

Energy management in plastics processing — framework for measurement, assessment and prediction

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Energy management is a task of growing importance to plastics processors but there is no established structure for measurement, assessment and prediction. Many companies are trying to measure the wrong things in the wrong ways. They then wonder why they get the wrong answers! This paper describes and illustrates a framework for measurement, assessment and prediction that can be used for most plastics processing companies. It looks at both internal and external benchmarking, at site level and at machine level and how this information can provide real insights into how the site and the process are performing. More importantly, the paper looks at how this information can be used to improve both operations and performance.

Keywords: Plastics, Energy, Management

Introduction

The concept of energy management is relatively new to the plastics processing industry but is now being strongly driven by the recent rises in energy costs and the rising insecurity of supplies for the future. Ten years ago, energy management was a 'minority sport' and it was difficult attracting the interest of industry in energy management. This is no longer the case and for most companies energy management is a real business issue. Energy costs represent the third largest variable cost (after materials and direct labour) and in some companies is even the second largest variable cost.

This is not a 'green' issue, it is not a 'carbon management' issue, it is a real business issue and in many cases is a survival issue. Getting the measurements wrong can be fatal to the company.

Despite this, there is no established or recognised structure for measurement, assessment and prediction and many companies are trying to measure the wrong things in the wrong ways. They then wonder why they get the wrong answers!

This paper describes and illustrates a framework for measurement, assessment and prediction that can be used for most plastics processing companies. It looks at both internal and external benchmarking, at site level and at machine level and how this information can provide real insight into how the site and the process are performing. More importantly, it looks at how this information can be used to improve both operations and performance.

The framework is shown in Fig. 1.

We will first look at internal benchmarking for the site to develop the concepts of 'base load' and 'variable' or 'process' loads and then use these to develop a simple method of assessing performance and predicting costs. Internal benchmarking is vital but is based on the 'status quo' and does not provide a driving force for improvement. We will therefore look at external benchmarking on a site basis and the essentials of process rate dependence for the site. This is then extended to the machine level where we can also benchmark machines to look at the process rate dependence for individual machines.

All the data presented in this paper is real industry data from real plastics processing factories around the world. In all cases the sites/factories have not been identified to preserve commercial confidentiality.

Some final words of introduction: sit back and relax, this is going to be fun.

Internal benchmarking: site

Getting data and presenting results

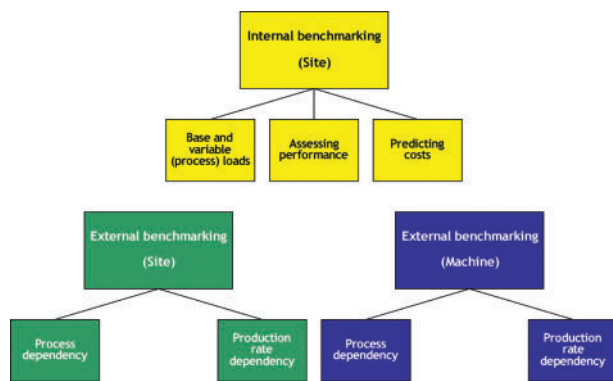
At a plastics processing site it is possible to determine the base and variable/process loads for the site from simple energy usage and production volume data. We will first illustrate the method using a sample injection moulding factory (real life) and then discuss the information that can be obtained from the data.

The total site base and variable loads can be quickly estimated using the following method:

- (i) record the factory output (in kg) for a number of months and record the energy usage (in kWh) for the same period. This is shown in Table 1 for the sample injection moulding factory.
- (ii) plot the energy usage (in kWh) versus production level (in kg) in a simple scatter chart. A graph using the above data is shown in Fig. 2 with a

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1 Energy management framework

linear line of best fit plotted for the points and the equation of the line of best fit shown. The intersection of the line of best fit line 'kWh' axis indicates the 'base load' for the factory. This is the energy usage when no effective production is taking place but machinery and services are available. The slope of the line of best fit is the 'process load' and shows the average energy being used to produce each kilogramme of polymer

(iii) the equation of the line of best fit for this data is

$$kWh = 1.5751 \times \text{production volume} + 152\,440$$

$$R^2 = 0.9397$$

The good R^2 value (0.9397) indicates that the data set is relatively consistent with the line of best fit – not all data is this good and we will return to this in later in this paper

(iv) the energy cost to the company therefore consists of a base load (the intercept of the line of best fit) of ~152 440 kWh and a process load (the slope of the line of best fit) of 1.5751 kWh kg⁻¹ of plastic processed.

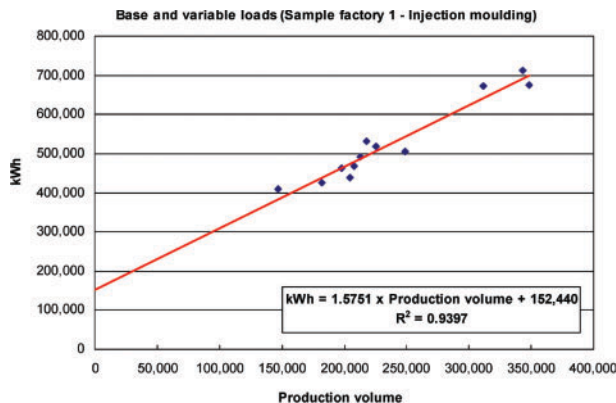
Obviously, it is possible to record the production volumes over other periods, such as weeks if data collection is possible and this gives faster data collection, faster feedback and quicker resolution of any concerns.

Base and variable loads

The base load information for sample factory 1 implies that that even if no production is taking place then the factory will consume ~152 440 kWh/month. At an energy cost of 7p/kWh, the total cost of the base load is approximately £10 671/month or £128 000/ year. On this basis, the base load represents approximately 30% of the monthly cost of energy to the company – this is

Table 1 Energy usage and production volume data (sample factory 1)

| | Month | Energy use, kWh | Production volume, kg | kWh kg ⁻¹ |
|----|----------------|-----------------|-----------------------|----------------------|
| 1 | January 2006 | 425 643 | 182 421 | 2.33 |
| 2 | February 2006 | 463 772 | 197 897 | 2.34 |
| 3 | March 2006 | 504 675 | 248 742 | 2.03 |
| 4 | April 2006 | 437 307 | 204 228 | 2.14 |
| 5 | May 2006 | 492 613 | 212 716 | 2.32 |
| 6 | June 2006 | 518 940 | 225 239 | 2.30 |
| 7 | July 2006 | 532 322 | 217 864 | 2.44 |
| 8 | August 2006 | 469 029 | 207 615 | 2.26 |
| 9 | September 2006 | 676 008 | 347 845 | 1.94 |
| 10 | October 2006 | 711 119 | 343 468 | 2.07 |
| 11 | November 2006 | 671 962 | 311 174 | 2.16 |
| 12 | December 2006 | 409 526 | 147 378 | 2.78 |



2 Determining base and process loads

regarded as approximately average for the plastics processing industry where base loads can be as high as 50%. The base load is effectively the energy 'overhead' and is primarily due to machinery being left on with no production being used and services being left operation with no productive output. Reductions in the base load (translating the line downwards) can be generally made without affecting production rates, quality or operations. They are also extremely profitable to carry out because the base load is largely a dead weight on the company that is unrelated to production output.

The process load information for sample factory 1 shows that for each kilogramme of plastic processed, the factory uses ~1.5751 kWh. The process load shows how efficient the company is at plastics processing. Reductions in the process load (reducing the slope of the graph) indicate improved process efficiency. These are often more difficult to achieve.

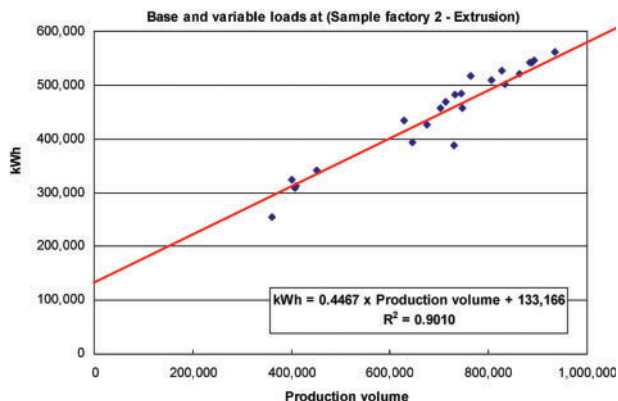
Plastics processors need this type of information to enable targeting of energy usage improvements for both the base and the process load. The actions required in each case are very different.

Reading charts

Simple data collection and analysis can enable management to 'see inside' the process. This type of chart reveals a great deal about a company's operations and some examples of various charts are now considered.

Process load dependence

The method is naturally process independent but the results are highly process dependent, particularly in terms of the process load. This is shown in Fig. 3 where the data are presented for an extrusion factory.



3 Base and process loads for extrusion

Figure 2 illustrates the base and process loads for an injection moulding factory, whereas Fig. 3 shows the base and process loads for an extrusion factory. Injection moulding has a higher process energy requirement than extrusion and therefore it is to be expected that the process loads will be significantly different. This is indeed the case. The factories have broadly similar base loads but the extrusion factory has a process load of $0.4467 \text{ kWh kg}^{-1}$ compared to the injection moulding factory, which has a process load of $1.5751 \text{ kWh kg}^{-1}$. We will return to the significance of these process loads later in this paper.

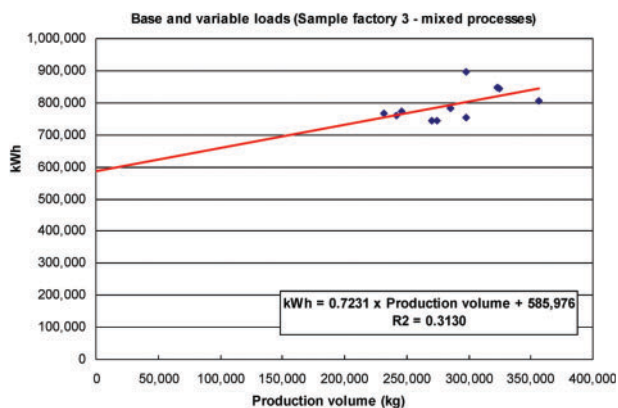
Mixed processes

In some cases, companies have a mixture of processes such as injection moulding, blow moulding and extrusion on one site and it is not always possible to separate the data for each process. The effect of this is shown in Fig. 4.

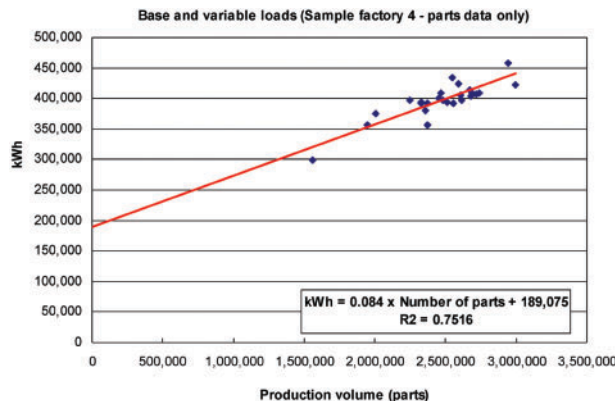
In this case, as would be expected, the data is much less consistent (R^2 is 0.3130) as the monthly product mix (and hence the process loads) has a large effect on the energy consumption. It is possible to use multivariate analysis to separate the data but submetering is much easier and more direct. Submetering gives direct data and is more relevant to the industry than a sophisticated analytical tool.

Alternative production measures

In other cases, the data for polymer usage is simply not available and the only measure of production available



4 Base and variable loads for mixed processing



5 Base and variable loads for parts data

is the number of parts produced in the week or the month. This is common in companies who regard themselves as being in ‘medical products’ or automotive products’ rather than in ‘plastics processing’. In this case, the production volume in ‘parts’ can be substituted for production volume in ‘kilogrammes’ and the typical result is shown in Fig. 5.

Provided there is a reasonably consistent mix of part size, the use of parts as a variable still allows assessment of the base load and the resulting information can also be used for the assessment and prediction methods that will be described later in this paper and where the real value of this simple data collection becomes apparent.

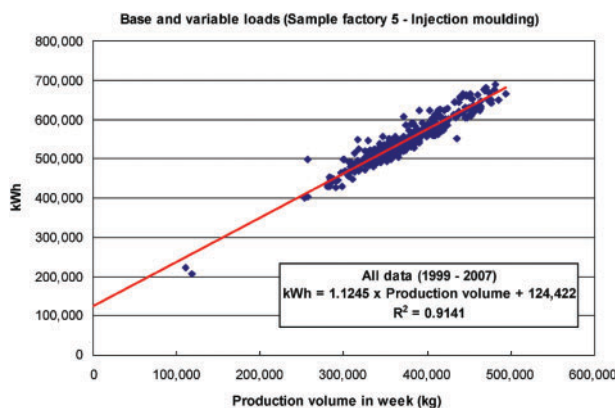
Long term data collection

While we initially only showed data gathered over a 12 month period, data collection and analysis over the long term can reveal some interesting patterns in the energy consumption of a company.

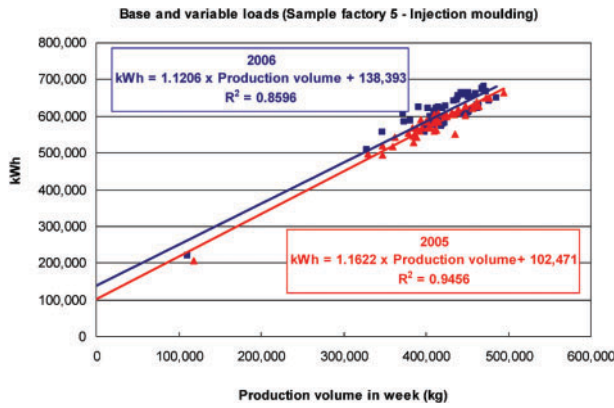
Figure 6 shows weekly energy and production data collected over eight years.

The consistency of the data and the base and process loads is remarkable over this extended time and the R^2 value of 0.9141 indicates a very close correlation of the data to the line of best fit.

In this case, there have been very significant changes in the number of injection moulding machines and the amount of services provided over the long term. Despite this, the changes do not appear to have dramatically



6 Base and process loads over long term (eight years of weekly data)



7 Comparing base and process loads after process changes

affected the base and process loads. There appears to be a signature of ‘operational consistency’ in the data, i.e. this is how we run our processes and machines and these are the base and process loads that result from the decisions we have made. This is by no means an uncommon phenomenon and it is interesting to speculate that companies and their management have a ‘biological’ energy signature that is almost independent of conventional changes or the scale of the process.

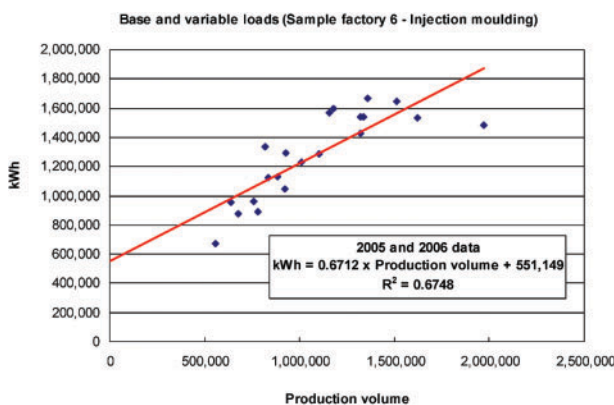
Process changes

Despite this strong consistency over time, it is still possible to see some valuable information in the data. The data for the last two years (2005 and 2006) was extracted from the eight years of data and this is shown in Fig. 7.

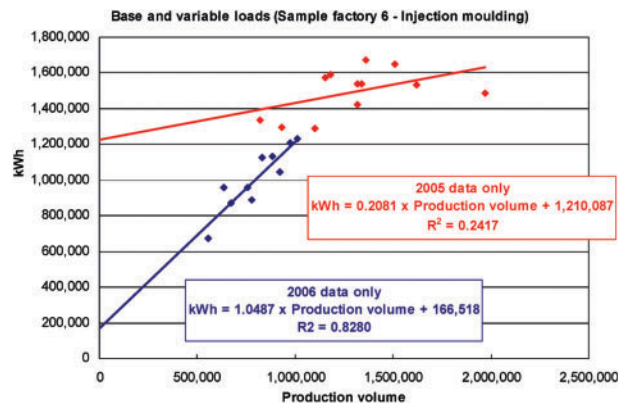
While the global pattern remains distinctively that of the original factory, the two years show easily discernible differences. A new cooling system was installed at the start of 2006 and this resulted in production improvements, i.e. a reduction in process load from 1.1622 to 1.1206 kWh kg⁻¹, but the system was not properly tuned to the system demands (it was running too cold) and as a result the base load increased slightly. The site is now resolving this concern and it is expected that the base load will decrease in the future.

Management changes

Changing the way a factory is run, i.e. management changes, can have an even more dramatic effect on the energy consumption. Figure 8 shows the data collected



8 Comparing base and process loads after process changes



9 Comparing base and process loads after management changes

from an injection moulding factory. The data shows a very low R² value and the scatter is large.

At the end of 2005, the entire management team was replaced with a new management team who were more concerned about energy management. No changes were made to the process, machines or other operations (although production volume did fall slightly). These management changes fundamentally changed the biological make-up of the operations. The data was therefore separated into data for 2005 and data for 2006. The best fit lines for these two data sets are shown in Fig. 9.

The two data sets are very different and the effect of the management changes is dramatic. The base load has decreased considerably from 1 210 087 to 166 518 and whilst the process load has increased from 0.2081 to 1.0487, it is now much more proportional to the production volume. Through good management, the base loads due to machinery being operational with no output have been converted to process loads where machines are only operational when actually producing. The new management team effectively changed the biological profile of the operations.

Performance assessment

This simple data presentation and equation can also be used to assess the performance of the factory on a monthly basis. The equation of the line of best fit for the data of Table 1 and Fig. 2 was

$$\text{kWh} = 1.5751 \times \text{production volume} + 152\,440$$

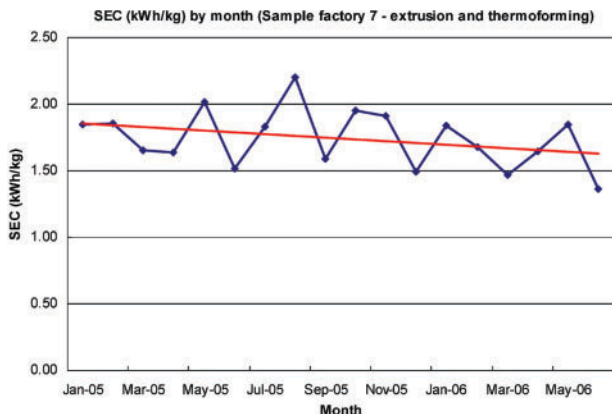
This equation can be then be used to assess the energy usage for a given production volume in a month, e.g. if the production volume is 200 000 kg, then the predicted energy usage will be

$$\text{kWh} = 1.5751 \times 200\,000 + 152\,440$$

Table 2 Assessing energy usage (monthly)

| Production volume, kg | kWh | £/month |
|-----------------------|---------|---------|
| 0 | 152 440 | £10 671 |
| 50 000 | 231 195 | £16 184 |
| 100 000 | 309 950 | £21 697 |
| 150 000 | 388 705 | £27 209 |
| 200 000 | 467 460 | £32 722 |
| 250 000 | 546 215 | £38 235 |
| 300 000 | 624 970 | £43 748 |
| 350 000 | 703 725 | £49 261 |

Energy cost calculated at £0.07/kWh



10 Specific energy consumption by month, kWh kg⁻¹

Therefore the predicted energy use is 467 460 kWh and predicted energy cost is £32 722 for the month. This simple approach enables the production of Table 2 for performance assessment and prediction of the monthly energy cost to the company.

The equation and Table 2 can be used to assess performance and generate production accountability by the following method:

- (i) determine the volume of material processed in a month and calculate the predicted energy usage
- (ii) determine the actual energy usage
- (iii) compare the predicted energy usage to the actual energy usage
- (iv) if the actual energy usage is less than the predicted energy usage then find out what the factory did right and do more of it
- (v) if the actual energy usage is more than the predicted energy usage then find out what the factory did wrong and do less of it.

Individual factory or process area managers can now be given targets for achievement and assessment that are based on real production volume and internal energy benchmarks generated from the historical factory performance.

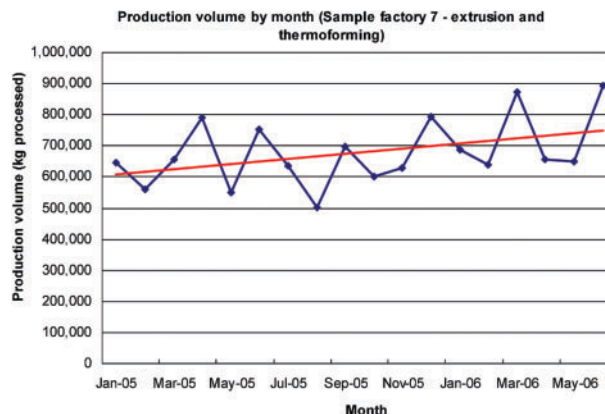
Predicting costs

The equation and Table 2 can also be used for budgeting and the prediction of energy usage based on the predicted sales volumes for the month/year. The sales volumes (in kg) can be taken from the sales forecasts and completed as shown in Table 3.

Table 3 Budgeting for future energy use

| Month | Kg | Total quantity, kWh | Cost for month |
|----------------|-----------|---------------------|----------------|
| January 2008 | 388 705 | 150 000 | £27 209 |
| February 2008 | 467 460 | 200 000 | £32 722 |
| March 2008 | 546 215 | 250 000 | £38 235 |
| April 2008 | 530 464 | 240 000 | £37 132 |
| May 2008 | 522 589 | 235 000 | £36 581 |
| June 2008 | 506 838 | 225 000 | £35 479 |
| July 2008 | 522 589 | 235 000 | £36 581 |
| August 2008 | 543 065 | 248 000 | £38 015 |
| September 2008 | 572 992 | 267 000 | £40 109 |
| October 2008 | 604 494 | 287 000 | £42 315 |
| November 2008 | 483 211 | 210 000 | £33 825 |
| December 2008 | 404 456 | 160 000 | £28 312 |
| Total | 6 093 076 | 2 707 000 | £426 515 |

Energy cost calculated at £0.07/kWh



11 Production volume by month

We now have a tool for the accurate prediction of the future energy use of the factory based simply on the historical energy usage of the factory corrected for production volume – much more useful than any current method available.

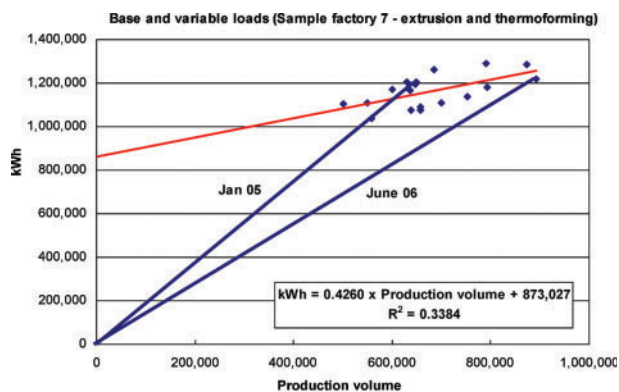
Pitfalls of simple kWh kg⁻¹

Many companies take a simplistic approach to energy efficiency and calculate a simple specific energy consumption (SEC) in terms of ‘kWh kg⁻¹’ each month as an assessment method. They calculate this from the kilograms processed in the month and simply divide by the kWh used in the month. This can lead to fundamental errors in assessing performance. Consider the following case (Fig. 10):

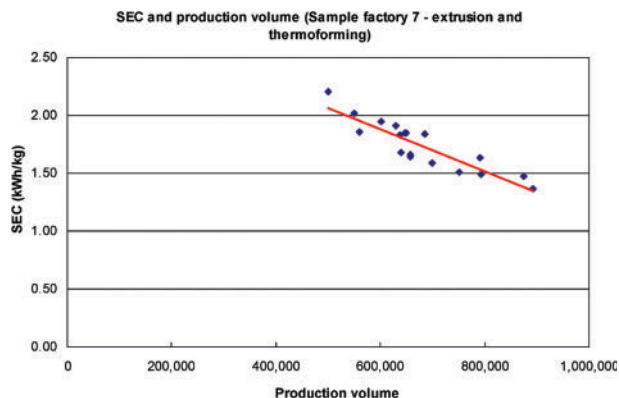
The SEC is apparently decreasing, i.e. it apparently takes less kWh to produce a kg of finished product. The management team is feeling happy and being congratulated for their efforts in improving energy efficiency. Unfortunately, all is not as it seems. The production volume over the same period is shown in Fig. 11 and this can be seen to be increasing over the measurement period.

In terms of the previous type of energy usage versus production volume graph the monthly measurement of kWh kg⁻¹ can be visualised as finding the slope of the line drawn between the origin and the individual monthly data point as shown in Fig. 12.

It is immediately obvious that the simple monthly SEC type of measurement is affected by both the production volume and the base load. Simply increasing the production volume will reduce the SEC because the base load will be amortised over a greater production volume and lead to the impression that energy efficiency



12 Simple SEC measurement



13 Production volume and SEC

is improving. The effect of production volume on SEC is illustrated in Fig. 13.

It is apparent that raising the production volume decreases the kWh kg⁻¹ value through simple amortisation, i.e. high production=low kWh kg⁻¹ and vice versa. Companies therefore must be careful in assessing energy efficiency changes by simply comparing SEC values; these can be affected by simple changes in production volume rather than real changes in the energy efficiency of the process. Obviously, this will be less significant where the base load is low in comparison to the process loads but the simple number can often be misleading.

This is not a problem when production volumes are rising and the management team sees a continuously decreasing SEC. They are happy to accept the congratulations for doing nothing at all. When production volumes are decreasing and the SEC is increasing despite their efforts then they are less happy to accept the criticism.

Summary

The simple data collection shown above can be used to analyse the current energy use for any plastics processing site and indeed for any manufacturing operation. The method gives not only an insight into the operations but also provides tools for performance assessment and future energy cost budgeting.

External benchmarking: site

The simple methods and analysis described above allow internal benchmarking against previous performance but do not provide the essential external reference to drive real improvements in performance. We will now look at external benchmarking for two of the main plastics processing methods: injection moulding and extrusion.

Process dependence

Plastics processes are not equally energy intensive and this has already been noted in section on 'Process load dependence' where the process load of injection moulding was seen to be 1.5751 kWh kg⁻¹ compared to an extrusion process load of 0.4467 kWh kg⁻¹. These are process only SEC values and do not include the base load of the site.

Average site SEC data (including base load) is available from two sources and this is shown in Table 4.

Despite the geographical variations in the site locations, the EURecipe and the Tangram internal data are remarkably consistent in terms of the overall average site SEC for the two processes considered.

As would be expected, the average site SEC (in kWh kg⁻¹) is somewhat higher than the process load (in kWh kg⁻¹) because the effect of the base load is included in the site SEC (see section on 'Pitfalls of simple kWh kg⁻¹') whereas the process load mainly considers the processing energy usage.

Production rate dependence

The data given in Table 4 is, however, of very limited use for the external benchmarking of any specific site. The energy use in any plastics processing method is extremely rate dependent due to the high fixed loads of operating most plastics processing machinery. The overall output rate matters and it is essential that the average results from Table 4 be clarified in terms of rate dependence. This will be carried out for the injection moulding and extrusion processes.

Processes

Injection moulding

The site SEC can be corrected for production rate dependence by calculating the production rate for the site in terms of kg h⁻¹/machine.

This is carried out by:

- (i) calculate the operating hours of the site over a full year
- (ii) calculate the material processed by the site over the full year
- (iii) define the number of machines in operation over the full year
- (iv) calculate the total electricity use of the site over the full year
- (v) calculate the production rate (in kg h⁻¹/machine) from 1/2/3
- (vi) calculate the site SEC (kWh kg⁻¹) from 4/2.

This has been carried out for 85 injection moulding sites throughout the world (internal data, Tangram Technology Ltd) to produce Fig. 14.

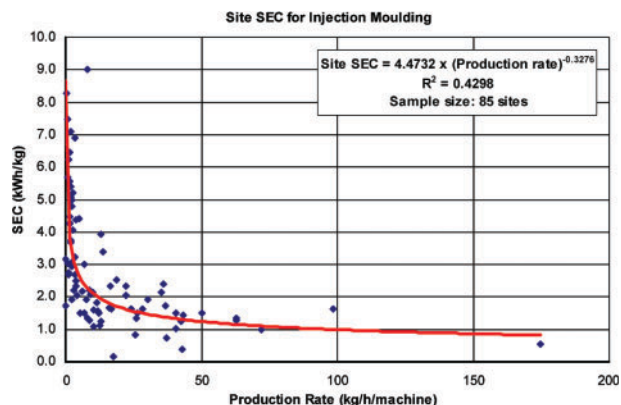
Figure 14 is only for electricity usage and allows the site SEC to be benchmarked against external data for

Table 4 Average site SEC for injection moulding and extrusion

| Process | Average site SEC, kWh kg ⁻¹ | | Sample process SEC, kWh kg ⁻¹ |
|--------------------|--|------------------------------------|--|
| | EURecipe data* | Tangram internal data [†] | See section on 'Internal benchmarking: site' |
| Injection moulding | 3.118 | 3.075 | 1.575 |
| Profile extrusion | 1.506 | 1.559 | 0.447 |

*2005 European Benchmarking Survey of Energy Consumption and Adoption of Best Practice – EURecipe, 30 September 2005.

[†]Tangram Technology Ltd: Internal data from 85 injection moulding and 32 extrusion sites throughout the world.



14 Site SEC for injection moulding versus production rate

the same process at the same production rate. The solid line is a power law best fit to the available data. The correlation coefficient R^2 is not exceptional but the overall trend from the data is clear.

The average of all the SEC results for injection moulding in the Tangram study is $3.075 \text{ kWh kg}^{-1}$ and the average of the SEC results reported by EURecipe is $3.118 \text{ kWh kg}^{-1}$. It is therefore highly likely that the EURecipe data would show a similar trend but it is not possible to verify this due to the failure of EURecipe to correlate the SEC to the production rates.

It is now possible for any injection moulding site to benchmark itself against established practice and other similar sites. This can be carried out by comparing the internal site SEC (kWh kg^{-1}) at a given production rate with the benchmark site SEC from Fig. 14 at the same production rate.

It should be noted that the benchmark SEC is an average value and some companies have a considerably lower site SEC for the injection moulding process particularly in the area of lower production rates. Achieving the benchmark SEC is not a sign of good practice, only a sign of average practice.

Several points should be noted with regard to this analysis:

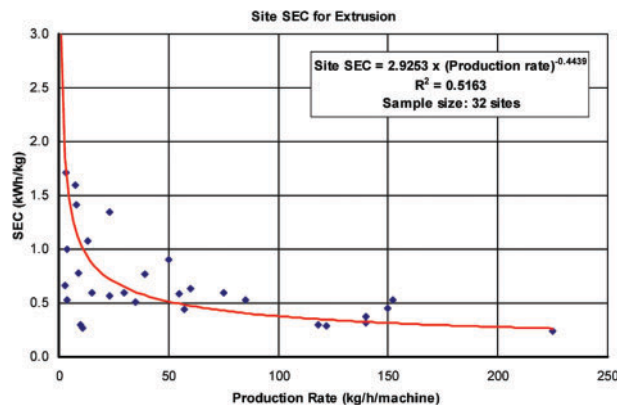
- (i) the machines used at any site will generally be of varying sizes but for the purposes of this analysis the average consumption is assumed. This assumption does not appear to introduce any large anomalies
- (ii) a large degree of the scatter seen in Fig. 14 is thought to be due to machines being operated at differing levels of production efficiency, i.e. poor or good overall machine utilisation
- (iii) the polymer processed would be expected to have some effect but the available data shows that this has little effect in the overall assessment.

Extrusion

A similar analysis is possible for extrusion and this has been carried out for 32 extrusion sites throughout the world (internal data, Tangram Technology Ltd) to produce Fig. 15.

As for Fig. 14, Fig. 15 allows the site SEC to be benchmarked against external data for the same process at the same production rate.

The average of all the SEC results for extrusion in the Tangram study is $1.559 \text{ kWh kg}^{-1}$ and the average of the SEC results reported by EURecipe is



15 Site SEC for extrusion versus production rate

$1.506 \text{ kWh kg}^{-1}$. Again, it is highly likely that the EURecipe data would show a similar trend were it to be corrected for production rate.

It is now possible for any extrusion site to benchmark itself against established practice and other similar sites using the methods of the section on 'Injection moulding' but again it is emphasised that achieving the benchmark SEC is not a sign of good practice, only a sign of average practice.

Other processes

Injection moulding and extrusion are the most common processes and data is therefore reasonably easily available. Data are also available for thermoforming (with and without the extrusion component), for extrusion blow moulding and for injection blow moulding. The data sets for these processes are smaller but do allow some valuable conclusions on process energy efficiency but naturally with a lower degree of confidence.

Energy efficiency versus production rate

Despite the reservations outlined regarding machine size, machine utilisation and polymer type (and the variations that these will inevitably introduce) the overall shape of Figs. 14 and 15 illustrate an important point, improving energy efficiency in plastics processing in no way contradicts improving processing output.

Unlike cars where it is recommended that you drive slowly to achieve better energy efficiency, in plastics processing the harder you push the machine the better the energy efficiency of the overall process. This comes back to the high fixed loads of operating most plastics processing machinery. Increasing output amortises the fixed loads over greater outputs and improves the overall energy efficiency. Being green can also be profitable.

Summary

External site benchmarking is possible for the main plastics processing methods but the high production rate dependence of energy use in plastics processing makes correction for production rate essential. The use of data uncorrected for production rate will inevitably lead to misleading information and incorrect conclusions regarding performance.

External benchmarking: machine

The analysis of a site SEC corrected for production rate provides a useful external benchmarking on a global

basis but many companies would also like to be able to benchmark individual machines against one another to determine which is the most energy efficient. The authors will now look at external benchmarking at the machine level both injection moulding and extrusion.

Process dependence

As with the dependence of the site SEC on the process, there is a high variation in machine SEC depending on the process used.

Average machine SEC data (including the machine base load) is available from only one source and this is shown in Table 5.

Production rate dependence

Initial inspection of Table 5 might lead to the conclusion that the sample companies used to illustrate section on 'Internal benchmarking: site' were performing better than average. However, the sample process SEC values have not been corrected for production rate. As with the site SEC, the energy efficiency at machine SEC level is extremely rate dependent. The overall output rate matters and it is essential that the average results from Table 5 be clarified in terms of rate dependence. This will be carried out for the injection moulding and extrusion processes.

Processes

Injection moulding

The machine SEC can be corrected for production rate dependence by calculating the production rate for the individual machine and tool combination in terms of kg h^{-1} .

This is carried out by:

- (i) monitor the machine to determine the average power usage over time
- (ii) calculate/measure the shot weight per cycle – including sprues and runners as these have also been through the process – and use the cycle time to calculate the production rate in kg h^{-1}
- (iii) use the energy usage and the production rate to calculate the machine SEC in kWh kg^{-1} .

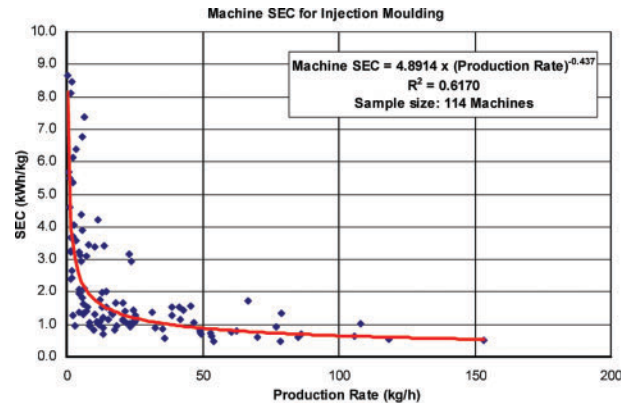
This has been carried out for 114 injection moulding machines throughout the world (internal data, Tangram Technology Ltd) to produce Fig. 16.

Figure 16 is only for electricity usage and allows the SEC for individual machine/tool combinations site to be benchmarked against external data for the same production rate. The solid line is a power law best fit to the available data. The correlation coefficient R^2 is better than the site SEC data for injection moulding and this is almost certainly due to the removal of the site base load effect. As with the site SEC data, the overall

Table 5 Average machine SEC for injection moulding and extrusion

| Process | Average machine SEC*, kWh kg^{-1} | Sample process SEC (see section 'Internal benchmarking: site'), kWh kg^{-1} |
|--------------------|--|--|
| Injection moulding | 2.20 | 1.575 |
| Profile extrusion | 0.57 | 0.447 |

*Tangram Technology Ltd: internal data from 114 injection moulding machines and 69 extrusion machines throughout the world.



16 Machine SEC for injection moulding versus production rate

trend from the data is clear and shows decreasing machine SEC with increasing production rate due to the greater amortisation of the machine base load.

It is now possible for an injection moulding site to benchmark individual machine and tool combinations against established practice and other similar sites. This can be carried out by comparing the internal machine SEC (kWh kg^{-1}) at a given production rate with the benchmark machine SEC from Fig. 16 at the same production rate.

Again the benchmark machine SEC is an average value and some machine/tool combinations companies have a considerably lower machine SEC particularly in the area of lower production rates. Achieving the benchmark machine SEC is not a sign of good practice, only a sign of average practice.

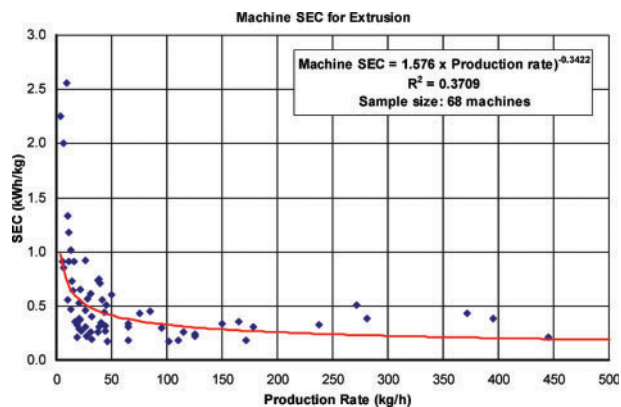
Several points should be noted with regard to this analysis:

- (i) the machines used at any site will generally be of varying sizes/clamp forces but the graph does not take this into account and appears reasonably consistent without any reference to the absolute machine size
- (ii) the machines considered are all standard hydraulic machines and no 'all-electric machine' data has been used for Fig. 16. All-electric machines are fundamentally different and we are in the process of collecting similar data for all-electric machines to produce a similar chart. The lack of a significant installed all-electric machine population base makes this a long term task
- (iii) a large degree of the scatter seen in Fig. 16 is thought to be due to machines being operated at differing levels of production efficiency, i.e. poor or good individual machine utilisation
- (iv) the polymer processed would be expected to have some effect but the available data shows that this has little effect in the overall assessment.

Extrusion

It is also possible to benchmark extruders using a similar method and this has been carried out for 69 extrusion machines throughout the world (internal data, Tangram Technology Ltd) to produce Fig. 17.

As for injection moulding machines, Fig. 17 allows extrusion machines to be benchmarked against external data for the same production rate. It is now possible for any extrusion site to benchmark itself against established



17 Machine SEC for extrusion versus production rate

practice and other similar sites using the methods of the section on 'injection moulding' but again it is emphasised that achieving the benchmark SEC is not a sign of good practice, only a sign of average practice.

Similar notes to those for injection moulding apply, i.e. no account has been taken of the nominal output of any extruder or of the L/D ratio or of the differences between single screw and twin screw machines, the scatter is thought to be due to machine utilisation and no effect relating to material is seen in the results.

Other processes

Injection moulding machines and extruders are the most common plastics processing machines but we also have some limited data on extrusion blow moulding machines and injection blow moulding machines that shows similar results. The data sets for these machines are again smaller but do allow some valuable conclusions on process energy efficiency but naturally with a lower degree of confidence.

Energy efficiency versus production rate

It appears that the machine level results confirm the site level results, i.e. improving energy efficiency in plastics processing in no way contradicts improving processing output. Increasing output amortises the fixed loads over greater outputs and improves the overall energy efficiency. Being green can also be profitable at both the site and the machine level.

Summary

External machine benchmarking is possible for the main plastics processing methods but the high production rate

dependence of energy use in plastics processing makes correction for production rate essential. The use of data uncorrected for production rate will inevitably lead to misleading information and incorrect conclusions regarding performance.

Conclusions

Our work in the field of energy management in plastics processing has brought us into contact with a wide range of plastics processors around the world and we have seen, at first hand, that many companies are trying to start to manage their energy consumption. Unfortunately, this has been hampered by the lack of any formal framework for their energy management activities and a lack of understanding of the first principles. The objective of this paper has been to provide an easily understood structure that will generate real improvement rather than paper and statistics.

Energy management can start at the simple internal measurements for performance assessment and prediction based on existing practices. It can then move on to more detailed benchmarking of the site based on the relevant production volume and finally encompass individual machine benchmarking based on individual machine production volumes.

There are potentially some very interesting discussions that arise out of these measurements and some further areas that we would like to investigate. At this stage the author would simply like to pose some questions.

1. Is the concept of a company 'biological' energy signature a real one and if it is then how do we change it and improve it?
2. Can we improve on the benchmarking data and reduce the scatter by accounting for machine utilisation?
3. Why is it that all the machines (injection moulding and extrusion) fit broadly onto a single process curve despite the huge varieties in machinery in the market and the differences in energy efficiency that are claimed for each type of machine?

Acknowledgement

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