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Energy consumption and weight loss in pig chilling

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Introduction

The substantial increase in the cost of energy over the last decade has focussed attention on the amount of energy consumed, particularly when new or modified processes are proposed. This is especially true of new pig chilling processes (James et al., 1983; Gigiel & James, 1983; Gigiel & James, 1984) which, in seeking to reduce both weight loss and process time, use low air temperatures and high air velocities to obtain faster rates of chill. Both factors greatly increase the power required by the refrigeration plant.

To compare the economy of new processes data are required on the amount and cost of energy and its relationship with weight loss for current pig chilling processes. This paper describes the results of surveys carried out at five abattoirs to measure the energy used and weight loss during conventional pig chilling operations.

Experimental

Five UK chilling systems were monitored over a 24 hour mid-week period during the summer. Four of them were single stage processes where hot pigs were loaded into the chiller immediately after weighing and grading. The fifth was a two stage process where hot pigs were passed through a pre-chiller for 1h 5m after weighing and grading before being placed in a chill room. In all cases the pigs were held overnight and unloaded the following morning.

Measurements

The electrical power supplied to the evaporator and condenser fans, the compressors and the defrost heaters were measured separately using portable power meters and recorded continuously on chart recorders. Two types of meter were used, either Northern Design ND 8310 meters, measuring true power to ±0.4% of the range, on balanced three phase and single phase supplies up to 900 kW, or YEW 3433 clip on auto-ranging meters measuring true power, to ± 1% of the reading, ± 0.5% of the range, on balanced 3 phase supplies up to 200 kW.

Air velocity was measured with an Airflow Developments Ltd., Edra Five anemometer near the hind leg of approximately every tenth pig along every other rail of each chill room, the orientation of the measuring head being aligned to give the maximum reading at that point. In areas where the velocity varied greatly within a small region readings were taken at smaller intervals. The anemometer was accurate to ± 0.05 m/s for velocities above 0.2 m/s but was unreliable at lower velocities. Temperatures were measured, using multi-point probes, in the hind leg and loin of three pigs in each chillroom, in positions of high, low and intermediate air velocity, and chosen to be of near average weight and fatness for that room. The probes consisted of 5 thermistors fixed at 10 mm centres on a 0.5 mm diameter rod and coated with Araldite surface coating resin. Air temperatures near the hind legs of the three pigs, at the return to the evaporators and outside the chillers were measured using individual thermistors. The temperatures were recorded on a Grant cassette data logger, accurate to ± 0.4 °C.

Between 10 and 50% of the total number of pigs from each chiller were weighed immediately before loading and again on unloading 20 to 22 hours later on the abattoir scales, read to ± 0.1 kg. In the two stage system the pigs were also weighed when they were transferred from the first to the second stage of the process. The position of these pigs in each chill room was chosen to represent the range of conditions in the whole chiller. The total number of pigs in each chiller and their total weight were taken from the MLC weighing and grading records.

Results

In the five abattoirs the chill room capacities ranged from 200 to 500 pigs and at the time of the survey utilization was between 38 and 100% (Table 1). The average weight of a pig in four of the systems was similar, approximately 65 kg, while pigs in system 1 were lighter averaging 42.7 kg (Table 1). Average values for the air velocity, obtained from readings taken every 10 pigs, ranged from less than 0.2 to 1.5 m/s. Maximum and minimum values, obtained from all the readings, were from below 0.2 to 2.2 m/s (Table 1). Weight loss varied by a factor of almost 2 from 1.85 to 3.6% with the two stage chilling system recording a loss of 2.06% that was near the lowest value measured.

Air temperatures varied in both time and space within each chiller but were uniform and steady (to ± 1°C) prior to unloading (Table 1). The temperature of the majority of the pigs had been reduced to within 1°C of the air temperature before unloading with the exception of those in low velocity areas of chiller No. 1 where deep leg temperatures of 10 °C were recorded.

The total electrical energy used by each system in the 24 hour monitoring period is shown in Table 2 together with the specific energy used to chill each kilogram. The latter values were obtained by dividing the total energy used by the total weight of pork chilled and vary by a factor of 3.7 between systems.

The cost of the total energy per kg of pork used at each abattoir, taking account of maximum demand charges, standing charges and separate day and night tariffs, is shown in Table 2. Since each abattoir paid for electricity under a different tariff structure an approximate average value of 1p/MJ (3.5 p/kWh) was used to calculate the cost of their energy for comparative purposes (Table 2). Comparative costs per kg differed my more than 3 fold between abattoirs.

The total energy used for pig chilling in each system was divided into a base demand and a product demand (Table 3). The former is the energy used to run the evaporator fan and maintain the room at its design temperature and the latter is the additional energy needed to remove the product load, i.e. the heat given off from the warm pigs. The base and product demands were calculated from the graphs of energy used in each hour period, plotted against time. Figure 1 shows the graph for chilling system No. 3 in which there were three peaks. The first and largest is when hot pigs were loaded into the chiller, this falling exponentially to the base demand. The second, coming at the end of this period, was due to the evaporator being defrosted electrically and the third was due to the coincidence of hot air entering the chiller during unloading the pigs and a second defrost. Thus the total energy used, the area under the curve, can be proportioned into the base and product demands. Energy curves for the other four rooms were similar.

Whilst the base demand (B) is independent of the number of pigs chilled, assuming that the weight range of the pigs is small the product demand (P) is directly proportional to that number. Consequently the total demand for energy (E) can be expressed by

$$E = B + nP$$

where n is the number of pigs chilled. Using this relationship the total energy consumed per kg of pork chilled by each system when fully loaded was estimated (Table 3). System 1, the most energy intensive, used 2.3 times as much energy as system 3, the most economic single stage plant. For the two stage system 5, the energy used in each stage was separately adjusted for room utilisation and the total shown in Table 3. This system used 2.9 times as much energy as system 3.

The specific energy consumption of the evaporator fans was obtained by dividing the total energy used by the fans by the weight of pork in the chiller when full and is shown in Table 3 and plotted against the specific total energy consumption in Figure 2.

Discussion

The specific energy consumption for 24h batch chilling of pigs in the abattoirs surveyed ranged from 97 to 360 kJ/kg (Table 2). However it is clear that the percentage utilization (i.e. the number of pigs being chilled compared with the total capacity) at the time of the survey has a substantial effect on this figure. In any comparison between chilling systems this factor must be taken into account and the range is then reduced to 89 to 258 kJ/kg. None of the chilling systems have novel features and therefore the minimum energy consumption for 24 hour batch chilling in the UK in summer cannot be more than 90 kJ/kg, using existing technology, and other chillers may even achieve less.

There is little point in achieving minimum energy consumption if the weight loss rises as a result, since weight losses are of the order of 2% and cost 1.6p/kg (with pork sold at 80p/kg) while energy costs are only of the order of 0.1p/kg. However systems 3 and 4 which had the lowest specific energy consumption also had low weight losses. Since the only other abattoir with a low weight loss used a 2 stage process, this suggests that for single stage 24 hour batch chilling systems the factors which reduce energy consumption may also reduce weight loss. It also sets a standard against which all other chilling systems can be compared. The survey was not extensive enough to be able to prove beyond reasonable doubt what practical factors influence weight loss and energy consumption, but in 24h batch chilling systems it gave a good indication.

The environmental conditions that theoretically minimise weight loss during chilling have been well discussed (Malton and James, 1984). During the initial stages a combination of high air velocities and low temperatures are required to rapidly lower the surface temperature thus reducing the vapour pressure which is the driving force for evaporation. As the surface temperature approaches the value ultimately required in the meat the air temperature should rise to this desired value and the velocity reduced to minimum needed to hold the surface constant. These conditions need to be maintained until the whole carcass has reached the desired temperature when effectively chilling has finished. Conditions should then be those suitable for storage, i.e. a high humidity, very low velocity and constant temperature.

Experiments have shown that using extreme conditions all the heat can be extracted in a three hour process with a resulting overall weight loss of less than 1% (Gigiel & James, 1984). However most existing systems work on a 24 hour cycle and use a single set of conditions throughout the chilling process. In this situation the choice of operating conditions is a compromise between the conflicting requirements, especially in terms of air velocity of the three stages. The results of this survey indicate that overall it is better to satisfy the requirements of the second and third stages for a low air velocity if low weight losses are to be achieved. There is little to be gained by installing a rapid chilling system if, after the pigs have been chilled, they are then held in conditions which cause high weight loss. For example system No. 5 in this survey did not save as much weight as the slower chilling system No. 4.

The total air movement over the 24 hour period may therefore be a practical guide to weight loss during this time. A measure of this total air movement is the integral of the power supplied to the evaporator fans related to each kg of pork chilled. Thus the specific fan energy consumed in 24 hours (Efan) is

$$\text{Efan} = \frac{\int_0^{24} p\,dt}{w}$$

where p is the power supplied to the fans, t is time and w is the total weight of pigs in the chiller.

This factor is also very important in specific energy consumption, not only because of the direct consumption of energy by the fan motors but also because the ensuing heat must then be removed by the refrigeration plant from the chiller thus adding to the refrigeration load and hence compressor power.

Thus specific evaporator fan energy consumption may be a useful guide to assessing the performance of 24 hour batch chilling systems with regard to energy consumption and weight loss. Figure 2 shows that this may be possible, as the only point not in linear relationship was that for the two stage process. However there were an insufficient no of chillers in the survey to make a meaningful statistical correlation between these factors.

This paper has shown that existing 24h batch pig chillers can achieve an energy consumption of 90 kJ/kg and a weight loss of 2%. Any chiller not performing as well as this could be improved using existing technology, and new chillers should be at least as good. Since the cost of weight loss is approximately 10 times the cost of the energy used in chilling it must be of prime concern. Any saving in weight loss may consequently justify the expenditure of greater amounts of energy. A useful indicator of weight loss and energy consumption may well be the specific energy consumption of the evaporator fans. The final point is that the biggest factor increasing specific energy consumption in practice is the extent to which the chillers are used and efforts should therefore be made to devise systems in which the chillers are always used to their maximum capacity.

Future work will be to develop chilling and refrigeration systems to overcome the shortcomings of existing systems.

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Table 1 For each chiller the number of pigs, their total and average weight, the maximum number that the chiller will hold, the average, minimum and maximum air velocity, the air temperature at the end of chill and the weight loss during chilling

Chilling system ID No.	No. of pigs in chiller	Total wt. of pigs in chiller kg	Av. wt. of pigs in chiller kg	No. of pigs in chiller when full	Av. air vel nr. hind leg of pigs m/s	Min & max air vel m/s	Air temp at end of chill C	wt loss %
1	76	3245	42.7	200	1.5	<0.2-2.2	6	3.5
2	465	29713	63.9	465	0.5	0.2-1.3	1	2.6
3	227	14714	64.8	270	0.5	0.3-1.0	2	2.17
4	320	21440	67.0	500	<0.2	<0.2-0.5	5	1.85
5	375	22249	64.1	780*	0.8	0.5-4.4	3	2.06
		2nd stage		500	0.7	<0.2-1.8		

* Assuming every position on the 1st stage conveyor is used and it runs for 7 hours.

Table 2 The total and specific energy used in 24 hours and the comparative and actual cost of pig chilling for each system.

Chilling system ID No.	Total energy used in 24h MJ	Total energy used in 24h per kg of pork chilled kJ/kg	Comparative cost of pig chilling p/kg	Actual cost of pig chilling p/kg
1	1156	360	0.36	0.35
2	3352	112	0.11	0.11
3	1429	97	0.1	0.13
4	2538	137	0.14	0.13
5	6029	271	0.27	0.39

Table 3 The total energy used, divided into base and product demands the specific energy used and the energy consumed by the evaporator fans in 24 hours if the chiller were fully loaded, for each chilling system.

Chilling system ID No.	Base demand MJ	Product demand MJ	Total energy used per kg of pork chilled if chiller fully loaded kJ/kg	Energy used by evap. fans per kg of pork chilled if chiller fully loaded kJ/kg
1	778	378	208	52.9
2	1728	1624	112	26.3
3	781	648	89	20.5
4	1332	1206	96	23.5
5	3658	2371	258	32.8

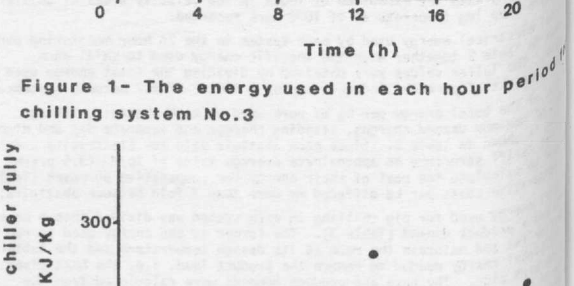

Figure 1- The energy used in each hour period fo chilling system No.3

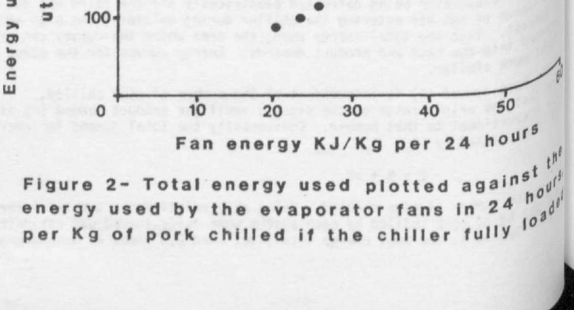

Figure 2- Total energy used plotted against the energy used by the evaporator fans in 24 hours per Kg of pork chilled if the chiller fully loaded