57% energy savings with tandem technology

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Rising electricity and energy costs have become an increasing burden for industrial companies in recent years. The reasons for this are, for example, the international challenges surrounding the Corona pandemic and the war in Ukraine. In addition, climate protection, the reduction of energy demand in production and the increase of international competitiveness poses great challenges for companies. Therefore, companies must increasingly examine, optimise, and adapt their own (production) processes. In addition, new or further technologies can be integrated into companies to focus on product quality, the production process, environmental protection, and economic efficiency.

Tire producers and rubber processing companies are also striving to optimise their own production processes. Tire manufacturers are increasingly looking at their own production processes from an energy perspective. One possibility for increasing energy efficiency is the tandem mixing process. This publication shows the advantages of the entire process regarding its economic efficiency, the increase in throughput, the reduction of mixing stages and especially in terms of specific energy reduction while maintaining the same mixing quality. The results were developed in a cooperation project between Kraiburg Austria and the HF Mixing Group. As a result, a concept has been developed that makes it possible to analyse and evaluate existing mixing processes, transfer them to tandem mixers and identify potential savings.

1. Introduction

The production of tire compounds in internal mixers is state of the art today. Historically, different mixer sizes and different systems have been used. The production is discontinuous which means batchwise. During the production of the mixture, different components must be dispersed and distributed in the compound to create a homogeneous batch. To achieve this goal, the input of mechanical energy is necessary. For energy and economic reasons, it makes sense to introduce only as much energy into the compound as is needed. [1], [2], [3]

Especially in the recent past, manufacturing companies in Europe have had to struggle with high energy prices to continue to produce economically. As a result, the industry is increasingly asking for lower electricity and energy prices for companies [4]. Due to national and international regulations, it is already foreseeable that energy prices will continue to rise. One reason for this is, for example, the "Green Deal" of the European Commission [5]. This contains, among other things, specifications for the future pricing of CO_2 emissions. These costs have already been set and will double over the next three years [6].

Innovations and modernisations are indispensable to meet the increasing pressure of rising energy costs and the simultaneous high cost and competitive pressure. In the tire industry, the tandem mixing process has been developed for this purpose [7] [8]. In the past, various considerations have been made regarding the advantages of tandem mixing [9]. A study on the estimation of the "carbon footprint" of tandem mixers has already dealt intensively with the topic of reducing CO_2 emissions [10]. Building on these approaches, previous calculations are now validated with trials in industrial practice to demonstrate the advantages of the tandem technology.

2. Tandem mixing technology

Tandem mixing offers a multitude of advantages in terms of procedural compound production, economic efficiency as well as logistics and storage costs. The tire industry has traditionally used several mixing stages due to the use of highly active carbon blacks and the need to reduce the compound viscosity. The individual stages have different roles to play in relation to the production of the final compound. This can be, for example, the dispersion and incorporation of fillers, the reduction of viscosity as well as the distribution of small and cross-linking chemicals. In multi-stage processes, these tasks are performed in different mixing processes that are separated in time and, if necessary, in location.

The tandem mixing process makes it possible to significantly reduce the number of mixing stages. For this purpose, two internal mixers are arranged in such a way that one internal mixer is located below the other. Due to the spatial arrangement, the first of the two machines is described as the upper mixer and the other as the lower mixer. Different process tasks can be assigned to each of the two mixers, resulting in design differences in the machine. A possible arrangement is shown in Figure **1**.

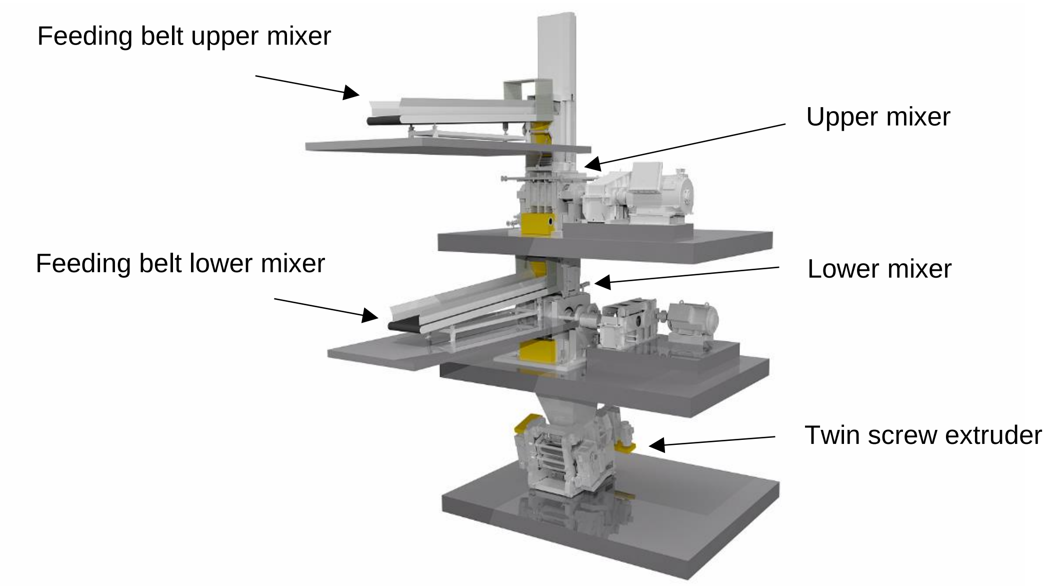

Figure 1: Example for a tandem mixer layout

In the tandem mixing process, the upper machine is designed as a ram kneader. The design of the machine does not usually differ from a "stand alone" machine. The lower machine of the tandem mixer is designed as a ram less kneader. It also has a larger mixing chamber than the upper machine. If, for example, an IM320E is used as the upper machine, an IM550E is usually used as the lower machine. It is advisable to use an intermeshing rotor in the lower machine, as this has better cooling characteristics. As shown in Figure 1, it is possible to add a feeding belt to the lower mixer to allow additional material to be fed into the lower machine. Tandem mixing and the separation of processes between the upper and lower machine provide various advantages in mixing, which will be explained in the following.

<u>Process separation into upper and lower mixer:</u>
Through the combination and design of the two internal mixers, different production tasks can be solved. By dividing the mixing processes, optimal conditions can be achieved for dispersion, distribution, viscosity reduction, cooling of the batch, etc.. By designing the upper machine as a ram-type kneader, correspondingly high shear forces can be applied. This results in good dispersion of the fillers and effective and good incorporation. The batch is then transferred from the upper machine to the lower machine. The larger mixing chamber volume of the lower machine results in a lower fill factor at a constant batch weight (specified by the upper mixer). This makes it possible to focus on distributive mixing. Due to the larger mixing chamber, the design of the kneader as a ram less machine offers the possibility to achieve additional space for place changing processes by pushing the compound up into

the shaft. This results in a very good distributive mixing effect. In addition, pre-mixed material and/or the cross-linking system can be added via the feeding belt of the lower mixer. The cold, premixed batch is used to reduce the temperature of the batch from the upper machine and to avoid critical overheating of the compound. Unlike stand-alone machines, the assignment of tasks to the upper and lower machine allows each mixer to be optimized for the specific mixing application/task.

Step reduction:
Separating the mixing process in upper and lower machines opens opportunities for consolidating mixing stages and even eliminating others. This segmentation of the machine processes leads to reduced preparation times and thus offers significant advantages in terms of efficiency and throughput.

Reduction of specific energy input:
The implementation of stage reduction and optimisation proves to be extremely beneficial, as it leads to a significant reduction in specific energy consumption in the mixing line. In addition to the immediate energy savings resulting from the stage reduction in the mixing process itself, there is a significant reduction in energy consumption in the downstream machines. As an example, a batch that originally was produced in four stages, passes the downstream equipment also four times. If it is possible to reduce the process to only two stages, the number of passes can be cut in half, resulting in a significant reduction of the energy consumption.

Increase in throughput:
By reducing the number of stages in tandem mixing, a significant reduction in the total mixing time can be achieved. The total mixing time is defined as the time the compound is processed in the internal mixer during all individual stages. Reducing mixing time results in free capacities that can be filled by increasing the company's own production or the production of additional material.

Reduction of warehouse and logistics costs:
In addition to reduce the total cycle time, the reduction of stages also leads to reduced storage and logistics costs. The reason for this is that transport costs within production (transport from warehouse to mixer, transport from mixer to warehouse, intermediate storage, ...) can be reduced analogously to the stage reduction. This means that tandem mixing not only has an impact on the mixing process, but also on surrounding processes.

Cost reduction:
All the previously mentioned and explained advantages contribute to reduce the specific production costs of the compound in a tandem mixer. Based on the individual points, the specific energy consumption and thus the energy costs during production can be reduced. In addition, it is possible to reduce various processes that are inevitably necessary in multi-stage compound production on a "stand alone" mixer (downstream flow, logistics costs, etc.) due to the reduction in stages. This reduction then leads directly to lower specific production costs.

3. Potential of tandem mixing

The previously mentioned advantages of tandem mixing will be explained using a concrete example. The results will be presented and discussed based on an industrially mixing recipe from Kraiburg Austria. This ensures that the results are as close as possible to industrial practice and can be transferred to other compounds, processes, and production plants. To point out as many advantages of tandem mixing as possible, a three-stage mixing process is considered as an example. In a current research and development project, the HF Mixing Group has developed a procedure to transfer existing mixing processes from a standalone mixer to a tandem mixer. The procedure is divided into the following four steps:

1. Analysis of current mixing process
2. Development of a tandem mixing process
3. Simulation of a tandem mixing process
4. Laboratory analysis of samples from tandem mixing process regarding the specifications

Based on the previously described steps, the concrete consideration of the respective advantages of the tandem mixing technology will be discussed.

3.1. Analysis of current process

The selected recipe is a blend of natural rubber and polybutadiene. In addition, an active carbon black is used as well as various small chemicals and a sulphur-based cross-linking system. The current production refers to a GK320E standalone mixer with PES5 rotors. Polymer and chemical addition are semi-automatic in the upstream. There are two mills and a batch-off in the downstream. For the analysis of the current process, the individual stages of the selected three-stage mixing process are considered.

For the energetic consideration, an energy consumption analysis of the entire line is carried out for each individual stage. The results are calculated separately for each stage and then summarised in a Sankey diagram. For the first stage of the compound, the percentage distribution of the energy flows is shown in Figure 2.

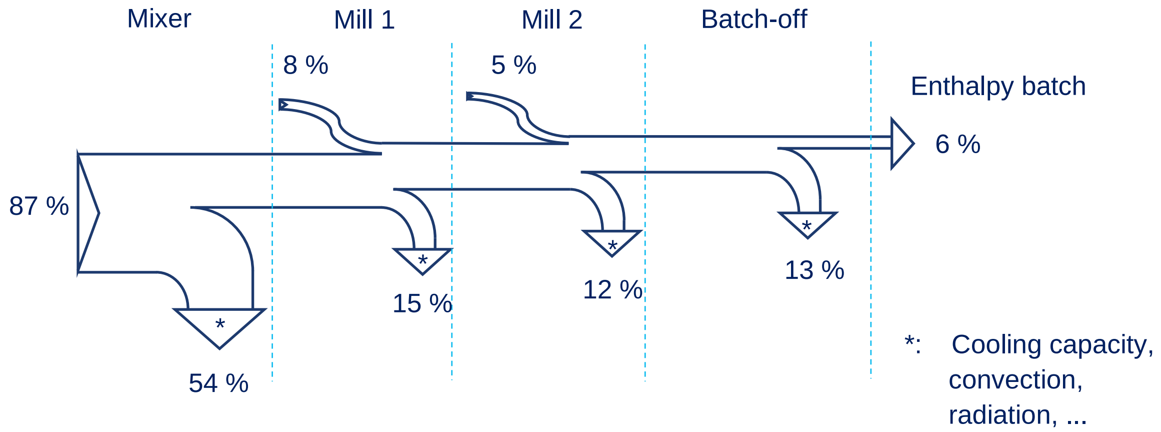

Figure 2: Sankey diagram for the first stage of the three-stage mixing process

By analysing the energy data of the mixer, the upstream and downstream, the specific energy input for each stage along the entire line and the mixing time in the mixer can then be specified. The time in the mixer is used as the decisive parameter for evaluating the throughput, as the mixer is usually the bottleneck of the mixing line. If the mixing times of all three mixing stages are added up and the total mixing time required to produce the final batch is calculated, the sums and values shown in figure 3 are obtained.

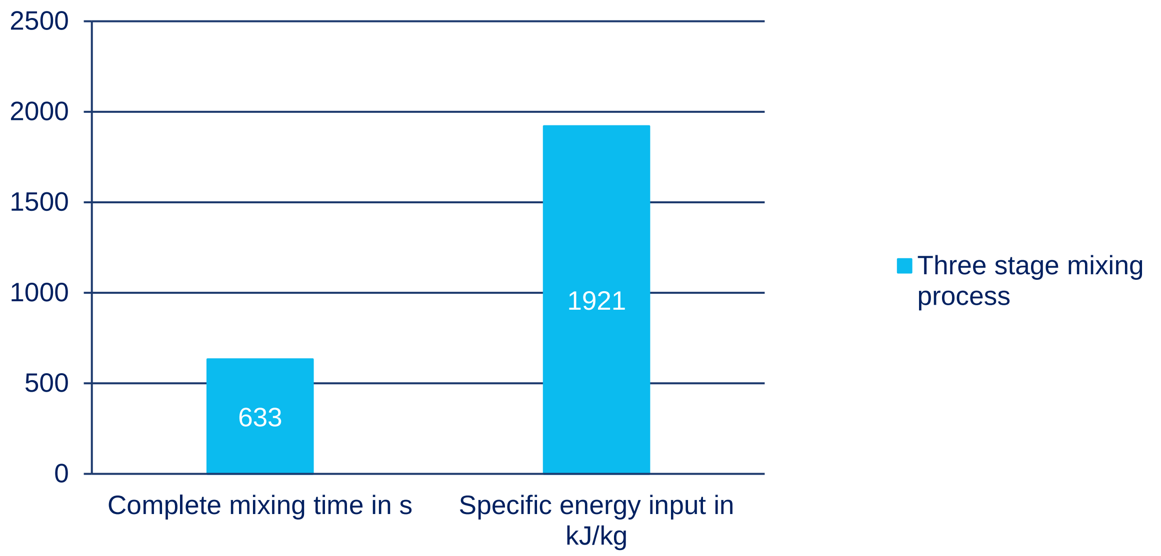

Figure 3: Mixing time and specific energy input summarised for all three stages and the respective entire line for the selected compound (average values per batch)

The variables shown in the previous figure are used as reference variables or initial values for the comparison with the tandem mixing process to be developed in the next step. The corresponding procedure is explained in the following chapter.

3.2. Development of a tandem mixing process

After analysing the current mixing process, a tandem mixing process is developed. To do this, the existing mixing processes are combined to create a mixing process for the upper and lower machine. In accordance with the basic idea of tandem mixing, the production of the masterbatch including the incorporation and dispersion of fillers is aimed in the upper machine, whereas in the lower machine the production of the final batch is done by distributive mixing effects. For the three-stage mixing process, no change is made to the recipe, so that the fill factor in the upper machine is kept constant. When designing the tandem mixing process, the process parameters such as rotor speed, mixing time, number of revolutions are adjusted. At the same time, the goal is to keep the mixing quality constant or to improve it.

As already explained, the lower machine usually has a larger mixing chamber than the upper machine (e.g., combination IM320E/IM550ET). This results in a lower fill factor in the lower machine, allowing more changing place processes, i.e., distributive mixing processes. In addition, cold material such as premixed masterbatch or rework material (material with cross-linking chemicals from the extrusion) can be added to the lower machine. This offers the possibility to reduce the batch temperature in the lower machine. It also makes it possible to avoid a critical increase of the batch temperature, allowing cross-linking chemicals to be added earlier. Although the cold masterbatch must be produced on a different mixer, it offers the possibility to increase the fill factor in the lower machine and thus to achieve a higher batch weight of the final batch. To describe the percentage of material added in the lower machine, this is related to the batch weight of the upper machine. The percentage share can then also be used to specify the stage of the mixing process. The compound selected as an example is produced on the tandem mixer in a 1,1-stage process. This means, that 10% of cold and premixed master batch is added in the lower machine to the batch from the upper machine.

Overall, the processes of the upper and lower machine must be synchronised. Only by optimally combining the two machines according to the tasks described above, all the advantages of tandem mixing can be fully utilised.

3.3. Simulation of a tandem mixing process

Simulation trials are carried out to compare the three-stage mixing process with the tandem mixing process. For this purpose, a "stand alone" mixer is used on which both machines are simulated. For the tandem simulation, a master batch is produced in a first step. This is then ejected and returned to the mixer without being processed in the downstream. To simulate the reduced fill factor of the lower machine, the batch weight is reduced according to the previously developed tandem mixing process. Therefore, a part of the batch from the first mixing step is not returned to the mixer. The manually measured temperature deviation between ejection from the upper machine and addition to the lower mixer is less than 10°C. To simulate the addition of cold material to the lower machine during the simulation of the tandem mixing process, cold, pre-mixed master batch is also added to the batch in the lower machine. According to the number of stages for the developed tandem process (1,1 steps), 10% of cold pre-mixed masterbatch is added to the lower machine.

For the tandem simulation, the same mixer is used for the upper and lower machine processes, and thus also the identical PES5 rotor. On an industrial tandem mixer, however, it is possible to achieve additional advantages such as faster intake and improved distribution behaviour by using an optimised rotor geometry for the lower machine.

A comparison between the three-stage mixing process and the tandem mixing process can then be derived from the process data and the batch weights. When calculating the specific energy input of the tandem mixing process, a twin-screw extruder and the batch-off have been considered in the downstream. The comparison of the mixing times and the specific energy input is shown in Figure 4.

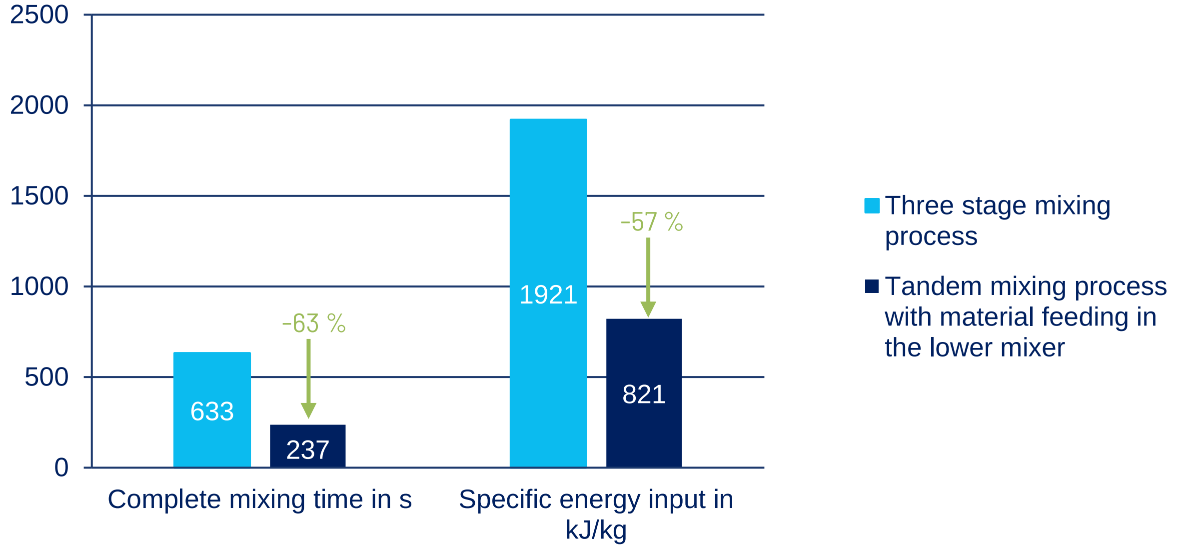

Figure 4: Mixing time and specific energy input for three-stage mixing process and tandem mixing process with consideration of pre-production of masterbatch (average values per batch)

As it is clear from the previous figure, a significant reduction in mixing time can already be achieved with the simulation of the tandem process. Since the upper machine is the clock for the tandem mixing processes, the mixing time of the upper machine is used for calculation. As shown in the figure, the mixing time is reduced by around 63%. Comparing the specific energy consumption, savings of 57% can be achieved for the entire mixing line.

Considering the specific energy of the two mixing processes along the mixing line, the savings can be derived for the Up-Stream, mixer and downstream from Figure 5.

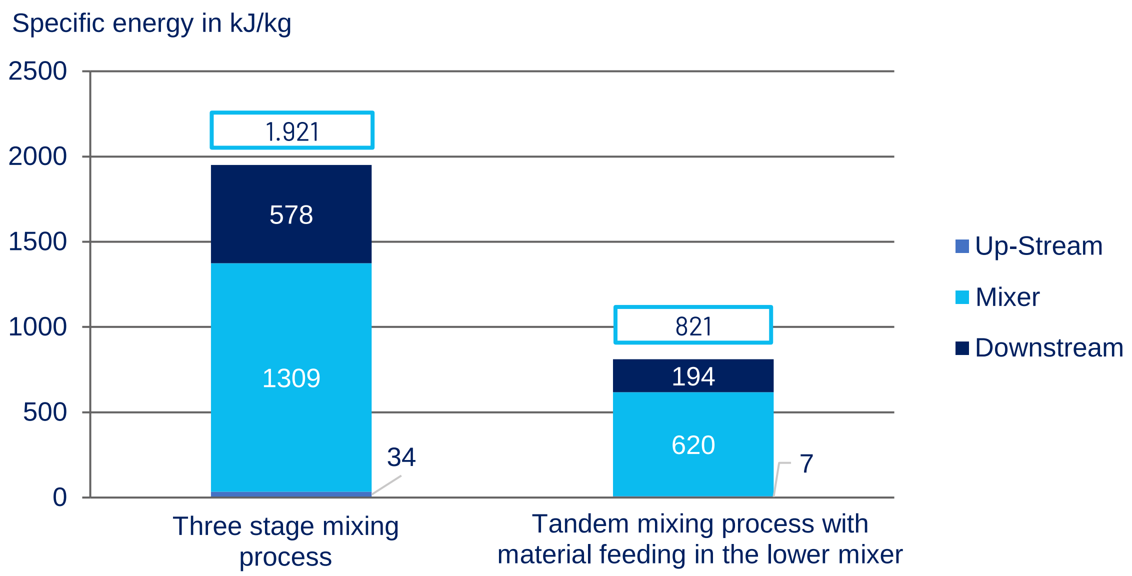

Figure 5: Breakdown of specific energy by mixer, upstream and downstream

The energy savings can be seen for the mixing process and the up- as well as for the downstream processes. Energy savings of up to 57% can be achieved precisely through the optimal division into upper and lower mixing processes and a better and more effective mixing time as a result. In the downstream, further energy savings are possible through the elimination of milling processes and the use of a twin-screw extruder.

3.4. Laboratory analysis of samples from tandem mixing process regarding the specifications

Changes in the process usually lead to changes of the compound properties. These include, for example, changes in viscosity, dispersion, or cross-linking properties. To ensure that the different specifications are met regarding the defined test specifications, extensive sampling and evaluation of samples is carried out during the tandem simulation. For this purpose, the quality test results of the tandem simulation are evaluated and compared with the three-stage initial process. The evaluation shows that eleven out of twelve measured values showed only minor deviations from the initial process values and were clearly within the specifications. Only the Mooney viscosity is a few points above the specification limit, so it must be checked whether the viscosity must be reduced further. In addition, it can be discussed whether the increased Mooney viscosity may even has an advantage regarding the subsequent product properties.

4. Economic advantages of tandem mixing

The reduction of mixing stages, the mixing time, and the specific energy input result in significant economic advantages for tandem mixing. The economic aspects of the comparison between mixing on a "stand-alone" machine and a tandem mixer are therefore explained below.

4.1. Reduction of specific costs

When considering the specific costs, a comparison is also made for the costs of the three-stage mixing process and the 1,1-stage tandem mixing process. In the following considerations, material costs are not considered, as they are the same. The comparison is only made for the current mixing production including the upstream and downstream processes. For the comparison, the three-stage mixing process is used as a reference process. The results are shown in Figure 6 for different parts around the mixing line/compound production.

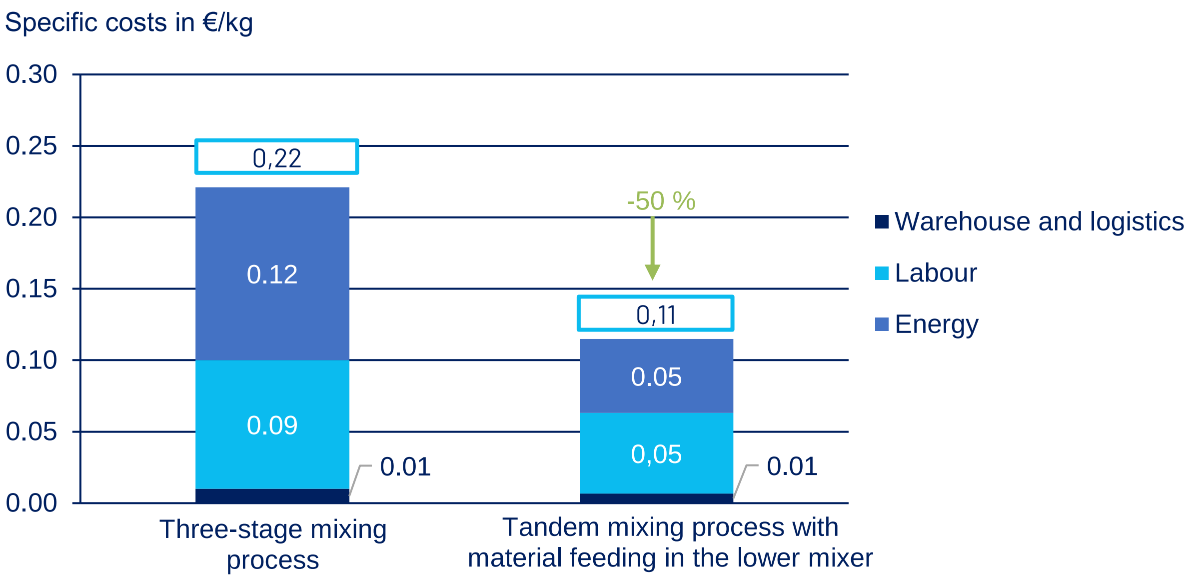

Figure 6: Specific costs for the three-stage mixing process and the tandem mixing process

As it can be seen from the previous figure, a cost reduction of up to 50% can be achieved for the exemplary considered compound. The reason for this is the reduction of stages and the elimination of energy costs and work. For the calculation of the specific costs, the number of staff required for the mixing line has not been varied. However, the shorter mixing time and the associated higher throughput result in lower labour costs per kilogram batch. In addition, in a further step, an additional reduction of costs could be achieved through personnel savings due to the increasing automation possibilities for tandem mixing. The costs shown thus effectively and clearly demonstrate the economic saving potential that can be exploited through tandem mixing and the reduction of stages.

4.2. Use of free capacities

In addition to reduce the specific costs, the creation of additional free capacity can be achieved by reducing the mixing time. This free capacity can then be filled individually. Following an example can be found that illustrate the possibilities of mixing time and mixing stage reduction. The calculations are based on 220 production days per year with a three-shift operation. For the sake of simplicity, the following calculation assumes that only three-stage mixing, or the tandem mixing process is carried out on the mixing line under consideration. If the annual production is calculated for the three-stage mixing process based on the mixing time and a batch weight of 220 kg, the result is shown in Figure 7. Based on the mixing time of the tandem process and a material addition of 10% in the lower machine, the annual production can also be calculated for the 1,1-stage process. The pre-production of the cold material is already considered in the calculation.

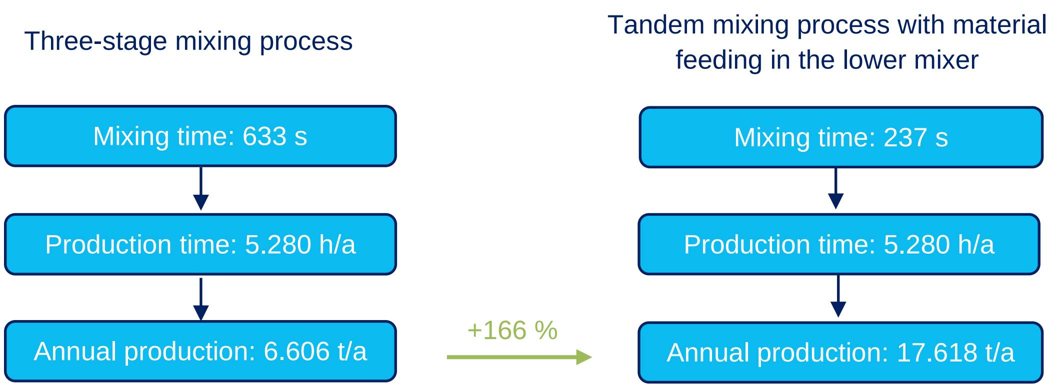

Figure 7: Comparison of the annual production of the three-stage mixing process and the tandem mixing process (including the pre-production of cold masterbatch)

As shown in the previous figure, an increase of the annual production of 166% can be achieved with tandem mixing. In a good approximation, the increase in annual tonnage is inversely proportional to the reduction of mixing time. Based on this, it can be considered individually how the additional capacity is used and filled. If the share of profit in the additional quantity produced does not change, the profit can be increased by using the free capacity analogously to the additional amount of the produced batch.

4.3. Reduction of CO_2- emissions

The reduction of the specific energy input leads to a lower absolute energy input per batch if the batch weight remains the same. Comparing the absolute energy inputs per batch for the three-stage mixing process and for the tandem mixing process, the absolute savings can be calculated. The CO_2 emissions can be derived from this. The basis for this is the electricity power mix in Germany in 2023, which contents an emission of around 434 g of CO_2 per kWh [11]. The comparison is shown in Figure 8.

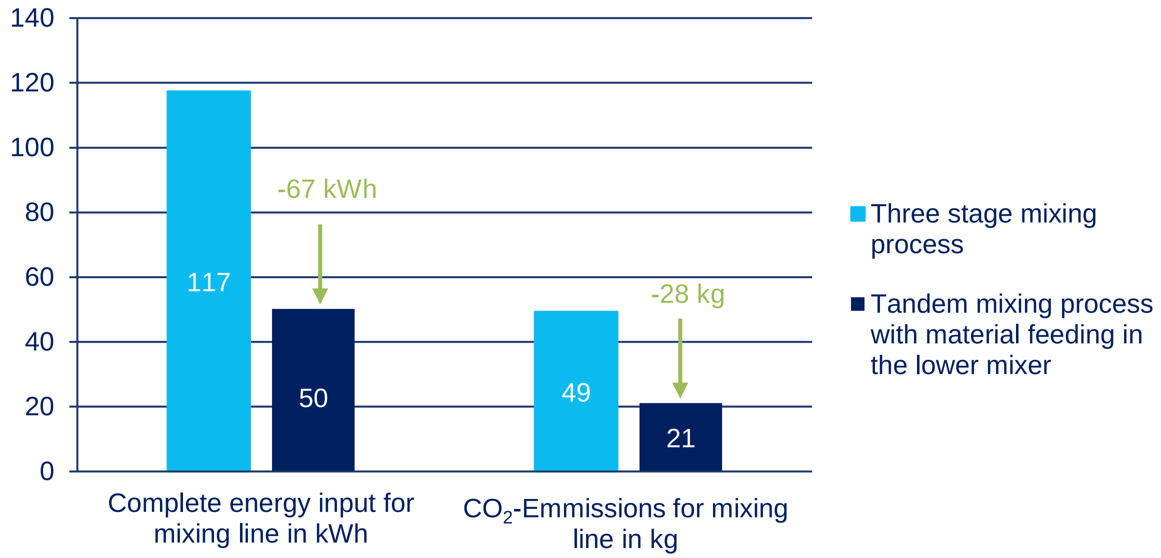

Figure 8: Absolute energy input and CO_2 emissions of the entire mixing line for the three-stage mixing process and the tandem mixing processes

As it can be seen from the previous figure, around 28 kg of CO_2 can be saved per batch. Assuming an annual production of 6.600 t of the three-stage batch, the saving potential corresponds to around 840.000 kg of carbon dioxide per year (based on real production days). For a good approximation, this corresponds to around 280 round trip flights from Frankfurt to Los Angeles.

In addition to the ecological aspect of reducing CO_2 emissions to protect the global climate, the savings also have economic advantages. A regulation of carbon dioxide emissions has been in force in Germany (and at the European level) since 2021. Due to this regulation, CO_2 emissions are priced, so that the CO_2 price has already been decided to increase gradually from the current €30/t to at least €60/t in 2026 [6].

4.4. Return on invest estimation

The previous calculations to reduce specific costs and the use of free capacity offer the opportunity to estimate the return on investment for installing a tandem mixing line. For this purpose, two different scenarios are considered, on the one hand the installation of a tandem mixing line in a brownfield and on the other hand the installation of a tandem mixing line in a greenfield. When considering the brownfield scenario, it is assumed that existing machines can (partially) be taken over. Accordingly, the costs for the actual tandem line are lower. Since the mixing line cannot produce during the conversion, a half-yearly loss of production is assumed for the brownfield scenario. Depending on the local conditions, this time can vary and be reduced through pre-engineering work during ongoing production depending on the respective mixing room. The total estimated return on investment for both scenarios is shown in table 1.

Table 1: Estimation of a return on investment for the installation of a tandem mixing line in a brownfield and a greenfield

Position	Name of position	Installation in brownfield	Installation in greenfield
1	Tandem line costs in €	4.500.000	10.000.000
2	Change building/new building in €	1.500.000	2.000.000
3	Costs for loss of production for ½ year in €	3.000.000	-
4	Complete costs in €	9.000.000	12.000.000
5	Savings of specific costs per year in €	726.000	726.000
6	Additional profit from using free capacity per year in €	5.506.000	5.506.000
7	Sum position 5 & 6	6.232.000	6.232.000
8	Return on investment period in months	17,0	23,1

As it becomes clear from the previous table, for the compound considered in this publication (three-stage to 1,1 stages) a return on investment for the brownfield scenario is calculated with 17,0 months. For an installation in a greenfield, the return on investment period is calculated with 23,1 months.

5. Summary

Using the tandem mixing technology, significant advantages can be achieved in terms of specific (and therefore also the absolute) energy input. Significant energy savings can be achieved precisely by reducing the number of mixing stages and shortening the mixing time by separating the mixing process into the upper and lower mixer. For the example considered in this publication, reducing the stages from three to 1,1 leads to energy savings of up to 57%. Tandem technology thus helps to reduce CO_2 emissions in the tire and rubber industry and thus makes a significant contribution to a more climate-friendly industry. Especially due to the constantly rising energy prices and the additional CO_2 pricing introduced in Europe, an increase in profitability and a reduction in production costs can be achieved.

Tandem technology can also be used to derive further, particularly economic, advantages. In addition to the elimination of storage and logistics costs due to fewer transport routes, the reduction of stages is also accompanied by a reduction of mixing time. The mixing time reduced by up to 63% when considering the three-stage mixing process makes it possible to generate additional free production capacity. This capacity can then be used to increase own annual production, produce additional compounds and, if possible, sell free capacity to external parties. The associated advantages/benefits make it possible to increase the economic production and generate additional profits for the production site.

As demonstrated in this publication and the industrial example, significant advantages can be achieved using the tandem mixing technology. Due to the pressure of competition and innovation as well as further increases in energy prices, these are likely to become more and more interesting for the rubber industry and especially for tire producers in the future.

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