Energy efficiency in industry: from existing technologies to innovative solutions

Laurent Levacher
EDF-R&D-ECLEER (European Center and Laboratories for Energy Efficiency Research)
France
laurent.levacher@edf.fr

Isabelle Hita
EDF-R&D-EPI-Utilities group
France
isabelle.hita@edf.fr

Cyril Bethenod
EDF-R&D-EPI-Energy optimisation of Industrial process group
France
cyril.bethenod@edf.fr

Sandrine Hartmann
EDF-R&D-EPI-Industrial sectors survey and assessment group
France
sandrine.hartmann@edf.fr

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Abstract

The European "20-20-20" climate change package requires strong changes in energy efficiency and CO_2 emissions.

In Europe, the energy savings potential in industry by using Best Available Technologies (BATs) are estimated at 20% (savings: 31% furnaces and dryers, 26% heat recovery, 14% boilers, 13% industrial buildings) of the baseline energy consumption.

During the last years, only short term solutions have been implemented, furthermore they still have to be applied quicker and stronger:

- EDF has installed an Energy Management System in a plant (11 GWh electricity, 7 GWh gas) which allows to follow fluids: electricity, gas, water, steam and compressed air. The annual savings represent 48 K€
- Up to 50% of the energy can be saved in clean rooms by combining, when the room is in activity, extraction of calories from exhaust air and free cooling, and when unoccupied, reduction of fresh air inlet and enlarging the temperature and humidity setpoint ranges.

Now new breakthrough solutions are required on industrial processes:

- A new Process Energy and Exergy Analysis method permits to identify incremental and radical energy efficiency improvements for SMEs.
- Electrical BATs become more and more relevant (especially in case of a low CO_2 electricity). In France, the size of energy saving potential based on induction is around 3 TWh/year. The new concept of "flexible heat induction" will increase significantly the induction market penetration.
- In the food industry and parachemistry, the energy saving potential with MVR and heat pumps amounts to several TWh. New researches in order to the condensation temperature of the heat pump by using a new refrigerant adapted to the compressors will increase the quantity of heat recovered.

Introduction

The European "20-20-20" climate change package requires strong changes in energy efficiency and CO_2 emissions. Even if the energy efficiency of the industrial sector has improved for the past years, it still remains energy savings potentials.

In Europe, the energy savings potential in industry by using Best Available Technologies (BATs) are estimated at 20% (savings: 31% furnaces and dryers, 26% heat recovery, 14% boilers, 13% industrial buildings) of the baseline energy consumption.

After presenting global figures regarding energy saving and CO_2 saving potentials, this paper presents different energy efficiency solutions for the industry sector.

Firstly, short term solutions are presented:

- Energy management devices allow to measure and control energy consumptions and then to guarantee the optimal situation on the long term.

- Improvement of actual energy uses: boilers, compressed air systems, chillers…

This document presents an example of energy management system implemented in a food industry plant and the main solutions to save energy in clean rooms.

Secondly, new breakthrough solutions on industrial processes are related to three main themes:

- The process analysis by new methods of energy integration including the exergy value (quality of the energy used) for sectors which have never been explored before must be engaged and it can lead to re-conceptions of parts of the process. The method AEEP is presented and developed through an example.
- Electrical BATs become more and more relevant (especially in case of a low CO_2 electricity): better quality and productivity with profitable payback time in case of investment. The example "induction heating" is presented later on.
- The systems to recover and valorise energy losses and energy inside waste and co-products increase drastically potential energy savings. In particular the feasibility and the use of MVR (Mechanical Vapour Recompression) and high temperature heat pumps is presented.

Energy saving potentials

In December 2008, the European Parliament gave its backing to the EU's climate change package, the so-called "20-20-20". The main objective of this package is to reach the following climate targets by 2020: a 20% reduction in greenhouse gas emissions, a 20% improvement in energy efficiency, and a 20% share for renewable in the EU energy mix. In the EU 27, the industry sector represents 28% of the final energy consumption and 21% of the greenhouse gas emissions[1] [Eurostat, 2007]. So it has to be considered in this legal framework.

The ODEX [Bosseboeuf and al., 2005] indicator[2] shows that energy efficiency in industry has improved by 1–1.5% from 1990 to 2002 for the EU-15. The analyses on the CO_2 emissions of the industry sector of the European Environment Agency and the ODEX indicator show that the industry sector in the EU-15 also that the decrease in direct CO_2 emissions of 69 Mt is due to fuel switch and efficiency improvement.

Nevertheless, an energy saving potential still remains in the industry sector. IEA [IEA, 2007] estimates for the OECD countries that manufacturing industry can improve its energy efficiency by the adoption of best practise commercial technologies between 18 and 26% in primary energy, compared to 2004. It also estimates that the manufacturing industry can reduce its CO_2 emissions between 19 and 32%.

Moreover different factors make these energy and CO_2 saving potentials achievable:

- the behaviour of those involved in industry is more rational than in other sectors and energy efficiency contributes directly to the competitiveness of a company
- the equipment renewal rate is high in industry (5 to 10% per annum), with modernisation integrating technological progress and consequently energy efficiency.

Achieving these energy efficiency savings and CO_2 emission reduction passes through three conditions.

Firstly, the implementation of careful energy management and optimisation of energy flows within plant facilities. Energy management systems help to monitor and interact with the running of industrial processes and utility production. It could be estimated that they help to save 10% of energy on well managed sites, but much more in many cases: 20-30%. They contribute to prevent adjustment drifts and to maintain rational use of energy over time.

Secondly, existing facilities must be improved, without them having to be renewed. There are many well-known ways of doing this: installation of variable speeds on engines, installation of economisers on boilers, optimisation of thermal insulation, reduction in drainage rate (adding reverse osmosis), adjustment of burners, use of efficient burners on industrial furnaces or boilers, recovery of heat from compressed air or chillers, … However, these incremental improvements which have already proved to be economically viable, are not widely implemented. Linked with efficient control systems, they can enable savings of about 10% on current energy consumption uses.

Thirdly, industrial process innovations are required: Best Available Technologies (BATs), new efficient technologies, process integration including heat recovery with exergetic approaches that take into account the quality of the energy used. In the context of rare and expensive energy, it is important that every energy unit consumed into a given activity, is used to its maximum potential.

In terms of CO_2 emissions reduction, the substitution of fossil fuel end uses by electrical uses can be a solution if the electrical mix is low in carbon. These substitutions represent therefore a 20 to 30% lowering of CO_2 emissions in their sector of application; this potential could be increased in the future by the emergence of new technology [Bamberger, 2008]. However, the advantage of substitutions by electricity decreases if the carbon content of the electrical mix increases. It has been estimated that "efficient" technologies (heat pumps, solar heated domestic hot water, industrial induction, electric powered transport) maintain positive results up to an average content of electricity of 450 g CO_2/kWh: they are therefore robust on the French scale and transferable to other European countries.

Energy efficiency solutions in industry

The technical and economic analysis of energy saving supplies in industry (France-based) helps to unravel from the complexity and diversity of industrial processes the major technical targets of energy efficiency: heat production (boilers, 34% of consumption and 14% of supplies), thermal facilities (drying ovens, 28% consumption and 31% supplies) and the ambient conditioning of the premises (only 8% consumption, but 13% supplies). The recovery of waste heat together with traditional

1. Industrial processes and fuel combustion of manufacturing industries and construction

2. ODEX is based for the industry sector on unit consumption expressed in terms of energy used per unit of physical output and production index.

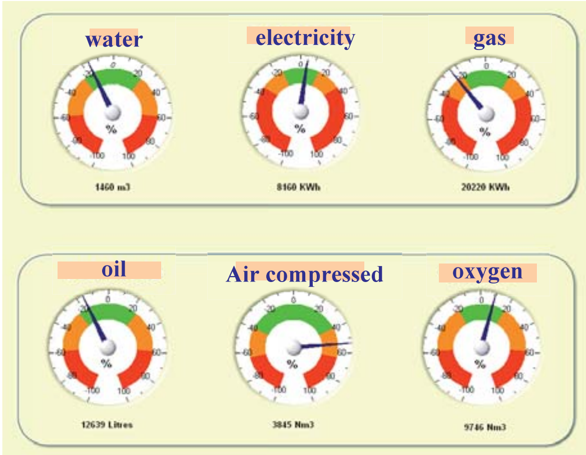

Figure 1: real-time view of the energy consumptions.

technology on boilers and the refrigeration, represent 26% of supplies [Terrien, 2008].

For last years, only short term solutions have been implemented, furthermore they still have to be applied quicker and stronger:

- Energy management devices allow to measure and control energy consumptions and then to guarantee the optimal situation on the long term.
- Improvement of actual energy uses: boilers, compressed air systems, chillers …

The use of efficient electrical techniques very often leads to higher investment costs, but in the majority of cases contributes not only to improved energy efficiency and reduce greenhouse gases emissions, but also to processes that are cleaner, more compact, more accurate, more reliable and faster. As a result, product quality is better managed, the productivity is increased and there is less scraps.

The process analysis by new methods of energy integration including the exergy value (quality of the energy used) for sectors which have never been explored before must be engaged and it can lead to re-conceptions of parts of the process.

From the whole range of technologies used in industry and without claiming to know them all, two particular technological areas are highlighted as they offer very sizeable energy saving potential, CO_2 reduction … and production efficiency:

- induction heating and melting,
- thermodynamic techniques: MVR (Mechanical Vapour Recompression) and heat pumps.

ENERGY MANAGEMENT AND IMPROVEMENT OF ACTUAL USES

We give two examples of incremental improvement.

Energy management in a food industry

The customer runs an average plant, in terms of energy consumption (11 GWh electricity and 7 GWh natural gas). His needs were:

- To dispose of a system allowing to alert as quickly as possible when abnormal consumptions occur,
- To establish adequate energy ratios, as close as possible from the production,
- To have a real-time follow-up on the plant equipment behaviour,
- To benefit from EDF consultancy on his energy consumptions.

The Energy Management System (EMS) installed by EDF in this plant allows to follow all kinds of fluids: electricity and gas of course, but also water, steam and compressed air. It ensures the traceability of temperatures, so important in that sector of activity. The system is built on a set of 60 sensors/meters, some of them being already present before, the others specifically installed for the purpose of the EMS. All the metering data is gathered into a EMS-dedicated supervisor (figure 1). We use the customer Ethernet network to communicate. The EMS allows the industrial:

- To follow-up with relevance the use of his various fluids,
- To effectively draw attention from the production teams onto Energy Management,
- To be alerted in case of over-consumption,
- To establish reports aiming the Direction of the plant as well as the occupants,
- To trace the impact of a change in the production on the energy pattern.

The annual savings are quite important, amounting to:

- 12.6 K Euro on compressed air consumption by reducing air leak (-40%),
- 27 K Euro on (drinking) water by reducing wasting (-22%),
- 8 K Euro on soft water used in the boiler (-25%).

These savings have been obtained by data analysis. For instance, it quickly appeared, using this software, that during certain weeks electricity consumption due to the compressors were higher although air production remained stable on the same periods. A quick look on the compressed air production ratios led s to have a further look on curves, which showed that one of the compressor, when running, produced a very small quantity of compressed air if any. The repair of this compressor allowed a return to a normal situation in the compressed air plant. The actual ratio, obtained in the new conditions, has become the target ratio used as a reference in the compressed air production supervision.

As a conclusion, we consider that an EMS allows not only to detect energy savings opportunities sometimes difficult to spot from an audit, but also to perpetuate these savings. Lastly, EMS is an efficient tool to bring the proof of energy savings, in an energy efficiency service context and a Measurement and Verification process.

Energy efficiency in clean rooms

Clean rooms are used in various sectors, for various applications. It is an airtight room in which the ambient properties are controlled (temperature, hygrometry, particles and micro-

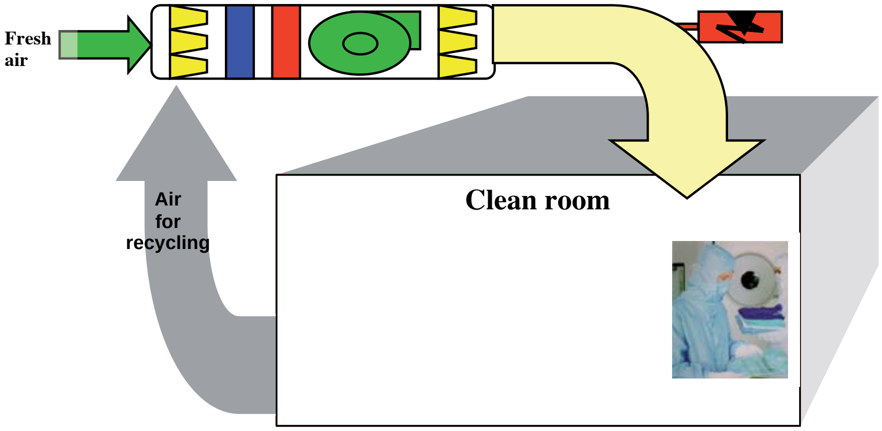

Figure 2: reference clean room.

Table 1: temperature and relative humidity setpoints for the selected sectors

Sector or application	Temperature (°C)	Relative humidity (%)
Personal comfort (temperature control between 20 and 25°C)	22.5°C ± 2.5°C	50% ± 10%
Microelectronics	22°C ± 0.2°C	45% ± 3%
Pharceuticals industry	23.5°C ± 0.5°C	50% ± 5%
Food industry	9°C ± 1°C	80% ± 20%

organisms content…). Energy consumption measurement in clean rooms needs to take into account the variety of conceptions and exploitation modes and this measurement is often costly. This is the reason why EDF R&D has developed a software tool, OpTHum™ which estimates energy consumptions of a clean room. The objective is to perform parametric studies for generic cases as well as specific preliminary research for a customer, to evaluate the energy savings before implementing an improvement, whether simple ones or a combination of several.

Even though each clean room has its specificities, a common set of parameters has a strong impact on the clean room energy efficiency. To identify the essential parameters EDF R&D has been leading for several years studies based on measurement made on real clean rooms

We are presenting here conclusions of a software study we conducted on different sectors or applications: microelectronics, pharmaceutical industry, food industry and the particular case of Air Handling Units dedicated to personnel comfort.

Energy efficiency actions are still few in clean rooms, however they present a very high potential in energy savings: it is possible to divide the energy consumption of a clean room by two when its running is not permanent. The principle states that a clean room that is not used 24/24 7/7 can be put into a low status without degrading its classification, the main reason being the absence of occupants and the stand-by of process lines, both leading to less pollutants emission.

The low status consists in widening the setpoint ranges for heating and cooling, and in reducing the air flowrates when unoccupied, while maintaining pressure cascades necessary between the different zones.

We took as a reference a clean room (figure 2) with a manufacturing schedule of 2 shifts, from 5 a.m. to 10 p.m., from Monday to Friday. In our simulations we consider a single AHU to treat both fresh and recycled air.

The AHU is equipped with two water loops:

1. A hot water loop heated by a gas boiler
2. A cold water loop cooled by a chiller.

The influence of different variables is studied:

- Inside heat input: this thermal contribution to the room is due to the process itself, as well as people present in the buildings. We simulate a range from 70 to 1 000 W/m²,
- The location of the plant through two weather data, one cold (Nancy) the other warm (Marseille),
- The amount of recycled air compared to fresh air inlet.

The energy efficiency actions we evaluate are summarized here below:

Free cooling is a system using fresh cold outside air to cool the room instead of the electric chiller. Heat recovery consists in installing a heat exchanger between cold fresh air and extracted warm air.

These different scenarios bring the following results:

- Enlarged T/RH ranges brings up to 30% in energy savings,
- Heat recovery brings 20% reduction in energy consumption,
- The combination of these two measures with free-cooling brings up to 50% savings.

Refered to figure 3.

Table 2: description of the six cases

Case 1	Reference: permanent functioning
Case 2	Enlarged T/RH range (doubling of the initial range when unoccupied)
Case 3	Reduction by 50% of the fresh air inlet (when unoccupied)
Case 4	Enlarged T/RH range + 50% fresh air inlet reduction (when unoccupied) (Case 2 and 3 cumulated)
Case 5	Reference Case 1 + heat recovery
Case 6	Combination of all the actions: Enlarged T/HR ranges + 50% fresh air inlet reduction+ free cooling + heat recovery

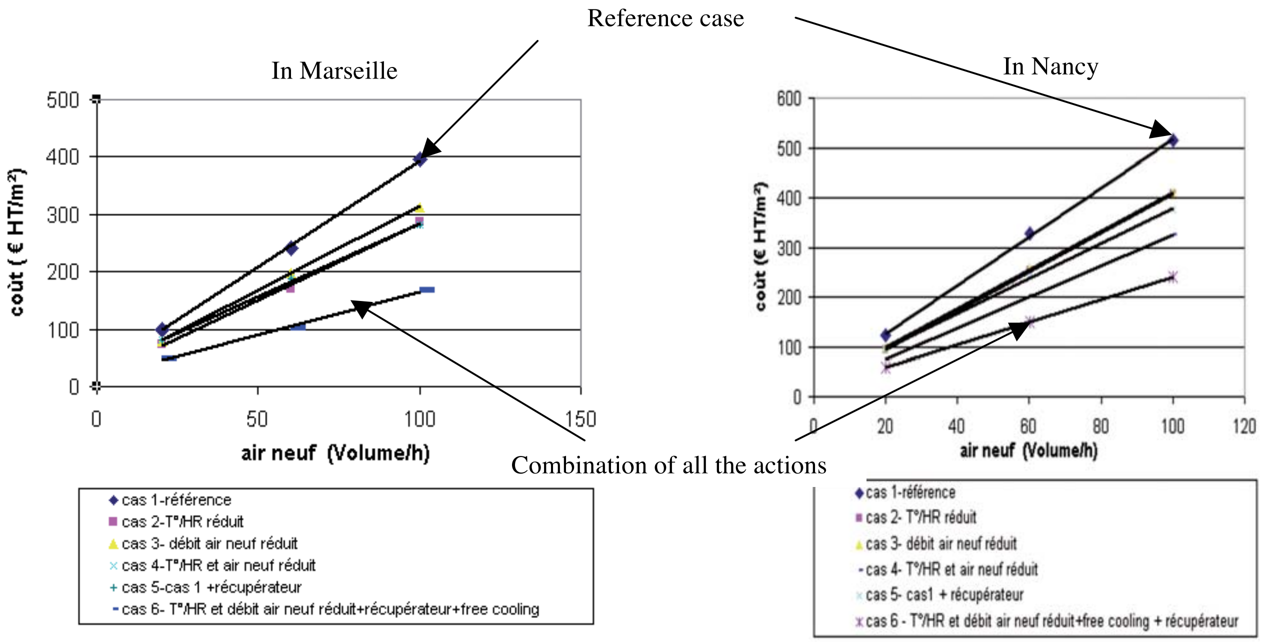

Figure 3: Evolution of the calculated energy cost according to the scenario.

As a conclusion, we observe that energy efficiency in clean rooms is still low in spite of the huge amount of potential savings. It is possible to save up to 50% of the energy combining:

- In activity:
  - A heat exchanger to extract calories from exhaust air and to transfer them to fresh air,
  - Free cooling, to cool directly inside air by fresh cold air, without request of the electric chiller,
- when unoccupied:
  - reducing fresh air inlet
  - enlarging the temperature and humidity setpoint ranges.

PROCESS ANALYSIS BY NEW METHODS

Standard energy efficiency assessment methods when applied to manufacturing plants generally consist in analysing and optimizing unit systems independently, without considering all the interactions between process utilities and manufacturing processes. On the contrary, advanced methods for process analysis are mainly based on process integration concept (PI), which consists in analysing the whole system constituted by the manufacturing plant and which aims at minimizing resources consumption and thus wastes generation. Energy process integration aims at first minimizing energy demand by exploiting heat recovery possibilities within manufacturing process at the most, and then optimizing utilities energy consumption in order to meet minimized process energy demand.

The most famous method of energy process integration is Pinch Analysis [Linnhoff and March, 1998]. This method, which is relatively costly because it requires lots of data, time and energy expertise, has by now been used in energy intensive manufacturing industry such as chemical and petrochemical, pulp and paper, or iron and steel industries. Efforts bear now on applying PI on Small and Medium size Enterprises by developing cheaper advanced process analysis methods such as Process Energy and Exergy Analysis (PEEA) [Abou Khalil et al., 2008]. Furthermore, these advanced tools can be (and are sometimes) behind energy analysis tools and softwares.

Process Integration allows to revisit the way manufactured goods are produced, especially PEEA which focuses first on the manufacturing product transformation considering product

Table 3: Energy savings and carbon emissions reduction of some identified energy efficiency solutions according to several European countries context

Energy efficiency improvements	Energy savings[1] (% of plant total energy bill)			Carbon emissions reduction[2] (% of plant total energy emissions)		
	France	Germany	Sweden	France	Germany	Sweden
MVR implementation for concentration	14.4	8.0	11.1	36.7	23.6	38.2
Minimizing heat treatment pinch	0.20	0.17	0.19	0.30	0.24	0.31
Minimizing heat treatment pinch & Heat pump implementation for pasteurisation pre-heating	0.89	0.25	0.56	3.15	1.83	3.31

[1] Financial energy savings are calculated from following energy prices : 52.2 Euro/MWh electricity for France, 83.9 Euro/MWh electricity for Germany and 61.4 Euro/MWh electricity for Sweden (EUROSTAT, 2008); 189 Euro/t heavy fuel oil for France, 209 Euro/t for Germany and 183 Euro/t for Sweden (DGEMP, 2008). Note that considered heavy fuel prices dating from January 2009 are very low and will probably rise in future. All these prices exclude taxes.

[2] Carbon emission reductions are calculated from following carbon emission factors based on LCA : 0.023 kg-eq C/kWh electricity in France ; 0.141 kg-eq C/kWh electricity in Germany; 0.012 kg-eq C/kWh electricity in Sweden and 0.087 kg-eq C/kWh (LHV) heavy fuel oil in all three countries (ADEME, 2007).

quality and plant productivity as only criteria, and not the process in place. PEEA is derived from Life-Cycle Assessment and from previously developed PI methods [Abou Khalil, 2008], and aims at analyzing the energy consumption of the product transformation from raw material to final product in order to identify and evaluate incremental as well as radical energy efficiency improvements. Incremental improvements consist in minimizing non-fatal losses like insulation losses in ovens and usually save from 1 to 5% plant energy consumption. Radical improvements consist in implementing an utterly different design that generates less fatal losses (and often less exergy losses) and result in much more significant energy savings. Although radical improvements have often large capital costs, they can still meet industrial payback time for investments criteria.

For instance, AEEP method has been experimented on several manufacturing processes, based on real and detailed audit data collected in a French dairy industry [Abou Khalil et al., 2008]. This plant uses about 31 TJ/yr of electricity (16% of plant total energy consumption), 16 TJ/yr of heavy fuel (84%) to produce more than 7,000 t/yr of cheese.

Performing PEEA in the studied plant revealed two significant operations: whey concentration and milk pasteurization. The radical improvement consisting in implementing MVR lead to almost total heavy fuel consumption removal in concentration operation but additional electricity would be consumed. It represents a reduction by more than 40% of plant heavy fuel consumption and an increase by 30% of plant electricity consumption, and so financial savings (table 3).

Concerning heat treatment operations, an incremental improvement consists in minimizing pinch temperature to 4 K in the double pasteurization process by increasing heat exchangers surface. It results in 5% fossil energy reduction. The radical improvement that consists in minimizing pasteurization pinch and implementing a heat pump to meet low temperature heat needs generates more than 40% of the heat treatment operation consumption, i.e. a reduction by 3% of plant heavy fuel consumption, assuming that heat is supplied as steam and considering steam production and distribution losses. Although additional electricity would be consumed by the heat pump (4% more in plant electricity consumption), there are still financial savings (table 3).

INDUCTION HEATING

Induction is the best available solid heating technology in the food and metallurgical industries. It enables in some cases the energy efficiency of an industrial furnace to be doubled. Precise and efficient, induction may be used either to heat metals directly or to heat fluids in a tank [Paya, 2008] [Baacke, 2008]. The induction technique is well established in heating before forming, thermal treatment of metal and in melting, thanks to the following benefits:

- Heat is generated at the very heart of the material to be heated, hence the excellent efficiency,
- High temperatures are achievable,
- Heat inertia is very low and power density high (up to 4 MW/m^2), this leads to compact solutions easy to integrate into a process,
- Power modulation, reproducibility, accurate control of processing cycles and automation are facilitated and offer great flexibility,
- Losses of product matter through oxidation are reduced; hence there are increases in productivity.

Above all, induction heating has high energy efficiency compared with fired or vapour heating; it could halve final energy consumption. Its "Stop and Go" use (no preheating or standby positioning) also helps to obtain substantial energy gains.

According to the application (mass, surface, fusion heat treatment), induction heating is in competition with fired heating (oxy-gas or gas furnaces), steam heating or resistance heating. The penetration into industry of induction as an efficient heating method is progressing even though it is already established in the foundry industry, forging industry, mechanical and automotive industries growing fast in primary steel processing and, more marginally, the parachemical and food industries. There have been a few successful trials in the food processing sector which should be repeated.

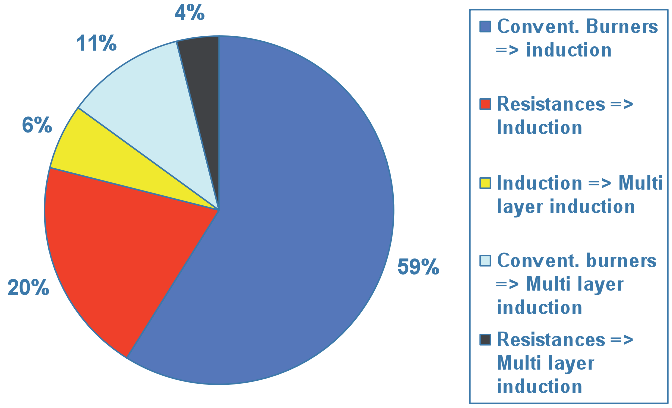

Figure 4: Distribution among replacement solutions

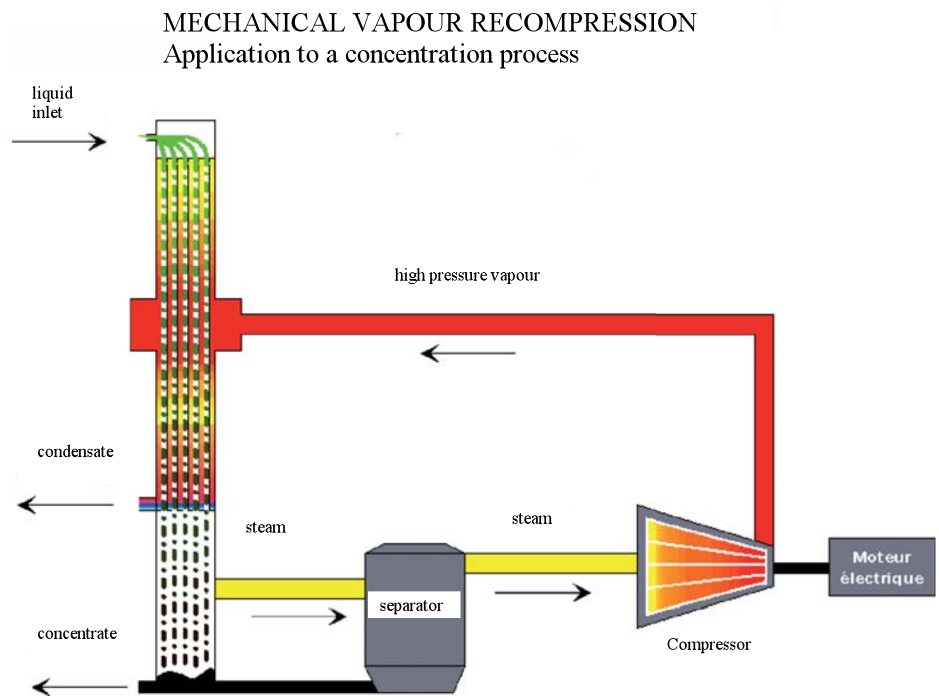

Figure 5: MVR-concentration unit

The replacement of furnaces equipped with conventional burners by induction heating devices in metallurgy allows to save 50% of the energy in a heat treatment process, 25% in a through heating process before forging and 20% in a melting process. In food industry, the use of induction on a belt conveyor for cooking flat products leads to 50% energy savings. Induction heating may also replace electrical resistance furnaces in through heating processes with an energy reduction of 20%. Nevertheless induction devices have fatal Joule losses due to high currents flowing through the induction coils. If they have a relatively high efficiency compared to gas furnaces, this efficiency strongly depends on the kind of metal constituting the heated part: heating steel is very efficient (typically 70 to 85%), but heating non ferrous metals is less efficient (typically 40% for copper alloys and 55% for aluminium alloys). Induction manufacturers recently developed solutions to improve the electrical efficiency of induction devices by reducing the fatal Joule losses. Multi-layer coils are used for heating copper or aluminium billets before extrusion; the energy saving reaches 15% compared to conventional induction heating device. The CELINE™ configuration patented by Five Celes is implemented successfully in steel production lines; the energy saving is 5 to 10% compared to conventional induction devices and allows to increase the compactness of the furnace or its productivity.

In France, the size of energy saving potential based on induction in the current markets is around 3 TWh/year (internal EDF study). This may be achieved with the replacement of conventional heating processes by the induction technology. The burners substitution represents 59% of the potential (figure 4).

But the substitution of a gas furnace by induction suppose a complete change of mind. Gas furnaces are mainly batch furnaces. That means that parts to be heated are introduced cold and extracted hot. The furnace is always in a transient state, the temperature of the refractory walls going up and down. Induction furnaces are mainly continuous furnaces: parts to

Table 4: Energy consumption for evaporators (mean values)

Type of evaporator	Specific consumptions	
	kg steam/tew (kWh)	kWh/tew (electricity)
1 effect	1200 (960)	10
2 effects	650 (520)	5
1 effect with TC	450 to 550 (400)	5
3 effects	350 to 450 (320)	5
3 effects with TC	175 to 300	5
6 effects with TC	115 to 140 (100)	5
1 effect with MVR	0 to 20 (8)	15 to 30

Table 5: Real case in the dairy industry: comparison of two types of evaporators

45,000t/year of lactoserum from 6% to 32% dry matter	Evaporator 3 effect with TC	Evaporator 1 effect with MVR
Steam specific consumption (t/tew)	0.300	0.010
Electrical specific consumption (kWh/tew)	5	18
Steam consumption (t/year)	10 968	365
Electricity consumption (kWh/year)	182 810	658 116
Gaz consumption (GWh/year)	9.026	0.300
Electricity consumption (GWh/year)	0.183	0.658

be heated are introduced at one end and extracted at the other end. The furnace mainly works at a steady-state regime, less energy consuming. So the substitution gas to induction requires to redefine completely the process line and not only the heating part of the process. The global investment cost may be very high. Other advantages than energy saving are required to tip the balance in favour of induction heating such as productivity improvement, quality improvement, etc.

This electrothermal technique harbours even greater opportunities for technological progress. In the first instance, the concept of "flexible heat induction", the development of generator/inductor communications offering greater load adaptability, should help to decrease the energy consumption and to make the equipment much more generic, consequently less costly and capable of taking on new applications. This real technological breakthrough could come on to the market between 2010 and 2015 and may significantly increase the induction penetration.

ENERGY RECOVERY: HIGH TEMPERATURE HEAT PUMP

The second key element for energy efficiency in industry is the recycling of lost heat which harbours substantial energy saving potential and merits considerable research. This is a question of developing energy approaches that enable heat recovery supplies and heat uses (sinks and sources) to be detected and coupled with adapted technology. Technology that enables heat to be recovered include: heat exchangers, heat pumps [Favrat, 2008] and mechanical vapour recompression (MVR) (figure 5). Today, vapour recompression and heat pumps offer diffusion potential above their current applications in the food industry and parachemistry, with energy saving potential in France of several TWh.

Vapour recompression recovers low pressure "used" steam from the process and, by compression, returns it to the temperature and pressure levels required. The obstacle to its diffusion is the cost of equipment and the limit of the compressor. Concentration of liquids by evaporation using vapour recompression is a well-established technique that is intrinsically energy efficient and which is well adapted for the concentration of liquids in processing (milk, whey, chemical process liquids…) and the concentration of waste water.

Final energy consumption may be reduced by a factor of 10 to 20 depending on whether or not it is introduced to applications which are already efficient (multi-effect concentrator).

There are important differences between specific consumptions on multiple-effect evaporators, with or without thermal compression (TC), and evaporators using mechanical vapour recompression (see table 4). Steam consumption (kg of high pressure steam /ton of evaporated water) and electrical consumption (kWh/ ton of evaporated water) are stated. Steam energy consumption is also expressed in kWh (we suppose that it needs 800 kWh to produce 1 ton of steam in the boiler).

In the case of a dairy, the replacement of a 3 effects evaporator (with thermal recompression) by a simple effect evaporator with a MVR device has led to a quite important consumption energy decrease. This evaporation process is used to concentrate 45,000 t/year of lactoserum from 6% to 32% dry matter; the amount of water evaporated is 36 562 t/year. The energy required for this operation dropped down from 8.7 GWh/year to 0.47 GWh/year.

Developments in this established technology concern mainly new applications. The main one is the concentration of waste water, because of environmental restraints particularly in the area of the mechanical engineering industry. Standardisation of equipment is necessary for low and medium MVR capacities in order to bring about tangible gain on investment, which is the chief stumbling block in the development of this technology.

For the heat pump, apart from its few current applications, its main interest is in recycling heat produced by processes. By recovering the main proportion of its energy from air, water or industrial fluids and waste, this technology could be considered to be a renewable energy. The number of heat pumps used

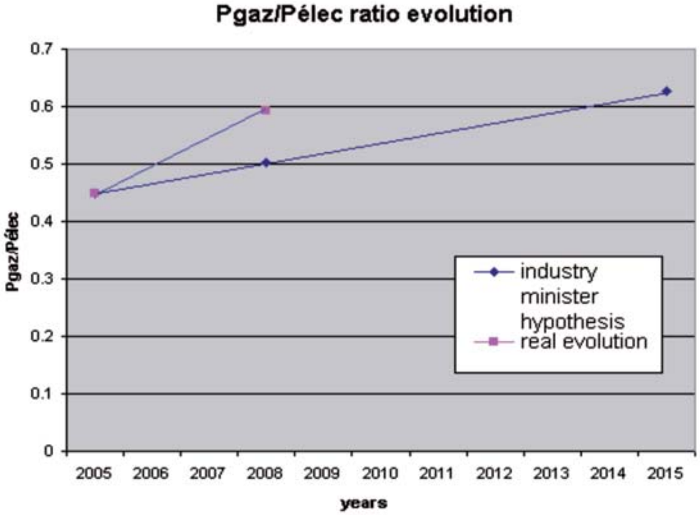

Figure 6: Gas price/electricity price evolution

in industry is still low. The principal sectors involved with the use of these installed heat pumps are the wood industry, the food processing industry and, to a lesser extent, the chemical industry.

In spite of it benefits, the heat pump is still not widely established in European industry. The main reason usually given is the length of time to get a return on investment, which is considered as too long for this kind of equipment in industry. However, with the current changes in energy costs, this argument is becoming weaker and weaker. Today, there is no doubt about the energy and economic benefits of developing the use of the heat pump in industry. It should be noted that the payback period has decreased by a factor of 2.5 between 2002 and today. And this trend is going to continue. In fact, the payback time can be calculated starting from the difference between the exploitation cost of a boiler and of a heat pump. Considering that the ratio Gas_Price/Electricity_Price is growing more and more (see figure 6) and the CO_2 emissions avoided provides more and more important financial gains, recent internal studies have shown that payback period is becoming acceptable for industrials.

In order to encourage market penetration, some developments have to be engaged: the development of refrigerants with very low environmental impact and the increase of heat release temperature levels in order to widen the field of application. For condensation temperatures up to 90°C, r1234yf seems to be the right refrigerant. This fluid has a GWP equal to 4. It's nowadays produced by some industrials, but it will be commercialised only in 2011. For higher condensation temperature this role can be played by water. Anyway, a cheap way to compress water (obtaining at least a 30°C temperature jump) can't be find in market. A research phase on water compression is necessary. Releasing the technological obstacles from very high temperature cycles would help to broaden the accessible supply to heat recovery in industry, which is currently estimated to be more than a dozen TWh [Lambauer, 2008] [Levacher, 2008].

Conclusion

European industry has recently experienced rising costs in fossil fuels and the launch of the emission permit trading system. Energy is now becoming a major focus of businesses, but with short-term economic strategies. The real tensions over oil and fossil fuel resources are still ahead of us, with a peak oil and restrictions on CO_2 emissions that will become more severe.

Reaching a large implementation of energy-efficient technologies is not straightforward and requires systematic and innovative methodologies that incorporate the following aspects:

- Increase the rational use of energy in the industry by a better energy management and by adopting a product based thinking. Identifying opportunities in industry is however complex and requires a holistic approach. Methods such AEEP accelerate and simplified the access to the energy efficiency solutions. This is a key point to increase the penetration of new solutions.
- Develop and promote the integration of advanced high performance technologies (like electrical technologies) in the process industry considering the energy sources substitution and promoting the use of renewable energy resources for reducing the CO_2 emissions.
- Increase the heat recovery and reduce the exergy losses by a better process integration and by using high performance energy conversion technologies such as high temperature heat pumps. New researches to put up the condensation temperature of the heat pump by using new refrigerant adapted with the compressors will increase the quantity of heat recovered.
- Identify, characterize and quantify energy saving sources in the industrial sectors in order the quantify energy saving markets and opportunities.

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