The factory of the future: two case studies to illustrate the role of energy in two industrial sectors

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Abstract:

The “factory of the future” is a widely discussed concept which promises to underpin the next wave of productivity in industry by integrating new technologies – especially information and communication technologies - into industrial production. Based on a comprehensive bibliography analysis, this article refines the concept of the factory of the future as a factory combining smart, green and human dimensions to achieve a higher level of productivity.The concept of the factory of the future stresses the central role of information networks for optimising and flexibilising production processes. In addition, energy supply and energy usage are decisive levers in enhancing the global productivity by using energy in the optimal way. The smart, green and human dimensions of the factory of the future are involved in each industry sector. However, each sector faces specific challenges. This is illustrated by two case studies on the role of energy in two different industry sectors. A sugar factory is analysed as an illustration of the energy intensive process industry, where gains are achieved by mastering local energy production and thermodynamic processes. Combined heat and power generation allows quasi-energy-autonomous factories and energy is reused several times in cascades in the production process. A production machine factory is analysed as an illustration of the downstream industry in which the smart use of energy increases productivity. This innovative factory uses the best available technologies, on site energy production with renewable energies, heat recovery and storage, the use of natural lighting and cooling for factory buildings and energy management systems. These two examples underline that the factory of the future will take multiple forms. These examples also show that the factory of the future is already built today. For energy companies, issues related to the factory of the future are the decentralised production of energy mainly based on renewable energies, the monitoring and management of energy consumption using information and communication technologies, flexible and adaptive energy networks to allow flexible and modular production and energy analysis methods for the improvement of energy-intensive production processes. The concept of the factory of the future remains a challenge for the energy companies. Many aspects of the factory of the future can be built through continuous improvement which can be integrated in daily operations. However, new business models and technological disruptions can bring unforeseen changes to industry.

Keywords:
factory of the future, smart production, energy, energy efficiency in industry, sectoral approach

1. Introduction

In a context of renewed focus on the importance of industry in developed countries, productivity is a major issue. New technologies, especially information and communication technologies (ICTs) will be decisive for industry to increase productivity. The concept of “factory of the future” brings together many different approaches. We present a holistic view of the elements which make up the factory of the future with a special interest in innovations that are already in development. Furthermore we analyse two exemplary factories from two different industry sectors with a special focus on the role of energy in the factory of the future.

2. General description of the “factory of the future”

Several different names describe the concept of the “factory of the future” or elements of it: smart factory, advanced manufacturing and industry 4.0. One study [1] gives a possible scientific definition of the “smart factory”:“A Smart Factory is a manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could on the one hand be related to automation, understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in reduction of unnecessary labour and waste of resource. “

The scope of the factory of the future includes the concept of a smart factory, as defined above, and in addition the concept of a green and human factory. A green factory aims at producing the maximum output value using a minimum of resources and emitting a minimum of waste. Green factories also come with new modes of designing products, such as eco-conception, and produce for new modes of consuming, such as the economy of functionality, in which not the ownership of a product (e.g. a copy machine) but its functionality (e.g. a certain number of photocopies) is sold. Human factories aim at creating employment for people and providing workers with good working conditions, i.e. via the reintegration of the factory in the city. It is important to stress that smart, green and human factories are all used to achieve the overall goal in industrial production, which is an increase in productivity.

One lever for achieving higher productivity in the factory of the future is the integration of new technologies. Innovations from the physical world like advanced robotisation and automation, additive manufacturing, new materials and ubiquitous sensors and tags will play an important role. In the virtual sphere, information and communication technologies, big data analytics and cloud computing as well as increasingly powerful simulation tools can change manufacturing. The big potential however lies in integrating the innovations from the physical and the virtual world: by creating cyber-physical system in which a network of computational elements controls machines, stocks and resources, factories can have a real-time and global view of their production processes. Machines can communicate directly and organise themselves via Internet of Things technology without needing a central computer. Production lines can assemble automatically to produce according to the current demand.

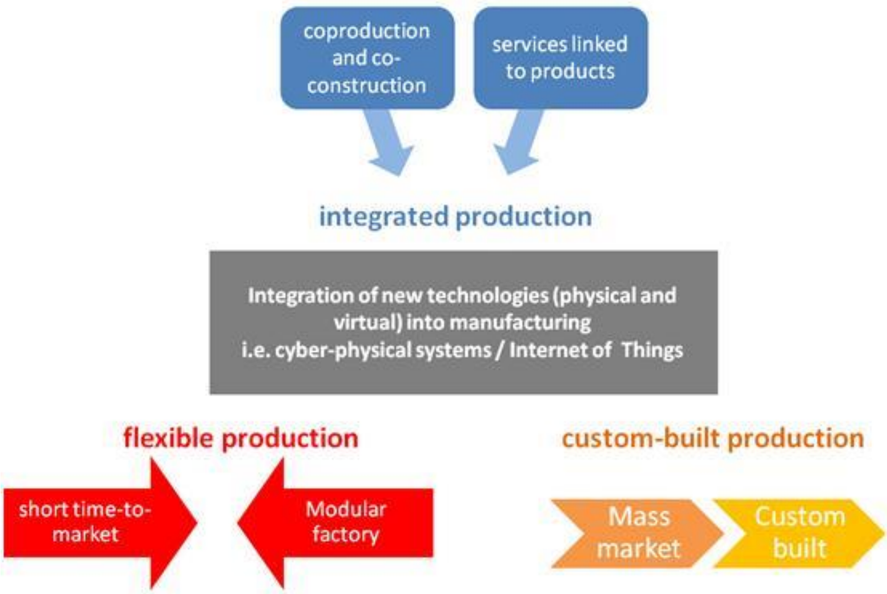


Fig. 1 The factory of the future is centred on the combination of physical and virtual innovation

The integration of those new technologies can help to realize new ways of producing, notably:

Integrated production will for example let the customer propose his wishes and integrate them already in the design and construction process (coconstruction). Suppliers and subcontractors will also be more involved in production (coproduction) and a higher level of information and control over the supply chain will be possible by real-time monitoring using sensors, tags and information networks. Integrated production also means that a factory will not only produce and sell products but increasingly link services to those products.

Flexible production will be rapidly adaptable to new external conditions. In today's rigid factories adaptations to new products or technologies – whose life time is generally shorter than the life time of a factory – are linked to important costs due to necessary investments and production downtime. Modular production lines can allow quick adaptation by exchanging single machines instead of whole production lines and by lining up additional modules instead of enlarging the entire production chain if larger quantities are needed.

Modular production facilitates the production of smaller batches with more rapid product cycles and shorter times-to-market.

Custom-made production will produce according to customer's individual and rapidly changing needs and wishes. The final goal would be a production of lot size 1 at cost and speed comparable to today's rigid mass production.

In summary, the concept of the future holds significant promises to increase productivity and to prepare factories for a future in which flexibility and speed will be required to respond to quickly changing external conditions. A study [2] states that the productivity increases by using internet-of-things and other new technologies might reach 30 %, and promises high annual growth rates in the related technological fields of sensors, internet-of-things technologies and software.

However, the concept of the factory of the future also generates concerns, i.e. on how SMEs can realize and benefit from those advanced manufacturing solutions. The protection of intellectual property will have to be adapted to integrated production processes in which a product is developed, designed and produced by many partners and in which additive manufacturing methods significantly reduce the threshold to copy products.

Different time horizons: Some elements of the factory of the future are already implemented today, while others will require significant additional time until they are operational. Other elements may be limited to special applications. We say that an investment into efficient technologies which reduce costs and increase a factory's competitiveness today is also an element of the factory of the future concept as it then allows investments into new technologies for manufacturing in the future.

3. Sector-specific approach

Some elements of the concept of the factory of the future concept (green production, flexible production and the integration of new technologies) will be important in any type of factory, but other elements will differ widely in their importance and applicability depending on the sector of production. We stress the importance of a sector-specific approach which takes into account each sector's challenges and specificities like the high capital and energy intensity in the process industry, or the labour- and trade-intensity of the electronic equipment industry. Several research projects already developed a sector-specific vision of e.g. the food factory of the future (EU project PickNPack) or the chemical factory of the future (EU project F^3 factory). In labour-intensive industries, advanced robotization and automation can allow the relocalization of manufacturing as the advantage of being closer to the end customer outbalances lower labour costs in other countries.

4. Focus on energy

4.1. Global changes concerning energy

The way energy is produced, distributed and consumed undergoes fundamental changes under the pressure from resource scarcity, growing energy prices and climate change but also from political conditions and consumers' increased attention to environmental aspects. Industrial production consumes large amounts of energy (27.8% of the total energy consumption in Germany [3], 21% in France [4]) and will therefore be affected by those changes.

In this article, we analyse the role of energy in the future factory. We assess the influence of the changing energy landscape on the factory. We also analyse how energy will be used inside the factory and state an evolution of energy from a simple utility towards a key performance indicator, information carrier and important factor for competitiveness.

Figure 2 shows the global changes we expect to occur related to energy in the factory of the future. Energy savings will be possible due to a smarter use of energy, for example by the reduction of used material in additive manufacturing processes or the continuous improvement of energy efficiency based on the availability of real-time consumption data. Generally, energy efficiency has become a key factor for a company's competitiveness and is therefore an important issue for industry, especially in the energy-intensive sectors. However, the increased use of robots, automatisation and the acquisition and analysis of large amounts of data will consume additional energy which may compensate parts of the possible savings. Today, the energy consumption in most factories is relatively stable. It will become more flexible as the production will be adapted to changing demands. Within the factory, a flexible energy supply network have to be developed to bring electricity, compressed air and other utilities but also materials to the points of the modular production line where they are needed. The factory of the future will be able to level out part of the consumption fluctuations by acting not only as a consumer but also as storage of energy. In addition, factories will auto-produce a larger part of their energy and improve the reuse of excess energy.

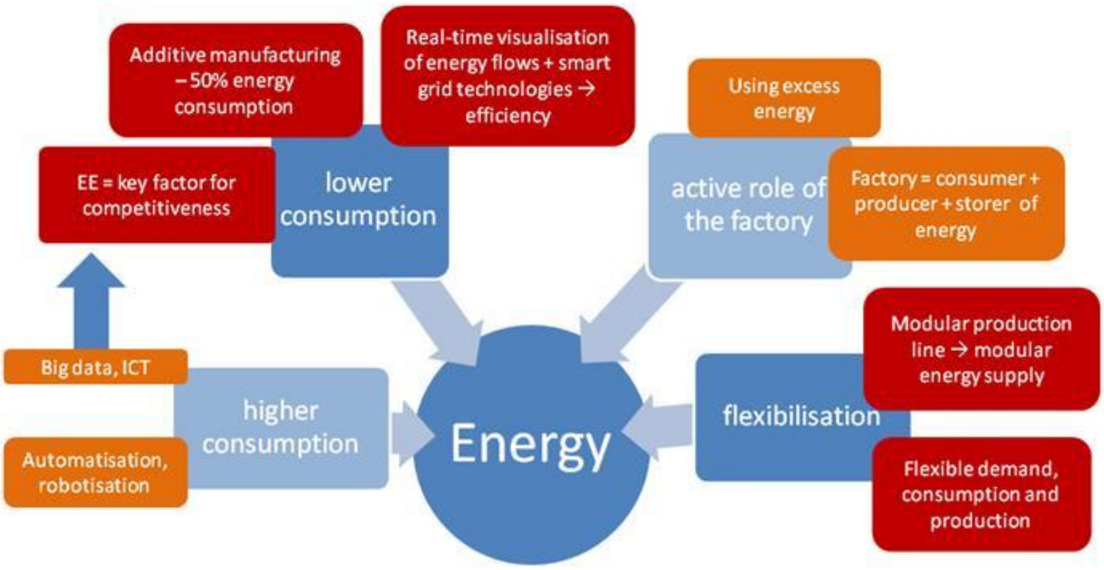


Fig. 2. The global changes concerning energy

The place of the factory of the future in the energy landscape of the future

New energy reglementation offers subsidies for energy efficiency, renewable energies and peak load reduction or imposes measures such as energy audits for large companies in France. The aim of carbon emission reduction will increase the use of electricity, which is easier to decarbonise than gas or fuel. Decarbonisation can also rely on technologies like carbon capture and storage [5]. Energy for future factories will be increasingly produced in a decentralised way with renewable energies or combined heat and power (CHP) units. Already today in Germany 20% of the energy consumption in industry is produced locally by CHP units [6]), which have become profitable because of low gas prices and existing subsidies. CHP is considered as a transition technology as it uses fossil fuels in most cases. CHP units allow decoupling the factory from problems in the grid caused by the intermittent character of most renewable energy sources. The increase of renewably-sourced electricity in the electricity mix reduces the reliability of the electricity supply. Therefore smart grids are necessary to ensure the reliability and quality of electricity supply which is vital for many industrial processes.

Globally, the energy consumption in industry is expected to grow due to higher output [7], but the efficiency could also be increased significantly: the EM² factory project aims at an energy and resource consumption reduction by more than 30% per unit produced by 2030, compared to the level of 1990 [8].

Energy inside the factory of the future

Studies [9-10] have shown that even with today’s available technology, the energy and resource efficiency in manufacturing companies can be reduced by more than 10%. A higher part of auto-produced energy and the use of factory buildings for peak load reduction and energy storage can help to reduce the energy cost. Examples of the implementation of those concepts are explained in section 4.2 and 4.3.

Our focus lies on the smart management of energy consumption inside the factory. The general idea is to implement a systematic way in which the energy consumption can be measured, analysed and continuously improved. For this sensors which measure the individual consumptions at different points in the factory are installed and IT systems are used to analyse this data. Excess consumption can indicate technical problems in machines or energy networks and allow targeted preventive maintenance. If energy efficiency measures are performed, their gain can be validated based on a comparison of data. If the data is acquired in real-time throughout the factory, the specific energy consumption for the production of a single product can be calculated [12] and communicated to consumers. If a monetary value is attributed to the consumption data, this corresponds to a real-time energy bill of the factory. An energy management system therefore gives a holistic and data-based view of the energy efficiency, security, use and consumption within the factory. Several energy management system solutions exist which make the link between the energy consumption inside the factory, including previsions on future consumption, and the real-time energy availability and price which is influenced by the availability of electricity from renewable sources. This link between offer and demand can help to optimise the energy costs of production.

A further step is an integration of the energy and resource consumption as a key performance indicator in the production management loop beside the conventional time, cost and quality oriented indicators [13]. One integrated approach is the Mitsubishi “e&eco-F@ctory” [14], which has resulted in significant energy savings in two model factories in Japan. This holistic factory automation system is now brought to the next level by integrating end-to-end Internet of Things connectivity and big data analytics in a collaboration with Intel [15].

Energy networks within the factory need to be planned differently if production lines are flexible and modular: as electricity, compressed air and other utilities as well as material flows must be quickly brought to different points in the factory. We stress the importance of considering the energy supply networks at the earliest stages of planning a new factory building or production line. A decentralised intelligence in the energy networks inside the factory – micro smart grids - can manage the evolution of consumption points and quantities and distribute peak loads. However, complex energy systems should always have an intuitively understandable and easily manageable interface.

Again, a sector-specific analysis is required as industries differ significantly in their use of energy. We differentiate between energy-intensive industries and non-energy-intensive industries. For each case, we analyse an example of a factory in which elements of the factory of the future are already implemented or developed today.

4.2. Sugar as an example of an energy intensive factory

Key numbers of the sugar industry

France is the first producer of beet-based sugar in the world, using 33 million tons of sugar beet per year. Alternative products which can be produced in a sugar factory are ethanol and beet molasses as well as products like sugar beet pulps and sugar factory lime which are returned to agriculture for soil pH enhancement. Sugar is the only processed food product traded world-wide and is therefore subject to international competition. The sugar industry being seasonal, beetroot processing plants are fully active only during the sugar beet campaign (about four months per year).

Energy costs are the second highest post in the budget of a sugar factory, after material costs for sugar beet and in front of workforce costs. The sugar industry in France has the third-highest percentage of energy costs relative to total costs (excluding investments) among all industrial sectors [16]. The overall share of energy costs in production costs is about 12%. The primary fuels consumed are: natural gas (69%), coal (18%) and heavy fuel (13%). The mean annual energy consumption of all sugar factories in France during sugar beet campaigns is about 180 kWh per ton of sugar beet. The sector has 25 combined heat and power (CHP) units for the 25 sugar factories in France, allowing quasi-autonomy in the electricity supply. However, no electricity is fed into the grid, contrarily to the sugar industry in Germany, where higher-pressure boilers are in place and a surplus of electricity is produced.

Since it has been followed by SNFS (French Sugar Manufacturers Association), the specific energy consumption per ton of sugar beet has decreased continuously until today as shown in Fig. 3. Sugar production has been object to extensive study and optimization concerning energy efficiency.

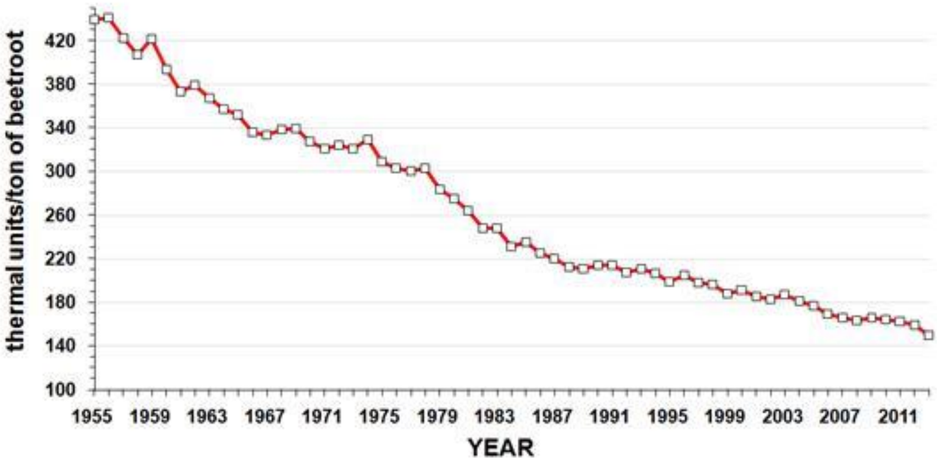


Fig. 3. Energy consumption in thermal units per ton of beetroot in sugar processing, SNFS

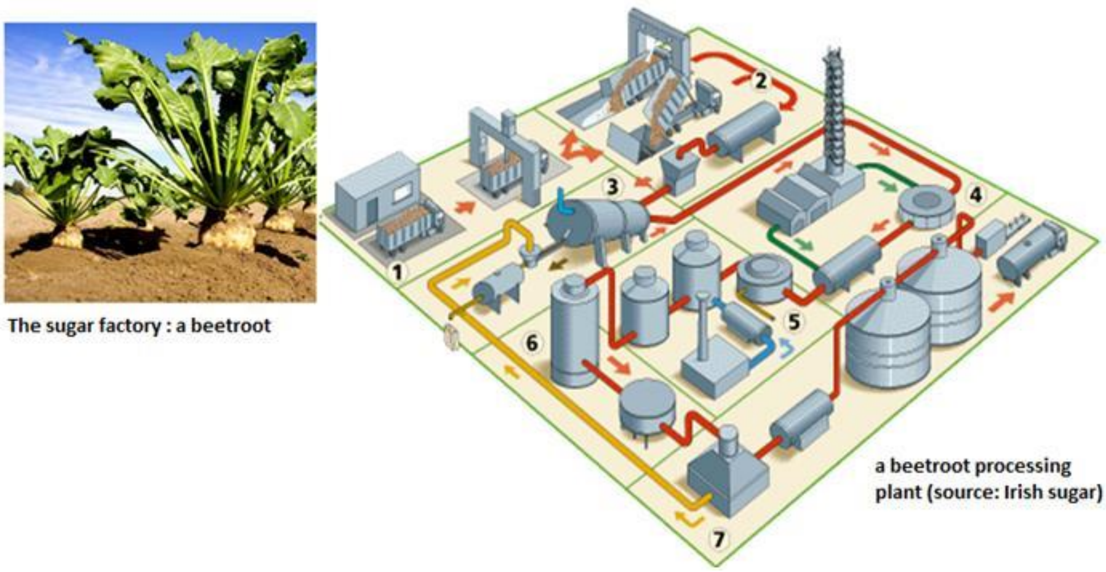


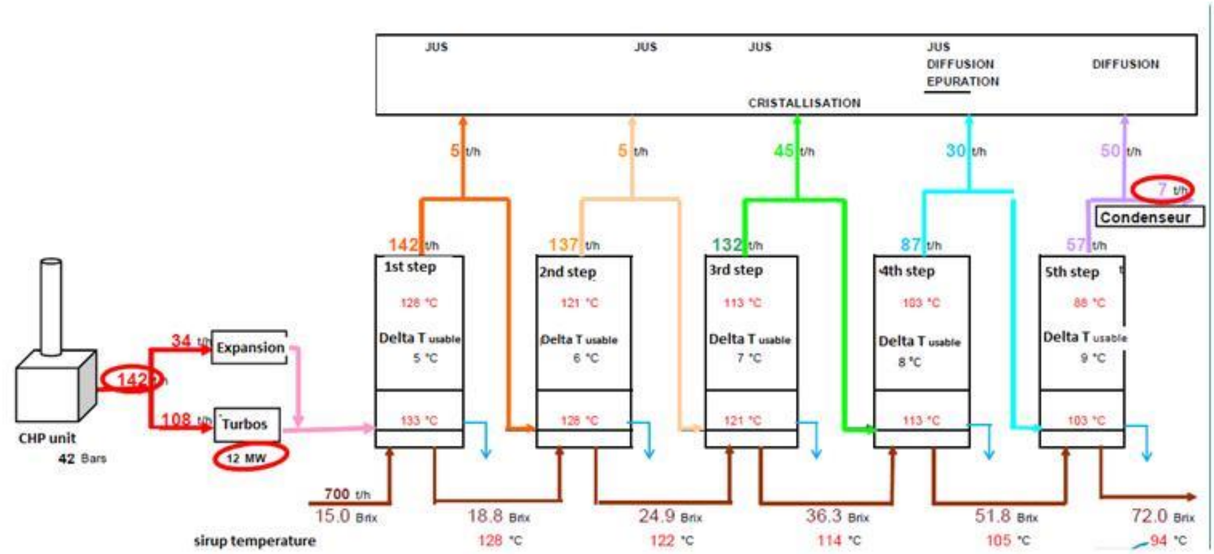
Fig.4. The stages of refined sugar production: inside a beetroot and inside a beetroot processing plant

An overview over the production process from sugar beets to crystallized sugar is given below (the numbers reference to parts of Fig. 4 in which the production takes place):

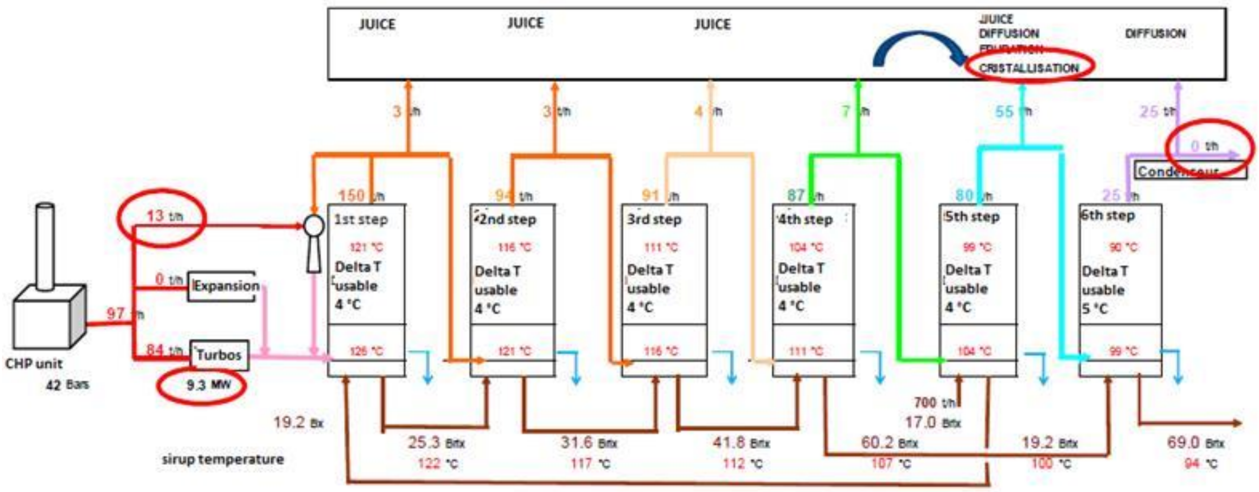
1. Reception
2. Beets unloading and washing
3. Diffusion: the sugar content of the chopped sugar beets is extracted into a hot water solution.
4. Purification: impurities are removed from the raw beet juice using lime and carbonation.
5. Evaporation: 5-fold concentration of the raw beet juice in a series of 4 to 6 evaporators.
6. Crystallisation: the concentrated raw beet juice is further concentrated by boiling under vacuum. Fine sugar crystals are seeded in, around which larger crystals form, which are then separated in a centrifuge, cleaned and dried.
7. Drying, storage and packaging

The energy flow through the sugar production process

Figure 5 schematically shows the energy flows through the sugar production process. This factory has a throughput of 16 000 t beet/day. The figure shows an oversimplified process[1] in order to give an idea about the multi stage evaporators.



(a)



(b)

Fig.5. Energy flows through sugar production process: a) standard, b) optimized as described in 4).

[1] This balance did not take into account recovered at each evaporation stages flash coming from condensates and juice which pass through lower and lower pressure conditions. It is not possible to show a typical flow diagram due to the large types of evaporation schemes (linked to various activities linked to the sugar production like ethanol production and thick juice storing).

The fuel (gas, coal or petrol) is transformed into overheated steam and electricity in a CHP unit (pressure 42 b, temperature 400 °C). After expansion in a turbo alternator for electricity production, the low pressure steam is then used to concentrate the raw beet juice by boiling in four to six consecutive evaporators. In an exemplary case, the steam cools down from 133°C to 88°C under vacuum during this process. The vacuum is produced by barometric condenser followed by vacuum pumps. The steam is used to heat the different stages of the sugar production process, depending on the temperature needed. Around one third of the steam is taken at 113°C from the third concentration step to provide energy for the crystallizer, while the rest of the steam is used for further concentration of the beet juice. Then another third of the steam, which is now at 103°C, is taken away to be used in the diffusion and purification unit. The remaining steam concentrates the beet juice in the fifth and final evaporator. In a last step, steam is taken to the diffusion unit. If the system is not balanced for the maximal reuse of energy, a surplus of steam is left after the production process. In the exemplary case shown in figure 5, 7 tons per hour of steam with a final temperature of 88°C are discharged to the environment, therefore wasted.

This described energy cascade in the production process allows using the input energy several times. The sugar production process has already been driven towards a high-performance system, in which the constraints are given by the rules of thermodynamic balance between the consecutive and interlinked production steps.

The sugar industry continuously further improves the production process an energy usage

1. The system is generally optimised by thermodynamic balancing: 128°C steam from the first effect may be reheated to 133°C by a compressor (steam injector). This increases the concentration level which can be attained in the first concentration step. In the example case, the total quantity of steam which is produced in the cogeneration unit can be reduced by 6 t/h and the loss of steam at the end of the process is only 1 t/h.
2. More steam produced in the cogeneration unit could be used for compression. This allows increasing the concentration level achievable in the first concentration step. In comparison to the example given in a), the achievable concentration is increased by 50%. In the example case, the total quantity of steam which is produced in the cogeneration unit can be reduced to 97.5 t/h and the loss of steam is cancelled, but the amount of electricity produced in the cogeneration process is no longer sufficient for the sugar plant. 6.2 MW of electricity must be bought from the grid at a higher cost.
3. The thermodynamic balance must be modified to avoid buying electricity and to reduce steam consumption. The number of effects in the evaporation station can be increased from 5 to 6. As crystallisation and diffusion units are heated by lower temperature steam, new heat exchangers are needed in these parts of the plant. In the example case, a small deficit in the produced amount of electricity remains.
4. The required amount of steam for the production process can be further reduced by shifting the crystallisation unit such that the steam which is fed in is taken from the fifth evaporator. This requires an increase in the crystallisation exchanger surface because the crystallisation is done at a lower temperature. In the example case, as depicted in Fig. 5b, all the required electricity can then be produced by the cogeneration unit, whose fuel consumption can be reduced by 31% compared the initial situation shown in Fig. 5a.

Potential of improving the energy-efficiency

Several energy efficiency actions – technological solutions or improvements in sub-processes - can save energy in the production process. If all possible actions were applied in today’s sugar factories, the energy consumption could be reduced from 180 kWh/ton of beet to 136 kWh/ton of beet. The possible energy efficiency gain is more than 20% and amounts to a total saving potential of all sugar factories in France of 1.15 TWh of combustible per year.

Below a threshold of 157 kWh/ton of beet, the cogeneration unit in the sugar factory cannot produce enough electricity to be autonomous and external electricity must be bought. From the industry's perspective, the energy efficiency gain economically profitable is evaluated at 10-15% of the total possible gain. The associated average investment payback periods lie between 6 and 7 years. With incremental process improvement strongly linked with the investment capabilities, the specific energy will continue to decrease.

4.3. Injection moulding machine factory as an example of a non energy-intensive factory

Arburg is an industrial company with a consolidated turnover of 480 Mio. € (2013) and around 2 350 employees worldwide, which produces injection moulding machines in a single production site located in Lossburg, Germany. The factory of Arburg is an illustrative example as their production processes, factory buildings and products already use elements of the factory of the future.

The main objective – both strategically and in daily operations - of the company is to increase the production productivity. Energy-efficiency is an essential lever to achieve this goal. Their products and their production are driven by the concept of a smart, green, human and efficient production. The participative management and regular internal meetings on energy savings allow integrating all the employees' ideas to improve the energy efficiency of the factory. Collaboration with the Institute for Resource Efficiency and Energy Strategies IREES gives the company outside ideas and expertise.

The management board has a long-term view and a continuous need to increase the production capacity. Therefore continuous investments are made to modernize the factory. The optimization of the interrelated topics quality, productivity, energy and environment is a continuous goal.

The factory was among the first companies in Germany to hold the triple certification ISO 9001 for quality management, ISO 14001 for environmental management and ISO 50001 for energy management in 2012. This shows that this example is indeed a pioneer in implementing the energy-efficient factory of the future already today.

Energy is a central item in the factory development, so energy is already taken into account during the planning stage for new production systems, buildings and extensions. This helps to maintain high energy performance at reduced cost throughout the evolution of the company.

A classical reference factory which produces injection moulding machines would use energy in the following way: electricity and gas are bought and used in the production. Gas is used in boilers to produce hot water and steam, which are mainly used for heating the building and processes in the production line. Electricity is used for lighting, ventilation, production of compressed air, running electric motors and other uses.

Arburg's actions to increase the energy efficiency and therefore the productivity of their factory can be grouped into 5 categories: auto production of energy, use of natural resources for energy-efficient low-consumption buildings, waste heat recovery for building and process heating, some of the best available technology for energy-efficient processes and central energy management system.

In 2013, **32% of the electricity consumption of the factory was auto-produced**, with 24% from combined heat-power units (total installed power of the CHP units: 1100kW), 5% from wind power and 3% from solar energy (total installed power photovoltaic panels: 1135 kWp, yielding an annual production of 1000 MWh, equivalent of the annual consumption of 100 households).

The energy-efficiency of the factory buildings is increased by favoring natural lighting and adapting the artificial light to the available natural light. The intelligent switching off of lights in parts of the factory buildings resulted in annual electricity savings of 4500 kWh. The buildings are naturally cooled by free cooling with external air, automatic window opening, cooling at night and movable shades.

A global water network inside the factory recovers waste heat from machine testing, compressed air systems and from waste heat in the evacuated air. This hot water at a temperature of 35°C is used inside a heat pump to produce hot water of 45°C. This hot water is used to heat the building via underfloor or façade heating. The hot water is also used for preheating and drying in production systems such as powder coating. The geothermal storage system (24 holes bore heels of 199m depth) represents a heating capacity of 600000kWh, respectively a 400000 kWh cooling capacity. By using this geothermic storage, the gas consumption for heating the newest factory building can be reduced to zero.

The energy efficiency in production processes is improved by several energy efficiency actions: classical actions include motors with electronic speed variation and replacement of motors at their end-of-life with highest-efficiency class motors IE2. Specific energy efficiency actions implemented in the factory are the decentralized compressed air production to avoid leaks, plasma nitriding as an eco-friendly and energy efficient hardening process, friction welding to reduce energy-intensive machine work and sheet metal construction instead of solid blanks, which substitutes and reduces materials use to reduce energy consumption. Suppliers are also consulted on energy-efficiency measures, e.g. on efficient furnaces for thermal treatment. Those energy efficiency actions are specific to the production chain in this factory.

A central technical facility management uses data acquired from the factory for control, regulation and optimization of the buildings (e.g. automatic adjustment of shades and artificial lighting according to measured weather conditions, natural ventilation via regulated drives in addition to mechanical ventilation and the use of the geothermal storage for either heating or cooling of the buildings). The central building services management is also used to distribute energy loads in such a way as to avoid energy peaks (e.g. slowing down regulated motors or switching off ventilation when energy peaks appear).

It would be interesting to compare in a quantitative way a fictive classical reference factory with this innovative factory. However, as the energy efficiency activities are ongoing processes in the innovative factory, no complete and precise comparative values are available.

4.4. Conclusion and comparisons between these two factories

Conclusion

The sugar industry has its own vision of the factory of the future: a process of continuous improvement in particular for the reduction of energy consumption. By this, the energy consumption per ton of beet has been halved in the past 40 years. The sugar industry has an expertise in mastering complex thermodynamic processes which is valuable in other energy-intensive production processes.

Arburg's 5 key points which make their factory an example for a factory of the future are:

- The overall goal is to improve the global production efficiency.
- Energy efficiency is one of the levers to achieve this goal
- The energy aspect is taken into account at the earliest stages of any project to develop the products, production processes or factory buildings. This allows to realize more energy solutions and notably at a lower cost.
- Long-term vision: The decision to realize projects on energy efficiency is not purely based on today's profitability calculations and short payback times but takes into account possible future economic and environmental conditions like rising energy prices or shortages in energy availability.
- Participative management: The organizational structure encourages employees all over the company to contribute with their ideas.

Today Arburg has implemented efficient and holistic ways to use and manage energy. In the future, for example due to rising energy prices or stricter regulation on energy, this might become the economically reasonable solution for all industrial companies. Up to now the strategy was to build the factory of the future by many small evolutive steps. Looking back, those steps correspond to a big innovative change. From Arburg's experience, the concept of the factory of the future must be translated into steps which can be implemented in daily operations.

Comparisons between these two, intensive energy and non intensive, factories

The two sectors have different energy issues. For the sugar industry, the cost of energy on the total cost is significant (12%) compared to injection molding machines factory where it amounts to less than 1% [16].

Energy is a key parameter in the productivity of sugar beet and the factories are investing in the continuous improvement of the energy performance of the process through the implementation of complex thermodynamic analysis results. The ratio of production of the co-generation unit, corresponds to the heat generated to the electricity produced (electricity represents 10 % of the total energy need). It is perfectly adapted as needed for all requirement of the process.

For the manufacturer of injection molding machines, energy is one of the levers to improve the productivity. The factory looks for reliability of power supply and anticipates the investments following scenarios of increasing cost of energy and electricity availability. The ratio of the co-generation unit isn't always adapted to the factory needs. The heat produced by the co-generation unit requirements depends on the space heating demand of the buildings. Outside the heating periods, the heat in excess must be stored

Besides the process aspect, there are however similarities between these two examples. They have both a long term vision and aim for continuous improvement of their processes. Energy is a competitive lever and its inclusion is integrated upstream of all investment projects be it on products, processes or on the extension of buildings. Both factories have co-generation facilities which bring them a certain degree of autonomy from the power grid.

The comparison of the energy-intensive sugar industry and the injection moulding production factory shows that energy plays a central role in both factories, but that the challenges and solutions differ significantly between the two sectors of industry. From those two examples we deduce that the main subjects linked to the factory of the future for which solutions need to be developed are:

- the decentralised production of energy mainly based on renewable energies,
- the monitoring and management of energy consumption using information and communication technologies,
- flexible and adaptive energy networks to allow flexible and modular production ,
- energy analysis methods for the improvement of energy-intensive production processes.

5. Conclusion

The global study of the concept "factory of the future" shows that it is mainly based on the integration of new technologies into industrial production which will allow productivity increases and the adaptation of industrial production to rapidly changing boundary conditions. The factory of the future will be smart, green and human and production will be integrated, flexible and custom-made.

We underlined the importance of differentiating the various sectors of industrial activity. This article stresses the central role of energy in the factory of the future. Two factories are analysed regarding innovative solutions concerning energy which they implement today in their development towards the factory of the future.

A sugar factory illustrates solutions for the energy intensive process industry, where gains are achieved by managing local energy production and thermodynamic processes. Combined heat and power generation allows quasi-energy-autonomous factories and energy is reused several times in cascades in the production process.

A production machine factory illustrates possible solutions for the discrete industry in which the intelligent use of energy holds the potential to increase productivity. This innovative factory uses the best available technologies, auto production with renewable energies, heat recovery and storage, the use of natural lighting and cooling for factory buildings and energy management systems.

The conclusion of those analyses is that with respect to energy, the factory of the future needs solutions for the decentralised production of energy mainly based on renewable energies, the monitoring and management of energy consumption using information and communication technologies, flexible and adaptive energy networks to allow flexible and modular production and energy analysis methods for the improvement of energy-intensive production processes. Energy plays a key role in the building the factory of the future. Our article underlines that some elements of the factory of the future are already developed and used today. Other elements of the factory of the future will require more time to be implemented. It is important that the concept of the factory of the future can be translated into small operational steps which factories can implement in an evolutionary manner in their daily operations. However, future technological and economic disruptions will surely change the vision we hold today of the factory of the future.

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