The Carbon Footprint of an Injection Molding Machine

Operational Use Is the Predominant Phase in the Four Life Cycle Phases of Production Plants

The CO₂ footprint is regarded as a reliable indicator of the way people, machines, and products affect climate. On the basis of its dual-platen GX series, KraussMaffei has investigated the climate impact of an injection molding machine and defined measurable data.

Manufacturers of plastics processing machines place special importance on energy and resource efficiency in the development of new sustainable machines and technologies. Much the same holds true of plastics processors – they face international competition and strive to maximize the efficiency of their plants, while maintaining product quality. So the recurring question is how to reconcile economic and ecological goals.

KraussMaffei Technologies GmbH of Munich, Germany, takes its social responsibilities seriously and tests the environmental impact of its products. In the development of its GX series, the company has gone one step further by investigating the climate impact of an injection molding machine. The GX 550-4300 (Fig. 1) is designed for optimum energy efficiency and high productivity. As a hydromechanical dual-platen machine, it represents the latest generation of machines found at modern production sites today.

The so-called carbon footprint was selected as an important methodological criterion for evaluating environmental impact. By considering the entire life cycle of the machine, including recycling, it is possible to build up a comprehensive picture of climate impact, identify emission-intensive processes, and make appropriate recommendations for action.

Definition of Accounting Boundaries and the Comparison Process

In the climate change debate, industry is held responsible for a large proportion of global CO₂ emissions. For the current commitment period of the United Nations Framework Convention on Climate Change, known as "Kyoto Protocol", the countries of the European Union have agreed to reduce the emission of greenhouse gases, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), by a total of 20% by 2020 compared with 1990 [1].

These various gases have very different potential effects on climate change. So, over a period of 100 years, the greenhouse gas methane contributes 21 times more to climate change than CO₂. For this reason, the Intergovernmental Panel on Climate Change (IPCC) [2] determines coefficients for the "equivalent effect" of greenhouse gases (Table 1). Global warming potential can be calculated via the coefficients of the various greenhouse gases. The result is expressed as CO₂ equivalent (CO₂-eq), so enabling improved comparability [3].

The International Organization for Standardization has developed ISO 14040 as an international standard for determining CO₂ footprints. This internationally recognized standard provides the basis for the life cycle assessment of products. In addition to the global warming effect, it covers a number of other potential environmental effects [5].

As a basis for accounting emissions, the functional unit of the product (utility) is determined and benchmarks are uniformly established [5]. An injection molding machine is used for various application purposes. Depending on the customer requirements and application, processing parameters and hence climate impacts can vary widely. In order to define a uniform basis for analysis, a comparison process was selected on the basis of the Euromap 60.1 Directive [6].
A system boundary determines which inputs and outputs are included in the accounting and which of them can be disregarded. Input and output parameters can be weights, volumes, and energies [4]. In order to determine the CO₂ footprint, it is important to define the system boundaries for accounting in advance, since they strongly influence the quality and comparability of the CO₂ footprint [3].

An injection molding machine is a complex product system linked to numerous partial systems. To avoid having to account for a large overall system with many unknowns, the interfaces with subsystems whose influence is small are disregarded. The criteria are based on the relevance of a single input in relation to the overall system. As a guideline, the common 1% rule is applied, whereby inputs such as energy, volume, and weight that contribute less than 1% to the overall system are disregarded [5].

Data Collection and Life Cycle Calculation

The life cycle of an injection molding machine can generally be divided into four phases:
- manufacture,
- transport,
- operation, and
- recycling.

For purposes of accounting, a detailed description of the individual processes within the life cycle phases is developed from this very general life cycle definition. To this end, the cycle phases are divided into individual process segments or so-called process modules. The input and output parameters, energy, and mass of the process modules are then identified and the process units defined. Greenhouse gas potential thus corresponds to the product of these two:

\[ \text{T(XY)} = \text{AX} \times \text{EFY} \]

The challenge in this accounting lies in the fact that the time and effort required for data collection increases with the complexity of the required amount of data. The machine design data provide the basis for data collection. Additional primary data sources, such as energy measurement, product data sheets or operating instructions improve the accuracy and informative value of accounting.

The greatest effort, however, is required to obtain and assign information that is not available from internal data collection. Reliable secondary data in these cases are provided by external databases, such as Gemis, ELCD or the “System of Environment-Economic Accounting” (SEEA) [5]. Given the large number of individual segments, however, to simplify accounting, similar components with the same processes and raw materials can be grouped together.

From Raw Material Extraction and Processing to the Injection Molding Machine

The "emissions" from the manufacture of a KraussMaffei GX 550-4300 injection molding machine weighing approx. 25,000 kg amount to 79,000 kg of CO₂ equivalent. Accounting for 94% of total weight, metal products are the largest CO₂ driver (91%). Plastic components and electrical equipment have a smaller influence on the result. Although the emission factors of these components are higher than those of metal products, their share of total weight is far lower (Fig. 2).

The most emission-intensive process in the manufacturing phase was identified as production of the moving and fixed platens (Fig. 3), which contribute 33% to total weight. The weight of the cast blanks (8,360 kg) and their 3.3 kg CO₂-eq/kg emission factor results in a greenhouse gas potential of 19% (Fig. 2).
gas potential of approx. 27,600 kg CO₂-eq. In the milling operation, the focus lies on the total electric power requirement of 371 kWh and the German power mix factor of 0.65 CO₂-eq/kWh. A cooling lubricant consisting of 92% water and 8% oil also enters the consideration as a manufacturing auxiliary.

The sum of the individual greenhouse gas potentials provides a total greenhouse gas potential of 28,000 kg CO₂-eq (Table 2). The percentages for the production process (approx. 1%) and consumables and supplies (less than 1%) are surprisingly low. This example illustrates how the choice of material when designing a machine immediately determines its CO₂ footprint in the manufacturing phase.

**CO₂ Footprint in the Use Phase of the Injection Molding Machine**

During the operating phase, the machinery manufacturer naturally has no direct influence on the CO₂ footprint from the use of the machine. Nevertheless, energy-efficient technologies and assistant functions, e.g. in the machine control system, can make valuable contributions.

The overall result depends largely on the type of plastic used and thus on the part being produced (injection mold). During the course of this analysis, the utility supplies proved to be a significant additional factor. Generation of the necessary cooling power can affect the result to a widely varying extent, depending on the cooling technology used.

Energy-efficient technologies obviously affect the CO₂ footprint of injection molding machines in a positive way. Here, the drive technology is key – energy consumption and the resulting CO₂ emissions can be significantly reduced by speed-controlled hydraulics (KraussMaffei brand name: BluePower). In direct comparison with machines lacking speed-controlled hydraulics, machines fitted with this sophisticated drive concept require up to 60% less electrical energy.

As a result, over one year’s operating time (250 days in 3-shift operation), assuming 90% machine availability, the greenhouse gas potential can be reduced by 9% (Fig. 4). In sensitized markets, the smaller CO₂ footprint, along with cost reductions due to reduced energy consumption, can be used as a sales argument. In this connection, the packaging and automotive industries should be particularly mentioned.

In addition to drive technology, optimized process setting of the machine can improve its carbon footprint. To this end, the MC6 machine control system offers an “eco button” function, among other things. When this function is activated, the machine takes over the (released) processing parameters and sets the energetically optimum process. The machine is then smart enough to eliminate any negative effect on cycle time and so maintain full productivity.

An additional positive effect is provided by a special “time clock” assistant. Instead of setting the startup times to pre-warm the machine, the operator now can program the desired production start time. The machine control system then determines the latest possible start time by itself, so actively avoiding unnecessary heat and energy losses to the environment.

The analysis also shows how the plastic being processed has a major influence on the result. When processing polypropylene (PP), for example, the CO₂ footprint of the machine in its operating phase is 1,372 t CO₂-eq (based on a Euro-map 601 process). In direct comparison, the total footprint is roughly 300% higher when polyamide (PA6) is being processed. The greenhouse gas potential here increases to 4,512 t CO₂-eq. This difference is a direct result of the different climate impact potential of the raw material (Fig. 5). Here it should be mentioned that, in accordance with the boundary conditions and system boundaries selected for this analysis, possible recycling of the processed plastic material was not taken into account.

Taking the total life cycle of the injection molding machine into consideration, what stands out is the high contribution made by the operating phase. Whereas this is 93.5% during the first year, over an assumed total operating life of 18 years (250 days/year in 3-shift operation), the percentage rises to 99.6%. A long way...

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**Table 1.** Greenhouse gas potential: carbon dioxide is not the most potent greenhouse gas by far

<table>
<thead>
<tr>
<th>Greenhouse gases</th>
<th>Molecular formula</th>
<th>Greenhouse gas potential with regard to 100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N₂O</td>
<td>310</td>
</tr>
</tbody>
</table>

**Table 2.** The most emission-intensive process in the construction of a GX 550-4300 with 5,500 kN clamping force is the manufacture of the platens (broken down into individual steps in the table)

<table>
<thead>
<tr>
<th>Process</th>
<th>Activity data</th>
<th>Emission factor</th>
<th>Greenhouse gas potential</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw part manufacture</td>
<td>8.364 kg</td>
<td>3.3 kg CO₂-eq/kg</td>
<td>27,601 kg CO₂-eq</td>
<td>98.6%</td>
</tr>
<tr>
<td>Production</td>
<td>371 kWh</td>
<td>0.65 kg CO₂-eq/kWh</td>
<td>241 kg CO₂-eq</td>
<td>0.9%</td>
</tr>
<tr>
<td>Auxiliary and operating</td>
<td>244 kg</td>
<td>0.63 kg CO₂-eq/kg</td>
<td>153 kg CO₂-eq</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

**Fig. 4.** Comparison of CO₂ emissions in operating with a basic drive and speed-controlled hydraulics (BluePower) for one year's operating period: the difference is a 9% reduction in emissions (figure: KraussMaffei)
behind in second place is the contribution accounted for by machine manufacture, while transport and recycling affect the total result to an even smaller degree (Fig. 6).

Conclusions

Based on the CO₂ footprint of a Krauss-Maffei GX 550-4300 machine, it is possible to show which factors have a positive or negative effect on the greenhouse gas potential of an injection molding machine. It can be seen that the operating phase is disproportionately relevant, since far more than 90% of climate-influencing emissions occur then. Even so, the use of high-quality, low-friction components, e.g. linear guides in the clamping unit or sufficiently large hydraulic components, can achieve positive results from the machine. Energy-efficient drives and/or the installation of thermal insulation can reduce emissions further.

Opportunities provided by various smart assistant functions in the MC6 machine control system that help relieve the machine operator and lower energy consumption at the same time should also not be ignored. In many areas of injection molding, these can already be used to advantage by companies to improve their “operational CO₂ footprint”.

This analysis helps us to understand the climate impacts of emission-intensive processes in the life cycle of an injection molding machine and take them into account in future decision-making. For KraussMaffei, this step forms a basis for future steps in the development of sustainable technologies. The current trend toward life cycle analysis of production machinery confirms this approach.

Less Vibrations and Extraordinary Sound

Trumpet Made of CFRP

By using carbon fiber compounds for wind instruments, it is possible to suppress vibrations in the tube, which are a waste of energy. Instrument makers, engineers, acoustic designers, and musicians have worked together intensively to develop a trumpet and a trombone that are easier to play, but still produce a warm and well-rounded sound.

In cooperation with project initiator daCarbo AG in Lachen, Switzerland, the music retailer Musik Spiri in Winterthur, Switzerland, the Hochschule für Technik Rapperswil, Switzerland, and the Institut für Wiener Klangstil at the Vienna University for Music and Performing Arts, Austria, Nägeli Swiss AG in Güttingen, Switzerland, was contracted to develop the first trumpet bell made of carbon fiber-reinforced plastic (CFRP). During development of the bell, Nägeli used Araldite composite resins from Huntsman Advanced Materials. The bell is manufactured with the RTM process (resin transfer molding).

The great advantage of the new daCarbo instrument lies in the measurably and noticeably reduced blowing energy required to produce a sound. Thanks to the high rigidity of the instrument panel and the good damping characteristics of the composite material, the percentage of inaudible bell vibrations is reduced, thereby increasing the sound reflection. Blind tests showed that these instruments correspond to the typical, conventional trumpet sound, and are readily accepted by professional orchestras.

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To the product presentation:
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