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Analysis and evaluation of energy efficiency of a shrinkwrap-packer

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Abstract. Since some years, European companies are interested in the issue of energy saving. In such context, a classification of industrial machines from the energetic point of view is becoming more and more important; currently, in the industrial context, no similar classifications exist.
The aim of this work is to formulate a standard method to evaluate the energy performance of an industrial machine, such as a shrinkwrap-packer. To this purpose, we studied a shrinkwrap-packer produced by OCME S.r.l, a mechanical machinery company located in Parma (Italy). Specifically, the shrinkwrap-packer was analyzed in terms of energy dissipations and other aspects related to the energy source utilized to power the oven.
As a result, we propose a general procedure that allows to compare different solutions from different perspectives related to energy efficiency. More precisely, we include three key performance indicators (KPIs) of energy efficiency, to build a comprehensive evaluation model. The first KPI concerns the energy efficiency class of the oven, the second KPI takes into account the impact of the oven on the work environment and the third one is an index of degradation of the energy resource utilized. A Global Index of Energy Efficiency (GI) is finally computed as the area of a triangle represented on a radar diagram on three axes, one for each KPI.

Key words

Classification, energy efficiency, performance, energy resource.

1. Introduction

In a lot of countries the role of energy is becoming more and more important; it is nowadays a strategic parameter for companies that want to remain competitive in a global market.[1].
Since some years, some European companies have been interested in the issue of energy saving, with the purpose, in particular, of reducing energy costs. In this context an energetic classification of industrial machines assumes a significant importance. Currently, this kind of classification exists for household appliances, but has not been developed for industrial machineries yet.
The aim of this work is to formulate a standard method to evaluate the energy performance of a shrinkwrap-packer, in order to classify this oven from the energetic point of view. To this purpose, we studied a shrinkwrap-packer produced by OCME S.r.l, a mechanical company located in Parma (Italy), in terms of energy dissipations and other aspects related to the energy resources required to power the oven.
As a result of the analysis, we propose a standard procedure that allows to compare different solutions considering many aspects of energy efficiency.
Before describing the procedure, it seems appropriate to provide some basic knowledge about shrinkwrap-packer machines. A shrinkwrap-packer is an automatic machinery that shrinks the film that winds the packs by means of a hot air flow, circulating into the shrinking tunnel. The packs can be composed by bottles or cans and they pass through the tunnel on a motorized conveyor.

2. Research methodology

As mentioned, at present an energetic classification exists for household appliances, but no similar classifications are available for industrial machineries.
In order to develop a new methodology to classify the shrinkwrap-packer produced by the company OCME, we thus started from the basic concepts used to classify the household appliances, which were adapted to be applicable to the industrial context. The energetic classification of household appliances and its legislation were thus analyzed in order to understand how such classification, as well as the tests for energy consumption measurement, are carried out.
Among the legislations, the Directive 2002/40/EC [2] concerns the indication by labeling and standard product information of the consumption of energy and other resources of household appliances. This Directive should

be applied only to household electric ovens and it should not be applied to the ovens that can use other energy sources.
The energy efficiency class of a cavity shall be determined as follows:

Table I. - Small volume cavities (12÷35 liter)

Energy Efficiency Class	**Energy consumption E in kWh and reported to standard load**
A	E < 0,60
B	0,60 ≤ E < 0,80
C	0,80 ≤ E < 1,00
D	1,00 ≤ E < 1,20
E	1,20 ≤ E < 1,40
F	1,40 ≤ E < 1,60
G	1,60 ≤E

Table II. – Medium volume cavities (35÷65 liter)

Energy Efficiency Class	**Energy consumption E in kWh and reported to standard load**
A	E < 0,80
B	0,80 ≤ E < 1,00
C	1,00 ≤ E < 1,20
D	1,20 ≤ E < 1,40
E	1,40 ≤ E < 1,60
F	1,60 ≤ E < 1,80
G	1,80 ≤ E

Table III. – Large volume cavities (more than 65 liter)

Energy Efficiency Class	**Energy consumption E in kWh and reported to standard load**
A	E < 1,00
B	1,00 ≤ E < 1,20
C	1,20 ≤ E < 1,40
D	1,40 ≤ E < 1,60
E	1,60 ≤ E < 1,80
F	1,80 ≤ E < 2,00
G	2,00 ≤ E

The information required by this Directive should be obtained by means of measurements made in accordance with harmonized standards adopted by the European Committee for Electrotechnical Standardization (Cenelec), particularly by “CEI EN 50304 - Electric ovens for household use - Methods for measuring the energy consumption” [3].
The object of this standard is to specify, in accordance with the Council Directive on energy labeling and standard product information:

- the energy consumption, using a standardised load coupled with a standardised testing procedure;
- some performance parameters (such as volume, time for heating a load and baking trays area);
- the admitted tolerances with respect to the values declared by the manufacturer and control procedures for checking these declared values.

This standard is concerned neither with safety nor with performance requirements.
The standard test procedure consists of two different tests, both made for three different heating functions (natural convection heating, forced convection heating and heating with superheated steam). Specifically, the testing procedure includes:

- Preheating of the empty oven: the purpose of this test is to measure the energy consumption and requested time to preheat an empty oven from room temperature to a given temperature rise;
- Energy consumption and time for heating a load: the purpose of this test is to measure the energy consumption and the requested time for heating a load. The load is a water saturated brick which simulates both the thermal properties and the water content of food.

The data collected during each test are recorded on a spreadsheet that allows to calculate the value of energy consumption (E) using a simple linear regression model. The resulting value is then inserted in the product label.
The energy efficiency class is a relevant indicator which allows to inform the user about the machine's energy consumption; in this way, it promotes the technological development of machines characterized by lower fuel consumption.
In fact, the purpose of research and technological innovation in recent years is more and more to develop new solutions and more efficient systems.
In the industrial context, however, the energy efficiency of a machinery is not the only parameter of interest to evaluate its overall performance. In fact, an industrial oven is usually placed inside a working environment, on which it could have some impact in terms of pollutant emissions (for example in case the oven is powered by methane and the fumes are emitted in the workplace), as well as in terms of possible required changes in the structure of the plant, due, for example, to the construction of a chimney or a hood necessary to remove the fumes.
A further relevant aspect to evaluate the energy efficiency of an industrial machine is the type of energy resource used to power it. As a matter of fact, in the case of the shrinkwrap-packer, using electrical energy to power the oven is more expensive than using methane, because, compared to this latter, electricity is a more refined energy..
To take into account the above considerations, as well as to make the evaluation comprehensive, three key performance indicators (KPIs) have been developed and included in the model, namely:

- The energy efficiency class (EEC).
- The impact on the work environment (IWE).
- The index of degradation of the energy source utilized (IDE).

The final performance of the shrinkwrap-packer (and, in particular, of its oven) is given by the area of a triangle

represented on a radar chart on three axes, each one measuring one of the above KPIs. In the radar chart, the specific values measured for each KPI are placed on the three axes, and are the vertexes of the resulting triangle. The axes are equidistant, then with angles of 120° between each other.
The maximum distance from the origin is the same for each axis; hence, if the value of the KPI is maximum for each axis, the resulting triangle would be equilateral. Moreover, the axes are oriented so as to achieve proportionality between the area of the triangle and the performance of the oven. As a consequence, the larger the area, the better the final performance of the oven.
The maximum distance from the origin is not defined (but it must be the same for each axis) because the calculated area of the triangle will be divided by the maximum area of the equilateral triangle previously described. The final performance of the machine examined is thus expressed as a percentage value. By using percentage values, the resulting performance does not depend on the units and the dimensional scale chosen for each axis.
Obviously, each KPI will be first computed according to the appropriate unit and it will be converted in percentage through a simple relation to calculate the area of the triangle.
For the computation of the area, it is sufficient to know the value of each KPI in according to its measurement unit and in the dimensional scale that we choose. The following equation can be used:

$$A = (a \cdot b + a \cdot c + b \cdot c) \cdot \frac{\sqrt{3}}{4} \quad (1)$$

Where a,b and c are the coordinates on the three axes.
The result of equation 1 will be divided by the maximum area of the triangle, which will be calculated in the same way with a, b and c set at their maximum values:

$$A_{max} = (a_{max} \cdot b_{max} + a_{max} \cdot c_{max} + b_{max} \cdot c_{max}) \cdot \frac{\sqrt{3}}{4} \quad (2)$$

The Global Index of Energy Efficiency (GI) is then calculated through the following formula:

$$GI = \frac{A}{A_{max}} \quad (3)$$

Figure 1 shows an example of a radar chart developed on the basis of the measurements which we have conducted on the shrinkwrap-packer produced by OCME S.r.l.

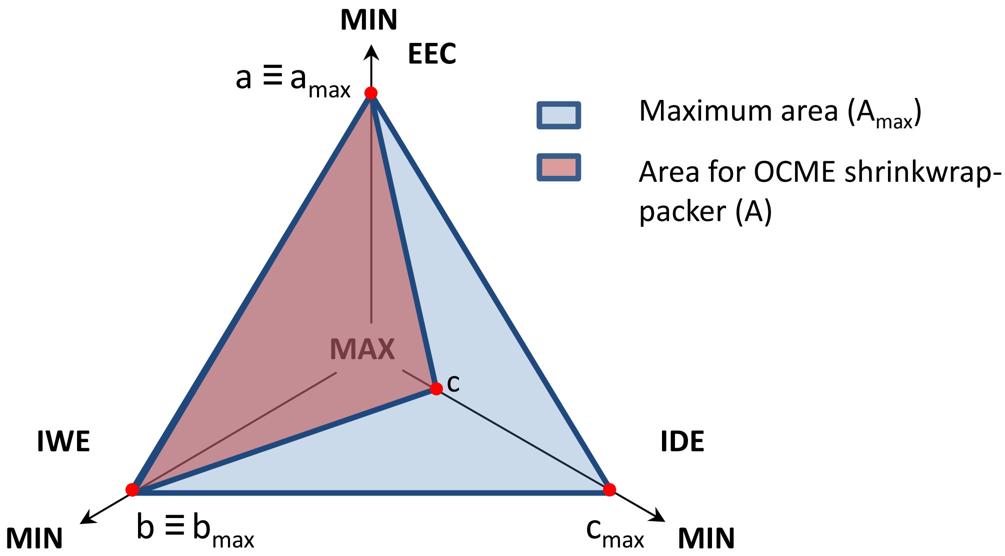

Figure 1. - example of the radar chart for the shrinkwrap-packer produced by OCME s.r.l.

3. KPIs and their measurement

The first KPI concerns the energy efficiency class (EEC) of the oven, i.e. the energy that the oven itself dissipates to the outside.
As said before, a standard procedure for evaluating the energy consumption of this oven does not exist at the moment; for this reason it was decided to start from the basic concepts used to classify the household appliances and then to adapt them to the industrial scenario.
A specific procedure has thus been developed for the energy classification of shrinkwrap-packer; in particular, a standard procedure has been defined for calculating the energy consumption of the machine. Furthermore, a series of measurements made on electricity consumption of the shrinkwrap oven produced by the Italian company OCME s.r.l. allowed the definition of the boundaries of the different energy classes.
The classes of energy efficiency are shown in the table below:

Table IV. – energy efficiency classes for a shrinkwrap-packer

Energy Efficiency Class	Energy consumption E in kWh/pack
A	$E < 6 \cdot 10^{-3}$
B	$6 \cdot 10^{-3} \leq E < 7 \cdot 10^{-3}$
C	$7 \cdot 10^{-3} \leq E < 8 \cdot 10^{-3}$
D	$8 \cdot 10^{-3} \leq E < 9 \cdot 10^{-3}$
E	$9 \cdot 10^{-3} \leq E < 10 \cdot 10^{-3}$
F	$10 \cdot 10^{-3} \leq E < 11 \cdot 10^{-3}$
G	$E \geq 11 \cdot 10^{-3}$

Since one of the axis measures the energy consumption, the maximum value on this axis should be assigned to that oven which is characterized by the minimum energy consumption, i.e. to the ovens classified in class A, which is the energy class with the maximum energy efficiency, as shown in the figure below:

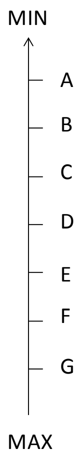

Figure 2. - axis refers to energy consumption

This KPI must be determined by measuring the energy consumption of the machinery to produce a pack; hence, if the oven is powered by electric energy, the energy consumption [kWh] is easily measured by an electricity counter. If the oven is powered by methane, the energy consumption [kWh] will be measured on the basis of the flow rate of the fuel consumed by the burners.
The second KPI takes into account the impact of the oven on the working environment (IWE).
Generally speaking, an oven can have two different kinds of impact on the working environment:

- Environmental impact, which refers to the quantity of pollutants (i.e., CO_2) emitted inside the working environment;
- Structural impact, which refers to the structural works required for the installation of the oven (for example the construction of chimneys or hoods for the removal of fumes, if the oven is powered by methane).

In the computation of this KPI, we take into account only the quantity of CO_2 emitted by the oven inside the working environment; conversely, the impact of the oven in terms of possible required changes in the structure of the plant (due, for example to the construction of a chimney or a hood necessary to remove the fumes) is neglected by this KPI. This choice is motivated by the fact that, in real contexts, this contribution will depend on the specific working environment; for example, if a factory is already equipped with hoods, no further actions would be required for the installation of the oven.
As for the previous case, the maximum value of the KPI on the axis is assigned to the oven which is characterized by the minimum impact on the working environment, as shown in Figure 3:

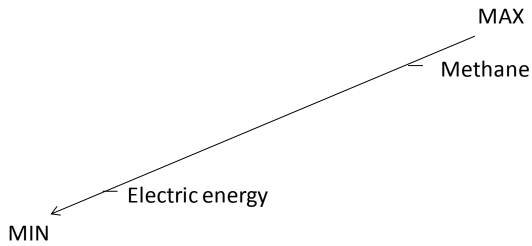

Figure 3. - axis refers to impact on the work environment

This KPI must be determined by measuring the flow rate of CO_2 emitted by the oven in the working environment [g CO_2/s]. We distinguish four different situations:

1. If the oven is powered by electric energy there are no CO_2 emissions in the workplace; consequently, the KPI reaches the maximum value on the axis (bmax).
2. If the oven is powered with methane with indirect heat exchange, there are no CO_2 emissions (fumes produced by combustion are expelled with a chimney); also in this case the KPI reaches the maximum value on the axis (bmax).
3. If the oven is powered with methane with direct exchange without external hoods, CO_2 emissions in the workplace is easily measured on the basis of the flow rate of fuel burned by the burners, taking in account the ratio of stoichiometric combustion.
4. If the oven is powered with methane with direct exchange with external hoods, it is more difficult to evaluate the real quantity of CO_2 emitted in the workplace, since the hoods cannot capture all the CO_2 produced; rather, they capture only a percentage of the CO_2 produced, that can be quite variable. We thus propose to carry out a continuous measurement of the CO_2 concentration at the exit of the exhaust duct. By subtracting the amount of CO_2 measured from the total flow rate of CO_2 produced by the combustion, we will obtain an estimate of the amount of CO_2 emitted in the workplace.

As mentioned, the third relevant aspect of energy efficiency is the kind of energy resource used to power the oven. For instance, using of electrical energy is more expensive than using methane, because the oven will consume a more refined energy source to produce heat. The third KPI is thus an index of degradation of the energy source utilized (IDE).
In this regard, different power systems have been analyzed to evaluate the energy efficiency of each one,

i.e. the original amount of chemical energy required to provide a defined heating capacity.
In this case, the maximum value of the KPI is assigned to the oven which utilizes the less refined energy source, or in other terms to the oven that exploits it in the most efficient way.

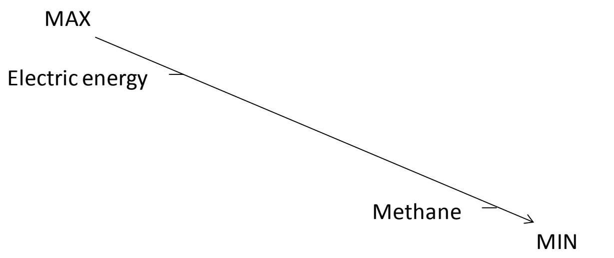

Figure 4. - axis refers to the index of degradation of the energy source utilized

This KPI must be determined by measuring the overall efficiency of the machinery [Ƞ]. We can distinguish three different situations:

1. If the oven is powered by electric energy, we consider the overall efficiency of a thermoelectric plant, because we assume that the electric energy is produced on it.
2. If the oven is powered by methane with direct heat exchange, we consider the overall efficiency as resulting from the product between the efficiency of the burning process and the efficiency of the direct exchange (exhaust fumes at the exit of the oven still have a heat content).
3. If the oven is powered by methane with indirect heat exchange, we consider the overall efficiency as resulting from the product between the efficiency of the burning process and the efficiency of the indirect exchange.

2
This KPI will be expressed in percentage [1 - Ƞ]; in this way, the maximum value of the KPI is assigned to the oven characterized by the maximum efficiency.

4. Discussion and conclusions

Nowadays the energy saving has become a central aspect of industrial contexts. In order to promote the development of industrial machines more and more efficient, a standardized classification of the machines themselves is required.
In industrial contexts, an exhaustive classification of the machines should take into account not only the issues related to the energy dissipation of the machines, but also to the economic optimization and maximization of job security. In this study, we have developed a new approach for the classification of the oven of a shrinkwrap-packer produced by the Italian company OCME Srl. This method allows to gather all the aspects mentioned above; in fact, the global index of energy efficiency (GI) is calculated from three key performance indicators, taking into account, respectively, the energy dissipation of the machine (energy efficiency), to the emissions of pollutants in the workplace (work safety), and the kind of energy source used(economic aspects) .
Starting from this study, next steps could be:

- The formalization of a standardized procedure for the measurement of the three KPIs;
- The generalization of the procedure in order to apply it to different industrial machineries.

In the future, it is expected that the standard method developed in this study will be applied to many industrial machineries, with the purpose of classifying them under energetic, economic and safety perspectives. The classification proposed will also allow companies to identify the characteristics of the machines which require improvements in order to reach the highest efficiency. The classification developed will inform the user of the machinery about its energetic performance, and will then promotes the technological development of machines characterized by high energy performances.

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