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Electric stunning: a humane slaughter method for trout

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Abstract

The most common commercial slaughter method for portion-sized rainbow trout is asphyxiation in ice slurry. This method is however widely believed to expose the fish to unnecessary pain and suffering. The industry is consequently seeking an alternative method, which offers improved welfare of the fish at slaughter. Electric stunning of fish in water is identified as a suitable method. Parameters of an electric field that stuns trout beyond the point of recovery without causing carcass damage have been identified. A 60-s exposure to a 1000-Hz sinusoidal electric field of 250 V/m r.m.s. is recommended. Several practical options for implementing this method on commercial trout farms are identified and equipment for one of these approaches has been built and tested. The UK trout industry appears to be moving towards electric stunning as its preferred slaughter method.

Keywords: Welfare; Trout; Slaughter; Electric stunning

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1. Introduction

Most rainbow trout in UK are grown in fresh water and are slaughtered at a weight of 350–400 g without bleeding. The usual slaughter method is to pump the fish directly from raceways, de-water them, and deliver them into an ice slurry where they asphyxiate. This method is now considered to cause unacceptable suffering since there may be a prolonged period of stress before death. Time to death when fish are removed from water has been shown to be around 2 min at 20 °C and as long as 14 min at a temperature of 2 °C (Robb et al., 2000; Southgate and Wall, 2001). Spreading awareness of fish welfare has resulted in the need for a more humane slaughter system. In 1996, the Farm Animal Welfare Council of UK (FAWC, 1996) expressed the view that none of the methods used to kill trout commercially were acceptable in terms of animal welfare.

The three main indicators of humane slaughter are that excitement, pain, and suffering in the pre-slaughter handling is minimised, that the animal becomes insensible to pain within less than 1 s of the application of any aversive stunning or slaughter procedure, and that this state of insensibility persists until the animal is dead. These features are a legal requirement for animal slaughter in UK, being a part of the “Welfare of Animals (Slaughter or Killing) Regulations (1995)”.

Slaughter is generally a two-stage process. The animal is first stunned to make it insensible to pain. Death then is induced by various methods that include bleeding, stopping the heart, or preventing access to oxygen. These two stages can occur together but where they are distinct operations, the stun-to-kill time must be minimised to prevent any recovery of consciousness before death occurs.

UK trout farms often operate with few staff and low capital investment. The required slaughter rate on a moderate-sized farm may exceed 10 000 fish/h, and may need to be carried out at night and at short notice. It is therefore important that the operation can proceed rapidly, requires only one man to achieve it, and is safe for the operator. Since trout are sold to consumers as fresh or smoked fillets and as entire fish, blood spotting and other haemorrhages must be avoided. Slaughter of trout by asphyxiation in ice slurry meets these requirements. Any replacement system must meet similar operational and quality constraints if widespread uptake is to be achieved without structural alterations to the industry.

A range of other methods is used to slaughter fish around the world. Some of these have the potential to meet the operational requirements of UK trout farms, others to meet the emerging standards for fish welfare at slaughter; however, none are able to satisfy both demands. Fish slaughter methods have been recently reviewed by Robb and Kestin (2002). The most relevant methods they identify are mechanical percussion, CO_2 narcosis, cold shock, anesthesia, and electric stunning.

Mechanical percussion is used to slaughter salmon and many other species. However to ensure permanent loss of sensibility, the blow to the head must be well aimed and powerful. Salmon are bled immediately after stunning. This ensures a rapid death before sensibility can return. Within the trout industry, the large numbers and low values of individual fish make individual percussion and bleeding by hand uneconomic. High-speed machinery to singulate, orientate, percuss, and bleed fish automatically and reliably would be complex and expensive.

Slaughter by immersion in CO_2-saturated water has also been widely used. Immersion in CO_2 results in narcosis and loss of brain function; however, it requires several minutes to take effect. During this time, the fish appears to be severely distressed (Robb et al., 2000). This slaughter method is less prevalent now due to increased concern about fish welfare.

In warm climates, when fish are immersed in ice water slurry, the temperature shock can cause the fish to become immobile and appear insensible. Rapid cooling also promotes good flesh quality. Whether the fish are really made insensible by this treatment is unknown. It is possible that the fish remain conscious but paralysed. Cold shock is seldom used in temperate countries since the fish are likely to be already acclimated to relatively low-temperature water (Robb and Kestin, 2002).

In Australasia, fish are sedated adding the fish anesthetic, iso-eugenol to the water. This is a food grade substance based on clove oil. Its addition to water results in no visible aversive response by the fish, but within 30 min they appear to be insensible (Robb and Kestin, 2002). Barriers to the use of this technique in UK include the cost of overcoming the legislative requirements to introducing a new medication and the possible public response to eating fish that could be perceived as having been poisoned.

Commercial slaughter of many food animals is by electric stunning prior to bleeding. If the voltage is applied across the body of the animal, care is needed to avoid blood spotting caused by bursting blood vessels. The use of excessive current is often associated with broken bones and haemorrhages in poultry (Bremner and Johnson, 1996; Richardson and Mead, 1999). The use of high-frequency waveforms has been shown to reduce haemorrhages (Simmons, 1989; Gregory, 1998). Where the electrical stun is applied directly to the head of the animal, haemorrhaging is confined to this region and so is commercially unimportant. The direct application of an electric stun to the heads of individual fish has been shown to kill or stun fish (Kestin et al., 1997). However, individual application of electrodes to portion-sized trout is likely to require a complex and expensive mechanism.

Some commercial electric slaughter systems are currently available where the fish are placed in a bath of water with a 50-Hz (mains) electric field strong enough to produce rapid insensibility. This system has the benefit that the fish are not removed from the water before they are insensible or dead. This slaughter method can result in quality problems due to haemorrhages and broken bones (Gregory, 1998). An alternative commercial approach has been to use a weaker electric field applied for long periods to de-watered fish in a tank. It is likely that the fish exposed to these low voltages are not stunned but electro-immobilised, death eventually occurring due to exhaustion of the muscle energy reserves (Robb and Kestin, 2002).

Despite the failure of current electric stunning systems to meet the required welfare and carcass quality standards, we felt that an in-bath electric stunning system offered the best chance of meeting the needs of the industry. We therefore investigated a range of electrical parameters to identify a method that would provide both humane slaughter and a damage-free carcass. Following this, we identified some methods for applying the stun in a variety of commercial environments and developed one approach to a pre-prototype stage. This has been tested in commercial harvests on trout farms.

This paper outlines the identification of acceptable electrical parameters for humane slaughter, discusses a range of approaches to apply the stun under commercial conditions, and describes the design and testing of pre-prototype equipment following one of these approaches.

2. Electrical stun parameters

A series of experiments was carried out to investigate the effect of varying the electrical parameters of the stun on the welfare of the fish and on the quality of the carcass. These are summarised here and are reported by the authors in more detail elsewhere (Robb et al., 2002).

The main parameters that characterise an electric stun are the duration for which the voltage is applied, the voltage across the animal, and the electrical waveform used. These affect both the welfare of fish at slaughter and the quality of the carcass. The duration, the voltage, and the frequency of the electrical waveform were varied in these trials to identify values that provided acceptable levels of both welfare and quality. A sinusoidal waveform was used for all experiments.

For most experiments, the fish were stunned in a small rectangular water tank with plate electrodes covering two opposite walls of the tank. An electric field was created by connecting the electrodes to an impedance-matched audio amplifier driven by a sine wave generator. Fish in small groups were taken from the raceway in which they were being grown, placed in water in the tank, and the electric field was applied for the required duration. Some experiments to determine the effect of current on insensibility duration were carried out by applying electrodes directly to each side of the head of fish while they were out of water. After stunning, the fish were placed in fresh water to monitor and record signs of recovery. Trials were in water with conductivity varied between 0.05 and 0.07 S/m (500–700 μS/cm).

2.1. Assessment criteria

The criteria used to evaluate welfare were that at the onset of the electric, the fish should become rapidly insensible, and that following removal from the electric field, the fish should be dead, or remain insensible until dead. As fish recover consciousness after an electric stun, they show irregular and then rhythmic motion of the gill covers, followed by uncoordinated body motion. Finally, the fish rights itself and starts to swim slowly in a coordinated way. Kestin et al. (1995) showed that prior to the return of rhythmic gill motion, the brain is likely to be showing an epileptiform brain pattern, and so the fish can be assumed to be insensible.

Preliminary quality work investigated the use of a range of quality indicators including the incidence of haemorrhages, frame damage, gaping, flesh texture, and flesh colour. Haemorrhages and frame damage were identified as the quality indicators, where ice slurry slaughter was superior to the electric stunning. However, the incidence of frame damage was low, and so assessment of various stun parameters with this criterion would have required large numbers of fish. We considered that the incidence of frame damage and haemorrhages was likely to be correlated, both being caused by muscle spasms, therefore opted to monitor and minimise the incidence of haemorrhages visible in the fillets. The objective was that this incidence should not exceed that observed in fish killed by asphyxiation in ice slurry following normal industry practice.

After slaughter, the trout were filleted and the incidence and size of haemorrhages were identified. Visible haemorrhages in each fillet were counted and subjectively rated on a 5-point scale for size and severity. Photographs of five haemorrhages spanning a range from commercially insignificant (one point) to haemorrhages that would result in carcass being rejected for fresh sale (five points) were used to guide the assessment. The product of the number and severity of the haemorrhages was used as a haemorrhage score for each fillet. The mean haemorrhage score was calculated for each batch of trout.

2.2. Results

Sample results indicating how the duration of insensibility varied with exposure duration are given in Fig. 1. This figure shows the results of a trial using a 50-Hz, 230 V/m r.m.s. electric field at five exposure durations. Ten fish were used with each exposure duration. As the duration of exposure to the electric field increased, the period of insensibility after removal of the field also increased and an increasing number of fish died or remained insensible until dead. Only one fish, out of the 50 used, recovered opercular motion after a duration of insensibility which exceeded 120 s and no fish recovered following a 30-s exposure to the electric field.

After only 1 s exposure to the electric field, the trout was insensible for 25–60 s. This indicates that the onset of insensibility occurs in less than 1 s and as such may be considered rapid.

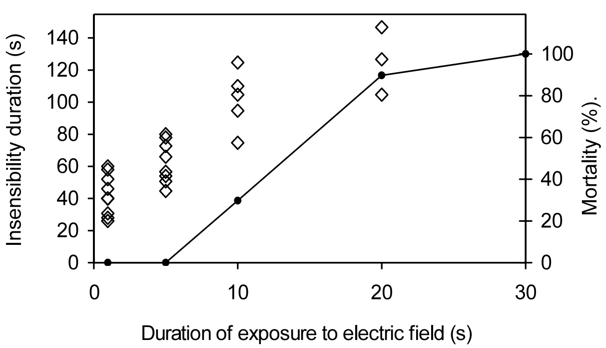

Fig. 1. The effect of duration of exposure to electric field on time to recovery of rhythmic gill motion (◇) and on mortality (line). Electric field 230 V/m r.m.s., 50 Hz. 10 fish per exposure duration.

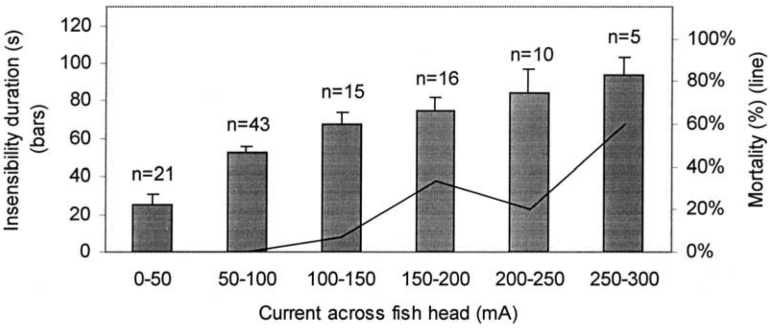

Fig. 2. The effect of current magnitude on time to recovery of rhythmic gill motion (bars) and on mortality (line). 5-s exposure to 50 Hz electric field. Error bars show standard error.

Fig. 2 shows that the duration of insensibility increases progressively with the current passed directly through the fish head. In a later experiment, fish in a waterbath were exposed to 1000 Hz electric fields of 166 and 250 V/m r.m.s. for 60 s. 50% of the fish exposed to 166 V/m recovered, while none of those exposed to 250 V/m recovered.

Fig. 3 shows that as the frequency of the waveform increased, the duration of insensibility decreased. The period of insensibility following a 1000-Hz electric stun was about half that which followed an equivalent 50 Hz stun. This phenomenon is found in many animals and is sometimes called the skin effect; however, consideration of frequencies and the magnitude of this effect clearly shows that this is not caused by the electrical transmission phenomena known by this name.

Fig. 4 shows that the haemorrhage score for trout killed using a high-frequency electric field is lower when a 50-Hz field is used. A further experiment showed that the haemorrhage score remained constant when the duration of exposure to the electric field was increased.

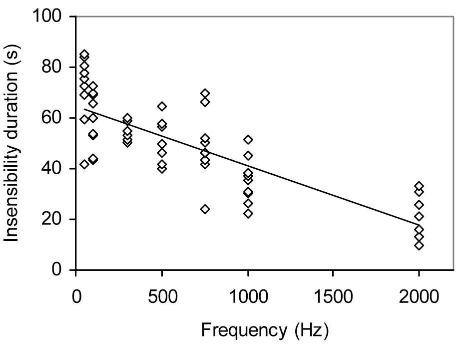

Fig. 3. The effect of waveform frequency on time to recovery of rhythmic gill motion. Electric field: 215 V/m, exposure time: 5 s. 10 fish per frequency condition.

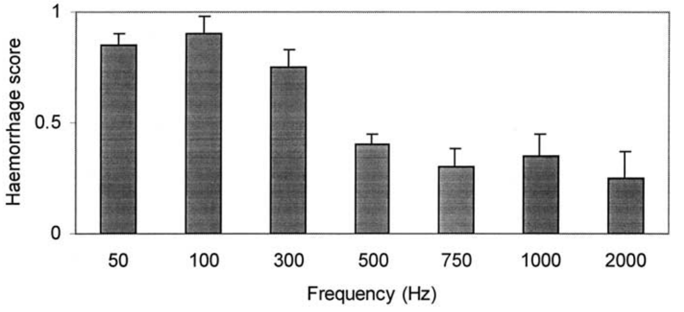

Fig. 4. The effect of waveform frequency on the haemorrhage score. Bars show standard error. Electric field: 215 V/m, 5-s exposure, fish killed by percussion while insensible. 10 fish per frequency condition.

2.3. Choice of electrical parameters

The results indicate that insensibility can be achieved within 1 s of exposure to the electric field but that to ensure this state is permanent, exposure must be prolonged. The mechanism by which the stun becomes irrecoverable is unknown, but is probably because the fish brain dies due to lack of oxygen when perfusion of blood is temporarily interrupted during the stun because the heart is stopped. Comparison of Figs. 1 and 2 suggests that a 1-s exposure to current directly across the fish head of about 50 mA is equivalent in effect to 1 s exposure to a 230 V/m electric field in water. This field strength will have resulted in a current density of 1.2–1.6 mA/cm^2 in the water. A 36-fold increase in power from this level (50–300 mA) results in around 50% mortality while increasing the stun duration and hence power requirement by a factor of 30 results in 100% mortality. It therefore appears that the use of a low-strength electric field for an extended duration if likely to be at least as power efficient as a short exposure to a high-strength field.

Priorities for selecting the parameters to be used for trout slaughter were that the system should meet the requirements for humane slaughter, and that it should not increase the incidence of haemorrhages. To achieve this, a low-voltage field, with high frequency and long exposure time was selected. A suitable set of parameters was found to be an electric field of 250 V/m r.m.s. using 1000 Hz sinusoidal voltage for a duration of 60 s.

A final carcass quality check was made before designing and building equipment for applying this stun. One hundred trout were slaughtered using the recommended electric stun parameters and 100 by ice slurry. The 400 fillets from these fish were randomised and individually assessed for visual quality in a blind trial. The assessors used were the fish buyers for two of the largest supermarkets in UK. The fish slaughtered by electric stunning were found to be of marginally better quality than those slaughtered in ice slurry, but this difference had no statistical significance.

3. Approaches to applying the stun

We have identified three basic approaches to applying an electric stun to trout. The most suitable method for any particular farm will depend on the quantities of trout being harvested, the rate at which they must be delivered, the conductivity of the water, and the availability of equipment, capital, and labour.

The simplest approach to applying an electric stun approach is the use of a batch system, where fish are placed in a tank and exposed to an electric field until they are permanently insensible. Another alternative approach is to use a continuous flow system, where the fish are moved along a channel through a volume in which an electric field is maintained. The length of this channel must be sufficient to ensure that the fish do not exit the electric field until they are permanently insensible. A third approach is to reduce the volume of the system by flowing the fish into an electric field so that they become insensible, then collecting the insensible fish at high density for the remainder to the exposure duration necessary to ensure permanent insensibility. The motivation for this third approach is to reduce the capital cost of the equipment required to generate the high-frequency sinusoidal voltage, since the power required to sustain an electric field in a volume of water is proportional to the volume of water. Water of conductivity 0.07 S/m requires a power of 4.38 W/l to sustain an electric field of 250 V/m r.m.s.

3.1. Batch stunning

Trout are removed from the raceway, placed in a stunning tank, and the electric field is applied. After exposure to the electric field for 1 min, the field is switched off and the trout carcasses removed from the tank. A 50-l tank could be used to slaughter a 10 or 20 kg batch of trout in this way. This would require a power of 220 W assuming the water conductivity was 0.07 S/m. A power supply for this tank could be based on a normal domestic amplifier and so would be relatively cheap.

The slaughter rate which could be achieved is dependent on the loading and unloading time. Assuming loading and unloading of a 50-l tank can each be achieved in 1 min using a brail, then 20 batches could be processed per hour, achieving a harvest rate of 200–400 kg/h. This would be labour-intensive but cheap and reliable slaughter system.

An increase in the slaughter rate using batch stunning might be achieved using a larger tank and more sophisticated loading and unloading system. A larger tank would require a proportionately larger and more costly power supply. Large increases in processing speed by increasing batch volume are likely to be uneconomic due to the limitations of loading and unloading times. In a large tank, the stunning volume could be subdivided by electrodes to reduce the total voltage required and so increase operator safety, however this may impede the loading and unloading processes.

An automatic batch stunning system which works for long periods at a relatively low rate might be achieved by immersing the stunning tank in a raceway with automatic gates where the fish can flow in and out of the unit without the need for a pump. Such a system might be suitable where the fish are slaughtered very close to a processing line. By matching the slaughter speed to the processing speed, fish could be processed, when freshly slaughtered, and the need for a cooled storage location avoided. In the design of this equipment, measures may need to be taken to limit the upstream propagation of the electric field to avoid pre-slaughter shocks in the raceway.

The authors are aware of farms where experiments in batch electric stunning have resulted in very poor carcass quality. Reasons for this poor quality can probably be attributed to the use of a 50-Hz sinusoidal waveform and to the use of rod or grid electrodes. Where the electrodes do not cover the entire tank wall, high-voltage gradients occur close to the edges of the electrodes. These could potentially cause carcass damage. Sheet electrodes should only be replaced by rods or grids after investigation of the effects of the high local voltage gradients they cause.

3.2. Continuous in-pipe stunning

For harvesting large quantities of fish at a high rate, a continuous flow device is likely to be more suitable than a batch device. On many commercial farms, fishes are pumped out of the water using a fish pump, and delivered directly into ice. A slaughter rate of 5 or more tonnes/h can be achieved in this way with only one operator. Humane slaughter could be achieved in this system, if the fish were stunned within the pipe delivering them to the tanks of ice slurry.

The main problem with this approach appears to be the volume of water that must be powered. A fish pump used to transport trout is likely delivering between 20 and 40 l of water per second, resulting in a speed of 1–2 m/s in a 150-mm diameter pipe. The stunning tube would therefore have to be at least 60 m in length with a powered volume in excess of 1000 l and a power requirement in excess of 4.4 kW in water with conductivity 0.07 S/m.

Partial de-watering might reduce the fish speed in the pipe and so reduce the length of pipe required; however, it would be important to ensure that the fish move through the pipe at a known speed. In areas of lower water conductivity, the electrical power required would be proportionately lower, which would make this simple arrangement a more attractive solution.

3.3. Volume reduction system

A system that stuns the fish, then collects them at high density, and drives them slowly through the electric field to extend the duration of the stun, should result in compact unit with a higher capacity but a lower power requirement than a stunning tube. It would however be mechanically more complex.

Of the three options discussed, we chose to develop this third option because it was the approach that was the most challenging and the most widely applicable. We anticipate and hope that individual farmers and small businesses will design and manufacture humane slaughter devices using each of the three approaches.

4. Design of a rotary stunning unit using the volume reduction approach

4.1. Concept

In order to achieve high processing speed with a lower power requirement, we designed, built, and tested a rotary stunning. This unit stuns the fish as they are delivered by a fish pump, then collects the insensible fish at a high density for the extended exposure duration necessary to ensure that the state of insensibility is permanent. This procedure reduces water volume that must be powered, and so reduces the power requirement. It also results in compact unit that can be easily transported.

The unit comprises a tank with entrance and exit ports which contains a slowly revolving rotor made up of 12 channels into which the trout are pumped directly from the raceway. On entering the tank, they flow into the channel on the rotor which is aligned with the entrance port. The channel walls are connected to an electrical power unit and function as electrodes, and so the fish becomes insensible as soon as they enter the channels. Excess water escapes through the mesh covering the channels into the enclosing tank while the insensible fish collects in the channels.

The rotor continuously rotates at just less than 1 rpm so that 60 s after aligning with the entrance port, each channel aligns with the exit port in the tank wall. The permanently stunned trout then flow out of the tank washed out by the water held in the tank which now flows back through the mesh along the channel and out of the exit port. The trout can then be de-watered and delivered onto ice.

The rotor and the stunning unit are illustrated in Figs. 5 and 6.

4.2. Design

The tank size was determined by the size of the rotor. The target harvesting rate was 3000 kg/h, and so a rotor with capacity for 50 kg of fish was required. A rotor

Fig. 5. Rotor removed from humane slaughter unit.

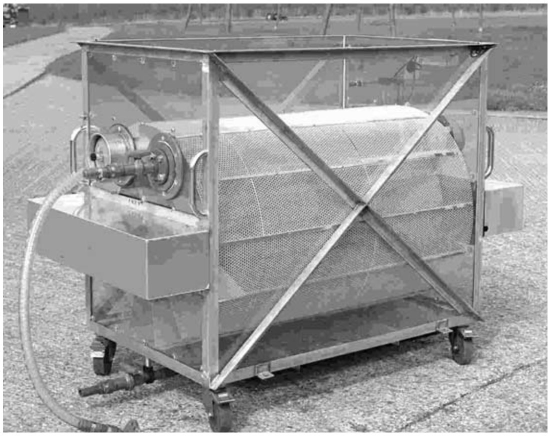

Fig. 6. Trout slaughter unit, showing rotor in transparent tank, entrance port, and tube for water jet.

with a capacity of 300 l was built, based on the assumptions that when stunned the fish can be held at a density of 0.5 kg/l, and that short-term variations in the supply of fish will result in a maximum delivery of three times the target rate. In order to use only relatively low voltages, the channels were made narrow. The rotor was therefore constructed to comprise 12 channels, each of which was 0.16 m wide, 1.05 m long, and 0.155 m deep. These were constructed on a PVC tube supported on half shafts at each end.

To prevent fish at the entry and exit ports being caught between the stationary port and moving rotor, a clearance of several centimetres was left between the two. This space was filled with flexible brushes. Earthed metal collars at the entrance and exit ports prevent the electric field propagating beyond the tank.

In preliminary trials, it was observed that some of the fish carcasses which were at the end of the channel away from the exit port did not flow out of the machine at the first pass. This appeared to be due to the low flow of water at this end. To assist with evacuation, a jet of water was introduced into the tank opposite the exit port. This substantially improved the evacuation of the channel.

When used in water of conductivity of 0.07 S/m, this unit requires about 1.4 kW of electrical power to stun the fish. This power is produced by a 1000 Hz sinusoidal signal generator, a high-power audio amplifier, and an impedance matching transformer. Micro-switches prevent the electrodes being energised if the tank lid is open or the water level is too low. The 250 V/m r.m.s. electric field is generated using a potential difference of 40 V r.m.s. between the plate electrodes. The power is supplied through slip rings to alternate electrodes on the rotor using the two half shafts supporting the rotor.

4.3. Field trials

This unit has been tested on commercial harvests of about 1 t on three commercial trout farms. Following the success of these trials, it was placed on a fourth farm for a period of several months for operation by the farm staff.

The rate at which this unit can be operated is determined by the experience of the operator and the ease with which he can monitor the operation of the machine while crowding the fish. For short durations, observations show it to be capable of operating at around 6 t of fish/h, however over the duration of a 1 or 2 t harvest, a rate of around 2 t/h has been found suitable. If the fish are fed into the unit too fast, then some fail to exit the unit, and so are exposed to the electric field for a second minute. Investigations with individual fish have indicated that this does not compromise the quality of the carcass, however it reduces the capacity of the machine and can eventually lead to a backlog of live and sensible fish in the delivery pipe. This has serious welfare consequences and must be avoided. A fish counter or load sensor would enable the capacity of the machine to be used more effectively while a more positive exit mechanism would increase the throughput. An increase in the rotor size would increase both throughput and power required proportionately.

Observations of the fish within the slaughter unit reveal that they are motionless and appear insensible from the moment they enter the channels. The fish flowing out of the slaughter unit into ice slurry rarely shows any discernable gill or muscle movements. This contrasts with traditional ice slurry slaughter, where the fish are very active.

Back to back comparisons have been made with traditional slaughter techniques using half tonne batches. These have shown that the electrically stunned trout have the same low level of haemorrhages as those slaughtered traditionally. They also show carcass quality improvements such as reduced fish slime and blood on the carcasses, and substantially increased time before the fish go into rigor during which they can be processed.

The humane slaughter unit has been tested on a farm with a water conductivity of only 0.007 S/m. Due to the low water conductivity, relatively little power was required to sustain the electric field of 250 V/m r.m.s. Observations of the fish emerging from the machine suggested that a small proportion of the fish might not have been stunned beyond recovery. Under this circumstance, the exposure duration or electric field strength should probably be increased.

5. Conclusions

The aspirations of the public for high quality, humanely slaughtered trout can be met by the use of an electric stunning procedure. Rapid and permanent insensibility together with high standards of carcass quality can be achieved when trout are held in water for a period of 60 s in an electric field of strength 250 V/m r.m.s. using a sinusoidal 1000 Hz waveform.

The optimum design of a humane slaughter unit for any particular farm is determined by the operational requirements and facilities of the farm, the water conductivity, and the cost and availability of suitable harvesting equipment components. Where small quantities of fish are required, a small batch-stunning tank is likely to be the best choice. Where larger quantities are required, selection becomes more complex.

Automatic batch stunning may be suitable where fish are required constantly at a low rate and where they do not need to be collected together for transporting. The cost of such a system is very dependent on the existing infrastructure. Electrical power requirements are likely to be low.

In-pipe stunning benefits from its mechanical simplicity and its ability to handle high fish rates. However, such a system is not portable, requires a lot of space, and may require expensive equipment for generating the electric field. Care is needed to ensure that the fish are not pumped too fast, resulting in an inadequate stun.

The rotary unit is mechanically more complex than the stunning tube but the speed at which the fish pass through the machine is positively controlled ensuring that the fish receive an adequate stun. The unit is also small enough to be transported from farm to farm and requires less electrical power, which results in a less expensive electronic power unit.

Humane slaughter of fish is a topic of increasing concern. Sensitivity to fish welfare is not as developed in the general population as sensitivity to mammal or avian welfare, however it is increasing. The perceived importance of humane slaughter of trout in UK has increased dramatically in the past 4 years. Some major trout retailers are expecting to introduce humane slaughter as a purchase requirement in the future. It is likely that this change in perception will be repeated in other western European countries and for other fish species.

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