always configured with the same frequency controller. Considering these properties, possible problems with fuel flexibility and air tightness with certain fuels will have to be addressed in particular. Two prototype screws are planned to be designed and manufactured after analysing the results from discrete element method (DEM) simulations, in which material models for different biomass will be established.

4. Conclusion

As mentioned in various previous works ([26], [27]), the reliability of a fuel-flexible feeding system, which is of major importance in application, is mainly affected by the wide range of different biomass particle properties. Therefore, more research and testing are necessary in every aspect of fuel-flexible feeding systems for popularisation of biomass energy. All those works have provided a common basis for further analysis, but are still incomplete regarding standardised engineering practice for designing biomass feeding systems.

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